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Bruxism and Temporomandibular Disorders

Current Advances and Future Challenges

Edited by
Grzegorz Zieliński and Eiji Tanaka

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Bruxism and Temporomandibular Disorders: Current Advances and Future Challenges

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Guest Editors

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About the Editors

Grzegorz Zieliński

Grzegorz Zieliński is affiliated with the Department of Stomatognathic System Rehabilitation at the Medical University of Lublin, Poland. His research focuses on temporomandibular disorders, physiotherapy, pain, and statistical methodology in the medical sciences. He is the author of widely cited systematic reviews, meta-analyses, and methodological guidelines on effect size and sample size estimation in medical research. His scientific research also includes innovations protected by patents. Grzegorz Zieliński's scientific achievements have been recognized through numerous distinctions, including the Minister of Higher Education Scholarship, the First-Class Rector's Award for Scientific Achievements from the Medical University of Lublin, and the Dr Wacław Mayzl Medical Award presented by the Polish Academy of Sciences. He is also a member of the International Association for the Study of Pain (IASP).

Eiji Tanaka

Eiji Tanaka is a professor and chair of the Department of Orthodontics and Dentofacial Orthopedics, Tokushima University Graduate School of Biomedical Sciences, Tokushima, Japan. After graduating from the Osaka University Faculty of Dentistry in 1988, he went on to complete his Ph.D. in 1993. He obtained a special orthodontic license in the same year and a orthodontic instructor license in 2000. He took up his current post in 2008, and in May 2015, he was also appointed as a distinguished adjunct professor at King Abdulaziz University, Jeddah, Saudi Arabia. Furthermore, he has several professional carriers: visiting professor at ACTA in the Netherlands (2003); visiting professor at University of Oviedo in Spain (2011); visiting professor at Hiroshima University in Japan (2016); visiting professor at the National Mongolian University of Medical Sciences in Mongolia (2019); distinguished adjunct professor at Saveetha Dental College in India (2022); and guest professor at Shanghai Tongji University in China (2024). His research centers on the biomechanics of the temporomandibular joint, the identification of the etiology of idiopathic/progressive condylar resorption, the application of low-intensity pulsed ultrasound in dental tissue engineering, and the development of orthodontic mini-screws. He has authored over 330 articles in peer-reviewed journals. Notably, a review article he published in the *Journal of Dental Research* in 2008 was selected as one of the top 10 most-cited publications in the field of temporomandibular disorders. Furthermore, he has been recognized as one of the top 2% most-cited scientists every year since 2021.

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Editorial

Bruxism and Temporomandibular Disorders: Current Advances and Future Challenges

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Bruxism and temporomandibular disorders (TMD) are among the most prevalent disorders affecting the masticatory system [1–3]. The prevalence of sleep bruxism is estimated at approximately 21%, while awake bruxism affects around 23% of the population, and TMD is reported to affect as many as 34% of individuals. The global co-occurrence of bruxism and TMD was 17%. The mean prevalence of TMD among patients with bruxism was 63.5% [1]. An increasing body of evidence confirms the multifactorial aetiology of these disorders, involving biological, psychological, and social factors [2,4,5]. Therefore, diagnosis and treatment require an interdisciplinary approach integrating dental, medical, psychological, and rehabilitative knowledge [6,7].

The articles published in this Special Issue present a broad spectrum of contemporary research directions. The significant role of psychological factors in the pathogenesis of painful forms of TMD was confirmed in a study analysing the relationship between masticatory muscle thickness and psychological status in female patients with myogenous TMD (Contribution 1). The importance of the biopsychosocial model is also emphasised in a review addressing predictors of pain chronicity (Contribution 2) and in a paediatric population study demonstrating associations between TMD, sleep disturbances, and emotional problems [8] (Contribution 3).

Many publications included in this Special Issue focus on occlusal and parafunctional factors. Associations between skeletal class, musculoskeletal pain patterns, and TMD were analysed by Nowak et al. (Contribution 4), whereas the influence of parafunctions, such as tooth clenching and abnormal mandibular positioning, was assessed among medical students (Contribution 5). Additional data are provided by studies investigating gum chewing (Contribution 6), occlusal interferences (Contribution 7), and non-functional occlusal habits in patients with craniofacial deformities (Contribution 8).

A substantial part of this Special Issue is dedicated to modern diagnostic methods. The potential of surface electromyography in TMD diagnostics is presented by Zieliński and Ginszt (Contribution 9), while the application of ultrasonography and elastography of the masseter muscle is demonstrated in studies by Wójcicki et al. (Contribution 1) and Sasajima et al. (Contribution 10). Valuable insights are also provided by MRI analyses of the temporomandibular joint (TMJ) [9] (Contribution 11).

Another important area of research concerned sleep bruxism. Two studies employing polysomnography and electromyography provided detailed characterisation of this phenomenon in young adults (Contribution 12 and 13). The pathophysiological perspective was further expanded by reviews addressing the association between bruxism and sleep-related breathing disorders as well as genetic determinants (Contribution 14), together with the effects of exposure to hypobaric hypoxia (Contribution 15).

Therapeutic strategies also represent an important research area. Promising results have been reported for myofunctional therapy in myogenous TMD [10] (Contribution 16). The effectiveness of minimally invasive treatment approaches was assessed in a study investigating arthrocentesis with the use of hyaluronic acid and platelet-rich plasma (Contribution 17), as well as in reviews focusing on autologous injections (Contribution 18), arthroscopic discopexy techniques (Contribution 19), and the safety of intra-articular injections (Contribution 20). In cases of advanced disorders, outcomes following total TMJ arthroplasty were analysed [11] (Contribution 21). Further evidence supporting the need for an individualised and multidisciplinary therapeutic strategy was provided by Dąbkowska et al. (Contribution 22).

Attention should also be drawn to reports concerning oxidative stress biomarkers (Contribution 23), sex-related differences in the diagnosis of limited mouth opening (Contribution 24), the co-occurrence of TMD and tinnitus (Contribution 25), and the impact of emerging environmental factors, such as intensive video gaming [12] (Contribution 26).

The collected publications clearly indicate that the future of research on bruxism and TMD will rely on the integration of advanced diagnostic methods, identification of biopsychosocial determinants, and the development of personalised therapeutic strategies. This is particularly relevant in view of projections suggesting a further increase in the global prevalence of TMD by 2050 [13] (Contribution 27). This Special Issue provides an up-to-date summary of current knowledge while also outlining future directions for research into these complex disorders.

Future Directions and Clinical Implications

Future research into bruxism and TMD should focus on further integrating the biopsychosocial approach through the use of advanced diagnostic methods and the development of therapies tailored to individual patient needs. Particular importance will be placed on developing more precise tools for assessing the risk of chronic pain development, identifying biomarkers, and gaining a better understanding of the interactions between genetic factors, sleep, stress, stomatognathic system function, and lifestyle. In clinical practice, it will be necessary to further strengthen interdisciplinary cooperation involving dentists, physiotherapists, doctors from other medical specialties, and mental health professionals. The increasing use of technologies such as surface electromyography, ultrasonography, elastography, magnetic resonance imaging, and digital tools for monitoring muscle activity may contribute to earlier detection of disorders and more effective treatment planning. At the same time, future therapeutic strategies should address not only symptom reduction but also the modification of risk factors and the improvement of patients' long-term quality of life.

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1. Wójcicki, M.; Litko-Rola, M.; Szkutnik, J.; Ginszt, M.; Gawda, P.; Różyło-Kalinowska, I. Association Between Psychological Factors and Masticatory Muscle Thickness Assessed by Ultrasonography in Female Dental Students with TMD-Related Myalgia: A Cross-Sectional Study. *J. Clin. Med.* **2026**, *15*, 3183. https://doi.org/10.3390/jcm15093183.

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Article

Association Between Psychological Factors and Masticatory Muscle Thickness Assessed by Ultrasonography in Female Dental Students with TMD-Related Myalgia: A Cross-Sectional Study

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Abstract

Objectives: The aim of this study was to compare the relationship between psychological factors and the thickness of masticatory muscles in patients with temporomandibular disorders (TMD) and healthy controls. **Methods**: This cross-sectional study included 106 female participants aged 18–35 years, recruited from students of the Medical University of Lublin. The study group consisted of individuals diagnosed with myalgia based on the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), while the control group included participants without TMD. Psychological factors were assessed using the PHQ-9, GAD-7, and PHQ-15 questionnaires. The thickness of the temporalis and masseter muscles was measured using an M-Turbo (Sonosite) ultrasound device under relaxed and contracted conditions. **Results**: Participants with TMD-related myalgia scored significantly higher on the PHQ-9 (mean ± SD: 8.82 ± 5.02 vs. 5.00 ± 3.41; $p < 0.001$), GAD-7 (8.53 ± 4.48 vs. 4.65 ± 3.58; $p < 0.001$), and PHQ-15 (9.47 ± 4.07 vs. 6.02 ± 3.89; $p < 0.001$) compared to controls. No statistically significant differences were observed in temporalis or masseter muscle thickness at rest or during contraction between groups ($p > 0.05$). Significant differences in correlations were found between depression scores and temporalis muscle thickness in the study group compared to the control group (r = 0.32 vs. −0.13, $p = 0.011$) as well as between anxiety scores and temporalis muscle thickness (r = 0.25 vs. −0.30, $p = 0.002$) No significant associations were found for the masseter muscle. **Conclusions**: Individuals with myalgia did not show increased muscle thickness compared to healthy individuals. Psychological distress, particularly depression and anxiety, was differentially related to temporalis muscle morphology in individuals with myalgia compared to healthy controls.

Keywords: temporomandibular disorders; myalgia; masticatory muscles; depression; anxiety; ultrasonography

1. Introduction

Temporomandibular disorders (TMD) according to the American Dental Association is a collective term used to describe functional disturbances of the masticatory system, including the temporomandibular joints, masticatory muscles, and associated structures [1]. These disorders are characterized by a similar location of symptoms and shared clinical manifestations. The most common symptoms include pain in the head and facial region and limitations in jaw mobility, while joint sounds (e.g., clicking or crepitation) may also occur in some patients [2]. TMD affects 34% of the general population, and projections suggest an increase to 44% by 2050 [3]. The most frequently occurring subgroup within TMD, accounting for 45.3% consists of masticatory muscle pain, also known as myofascial pain [2].

The etiology of TMD is currently understood within the biopsychosocial model, which assumes that biological, psychological, and social factors interact in the development and persistence of the disorder. Biological factors include anatomical characteristics, muscle activity, occlusal conditions, and functional loading of the masticatory system. Demographic factors such as age and sex have also been associated with the prevalence of TMD, with the condition occurring more frequently in young and middle-aged adults and significantly more often in women. Psychological factors such as stress, depression, anxiety, and somatization are also considered important contributors to the onset and maintenance of TMD symptoms [1].

Muscular TMD is often associated with masticatory muscle hypertrophy. Muscle growth is stimulated by mechanical tension, cell damage, or metabolic stress, usually from excessive muscle work, hypoxia, or lactic acid buildup. In masticatory muscles, parafunctional activity is the main trigger [4]. Muscle mass increases through hyperplasia (fiber multiplication) and hypertrophy (fiber enlargement), with the latter being dominant. Hypertrophy occurs as an adaptation to overload, involving increased contractile proteins (actin, myosin) and possibly sarcoplasmic hypertrophy, where muscle volume grows without a proportional gain in strength [4].

From the perspective of human anatomy and physiology, mental state plays a significant role in the development and progression of TMD [5,6]. In recent years, numerous studies have demonstrated a relationship between various psychological factors and TMD [7,8]. The relationship is considered bidirectional: psychological distress may enhance pain perception through central sensitization and dysregulation of descending inhibitory pathways, while chronic pain may increase emotional burden. Increased psychological stress, depression, anxiety, and chronic emotional tension are associated with increased muscle tension, especially in the facial muscles, neck, and shoulder girdle [9,10]. In the case of the masticatory muscles, such as the masseter and temporalis, chronic tension can result in overload, pain, and even inflammation.

Psychological disorders such as depression and anxiety have been shown to be associated with increased pain intensity and reduced treatment effectiveness in patients with chronic pain conditions, including TMD [11]. Individuals experiencing psychological distress may also exhibit increased masticatory muscle activity and more frequent parafunctional tooth contacts. In addition, anxiety-related behaviors such as teeth clenching and other oral parafunctions may further contribute to functional overload of the masticatory system [11].

Another psychological factor relevant to TMD is somatization, which manifests as physical symptoms originating from psychological distress, including headaches, nausea, or gastrointestinal complaints. Somatization frequently co-occurs with TMD and affects approximately 14–17% of the general population [12]. Some etiological factors may be

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common to both somatization and TMD, with high levels of emotional stress that warrant particular attention [13].

Anxiety, depression and prolonged stress may cause unconscious parafunctional habits, with bruxism being the most common [5,14]. Bruxism is characterized by repetitive and sustained contractions of the masticatory muscles, particularly the masseter and temporalis, leading to increased muscle activity. Prolonged or repetitive jaw-muscle activity may result in muscle fatigue, mechanical overload, and, over time, adaptive structural changes such as increased muscle thickness. Therefore, bruxism represents a potential functional link between psychological factors and alterations in masticatory muscle morphology. Bruxism also puts considerable strain on the temporomandibular joint, which may result in joint displacement, clicking or popping sounds, limited mobility, and pain radiating to nearby structures such as the ear or temple [5,14].

It has been shown that serotonin and norepinephrine play a role in inhibiting central nociceptive input, which may explain why disruptions in the regulation of these neurotransmitters, underlying depression, exacerbate pain symptoms in these patients [15]. This may also explain the pain-relieving effect of antidepressant medications [16]. On the other hand, selective serotonin reuptake inhibitors (SSRI) widely used in the treatment of depression and anxiety tend to cause sleep bruxism [17].

The evaluation of muscle structure can be performed using various imaging techniques, including computed tomography, magnetic resonance imaging, and ultrasound. Currently, ultrasound is a readily available, low-cost, and non-invasive method that provides accurate visualization of the structure and dimensions of the masticatory muscles [18]. Several studies have examined masticatory muscle thickness using ultrasound to understand the relationship between muscle dimensions and morphofunctional factors such as age, sex, bite force, facial type, arcade shape, and occlusion [18,19].

Although the association between psychological factors and TMD symptoms is well documented, it remains unclear whether psychological distress is associated with measurable structural changes in masticatory muscles. Only a limited number of studies have explored the relationship between psychological variables and ultrasonographically assessed muscle thickness. For example, Ahısha et al. [20] evaluated the relationship between psychological distress and masseter muscle thickness in patients with chronic neck pain, while Öçal et al. [21] analyzed the association between anxiety levels and masseter muscle thickness in patients with disc displacement. However, neither of these studies investigated patients with TMD-related myalgia or evaluated both masseter and temporalis muscles simultaneously.

Therefore, the existing literature provides limited evidence regarding whether psychological factors are associated with morphological characteristics of the masticatory muscles in patients with TMD-related myalgia.

Thus, the aim of this study was to assess the relationship between the thickness of masticatory muscles observed in ultrasound images and psychological factors among TMD patients with myalgia. The study hypothesized that TMD patients would show a stronger positive correlation between masticatory muscle thickness and psychological factors such as depression, anxiety, and somatization compared to individuals without TMD.

2. Materials and Methods

This study was designed as a cross-sectional study. The study was approved by the Bioethics Committee of the Medical University of Lublin (decision number KE-0254/160/2019), and all participants provided informed consent prior to participation. It involved 106 female students of the Medical University of Lublin aged 18 to 35, who volunteered to participate between April 2021 and June 2022. The selection of medical

university students as the study population was intentional, as it allowed access to a relatively homogeneous group in terms of educational background, socioeconomic status, and health awareness. Additionally, this population is characterized by increased exposure to academic stress, which may influence psychological well-being and, consequently, TMD-related symptoms [6]. To ensure greater sample homogeneity and to reduce potential confounding effects associated with sex-related differences, we limited the study population to women within this age range. This decision was based on evidence indicating that both sex and age are associated with the prevalence of TMD [3,22,23], and that females generally present thinner masticatory muscles compared to males [18]. The inclusion criterion for the study group was the presence of myalgia diagnosed based on a clinical examination according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [24]. Participants in the control group were selected based on the absence of symptoms of temporomandibular disorders. Exclusion criteria included systemic diseases, ongoing orthodontic treatment, malocclusions, and pregnancy. A total of 55 individuals were included in the study group, while 51 were assigned to the control group. This sample size was consistent with guidelines assuming a medium effect size and a power level of 70% [25]. A comparison of the study and control groups in terms of age and range of mouth opening is presented in Table 1.

Table 1. Comparison between study and control group in terms of age and range of opening.

	Study Group (*n* = 55)	**SD**	**Control Group (*n* = 51)**	**SD**	**U**	***p***
Age [years]	23.49	2.31	23.35	2.50	1274.00	0.41
Pain-free opening [mm]	46.69	9.03	48.86	5.66	1269.50	0.40
Maximum unassisted opening [mm]	50.20	5.60	49.18	5.85	1208.00	0.22
Maximum assisted opening [mm]	53.38	5.64	51.82	5.76	1150.50	0.11

SD: standard deviation; U: U—Mann–Whitney U test statistic; *p*—significance level.

The Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) is a standardized and validated diagnostic protocol developed to ensure reliable and reproducible assessment of TMD. It consists of two axes: Axis I focuses on clinical conditions based on a structured clinical examination, while Axis II evaluates psychosocial status and pain-related disability using validated questionnaires. The DC/TMD protocol has been formally validated and officially translated into Polish, and the validated Polish version was used in the present study [24]. The diagnosis of myalgia was established according to Axis I criteria, which include a history of pain modified by jaw function during last 30 days and confirmation of familiar pain during standardized examination of the masticatory muscles. Since subclassification of myalgia according to the DC/TMD criteria (local myalgia, myofascial pain with spreading, and myofascial pain with referral) was not essential for the objectives of the present study, we elected not to differentiate between these subtypes. For the sake of methodological simplicity and clarity, the analysis was therefore limited to the general diagnosis of myalgia.

The DC/TMD examinations were performed at the Dental Clinical Centre of the Medical University in Lublin by M.L.-R. under the supervision of J.S., both of whom are licensed dentists and experienced in the clinical assessment of temporomandibular disorders. The DC/TMD protocol ensures high diagnostic validity and inter-examiner reliability and is widely used in both clinical and research settings.

In line with DC/TMD guidelines, the following questionnaires were used to determine the presence of psychological factors:

- Patient Health Questionnaire-9 (PHQ-9)—for the preliminary diagnosis and assessment of depression severity,
- Generalized Anxiety Disorder-7 (GAD-7)—to evaluate the severity of anxiety disorders.
- Patient Health Questionnaire-15 (PHQ-15)—to evaluate the severity of the patient's nonspecific somatic symptoms.

All questionnaires in the local language version were downloaded from the website https://www.phqscreeners.com/select-screener (accessed on 4 January 2019). The PHQ-9, GAD-7, and PHQ-15 questionnaires were selected because they are validated, widely used, and recommended within the DC/TMD Axis II framework for the assessment of depression, anxiety, and somatic symptom burden. All instruments were completed by the participants during the same session. Missing data were handled in accordance with the DC/TMD guidelines, which include predefined rules for managing incomplete responses, such as calculating scores based on available items when permitted or excluding questionnaires with excessive missing data [24].

The thickness of the temporalis and masseter muscles was assessed using an M-Turbo ultrasound device with a linear probe, operating within a frequency range of 6 to 15 MHz and an imaging depth of up to 6 cm (SonoSite Inc., Bothell, WA, USA) [26]. All ultrasonographic measurements were performed by M.W. under the supervision of I.R.-K., a board-certified radiologist with many years of clinical experience in radiology. The masseter muscle was examined at the height of the occlusal plane, with the probe perpendicular to the ramus of the mandible and parallel to the occlusal plane (Figures 1 and 2) [27]. The temporalis muscles were examined in their anterior part, with the probe placed parallel to the zygomatic arch and 1 cm above it, and perpendicular to the temporal bone, anterior to the hairline (Figures 3 and 4) [28]. The selection of these measurement sites was based on a review of previous ultrasonographic studies on masticatory muscles. The adopted locations are among the most commonly used in the literature and provide high repeatability of measurements. Each muscle was measured in two conditions: during relaxation with minimal contact between antagonistic teeth, and during maximum voluntary clenching. The probe was applied with as little pressure as possible, with additional ultrasound gel used to minimize tissue compression. Muscle thickness was measured directly on the screen at the thickest visible point using the ultrasound device's built-in measuring tool, with an accuracy of 0.1 mm. During the examination, participants were positioned in the supine position with the head comfortably supported on a headrest to ensure stabilization and standardization of measurements. The entire examination was performed twice, yielding four measurements for each muscle (two during relaxation and two during contraction).

Each participant was examined on a single day within the same facility to ensure consistency of the patient's condition across all assessments and to minimize the risk of dropouts. The assessments were conducted in the following sequence: clinical examination, questionnaire assessment, and ultrasonographic evaluation.

For statistical analysis, the average of the two measurements was used, along with the ratio of muscle thickness during contraction to muscle thickness at rest, calculated by dividing the thickness during contraction by the thickness at rest. The error in muscle thickness measurement using ultrasound was calculated based on the difference between the first and second measurements for each muscle according to Dahlberg's formula [29]:

$$SE = \sqrt{\frac{\sum d^2}{2n}}$$

where:

SE = Standard Error
d—difference between first and second measurement
n—number of examined patients

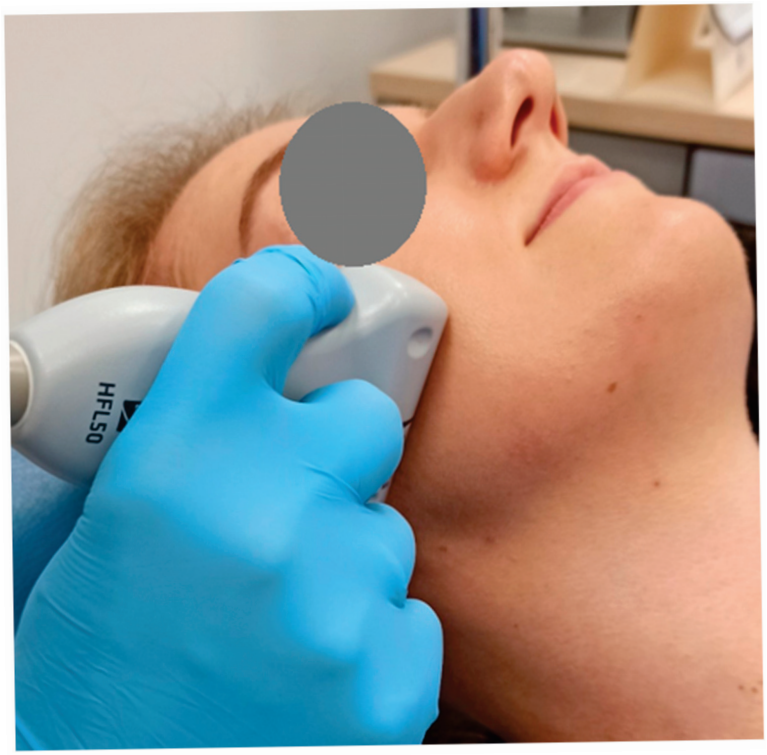

Figure 1. Placement of ultrasound probe during measurement of masseter muscles thickness.

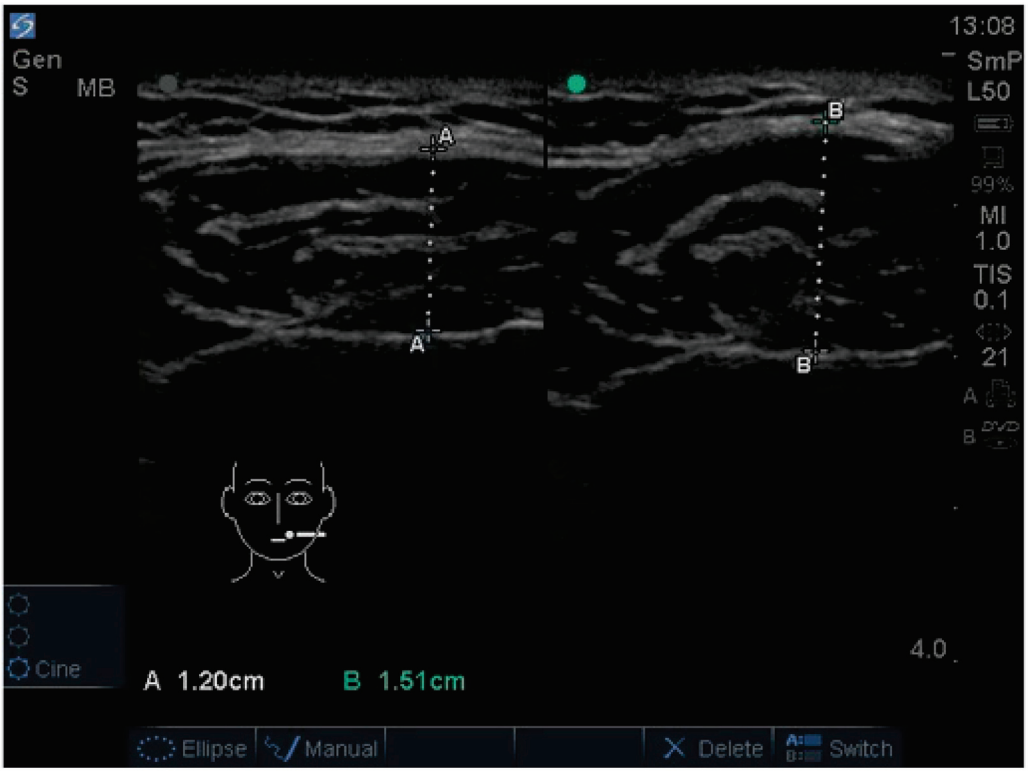

Figure 2. Ultrasound image of masseter muscle. Relaxed muscle on the left (measurement **A**). Contracted muscle on the right (measurement **B**).

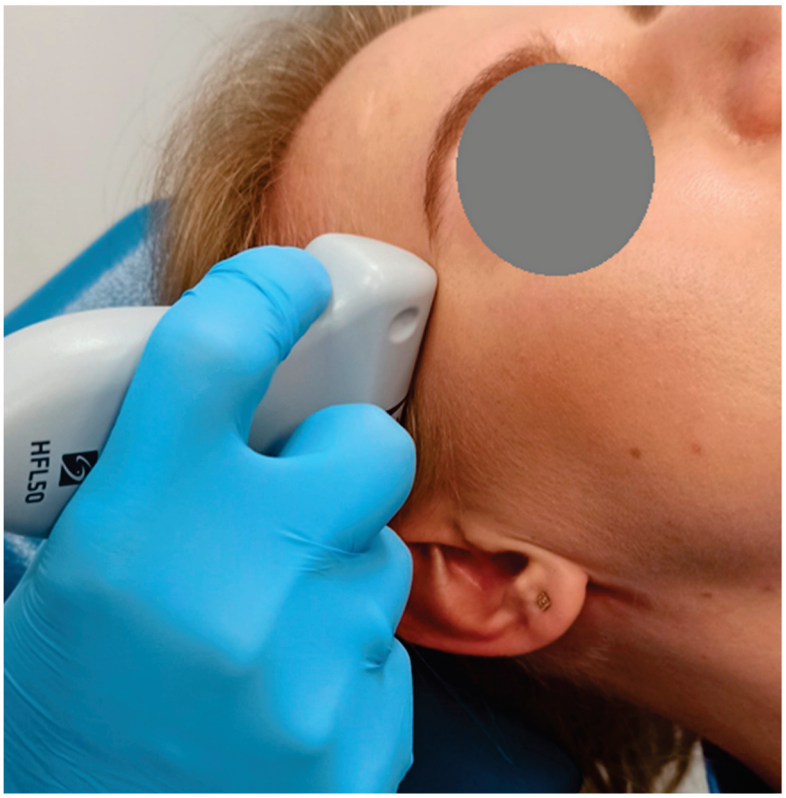

Figure 3. Placement of ultrasound probe during measurement of temporalis muscles thickness.

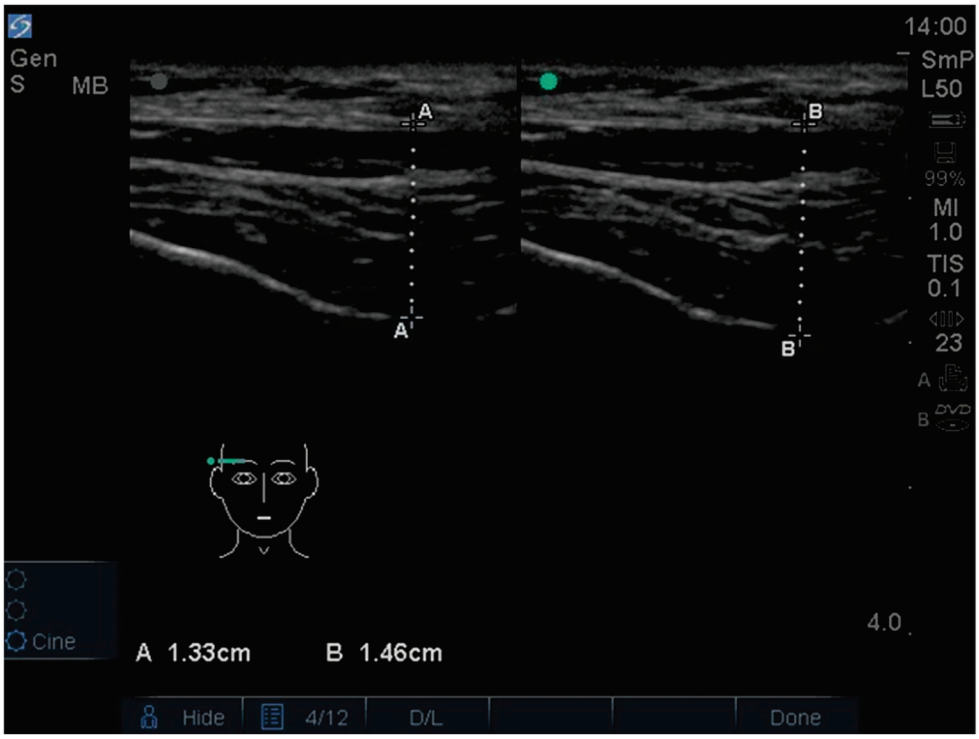

Figure 4. Ultrasound image of temporalis muscle. Relaxed muscle on the left (measurement **A**). Contracted muscle on the right (measurement **B**).

Absolute error (expressed in millimeters) reflects the magnitude of measurement variability, while relative error (expressed as a percentage) represents this variability in relation to the mean muscle thickness, allowing comparison between muscles and measurement conditions.

The results are presented in Table 2.

Table 2. Measurement error of muscle thickness using ultrasound examination.

	Measurement Error of Realxed Muscle		Measurement Error of Contracted Muscle	
	Absolute [mm]	**Relative [%]**	**Absolute [mm]**	**Relative [%]**
left temporalis muscle	0.88	7.15	0.86	6.61
right temporalis muscle	1.01	8.09	1.04	7.91
left masseter muscle	0.62	4.76	0.55	3.96
right masseter muscle	0.63	4.85	0.50	3.52

Descriptive statistics were used to summarize the data and included the mean, median, standard deviation, minimum, and maximum values. The normality of the variable distribution was checked using the Shapiro–Wilk test. Inferential statistical methods were applied to analyze differences and relationships between variables. The Mann–Whitney U test was used to determine differences between groups. Correlations were assessed using Spearman's rho coefficient. The Spearman rho coefficient (ρ) ranges from −1 (perfect negative monotonic association) to +1 (perfect positive monotonic association). A correlation was considered strong for values greater than 0.5, and moderate for values between 0.3 and 0.5 [25,30]. Differences between correlations were tested using Fisher's z test. The significance level was set at $p < 0.05$. Effect size was calculated according to Tomczak et al. [31].

3. Results

The average thickness of the temporalis muscles in the study group was 12.41 mm, while in the control group, it was 12.47 mm. For the masseter muscles, the thickness was 12.91 mm in the study group and 13.07 mm in the control group. The ratio of temporalis muscle thickness during contraction to its thickness at rest averaged 1.049 in the study group, while it was 1.054 in the control group. Similarly, the ratio for the masseter muscles was 1.091 in the study group and 1.087 in the control group. No statistically significant association was found between the occurrence of TMD and any of these muscle parameters (Table 3).

Table 3. Comparison of masticatory muscle thickness measured by ultrasound.

	Study Group (n = 55)	**SD**	**Control Group (n = 51)**	**SD**	**U**	**p**	**ES**
TM R [mm]	12.47	1.70	12.40	1.24	1385.50	0.92	0.05
MM R [mm]	13.09	2.02	12.89	1.49	1386.00	0.92	0.11
TM C/R	1.05	0.03	1.05	0.02	1276.50	0.43	0.20
MM C/R	1.09	0.04	1.09	0.04	1310.00	0.56	0.08

SD: standard deviation; U: U—Mann–Whitney U test statistic; p—significance level; ES—effect size; TM R: average resting temporalis muscle thickness; MM R: average resting masseter muscle thickness; TM C/R: average ratio of temporalis muscle thickness during contraction to its thickness at rest; MM C/R average ratio of masseter muscle thickness during contraction to its thickness at rest.

In the study group, the average score on the PHQ-9 questionnaire was 8.91, compared to 4.98 in the control group. For the GAD-7 questionnaire, the average score was 8.57 in the study group and 4.67 in the control group. For the PHQ-15, the average score was 9.57 in the study group and 5.98 in the control group. A statistically significant relationship was established between the results of each questionnaire and the occurrence of TMD (Table 4).

Table 4. Comparison of questionnaire results for assessing psychological factors based on DC/TMD.

	Study Group (n = 55)	SD	Control Group (n = 51)	SD	U	p	ES
PHQ 9	8.82	5.02	5.00	3.41	760.50	<0.001	0.88
GAD 7	8.53	4.48	4.65	3.58	674.50	<0.001	0.95
PHQ 15	9.47	4.07	6.02	3.89	724.50	<0.001	0.87

SD: standard deviation; U: U—Mann–Whitney U test statistic; p—significance level; ES—effect size; PHQ 9: average score of patient health questionnaire 9; GAD 7: average score of general anxiety disorders; PHQ 15: average score of patients health questionnaire 15; DC/TMD: Diagnostic Criteria/Temporomandibular Disorders.

A statistical analysis was conducted to examine the correlation between masticatory muscle parameters and questionnaire scores, separately for both the study and control groups, followed by a comparison of these correlations. A statistically significant relationship was found between the PHQ-9 score and temporalis muscle thickness in the study group. Similarly, in the control group, a significant relationship was noted between the GAD-7 score and temporalis muscle thickness. Additionally, the differences in correlation coefficients between the study and control groups for temporalis muscle thickness and the scores on the PHQ-9 and GAD-7 questionnaires were statistically significant (p = 0.011 and p = 0.002, respectively). In the study group, higher scores on the PHQ-9 or GAD-7 questionnaires were associated with thicker temporalis muscles. In contrast, the control group exhibited the opposite trend: higher questionnaire scores corresponded to thinner temporalis muscles. Differences in other correlation coefficients did not reach statistical significance (Table 5).

Table 5. Correlations between questionnaire results assessing psychological factors and masticatory muscles thickness in ultrasound examination.

		Study Group (n = 55)		Control Group (n = 51)		p (Fisher z-Test)	ES
		r	p	r	p		
TM R	PHQ 9	0.32	0.020 *	−0.13	0.359	0.011 *	0.46
	GAD 7	0.25	0.066	−0.30	0.030 *	0.002 *	0.57
	PHQ 15	0.18	0.183	−0.13	0.365	0.058	0.31
MM R	PHQ 9	0.20	0.139	0.15	0.291	0.389	0.05
	GAD 7	0.14	0.299	−0.12	0.393	0.091	0.26
	PHQ 15	−0.08	0.551	−0.16	0.251	0.344	0.08
TM C/R	PHQ 9	0.08	0.565	0.25	0.072	0.188	0.18
	GAD 7	0.02	0.874	0.10	0.459	0.339	0.08
	PHQ 15	0.12	0.380	0.07	0.610	0.402	0.05
MM C/R	PHQ 9	−0.10	0.476	0.17	0.228	0.088	0.27
	GAD 7	−0.14	0.317	0.14	0.324	0.081	0.28
	PHQ 15	−0.11	0.437	0.07	0.618	0.185	0.18

r: Spearman's rank correlation coefficient; p—significance level; ES—effect size; *—indicates statistical significance at the $p < 0.05$ level; TM R: resting temporalis muscle thickness; MM R: resting masseter muscle thickness; TM C/R: ratio of temporalis muscle thickness during contraction to its thickness at rest; MM C/R ratio of masseter muscle thickness during contraction to its thickness at rest; PHQ 9: health questionnaire 9; GAD 7: general anxiety disorders; PHQ 15: health questionnaire 15.

4. Discussion

Results of our research partially confirmed the stated hypothesis. Statistically significant differences in the relationships between the study and control groups were found

only for the temporalis muscle and anxiety disorders and depression. No statistically significant correlation was observed for the masseter muscles. Furthermore, somatization did not show statistically significant differences in the relationship with masticatory muscle thickness between the control and study groups.

Importantly, the presence of myalgia does not necessarily imply structural muscle hypertrophy. Myofascial pain is primarily associated with altered neuromuscular function, increased muscle activity, peripheral and central sensitization, and local ischemic or metabolic changes rather than with permanent morphological enlargement of the muscle. Therefore, the absence of significant differences in masseter muscle thickness between the study and control groups in our research should not be interpreted as contradictory to the presence of muscle-related pain. Pain may occur independently of measurable structural changes detectable by ultrasonography.

Our findings support the concept that TMD-related myalgia may reflect functional and neurophysiological alterations rather than macroscopic structural remodeling of the masticatory muscles. This distinction is clinically relevant, as it suggests that increased muscle thickness should not be considered a necessary diagnostic or pathophysiological marker of myogenous TMD.

These findings suggest that the role of psychological factors in TMD may be primarily reflected in pain perception and functional alterations rather than in measurable structural muscle changes. Psychological distress may influence muscle activity patterns, central pain modulation, and behavioral responses without necessarily leading to detectable morphological remodeling. Therefore, the absence of significant differences in muscle thickness does not diminish the clinical relevance of psychological variables in TMD.

Our study revealed a strong correlation between each of the evaluated psychological factors and TMD, aligning with the findings of the literature [11–13,32–35]. These results further support the growing body of evidence highlighting the significant impact of psychological factors on the development and progression of TMD.

Numerous studies have explored variations in masticatory muscle thickness, with the masseter and temporalis muscles being the most frequently examined due to their accessibility via ultrasound. Previous research has examined the thickness of these muscles in relation to bite force [36,37], muscle electrical activity [38], nocturnal bruxism [39], facial morphology [36], body structure [40], occlusal disorders [40], tooth wear [41], stabilization splint use [42], muscular dystrophy [43], temporomandibular joint osteoarthritis [44], and submucosal fibrosis [45].

The average muscle thickness largely depended on the measurement site. In studies with similar methodology, masseter thickness ranged from 9.47 to 12.74 mm at rest [27,36,41,42,45–47] and from 11.03 to 16.65 mm during contraction [27,36,41,45–47], while temporalis thickness ranged from 7.12 to 13.1 mm at rest [41,46,47] and from 8.05 to 14.4 mm during contraction [41,46,47], aligning with our study's results. Two studies examined the ratio of masseter thickness in contraction to rest, reporting an average ratio of 1.24 to 1.42 [41,48]. One study assessed the same relationship for the temporalis muscle, with an average of 1.2 [41]. Both of these ratios are higher than the values obtained in our study, possibly due to differences in the force applied by the ultrasound probe, as our contraction measurements were similar, but there were notable differences in the resting state, where probe pressure has a greater impact. In general, the ranges of muscle thickness reported in these studies are consistent with our findings, suggesting that our measurements fall within the expected physiological variability.

Five studies explored the relationship between TMD and masticatory muscle thickness. Marcelo Palinkas et al. [39] examined the relationship between masseter and temporalis thickness and bruxism, using polysomnographic assessment as the diagnostic standard.

Similarly to our study, they measured muscle thickness at rest and during contraction. Luciano Jose Pereira et al. [37] investigated the correlation between masseter and temporalis thickness and TMD symptoms using the craniomandibular index (CMI), measuring muscle thickness in both rest and contraction. Mariah Acioli Righetti et al. [44] assessed the link between the thickness of these muscles and temporomandibular joint osteoarthritis, with a diagnosis based on American College of Rheumatology guidelines. Hasan Erkan Kilinc et al. [49] explored the association between muscle thickness and myofascial pain, finding no significant differences between TMD patients and controls in terms of muscle thickness, consistent with our results.

This distinction becomes particularly relevant in the context of bruxism. Increased muscle thickness, especially of the masseter, may occur in individuals with bruxism and often presents as hypertrophy without accompanying pain. In such cases, structural adaptation may result from repetitive mechanical loading rather than from pain-related mechanisms. Our results support the concept that muscle hypertrophy and myalgia represent distinct phenomena that may coexist but are not causally dependent on one another.

The literature also discusses the relationship between psychological factors and TMD. Louis Simoen et al. [50] examined the link between anxiety, depression, and TMD-related pain, using the PHQ-9 and GAD-7 questionnaires, and found a strong correlation between depression, anxiety, and TMD pain, which aligns with our findings. Ema Vrbanović et al. [51] also found that psychological factors such as depression and anxiety correlated with increased pain in TMD patients, but they did not find this correlation when comparing TMD patients to healthy individuals, possibly due to group selection differences. The COVID-19 pandemic, which heightened psychological distress, may have affected their results.

Chengxinyue Ye et al. [52] also demonstrated strong correlations between TMD and both depression and anxiety, using DC/TMD criteria and PHQ-9 and GAD-7 questionnaires, in line with our results. Birgitta Häggman-Henrikson et al. [53] and Adrian Ujin Yap et al. [54] both showed correlations between somatization and TMD, as well as between psychological distress and TMD, matching our findings.

Among the available literature, only two studies assessed the relationship between masticatory muscles thickness and psychological factors. Ahısha et al. [20] examined the correlation between the masseter muscle thickness and depression, anxiety, and somatization using the same questionnaires (PHQ-9, GAD-7 and PHQ-15) in female patients with chronic non-specific neck pain. They demonstrated significant positive correlation between masseter thickness and scores on PHQ-9 and GAD-7 in the studied population.

Öçal et al. [21] also assessed the relationship between masseter thickness and psychological factors. They found that patients with unilateral disc displacement and higher anxiety levels had thicker masseters on the unaffected side compared to patients with normal anxiety levels. However, they reported no such relationship on the affected side.

In contrast, in our study, no significant correlation was observed between masseter muscle thickness and psychological factors. The discrepancies between our findings and those reported by Ahısha et al. may be attributed to differences in the studied populations. While their research focused on female patients with chronic non-specific neck pain, our study included individuals diagnosed with TMD-related myalgia. Furthermore, our participants were considerably younger (mean age: 23 years) compared to their cohort (mean age: 41 years). Age-related variations in muscle morphology, adaptive capacity, and chronicity of symptoms, as well as differences in the underlying pain condition, may have influenced the observed associations. Similarly, differences between our results and those of Öçal et al. may be explained by variations in study design and population characteristics. We examined exclusively female patients with myalgia, whereas Öçal et al. included both male

and female patients diagnosed with disc displacement. These clinical and demographic differences may account for the divergent findings. Notably, neither of these studies evaluated temporalis muscle thickness, which further limits direct methodological comparability with our investigation. Taken together, these findings suggest that the relationship between psychological factors and masticatory muscle morphology may be context-dependent and influenced by age, type of TMD, and study design.

The present study has several strengths. First, it combined standardized clinical diagnostics based on the DC/TMD protocol with validated psychological assessment tools (PHQ-9, GAD-7, and PHQ-15) and objective ultrasonographic measurements of masticatory muscle thickness. Second, all assessments were performed on the same day and within the same facility, which minimized temporal variability and ensured consistency of the participants' clinical condition across examinations. Third, ultrasonographic measurements were conducted under standardized conditions and supervised by an experienced radiologist, enhancing methodological reliability. Finally, the study addressed a relatively underexplored research question by examining the association between psychological factors and muscle thickness in TMD-related myalgia.

Several limitations should be acknowledged. First, psychological factors were assessed exclusively using self-report questionnaires without formal psychiatric evaluation, which may limit diagnostic precision. Second, we did not control for potential confounders such as facial morphology or body mass index, both of which may influence masticatory muscle thickness. Third, the study population consisted exclusively of young female dental students, which enhances internal homogeneity but limits the generalizability of the findings to broader and more diverse populations. Additionally, the cross-sectional design precludes causal inference regarding the relationships observed.

5. Conclusions

- Individuals with myalgia did not show increased muscle thickness compared to healthy individuals.
- Individuals with myalgia exhibited more symptoms of depression, anxiety, and somatisation.
- A significant association between depression and anxiety scores and temporalis muscle thickness was identified; however, the direction of this association differed between groups. In the myalgia group, higher PHQ-9 and GAD-7 scores were associated with greater temporalis thickness, whereas in the control group, higher scores were associated with lower temporalis thickness.
- No significant associations were found between psychological factors and masseter muscle thickness.

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Abbreviations

The following abbreviations are used in this manuscript:

TMD	Temporomandibular disorders
DC/TMD	Diagnostic criteria for temporomandibular disorders
PHQ-9	Patient health questionnaire 9-item depression scale
GAD-7	Generalized anxiety disorder 7-item anxiety scale
PHQ-15	Patient health questionnaire 15-item somatic scale

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The Effectiveness of Orofacial Myofunctional Therapy in Adults with Myogenous Temporomandibular Disorders: Insights from a Pilot Study

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Abstract

Background: Temporomandibular disorders (TMDs) are increasingly understood within the biopsychosocial framework, which highlights the interplay of biological, psychological, and social factors in their onset and persistence. Within this context, orofacial myofunctional disorders (OMDs) represent a significant biological component, reflecting structural and functional disturbances of the orofacial system that may contribute to temporomandibular dysfunction. **Objectives:** This pilot study evaluated the effectiveness of orofacial myofunctional therapy (OMT) in improving functional parameters and reducing pain in adults with myogenous TMD accompanied by OMDs. **Methods:** In this prospective single-arm pilot study, twenty-five adults (aged 25–39 years) with myogenous TMD and coexisting OMDs, diagnosed according to DC/TMD criteria by a dentist trained in DC/TMD assessment and referred for the intervention, completed three biweekly OMT sessions. The therapy comprised myofascial release, oromotor exercises, functional retraining of breathing, chewing, and swallowing, as well as mandibular stabilization and dissociation exercises, complemented by home-based practice. Functional parameters—maximum mouth opening (MAX) and tongue mobility (TRMR-TIP, TRMR-LPS)—were measured before and after each session. Pain intensity (VAS) and quality of life (SF-36) were assessed at baseline and post-intervention. Data were analyzed using the Shapiro–Wilk test, paired t-test, and Wilcoxon signed-rank test. **Results**: Statistically significant improvements ($p < 0.001$) were observed across all evaluated parameters. Participants demonstrated increased maximum mouth opening and tongue mobility, along with decreased pain intensity and improved quality of life following the intervention. **Conclusions**: This pilot study provides preliminary evidence that short-term OMT can yield measurable functional improvements and pain reduction in adults with TMD and associated OMDs. These findings underscore the relevance of addressing orofacial myofunctional impairments as part of the biological dimension within the biopsychosocial model and support the integration of OMT into interdisciplinary TMD management.

Keywords: orofacial myofunctional therapy; temporomandibular disorders; myofunctional disorders; orofacial dysfunction

1. Introduction

Temporomandibular joint disorders (TMDs) comprise a heterogenous group of conditions affecting the masticatory system, including the temporomandibular joints (TMJs), associated muscles, and the surrounding neural and connective structures [1,2]. Clinical manifestations typically include pain, joint sounds, abnormal jaw mobility and masticatory muscle tension [3,4]. According to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), myogenous TMDs (M-TMDs) are classified by the pattern and distribution of pain elicited during examination, including myalgia, local myalgia, myofascial pain, and myofascial pain with referral [5,6]. Temporomandibular disorders (TMDs) are among the most prevalent musculoskeletal conditions, currently affecting approximately 34% of the population, with projections suggesting an increase to 44% by 2050 [7]. Their multifactorial etiology and increasing prevalence underline the clinical relevance of early, function-oriented management.

The current understanding of TMDs is grounded in the biopsychosocial model, which integrates biological, psychological, and social dimensions of disease (Figure 1). Figure 1 illustrates how biological, psychological, and social factors interact in the onset and persistence of TMD. Psychological stress and parafunctional habits (e.g., clenching, bruxism) can increase muscular tension, while social and lifestyle components (e.g., occupational strain, dietary habits) influence compensatory oral behaviors.

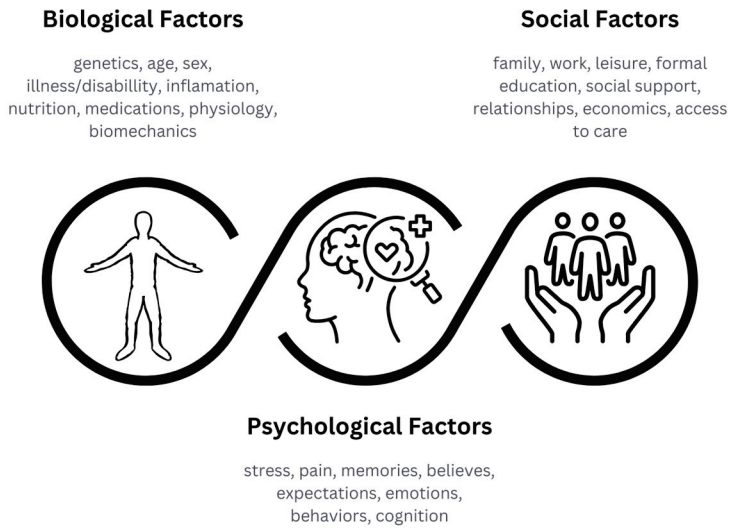


Figure 1. Biopsychosocial model of temporomandibular joint disorders (TMDs). The model illustrates the interaction of biological, psychological and social factors contributing to the onset and maintenance of temporomandibular dysfunction. Original figure by the authors, conceptually adapted from Engel's biopsychosocial model [8].

Within this multidimensional framework, orofacial myofunctional disorders (OMDs) are recognized as a relevant biological component contributing to the onset and persistence of TMDs. OMDs involve structural and functional disturbances of the lips, jaw, tongue, and oropharynx that can influence or condition the normal development and function [9]. They manifest through dysfunctional respiration, atypical oral resting posture, impaired mastication and deglutition, and asymmetric muscular activity, all of which can disrupt the equilibrium of the stomatognathic system and contribute to musculoskeletal strain within the TMJ complex. In this study, OMDs were operationally defined based on dysfunctional orofacial resting posture, restricted tongue mobility (TRMR values below normative references), and impaired mastication or swallowing confirmed during structured clinical myofunctional assessment.

OMDs often arise from maladaptive patterns such as chronic mouth breathing or insufficient nasal breathing, which can lead to altered craniofacial growth and malocclusion [9,10]. The relationship between OMDs and TMDs is illustrated in Figure 2. Physiologically, OMD and TMD are interrelated through compensatory muscle activity and altered proprioceptive feedback within the orofacial system. Dysfunctional tongue and jaw postures can increase tension in the elevator and suprahyoid muscles, modify mandibular kinematics and occlusal loading, and elevate temporomandibular joint stress. Persistent imbalance of orofacial muscle tone may disrupt the coupling among breathing, mastication, and swallowing, promoting myogenous pain and functional limitation.

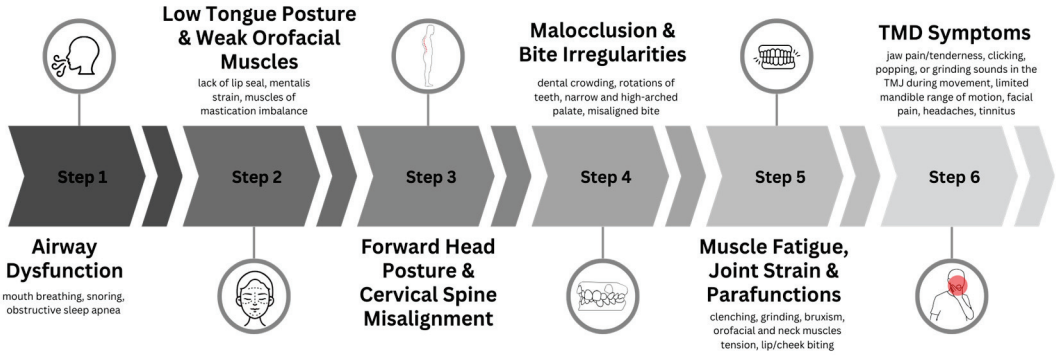


Figure 2. Hypothetical mechanism linking myofunctional disorders (OMDs) to temporomandibular disorders (TMDs).

Their multifactorial origin includes learned behaviors, anatomical deviations, genetic predispositions, and environmental factors [9,11,12]. OMDs have been associated with restricted tongue mobility (ankyloglossia), obstructive sleep apnea (OSA), bruxism, and postural alterations including forward head posture [13–20]. These dysfunctions necessitate targeted therapeutic interventions [20–22].

Orofacial myofunctional therapy (OMT) is a structured, exercise-based approach aimed at re-educating the neuromuscular patterns of the orofacial system to restore balanced muscle function and physiological resting posture. OMT may influence both peripheral and central neuromuscular processes, although causal mechanisms cannot be determined from this pilot study. Further neuroimaging research in this field is highly warranted.

An overview of OMT objectives is presented in Figure 3.

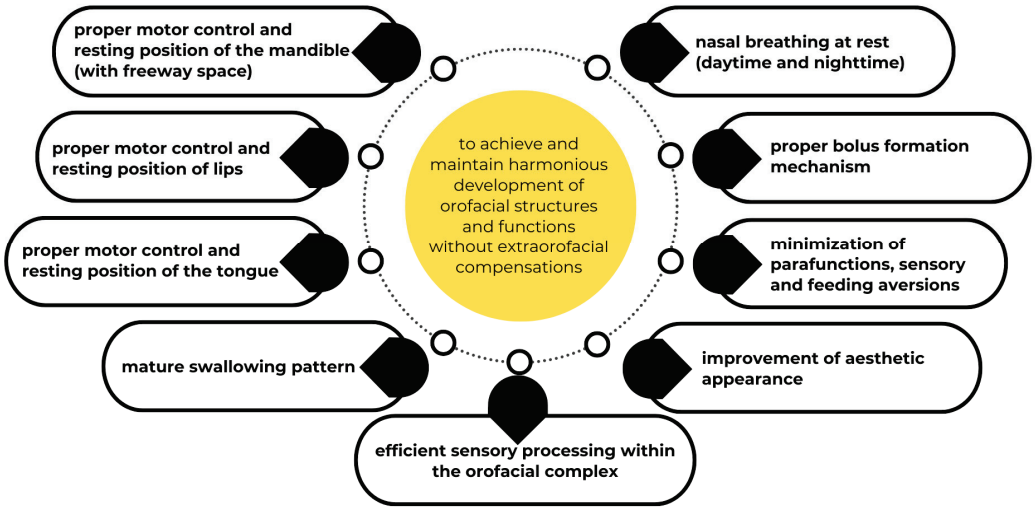


Figure 3. Goals of orofacial myofunctional therapy (OMT).

Given the shared musculature and neural pathways involved in mastication, swallowing, and breathing, dysfunction in one component may influence the others. OMDs can therefore maintain or exacerbate TMD symptoms.

Previous studies have indicated that OMT may improve mandibular range of motion, tongue mobility, and pain perception, as well as alleviating otologic symptoms associated with TMD [23–29]. OMT thus represents a potential non-invasive, function-oriented approach that complements conventional dental, orthopedic, and physiotherapeutic interventions.

Despite growing clinical use of OMT, evidence supporting its effectiveness in adults with myogenous TMD remains limited. Most studies present substantial methodological variability and clear gaps that justify our pilot design. Existing OMT studies [23,24,26,27] include inconsistent protocols and typically omit components that are essential in myofunctional rehabilitation, such as orofacial awareness training, muscle–fascial relaxation work, and structured self-massage, all of which are integral to our protocol. These methodological gaps justify the need for exploratory pilot data to support future controlled research. Therefore, this pilot study sought to explore the potential impact of OMT on pain and function in adults with TMD. The present pilot study aimed to assess the effectiveness of structured OMT protocol in adults with myogenous TMD and coexisting OMDs. Specifically, it investigated changes in mandibular and tongue mobility, pain intensity and self-reported quality of life (QoL) following a short-term intervention. Based on this rationale, the null hypothesis was that there would be no significant pre- to post-intervention changes in mandibular mobility, tongue mobility, pain intensity or self-reported quality of life. The study further sought to provide preliminary evidence supporting the integration of OMT into interdisciplinary management of TMD within the biopsychosocial framework.

2. Materials and Methods

2.1. Study Design

This pilot study employed a prospective interventional design to evaluate the effects of structured orofacial myofunctional therapy (OMT) protocol on functional and subjective outcomes in adults with myogenous temporomandibular disorders (TMDs) and coexisting orofacial myofunctional disorders (OMDs). The study was conducted between July and October 2025 in private practice in Zabrze, Poland. Each participant completed three therapeutic sessions spaced two weeks apart. Measurements were obtained immediately before and after each session to capture both cumulative and session-specific effects.

2.2. Participants

Twenty-five adults (both men and women) aged 25–39 years were recruited. All participants had a confirmed diagnosis of myogenous TMD with a muscular pain component (ICD-9: 729.1-myalgia, localized myalgia, or myofascial pain) based on DC/TMD criteria, established by a dentist trained in DC/TMD assessment prior to referral, and presented with coexisting OMDs. The DC/TMD distinction between local myalgia, myofascial pain and myofascial pain with referral was applied during diagnostic classification. The presence of OMDs was verified using a structured clinical myofunctional assessment including evaluation of tongue mobility (TRMR), orofacial resting posture, mastication and swallowing, aligned with current international consensus recommendations. Exclusion criteria included active oral infections, recent maxillofacial surgery (within six months), initiation of orthodontic treatment during the study period, and systemic or neurological conditions that influence therapy outcomes. All participants provided written informed consent prior to study inclusion. The age range of 25–39 years was chosen to ensure relative homogeneity of musculoskeletal properties and to minimize confounding age-related differences in muscle tone and tissue elasticity.

2.3. Therapeutic Intervention

All participants received treatment according to an original OMT program developed by the authors to normalize muscle balance and functional coordination in the orofacial region. While the same structured therapeutic progression was applied to all participants, the intensity and complexity of exercises were individually adapted to neuromuscular capacity in accordance with established principles of myofunctional therapy. Each participant attended three therapy sessions over a four-week period (one session every two weeks). Each session lasted approximately 30 min and followed the same structured sequence. Exercise intensity and complexity were progressively adjusted according to individual performance. Home exercises were supported by written and video instructions, and compliance was verified through exercise logs reviewed at each session. The same licensed speech-language pathologist conducted all sessions to ensure methodological consistency. The intervention consisted of five integrated components:

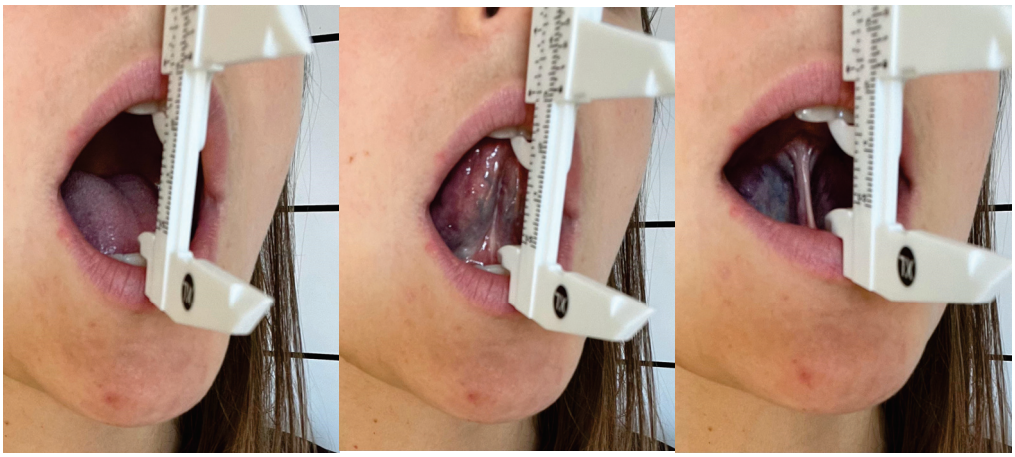
1. Awareness and mindfulness training: Participants were educated on physiological versus dysfunctional orofacial patterns and introduced to breathing awareness and orofacial mindfulness, both during in-office sessions and at home.
2. Logopedic Myofascial Massage: Manual myofascial release techniques targeted soft-tissue restrictions in the shoulder girdle, neck, suprahyoid region, and masticatory and facial muscles. The logopedic myofascial massage used in this study represents an adaptation of classical myofascial release techniques for the orofacial region, designed and applied by a speech-language pathologist trained in manual therapy.
3. Oromotor training: passive, active, and resistance exercises were applied to enhance range, precision, and strength of movements of the lips, tongue, and mandible. Exercises were adapted to individual functional capacities.
4. Functional Re-education: Training focused on restoring physiological orofacial functions, including nasal–diaphragmatic breathing (Buteyko method), mandibular stabilization and dissociation, bilateral mastication, physiological swallowing and physiological resting posture of the tongue, lips, and mandible with freeway space [30,31]. These components were introduced in a progressive sequence, prioritizing breathing normalization before masticatory and swallowing re-education to support coherent neuromuscular integration.
5. Habituation and self-therapy: Participants received an individualized home program to reinforce newly acquired motor patterns through daily self-massage and consolidation exercises. The habituation phase lasted approximately two weeks after completion of the in-office sessions. Participants were contacted once by phone to verify stability and continued adherence. Adherence was monitored through daily exercise logs and self-reports collected at each session. Participants were instructed to record frequency and duration of home practice to ensure consistency in exercise performance. The applied OMT protocol extended the established approach proposed by de Felício et al. which provide structured frameworks for orofacial myofunctional retraining [23].

2.4. Measurement Protocol

Outcome measures included tongue and mandibular mobility, pain intensity, and self-reported quality of life. All assessments were conducted by the same examiner under standardized conditions:

- Maximum mouth opening (MAX): The interincisal distance (mm) was measured with a caliper before and after each therapy session. (Figure 4a). Maximum mouth opening was measured actively. Participants were instructed to stop before pain occurred to ensure measurement safety.

- Tongue Range of Motion Ratio (TRMR): Two indices were recorded—TRMR-TIP (tongue tip to incisive papilla: Figure 4b) and TRMR-LPS (lingual-palatal suction: Figure 4c)—following the methods of Zaghi et al. [32]. Values were expressed in millimeters and represented the ratio between maximum mouth opening and tongue elevation tasks. Each measurement was repeated three times with participants seated upright; the mean value was used for analysis. Intraclass correlation coefficients (ICC) were calculated, indicating excellent reliability (ICC > 0.90).
- Visual Analogue Scale (VAS): Participants rated intensity on a 10-point scale at base and after the third session.
- SF-36 Questionnaire [33]: Self-reported quality of life was evaluated before the first and after the third therapy session. Lower scores indicated a better perceived quality of life. In this pilot context, the global SF-36 score was used to provide an overall proxy of health-related quality of life while minimizing respondent burden and enabling preliminary feasibility assessment.



(**a**) (**b**) (**c**)

Figure 4. (**a**) Measurement of MAX; (**b**) Measurement of tongue tip to the incisive papilla—TIP; (**c**) Measurement of tongue in lingual-palatal suction—LPS.

All measurements were performed twice and averaged. Intra-rater reliability, assessed by repeated measurements in five randomly selected participants, exceeded 95%.

2.5. Statistical Analysis

All analyses were performed using Statistica 13.3 (StatSoft Inc., Tulsa, OK, USA). Normality was verified with the Shapiro–Wilk test. For normally distributed data, paired *t*-tests were applied; for non-normal data, Wilcoxon signed-rank tests were used. Effect sizes (Cohen's d) and 95% confidence intervals (CI) were calculated and interpreted using thresholds for TMD research (small = 0.10, medium = 0.30, large = 0.70). CI interpretation followed established recommendations [34]. Significance was set at $p < 0.05$.

3. Results

All 25 participants completed the three sessions and associated assessments. Statistical analyses were associated with improvements across all measured parameters.

3.1. Changes in Mandibular Mobility

A progressive increase in maximum mouth opening (MAX) was observed over the course of therapy. Median values rose from 45 mm before the first session to 47 mm after session one, with continued improvement across subsequent sessions (Figure 5). Analyses of maximum jaw opening across the three therapy sessions revealed consistently large

and statistically significant effects ($p < 0.0001$). Because the data did not meet normality assumptions for any of the sessions, all comparisons were conducted using the Wilcoxon signed-rank test. The first therapy session showed a substantial increase in maximum jaw opening, with an effect size of d = 1.20 (95% CI: 0.79–1.62). An even larger effect was observed following the second therapy session (d = 1.39; 95% CI: 0.98–1.80), representing the most pronounced improvement in the series. The third session also yielded a large effect, with d = 1.16 (95% CI: 0.75–1.58). Collectively, these findings indicate robust and clinically meaningful gains in maximum jaw opening across all stages of therapy.

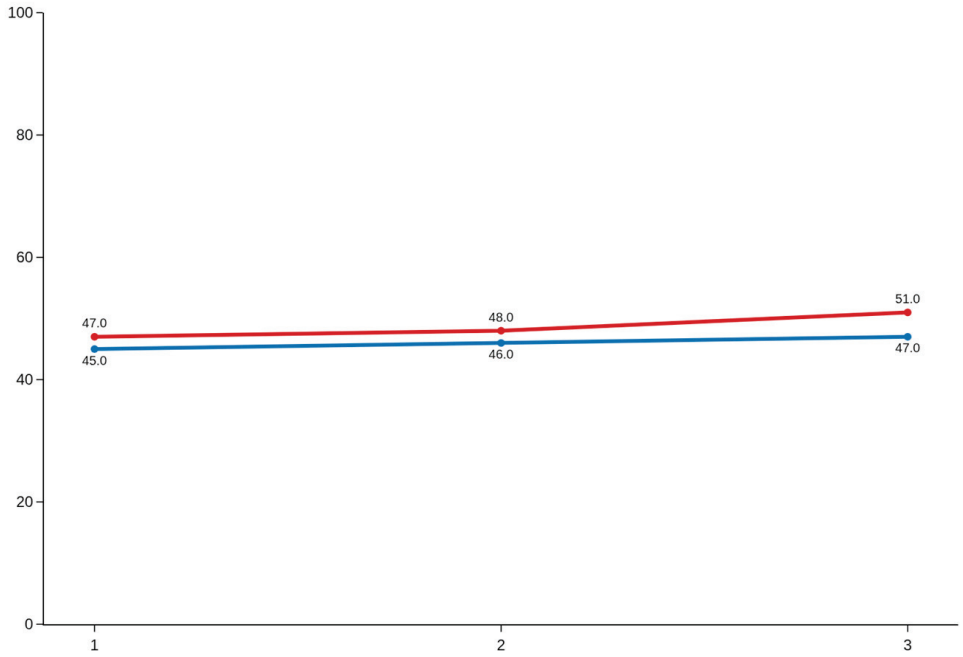


Figure 5. MAX [mm] along 3 sessions; blue line—before, red line—after.

As objective myofunctional biomarkers remain limited, quantifiable measures such as mandibular range of motion continue to serve as useful indirect indicators of short-term neuromuscular responsiveness. Even minimal changes may reflect early adaptive processes within the masticatory muscles, especially when assessed systematically across multiple sessions. This pattern suggests potential functional enhancement in mandibular mobility. In individuals with myogenous TMD, even modest increases in maximum mouth opening are considered clinically meaningful because improvements typically reflect reduced pain-related guarding and enhanced functional mandibular mobility.

3.2. Changes in Tongue Mobility

Significant improvements were also noted in tongue range of motion. For TRMR-TIP, paired t-tests indicated statistically significant changes at all time points, with medium effect sizes: d = 0.76 (95% CI: 0.35–1.18) for session 1, d = 0.57 (95% CI: 0.16–0.98) for session 2, and d = 0.53 (95% CI: 0.12–0.95) for session 3 (Figure 6). Even larger effects were observed for TRMR-LPS. Although the first comparison required a Wilcoxon signed-rank test due to non-normality, the resulting effect size remained substantial (d = 1.14; 95% CI: 0.73–1.55). Significant improvements were also noted for session 2 and 3, with paired *t*-tests yielding large effect sizes of d = 0.96 (95% CI: 0.55–1.38) and d = 1.16 (95% CI: 0.75–1.57), respectively (Figure 7). Overall, the data indicate robust and consistent enhancement in tongue mobility across sessions, particularly for the lingual–palatal suction measure.

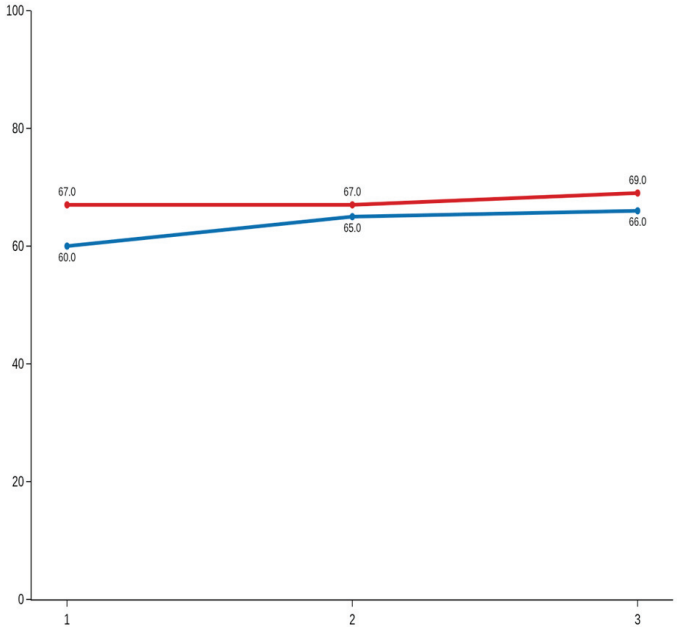


Figure 6. TRMR-TIP [%] along 3 sessions; blue line—before, red line—after.

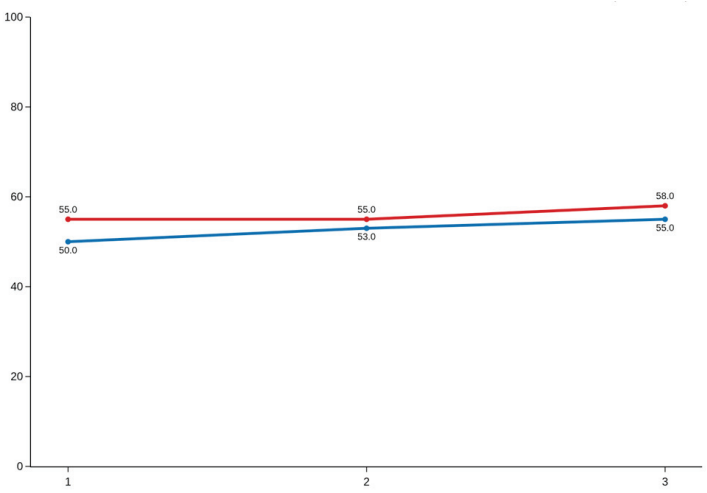


Figure 7. TRMR-LPS [%] along 3 sessions; blue line—before, red line—after.

These results demonstrate a consistent session-by-session improvement in lingual mobility and functional control, without evidence of regression between sessions. These mobility improvements may reflect reduced pain-related guarding and enhanced motor control, even if patients do not yet perceive changes in maximum opening as functional improvements.

3.3. Pain Intensity and Quality of Life

Pain intensity, measured by the Visual Analogue Scale (VAS), decreased systematically throughout the study period, while SF-36 scores reflected improved self-reported quality of life. For all comparisons, $p < 0.001$. Tables 1 and 2 summarize the findings. The data has been updated and completed as requested. The reduction in VAS scores following OMT was not only statistically significant but also clinically substantial. The paired-samples effect size was exceptionally large (Cohen's d = −2.62, 95% CI [−3.77, −2.07]), indicating a robust and consistent shift toward lower pain intensity across participants. The corresponding effect size expressed as r (0.94) likewise reflects a very strong association between the intervention and the observed change. Taking together with the descriptive statistics shown in Table 1,

these results suggest that the analgesic response to OMT was both pronounced and broadly shared within the cohort. A similarly strong pattern emerged for the SF-36 scores, where improvements in self-reported quality of life were marked by an even larger effect size. The magnitude of change (Cohen's d = −3.71, 95% CI [−5.23, −2.93]) underscores an intervention effect of exceptional strength, with the effect size r reaching 0.97. This indicates that the post-treatment shift was not only statistically reliable but also pervasive across individuals. In line with the descriptive trends presented in Table 2, the data point to a meaningful enhancement in perceived functional well-being following OMT, consistent with a substantial therapeutic impact.

Table 1. VAS scores before and after OMT.

Measurement	Median	Minimum	Maximum	SD
VAS before OMT	7	5	9	1.15
VAS after OMT	4	1	7	1.38

Table 2. SF-36 scores before and after OMT.

Measurement	Median	Minimum	Maximum	SD
SF-36 before OMT	28	21	47	6.83
SF-36 after OMT	19	13	38	6.83

The results demonstrate statistically significant gains in mandibular opening and tongue mobility following OMT accompanied by marked reductions in pain and perceived well-being. The magnitude and consistency of these changes support the clinical relevance of the intervention and reduce the likelihood that the outcomes resulted from random variation.

4. Discussion

This pilot study suggests that a short-term, structured orofacial myofunctional therapy (OMT) program may be associated with functional and symptomatic improvements in adults with myogenous temporomandibular disorders (TMD) and coexisting orofacial myofunctional disorders (OMD). OMT appears to exert a multidimensional influence through neuromuscular rebalancing and improved integration of stomatognathic subsystems. Medium and large effect sizes were primarily observed for tongue mobility and pain reduction, suggesting that these domains may be most sensitive to short-term OMT. The consistent upward trends in mandibular and lingual mobility after each session may indicate neuromuscular adaptations, although causal inferences cannot be drawn in the absence of a control group. These results are comparable in magnitude to improvements reported in physiotherapy-based interventions for TMD, but OMT differs by focusing on neuromuscular re-education rather than joint mobilization or passive tissue manipulation. This distinction underscores the functional nature of OMT and its potential to complement manual therapies within multimodal programs. The observed effects should be interpreted with caution due to the limited sample size and absence of randomization.

The findings align with previous reports by de Felicio et al. [23,24] and Melis et al. [25], who documented similar gains in mandibular function and pain reduction following structured orofacial exercises. Improvements in tongue mobility are particularly noteworthy, given that limited lingual range of motion and atypical tongue posture are frequently implicated in maintaining TMD-related dysfunction. The results reinforce the hypothesis that OMDs not only coexist with TMDs but may act as perpetuating factors within the

pathophysiological mechanism. Integrating consistent cognitive-behavioral and functional-behavioral strategies may further support sustainable neuromuscular re-education as long-term adherence within interdisciplinary care models.

From the clinical standpoint, the integration of OMT into interdisciplinary care appears justified. Addressing muscular imbalance, atypical postures, and dysfunctional breathing or swallowing patterns provides a biological foundation for sustainable recovery. Combining OMT with dental, orthopedic, and physiotherapeutic approaches may enhance functional restoration and prevent relapses by targeting both structural and neuromuscular dimensions. This integrative perspective corresponds with the biopsychosocial model, emphasizing interaction among physiological, behavioral, and environmental components. In practical terms, OMT can be integrated into interdisciplinary orofacial pain clinics, dental rehabilitation programs, or speech therapy settings. Effective implementation requires professional training in orofacial myofunctional assessment, coordinated referral pathways, and structured collaboration between speech-language pathologists, dentists, and physiotherapists. The functional gains observed may reflect sensorimotor recalibration involving both peripheral and central mechanisms. Neuroimaging studies have demonstrated cortical plasticity in orofacial motor and somatosensory cortices following targeted oral exercises, supporting the hypothesis of central adaptation through repeated neuromuscular activation [35].

Several limitations must be acknowledged. The absence of a control group prevents exclusion of placebo or other non-specific treatment effects, and the same clinician conducted both therapy and assessments, which may introduce measurement bias. No blinding procedures were implemented, and a Hawthorne effect related to participant motivation cannot be excluded. The short observation period does not allow conclusions regarding long-term stability of the outcomes, and the homogeneous, relatively young sample limits generalizability. Applying DC/TDM classification, including Axis I and Axis II, is essential since psychosocial factors may influence therapeutic outcomes [5]. Furthermore, the single-arm design prevents differentiation of specific contributions of the myofascial massage component versus the functional exercise component. Future research should therefore adopt randomized controlled designs with larger and more diverse samples, follow-up measurements, and objective measures such as surface electromyography or motion-tracking analysis to better elucidate underlying neuromuscular mechanisms. Standardized, evidence-based OMT protocols will also be essential to enable replication and strengthen evidence synthesis across studies.

5. Conclusions

This pilot study demonstrated that a brief course of structured orofacial myofunctional therapy (OMT) can yield clinically and statistically significant improvements in tongue and mandibular mobility, accompanied by reduced pain intensity and enhanced quality of life in adults with temporomandibular disorders (TMDs) and coexisting orofacial myofunctional disorders (OMDs). These findings highlight the relevance of neuromuscular re-education within the orofacial system as part of a comprehensive, interdisciplinary treatment approach. Orofacial myofunctional disturbances should be regarded as meaningful biological contributors within the biopsychosocial framework of TMD. Their systematic identification and targeted management can complement conventional dental, physiotherapeutic, and behavioral strategies, potentially enhancing functional recovery and patient well-being.

Further controlled and longitudinal studies are required to confirm the durability of these outcomes, define standardized therapeutic protocols, and explore the physiological mechanisms underlying the efficacy of OMT in temporomandibular rehabilitation. Establishing evidence-based clinical guidelines will be essential for integrating OMT into

mainstream interdisciplinary care for TMD. The present results emphasize that restoration of neuromuscular function, rather than symptomatic relief alone, should be regarded as a primary therapeutic goal in TMD rehabilitation.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Silesia in Katowice, Poland (KEUS/O/21/11.2024, approval date 8 December 2024).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Relevant data underlying the findings of this study can be obtained from the corresponding author, Paulina Czarnecka, upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

TMD	Temporomandibular Disorders
OMD	Orofacial Myofunctional Disorders
OMT	Orofacial Myofunctional Therapy
TRMR	Tongue Range of Motion Ratio
TIP	Tongue to Incisive Papilla
LPS	Lingual Palatal Suction
MAX	Maximum mouth opening
VAS	Visual Analogue Scale

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Article

Associations Between Anteroposterior Occlusal Class, Musculoskeletal Pain Patterns, and Temporomandibular Disorders in Young Adults: A Cross-Sectional Study

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Abstract

Background: The relationship between sagittal malocclusion, temporomandibular disorders (TMD), and musculoskeletal pain remains uncertain. **Methods**: Cross-sectional study (April 2020–August 2021) in Małopolska, Poland. Ninety participants (ages 19–35) were classified into Angle Classes I–III (n = 30 each) and examined using RDC/TMD (Axis I/II). A proprietary, nonvalidated, piloted whole-body pain-map questionnaire, presented in anterior and posterior views and subdividing the body into predefined craniofacial, spinal, and limb regions, was used to capture pain presence, Numerical Rating Scale (NRS, 0–10) scores by region, and the total number of painful sites. Group differences were analyzed using χ^2 and Kruskal–Wallis tests with corresponding effect sizes (measures of association strength). For NRS outcomes, a minimal clinically important difference (MCID)—defined as the smallest difference in NRS considered clinically relevant—was prespecified as approximately 1 point. **Results**: Occlusal class was not associated with TMD Axis I prevalence. However, sagittal malocclusion—particularly Class III—was linked to a less favorable pain profile. Left temporal pain was more frequent in Class III than in Classes I–II (p = 0.024, Cramér's V = 0.31, medium effect), and cervical spine pain occurred more often in malocclusion groups than in Class I (p = 0.043, Cramér's V = 0.26, small effect), indicating statistically significant associations. Cervical pain intensity was higher in Classes II–III than in Class I, with a pooled mean difference—defined as the difference in mean NRS between the combined Classes II–III and Class I—of 1.23 NRS points (95% CI 0.38–2.08), exceeding the ≈1-point MCID and suggesting a clinically important burden. The total number of painful sites was also greater in Class III than in Class I (p = 0.023, η^2 = 0.09; Δ = 1.40 sites, 95% CI 0.39–2.41), which indicates a statistically significant association with a medium effect size and a higher overall pain burden. **Conclusions**: Sagittal occlusal class was not associated with TMD diagnosis, but malocclusion—especially Class III—was associated with a more unfavorable craniofacial pain pattern and higher cervical pain burden ($p \leq 0.05$), with effects of potential clinical relevance.

Keywords: malocclusion; temporomandibular disorders; craniofacial pain; cervical spine pain; pain intensity

1. Introduction

Modern medicine increasingly emphasizes an interdisciplinary approach to the diagnosis and treatment of complex disorders. Building on this paradigm, structured care pathways for complex craniofacial conditions explicitly link dentistry with physiotherapy, neurology, otolaryngology (ENT), sleep medicine, and pain psychology [1]. In parallel, orofacial pain has been established as a formal dental specialty, thereby consolidating team-based care and shared standards across these disciplines [2]. This integration is grounded in a biopsychosocial perspective, which views pain and dysfunction as emerging from interacting biological, psychological, and social determinants and therefore supports conservative, multimodal treatment plans delivered by interdisciplinary teams. This biopsychosocial framework is also embedded in contemporary diagnostic criteria, including the DC/TMD, which integrates physical and psychosocial assessment to guide coordinated, conservative care [3]. Abnormalities of the stomatognathic system—including malocclusions and temporomandibular joint (TMJ) dysfunctions—are common health concerns in contemporary society [4,5]. An expanding body of literature highlights the potential coexistence of these conditions and their consequences, not only for the head and neck region but also for more distal body structures [6–8].

Malocclusions rank among the most prevalent dentofacial conditions in the general population. A recent systematic review and meta-analysis reports continent-specific estimates—Africa 81%, Europe 72%, the Americas 53%, and Asia 48%—with a pooled global prevalence of approximately 54% [4]. Longitudinal cohort studies indicate that malocclusion severity tends to worsen from adolescence into mid-adulthood, with measurable changes in occlusal traits between ages 15 and 45 years [9,10]. Beyond their high prevalence, malocclusions may compromise fundamental physiological functions such as respiration, mastication, and biting. Reported sequelae also include speech disturbances, snoring, obstructive sleep apnea, dental trauma, periodontal disease, and degenerative changes in the TMJ. In addition to these functional and systemic effects, malocclusions exert a significant psychosocial burden by impairing facial and dental esthetics, thereby negatively influencing self-esteem and overall quality of life [11,12].

In epidemiological terms, temporomandibular disorders (TMDs) likewise show marked geographical variation, with pooled prevalence reported as higher in South America (47%) than in Asia (33%) and Europe (29%) [5]. Complementing these cross-sectional differences, time-trend analyses indicate an increase in TMD prevalence in recent years [13].

Some researchers have suggested that malocclusal abnormalities may be associated with alterations in the musculoskeletal system as a whole, including chronic pain and postural defects [14–17]. Despite numerous investigations into the relationship between malocclusions, temporomandibular disorders, and musculoskeletal pain, the evidence remains inconsistent. While some studies report significant associations [6,17–19], others fail to provide conclusive results [20–22]. This inconsistency may result from methodological heterogeneity, varied diagnostic protocols, and limited interdisciplinary approaches. Moreover, recent research indicates that additional factors—including psychological stress, genetic predisposition, and lifestyle—may play equally important roles in the etiology and expression of TMD [23].

The mechanisms that might link malocclusions with TMD and musculoskeletal pain are complex and multifactorial. One explanatory model—the biomechanical theory—proposes that malocclusions may contribute to uneven force distribution during mandibular movements, potentially leading to overload and microtrauma in the TMJ and, over time, degenerative changes. Another model—the neurophysiological theory—suggests that altered occlusion may be associated with abnormal activation of masticatory and perioral muscles, with pain reported along myofascial chains extending

to the cervical spine and even more distant structures [24]. Electromyographic studies are consistent with these hypotheses, reporting increased muscular activity in cervical and shoulder regions in patients with malocclusions [25], as well as a higher prevalence of headaches and neck and shoulder pain among this group [26]. Saito et al. [27] further suggested that, once compensatory mechanisms are exceeded, altered alignment of these body regions may occur, potentially increasing overload and adversely affecting the musculoskeletal system as a whole.

Although malocclusions are widely recognized as common dental conditions with functional and psychosocial consequences, their relationship with temporomandibular disorders and pain-related musculoskeletal symptoms remains unclear. This inconsistency underscores the need for further interdisciplinary research that integrates dental and musculoskeletal perspectives.

Therefore, the aim of the present study was to evaluate the coexistence of anteroposterior malocclusions with temporomandibular disorders and pain-related symptoms in the musculoskeletal system in young adults. We hypothesized that anteroposterior malocclusions (Angle Classes II/III) would co-occur with temporomandibular disorders and a higher burden of pain-related musculoskeletal symptoms, particularly within the upper quarter (head, cervical region, shoulder girdle).

2. Materials and Methods

2.1. Study Design, Recruitment and Participants

This study employed a cross-sectional observational design and was conducted between April 2020 and August 2021 in the Małopolska region, Poland. Participants were recruited primarily from universities in Kraków and a local dental clinic using a convenience sampling approach. Eligibility spanned 18–35 years; however, all enrolled participants were aged 19–35 years [28,29].

Inclusion criteria comprised (1) age 18–35 years, (2) presence of at least 28 permanent teeth, and (3) diagnosis of Angle's Class I, II, or III malocclusion. Exclusion criteria were: (1) ongoing orthodontic treatment, (2) neurological disorders affecting the central or peripheral nervous system, (3) physician-diagnosed chronic systemic musculoskeletal disorders such as rheumatoid arthritis, ankylosing spondylitis, other spondyloarthritis, generalized osteoarthritis, inflammatory myopathies, fibromyalgia or other chronic widespread pain syndromes, (4) permanent locomotor system injuries or major post-traumatic muscle or tendon injuries leading to persistent structural changes, functional deficit or chronic pain (for example, post-traumatic joint ankylosis, joint replacement, chronic massive rotator cuff tear, spinal fusion), and (5) regular use of analgesic medication or centrally acting muscle relaxants for pain control. All enrolled participants were additionally instructed to refrain from taking any analgesic medication immediately before the clinical examination.

Out of 420 individuals examined, a total of 90 participants (52 women and 38 men) were ultimately enrolled in the study. Consistent with published guidance, this sample size was sufficient to detect large effect sizes with 90% power at $\alpha = 0.05$ for the planned between-group comparisons across the three occlusal classes [30]. Given the exploratory nature of the study and feasibility constraints in recruiting well-characterized young adults in three occlusal groups, the study was a priori powered to detect large between-class differences in TMD- and pain-related outcomes; smaller or moderate effects may not have been reliably detected. Participants were divided into three groups according to the diagnosed occlusal class. Occlusal class was determined clinically according to Angle's criteria based on the first permanent molar relationship [31]. Group I included 30 participants (17 women, 13 men) with Angle's Class I, Group II included 30 participants (16 women, 14 men) with

distal occlusion (Angle's Class II), and Group III included 30 participants (19 women, 11 men) with mesial occlusion (Angle's Class III) (Table 1).

Table 1. Basic demographic characteristics of the study participants.

Group	N	Age [Years], Mean ± SD (Range)	Body Height [cm], Mean ± SD (Range)	Body Weight [kg], Mean ± SD (Range)
I (Angle Class I)	30	22.6 ± 3.1 (19–32)	171.7 ± 9.2 (155–192)	67.3 ± 10.8 (47–90)
II (Angle Class II)	30	23.9 ± 4.2 (19–35)	172.8 ± 7.5 (157–183)	66.9 ± 11.2 (48–91)
III (Angle Class III)	30	22.8 ± 2.9 (20–30)	170.9 ± 8.1 (157–186)	68.2 ± 13.4 (48–100)

N—number of participants; SD—standard deviation; cm—centimeters; kg—kilograms.

The study was conducted in accordance with the Declaration of Helsinki, and its protocol was approved by the Bioethics Committee of the District Medical Chamber in Kraków (No. 35/KBL/OIL/2019). All participants provided written informed consent prior to inclusion.

2.2. Clinical Procedures and Outcome Measures

The procedure involved a clinical assessment of occlusion and classification according to Angle's system, followed by a functional examination of the stomatognathic system performed in accordance with the RDC/TMD protocol (Axis I and II). This included standardized evaluation of the temporomandibular joints. Axis II grading referred to the Graded Chronic Pain Scale (GCPS v1.0) embedded within RDC/TMD [32,33]. All examinations were carried out by the same prosthodontist, trained in the application of the RDC/TMD protocol.

Because a clinically implemented, language-adapted DC/TMD protocol was not available in our setting at the time of data collection (April 2020–August 2021), the RDC/TMD (Axis I/II) was used [34]. DC/TMD offers higher diagnostic validity and inter-examiner reliability for pain-related TMD; this is acknowledged as a study limitation. Using this standardized clinical protocol, participants were classified into three primary diagnostic groups: Group I (myofascial pain), Group II (disk displacement), and Group III (arthralgia/arthritis/degenerative joint disease).

A proprietary body-map questionnaire (anterior/posterior views) was developed specifically for this study to capture the presence and intensity of musculoskeletal pain. The layout was adapted from commonly used whole-body pain drawings and body maps for multisite musculoskeletal pain assessment, with the body surface subdivided into predefined anatomical regions (head/face subregions; cervical, thoracic, lumbar and sacroiliac spine; upper and lower limbs) [35]. Head/face subregions included the forehead, temples (left/right), TMJ (left/right), cheeks (left/right), occiput, chin, and vertex. For each region, participants were instructed to mark current pain sites directly on the silhouette and to assign a numerical rating (0–10) next to each marked area (NRS).

The development process comprised several steps. First, the research team defined the set of regions and their graphical boundaries to balance anatomical detail with feasibility of scoring. Second, the preliminary version of the body-map was piloted in a convenience sample of 20 young adults from the same age range as the study population to assess clarity of the instructions, recognizability of regions and overall usability. Participants were asked to complete the map and report any ambiguities or difficulties; minor wording changes and graphic adjustments were made based on this feedback. Third, two independent examiners applied the planned scoring procedure to a subset of completed pilot maps to standardize how marked areas were translated into regional yes/no variables and numeric pain scores; discrepancies were discussed and resolved to produce a final coding manual. In the main study, participants received standardized written and verbal instructions on

how to complete the body-map. The primary derived variables were: presence of pain by region (yes/no), NRS intensity by region (0–10 for each marked region) and the total count of painful sites. As the instrument has not undergone formal validation, its use is considered a limitation of the study.

Pain intensity was assessed using the Numerical Rating Scale (NRS), a simple and sensitive tool for the subjective evaluation of pain severity. Study participants indicated the intensity of their pain on a scale from 0 to 10, where 0 represented no pain and 10 denoted the worst imaginable pain. The NRS is characterized by high test–retest reliability and ease of application, which makes it widely used in clinical research and in the assessment of pain intensity [36]. To aid clinical interpretation of NRS (0–10) differences, we prespecified the minimal clinically important difference (MCID) as ~1–2 points or ~30% change from baseline, consistent with established methodological work in chronic pain; in between-group analyses, contrasts $\geq$1.0 point were interpreted as potentially clinically relevant alongside statistical significance and 95% CIs [37,38].

Reporting followed the STROBE guidelines [39] for observational studies and complied with ICMJE and COPE recommendations.

2.3. Statistical Analysis

Analyses were conducted in R, version 4.1.1 (R Core Team, 2021) [40]. Hypothesis testing, effect-size estimation, and multiple-testing correction were performed using the rstatix package [41]. Dunn's post hoc pairwise comparisons following Kruskal–Wallis tests were obtained using the FSA and dunn.test packages [42,43]. Effect sizes and, where applicable, their 95% confidence intervals (CIs) were computed using the effectsize and DescTools packages [44], as appropriate: η^2 for Kruskal–Wallis tests; r for Dunn's post hoc tests (calculated as $r = Z/\sqrt{N}$ and interpreted as small, medium, or large according to Cohen's framework and dentistry-specific thresholds); Cramér's V for χ^2 tests; and Cohen's d for mean differences in NRS scores and the number of pain sites [30,45]. For selected proportions, absolute percentage-point differences with 95% CIs were also reported to facilitate clinical interpretation. The normality of data distributions was assessed using the Shapiro–Wilk test and visual inspection of Q–Q plots, and the homogeneity of variances was evaluated with Levene's test (base R/car) [46]. All categorical analyses were performed using χ^2 tests; expected cell frequencies were inspected to verify the assumptions of the χ^2 test. To control for multiple testing, Bonferroni correction [47] was applied to all post hoc pairwise comparisons (Dunn's tests). Bonferroni-adjusted *p*-values (p_adj) were used for inference and, for key post hoc contrasts, are reported together with effect sizes and 95% CIs. Effect-size magnitudes were interpreted as small, medium, or large: η^2 ($\approx$0.01, 0.06, 0.14), r ($\approx$0.20, 0.40, 0.70), Cramér's V ($\approx$0.10, 0.30, 0.50), and Cohen's d ($\approx$0.10, 0.40, 0.90) [30,45]. All analyses were two-tailed, and the significance level was set at $p < 0.05$.

3. Results

3.1. TMD Prevalence by Occlusal Class

Based on the measurements obtained from the RDC/TMD clinical assessment form, it was possible to diagnose and classify the participants' symptoms into one of the three groups of temporomandibular disorders: Group I—myofascial pain, Group II—disk displacement, or Group III—arthralgia, arthritis, and degenerative joint disease.

No significant associations were found between occlusal class and the presence of temporomandibular disorders (all $p > 0.05$; Cramér's V = 0.07–0.20, negligible to small effects), either at the myofascial level or in relation to disk displacement and temporomandibular joint involvement (Table 2). Although these differences were not statistically significant, the

prevalence of Group I myofascial disorders was numerically higher in Class III compared with Classes I and II (Class III vs. Class I: Δ = 23.3 percentage points, 95% CI 8.0 to 38.7; Class III vs. Class II: Δ = 13.4 percentage points, 95% CI −3.5 to 30.4).

Table 2. Prevalence of TMD subtypes (RDC/TMD Axis I) across occlusal classes.

Assessed Parameter	Class I N (%)	Class II N (%)	Class III N (%)	X^2 (df)	*p*-Value	Cramér's V	Magnitude
Group I: Myofascial disorders					0.113	0.20	Small
No disorder	29 (96.7)	26 (86.7)	22 (73.3)	7.46 (4)			
Ia. Myofascial pain	1 (3.3)	4 (13.3)	7 (23.3)				
Ib. Myofascial pain with limited mouth opening	0 (0.0)	0 (0.0)	1 (3.3)				
Group II: Disk displacement (right TMJ)				2.07 (2)	0.355	0.15	Small
Absent	29 (96.7)	30 (100.0)	28 (93.3)				
IIa. Displacement without locking	1 (3.3)	0 (0.0)	2 (6.7)				
IIb. Displacement with locking and restricted range of abduction	0 (0.0)	0 (0.0)	0 (0.0)				
IIc. Displacement with locking and without restricted range of abduction	0 (0.0)	0 (0.0)	0 (0.0)				
Group II: Disk displacement (left TMJ)				0.42 (2)	0.809	0.07	Negligible
Absent	29 (96.7)	28 (93.3)	28 (93.3)				
IIa. Displacement without locking	1 (3.3)	2 (6.7)	2 (6.7)				
IIb. Displacement with locking and restricted range of abduction	0 (0.0)	0 (0.0)	0 (0.0)				
IIc. Displacement with locking and without restricted range of abduction	0 (0.0)	0 (0.0)	0 (0.0)				
Group III: Arthralgia/Arthritis/Arthrosis (right TMJ)				–	–	–	–
Absent	30 (100.0)	30 (100.0)	30 (100.0)				
IIIa. Arthralgia	0 (0.0)	0 (0.0)	0 (0.0)				
IIIb. Arthritis	0 (0.0)	0 (0.0)	0 (0.0)				
IIIc. Arthrosis	0 (0.0)	0 (0.0)	0 (0.0)				
Group III: Arthralgia/Arthritis/Arthrosis (left TMJ)				2.02 (2)	0.364	0.15	Small
Absent	30 (100.0)	29 (96.7)	30 (100.0)				
IIIa. Arthralgia	0 (0.0)	1 (3.3)	0 (0.0)				
IIIb. Arthritis	0 (0.0)	0 (0.0)	0 (0.0)				
IIIc. Arthrosis	0 (0.0)	0 (0.0)	0 (0.0)				

p-value—χ^2 test; effect size—Cramér's V (negligible < 0.10, small 0.10–0.29, medium 0.30–0.49, large ≥ 0.50); TMJ—temporomandibular joint; N—total in group.

Axis II analysis revealed significant differences in chronic craniofacial pain grades between occlusal classes ($\chi^2(4) = 11.80$, $p = 0.019$, Cramér's V = 0.26, small effect). High-

intensity chronic pain (Grade II) was most frequent in Class III (9/30; 30.0%) and less common in Class II (6/30; 20.0%), while it was absent in Class I. In contrast, low-intensity chronic pain (Grade I) was most frequent in Class I (13/30; 43.3%), compared with Class II (7/30; 23.3%) and Class III (10/30; 33.3%).

3.2. Pain Outcomes: Craniofacial and Musculoskeletal

Using a proprietary questionnaire containing a human body diagram, participants marked the locations of their current pain symptoms within the musculoskeletal system and the craniofacial region. The analysis included pain location, pain intensity (NRS), and the number of reported areas across individuals with different occlusal types.

The most frequently reported craniofacial pain sites were the occipital region and the right and left temporal regions, with the highest prevalence observed among participants with malocclusions (Table 3). Statistically significant between-class differences were observed only for the left temporal region ($p = 0.024$, Cramér's V = 0.31, medium effect; Table 3). Pain in this area was most frequently reported by individuals with Class III malocclusion and least frequently by those with normal occlusion (Class III vs. Class I +20.0 pp, 95% CI +1.8 to +38.2; Class III vs. Class II +23.3 pp, 95% CI +6.3 to +40.4). For all other craniofacial sites, no significant associations were found (all $p \geq 0.109$; Cramér's V = 0.06–0.25, negligible-to-small effects).

Table 3. Association between occlusal type and craniofacial pain.

Pain Location	Pain Occurrence			*p*-Value	Cramér's *V*	Magnitude
	Class I (N = 30)	Class II (N = 30)	Class III (N = 30)			
Forehead	3 (10.00%)	2 (6.67%)	2 (6.67%)	$p = 1.000$	0.06	negligible
TMJ Right	0 (0.00%)	1 (3.33%)	4 (13.33%)	$p = 0.122$	0.25	small
TMJ Left	2 (6.67%)	1 (3.33%)	3 (10.00%)	$p = 0.868$	0.11	small
Temple Right	3 (10.00%)	2 (6.67%)	8 (26.67%)	$p = 0.109$	0.25	small
Temple Left	2 (6.67%)	1 (3.33%)	8 (26.67%)	$p = 0.024$ *	0.31	medium
Occipital region	4 (13.33%)	8 (26.67%)	8 (26.67%)	$p = 0.358$	0.15	small
Cheek Right	0 (0.00%)	4 (13.33%)	4 (13.33%)	$p = 0.119$	0.22	small
Cheek Left	0 (0.00%)	3 (10.00%)	2 (6.67%)	$p = 0.363$	0.18	small
Chin	1 (3.33%)	0 (0.00%)	1 (3.33%)	$p = 1.000$	0.11	small
Vertex	2 (6.67%)	2 (6.67%)	1 (3.33%)	$p = 1.000$	0.07	negligible

p-value—χ^2 test; effect size—Cramér's V (negligible < 0.10, small ≥ 0.10, medium ≥ 0.30, large ≥ 0.50); TMJ—temporomandibular joint; N—total in group; * $p < 0.05$.

Subsequently, the intensity of pain in the indicated craniofacial regions was assessed using the NRS scale. Participants with Class III malocclusion demonstrated higher mean levels of perceived pain in most of the analyzed sites compared with the other groups (Table 4). Within the Class III group, the highest mean pain levels were recorded in the right and left temporal regions, whereas participants with Class I and Class II malocclusions reported the highest mean pain intensity in the occipital region.

Table 4. Pain intensity (NRS) in craniofacial regions by occlusal class.

Pain Location		Pain Intensity (NRS)			*p*-Value	η^2	Magnitude
		Class I (N = 30)	Class II (N = 30)	Class III (N = 30)			
Forehead	Mean ± SD	0.4 ± 1.3	0.4 ± 1.61	0.2 ± 0.92	$p = 0.866$	0.00	negligible
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
TMJ Right	Mean ± SD	0 ± 0	0.1 ± 0.55	0.7 ± 1.93	$p = 0.062$	0.06	medium
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
TMJ Left	Mean ± SD	0.13 ± 0.57	0.1 ± 0.55	0.53 ± 1.76	$p = 0.561$	0.01	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
Temple Right	Mean ± SD	0.4 ± 1.3	0.3 ± 1.15	1.33 ± 2.35	$p = 0.052$	0.07	medium
	Median	0	0	0			
	Quartiles	0-0	0-0	0-2.25			
Temple Left	Mean ± SD	0.43 ± 1.65	0.13 ± 0.73	1.33 ± 2.37	$p = 0.014$ * Cl.III > Cl.I, Cl.II	0.10	medium
	Median	0	0	0			
	Quartiles	0-0	0-0	0-2.25			
Occipital region	Mean ± SD	0.47 ± 1.22	1.23 ± 2.18	1.1 ± 2.07	$p = 0.292$	0.03	small
	Median	0	0	0			
	Quartiles	0-0	0-2.25	0-0.75			
Cheek Right	Mean ± SD	0 ± 0	0.5 ± 1.33	0.8 ± 2.09	$p = 0.113$	0.05	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
Cheek Left	Mean ± SD	0 ± 0	0.33 ± 1.03	0.37 ± 1.4	$p = 0.240$	0.03	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
Chin	Mean ± SD	0.07 ± 0.37	0 ± 0	0.13 ± 0.73	$p = 0.603$	0.01	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
Vertex	Mean ± SD	0.2 ± 0.76	0.43 ± 1.7	0.1 ± 0.55	$p = 0.798$	0.01	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			

p-value—Kruskal–Wallis test; effect size—η^2 (negligible <0.01, small ≈ 0.01, medium ≈ 0.06, large ≈ 0.14); * $p < 0.05$; TMJ—temporomandibular joint; N—total in group; NRS—Numerical Rating Scale.

For most sites, Kruskal–Wallis tests did not show statistically significant differences between occlusal classes (all $p \geq 0.052$; $\eta^2 = 0.00$–0.07, negligible-to-small effects; Table 4). A significant between-class difference was observed only for the left temporal region ($H(2) = 8.52$, $p = 0.014$, $\eta^2 = 0.10$, medium effect). Post hoc Dunn tests with Bonferroni correction showed higher NRS scores in Class III compared with Class II (p_adj = 0.019, r ≈ 0.29, small-to-medium effect), whereas the difference between Class III and Class I did not remain statistically significant after correction (p_adj = 0.071, r ≈ 0.24, small effect); no difference was found between Class I and Class II (p_adj = 1.000, r ≈ 0.05, negligible).

For the left temple, effect estimates for mean NRS differences were as follows: Class III vs. Class I, Δ = 0.90 points (95% CI −0.13 to +1.93; Cohen's d ≈ 0.44, medium effect) and Class III vs. Class II, Δ = 1.20 points (95% CI +0.31 to +2.09; Cohen's d ≈ 0.68, medium effect). The magnitude of these differences approaches the lower MCID bound (~1 NRS point) and should be interpreted with caution given the partial loss of statistical significance after correction and the multiple comparisons performed.

The subsequent section of the questionnaire included a human body diagram in anterior and posterior projections. For the purposes of analysis, the body was divided into the following regions: spine, trunk, upper limbs, and lower limbs. The association between occlusal class and spinal pain location was examined using chi-square tests with Cramér's V as the effect size (Table 5).

Table 5. Type of occlusion and the occurrence of pain symptoms in different regions of the spine.

Pain Location	Pain Occurrence			*p*-Value	Cramér's *V*	Magnitude
	Class I (N = 30)	Class II (N = 30)	Class III (N = 30)			
C	2 (6.67%)	9 (30.00%)	9 (30.00%)	$p = 0.043$ *	0.26	small
Th	3 (10.00%)	2 (6.67%)	4 (13.33%)	$p = 0.690$	0.09	negligible
L	4 (13.33%)	2 (6.67%)	8 (26.67%)	$p = 0.094$	0.23	small
Sacroiliac joints	0 (0.00%)	0 (0.00%)	1 (3.33%)	$p = 0.364$	0.15	small

p-value—χ^2 test; effect size—Cramér's V (negligible < 0.10, small ≥ 0.10, medium ≥ 0.30, large ≥ 0.50); C—cervical; Th—thoracic; L—lumbar; * $p < 0.05$; N—total in group.

A statistically significant difference between occlusal classes was observed only for cervical spine pain ($\chi^2(2) = 6.30$, $p = 0.043$, Cramér's V = 0.26, small effect), which was more frequent in individuals with malocclusions (Class II and Class III) than in those with Class I occlusion. For cervical pain occurrence, absolute differences vs. Class I were +23.3 percentage points for Class II (95% CI +4.7 to +42.0) and +23.3 percentage points for Class III (95% CI +4.7 to +42.0). No significant between-class differences were found for thoracic, lumbar or sacroiliac pain (all $p \geq 0.094$; V = 0.09–0.23, negligible-to-small effects).

Class III malocclusion demonstrated higher mean NRS scores in most spinal regions compared with Class I and Class II (Table 6). The association between occlusal class and spinal pain intensity was examined using Kruskal–Wallis tests with η^2 as the effect size. A statistically significant between-class difference was found for cervical spine pain ($H(2) = 6.95$, $p = 0.031$, $\eta^2 = 0.08$, medium effect). However, post hoc Dunn tests with Bonferroni correction did not identify any pairwise comparison that remained statistically significant at $\alpha = 0.05$ (Class II vs. Class I: p_adj = 0.370, r ≈ 0.16, small effect; Class III vs. Class I: p_adj = 0.232, r ≈ 0.19, small effect; Class III vs. Class II: p_adj = 1.000, r ≈ 0.02, negligible). Nevertheless, mean NRS scores suggested higher cervical pain in malocclusion groups: when Classes II and III were combined, the pooled malocclusion group showed a mean cervical NRS score of 1.43 versus 0.20 in Class I (Δ = 1.23 points, 95% CI 0.38 to 2.08; Cohen's d ≈ 0.64, medium effect). This difference exceeds the lower MCID threshold (~1 NRS point) and may indicate a clinically relevant burden; however, given that adjusted pairwise comparisons were not statistically significant and multiple pain outcomes were analyzed, this finding should be regarded as exploratory and interpreted with appropriate caution.

Table 6. Type of occlusion and pain intensity in different regions of the spine.

Pain Location		Pain Intensity (NRS)			*p*-Value	η^2	Magnitude
		Class I (N = 30)	Class II (N = 30)	Class III (N = 30)			
C	Mean ± SD	0.2 ± 0.81	1.27 ± 2.07	1.6 ± 2.54	$p = 0.031$ *	0.08	medium
	Median	0	0	0			
	Quartiles	0-0	0-3	0-4			
Th	Mean ± SD	0.43 ± 1.38	0.27 ± 1.01	0.77 ± 2.03	$p = 0.639$	0.01	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			
L	Mean ± SD	0.53 ± 1.41	0.27 ± 1.05	1.27 ± 2.23	$p = 0.077$	0.06	medium
	Median	0	0	0			
	Quartiles	0-0	0-0	0-2.25			
Sacroiliac joints	Mean ± SD	0 ± 0	0 ± 0	0.23 ± 1.28	$p = 0.368$	0.02	small
	Median	0	0	0			
	Quartiles	0-0	0-0	0-0			

p-value—Kruskal–Wallis test; effect size—η^2 (small ≈ 0.01, medium ≈ 0.06, large ≈ 0.14); * $p < 0.05$; C—cervical spine; Th—thoracic spine; L—lumbar spine; N—total in group; NRS—Numerical Rating Scale; Cl.—Class.

Further analyses revealed no significant differences among the study groups with respect to trunk pain. For pain distribution (χ^2 tests with Cramér's V), no between-class differences were observed for the right scapular ($p = 0.318$, Cramér's V ≈ 0.20, small), left scapular ($p = 0.326$, V ≈ 0.21, small), right nape ($p = 0.487$, V ≈ 0.13, small), left nape ($p = 0.470$, V ≈ 0.14, small) or sternal region ($p = 0.770$, V ≈ 0.15, small; all $p > 0.05$). Likewise, NRS pain intensity at these sites did not differ significantly between occlusal classes (right scapular $p = 0.172$, $\eta^2 \approx 0.04$; left scapular $p = 0.132$, $\eta^2 \approx 0.05$; right nape $p = 0.472$, $\eta^2 \approx 0.02$; left nape $p = 0.358$, $\eta^2 \approx 0.02$; sternum $p = 0.364$, $\eta^2 \approx 0.02$; all $p > 0.05$), with all η^2 values indicating small or negligible effects.

For the limbs, no upper-limb pain was reported in any group. In the lower limbs, neither pain occurrence nor NRS intensity showed significant associations with occlusal class. The presence of pain in the right hip ($p = 1.000$, Cramér's V ≈ 0.00), right knee ($p = 0.770$, V ≈ 0.15, small), left knee ($p = 0.770$, V ≈ 0.15, small) and right calf ($p = 1.000$, V ≈ 0.00; all $p > 0.05$), as well as NRS scores at these sites (right hip $p = 0.368$, $\eta^2 \approx 0.02$; right knee $p = 0.351$, $\eta^2 \approx 0.02$; left knee $p = 0.361$, $\eta^2 \approx 0.02$; right calf $p = 0.368$, $\eta^2 \approx 0.02$; all $p > 0.05$), were accompanied by negligible-to-small effect sizes, providing no evidence for a strong relationship between occlusal class and trunk or lower-limb pain.

An overall analysis of the relationship between the number of current pain locations in the body and occlusal type, performed with the Kruskal–Wallis test, showed a statistically significant between-class difference ($H(2) = 7.57$, $p = 0.023$, $\eta^2 = 0.09$, medium effect; Table 7), indicating a meaningful association between occlusal class and the burden of pain. Post hoc Dunn tests with Bonferroni correction demonstrated that this effect was driven primarily by the contrast between Class III and Class I: the Class III group reported, on average, 1.40 more painful sites than Class I (Δ = 1.40 sites, 95% CI 0.39 to 2.41; Cohen's d ≈ 0.72, medium-to-large effect), and this difference remained statistically significant after adjustment (p_adj ≈ 0.019, r ≈ 0.29, small-to-medium effect). In contrast, the pairwise comparisons involving Class II (Class II vs. Class I and Class III vs. Class II) did not reach statistical significance after Bonferroni correction (all p_adj > 0.05, $r \leq 0.17$, small effects).

Table 7. Number of pain sites identified in the body across different occlusal classes.

Pain Site Count	Occlusal Type			*p*-Value	η^2	Magnitude
	Class I (N = 30)	Class II (N = 30)	Class III (N = 30)			
Mean ± SD	1.33 ± 1.58	1.80 ± 1.81	2.73 ± 2.24	$p = 0.023$ *		
Median	1	2	2		0.09	medium
Quartiles	0-2	0.25-2	1-4	Cl.III > Cl.I		

p-value—Kruskal–Wallis test; effect size—η^2 (small ≈ 0.01, medium ≈ 0.06, large ≈ 0.14); * $p < 0.05$; Cl.—Class.

4. Discussion

In line with contemporary medical practice, which increasingly emphasizes a holistic view of the human body, this interdisciplinary study aimed to evaluate the coexistence of malocclusions, musculoskeletal pain, and temporomandibular joint dysfunctions.

No significant association was observed between anteroposterior malocclusions and TMJ disorders (RDC/TMD Axis I). Nevertheless, several statistically and clinically relevant relationships emerged between occlusal type and pain outcomes in the craniofacial region and spine. Participants with Class III malocclusion more frequently reported left temporal pain, and cervical spine pain was more common in malocclusion groups than in Class I, both with small-to-medium effect sizes. For cervical pain intensity, between-class differences reached the prespecified ≈1-point MCID, which may indicate a clinically relevant burden in the malocclusion groups; however, this finding should be interpreted with caution in view of the multiple comparisons performed and only partially consistent post hoc results, whereas temporal NRS differences in Class III approached but did not clearly exceed this threshold. Thus, our data partially confirm the initial hypothesis by demonstrating an association between sagittal malocclusions and the burden and distribution of pain in the upper quarter, but not with TMD prevalence itself, and should be interpreted as associative rather than causal.

Malocclusion is a pathological condition that, as noted by Głowacka [48], can substantially affect the temporomandibular joints, masticatory muscles, and associated tissues. The role of occlusion as an etiological factor in temporomandibular disorders (TMD) has been debated for decades [21,49–51]. It is now well established that TMD is multifactorial, with additional determinants such as facial deformities, bruxism, traumatic craniofacial injuries, sex, parafunctions, sleep disturbances, body posture, and psychosocial stress playing important roles [22,24,52–56].

Epidemiological studies conducted by Thilander [57], Alamoudi [58], Celić [59], and Schmitter [60] have demonstrated associations between the occurrence of TMD and various forms of malocclusion, particularly in individuals with crossbite, open bite, deep bite, and Angle's Class II and III malocclusions. However, most of these investigations were conducted in children, whereas other authors have emphasized that both subjective and clinical TMD symptoms tend to increase with age [61–63]. Accordingly, comparisons with our young adult cohort should be viewed as contextual rather than directly extrapolated, given developmental and age-related differences in TMD expression. Recent MRI-based studies have confirmed structural alterations in Class II patients that may predispose them to TMD development [64]. Thilander [57] further highlighted that whether such disturbances progress to TMJ damage depends largely on individual adaptive capacity, personality traits, and susceptibility to stress.

The vast majority of researchers evaluating the coexistence of malocclusions and TMD report no significant associations between these conditions [21,22,65]. When analyzing the anteroposterior relationship of the maxilla and mandible, Rey et al. [65] found no difference in the prevalence of TMD between individuals treated for Class III malocclusion and those

with Class I occlusion. These observations are consistent with the results of our study, which also did not demonstrate a correlation between occlusal type (Angle's Classes I, II, and III) and the occurrence of temporomandibular disorders, including myofascial pain disorders, disk displacements, arthralgia, or degenerative joint disease.

A coherent explanation for the frequent null findings in the occlusion–TMD literature likely combines methodological and biological factors. Methodologically, studies differ in case definitions (RDC/TMD versus DC/TMD), examiner calibration, and sampling frames (adolescents vs. adults; clinical vs. community samples), all of which reduce comparability and statistical power to detect small effects [34,66–68]. Biologically, TMD spans a biopsychosocial spectrum in which bruxism, psychosocial distress, and central pain modulation may overshadow relatively small biomechanical inputs from occlusion in many individuals [3,68]. Consistent with this view, recent data from Italian university students by Cannatà et al. [69] have highlighted strong links between pain-related TMD, emotional distress and waking-state oral behaviors in young adults. In addition, the adaptive capacity of the stomatognathic system over time (e.g., neuromuscular adaptation, occlusal wear) can decouple static occlusal morphology from current symptom expression, helping to explain why several high-quality reviews and meta-analyses have concluded that occlusion is not a primary driver of TMD pathophysiology [68]. Importantly, this perspective does not preclude context-dependent contributions of occlusion in selected phenotypes (e.g., pronounced sagittal or transverse discrepancies), but suggests that such effects are unlikely to be predominant at the population level.

The present findings were based on a combination of subjective assessment (patient interview) and objective clinical examination, which helps to reduce the risk of bias. However, certain tendencies were observed. Specifically, the most frequently occurring group of TMD according to the RDC/TMD classification among the study participants was Group I, namely myofascial pain disorders, which were most prevalent in individuals with Class III malocclusion (23.33%). Furthermore, in our study, analysis of Axis II of the RDC/TMD questionnaire revealed the presence of chronic craniofacial pain, with the highest grade and intensity reported in patients with Class III malocclusion and the lowest in those with Class I occlusion. These patterns are descriptive and should be interpreted as reflecting co-occurrence rather than implying a direct causal role of occlusal class.

Manfredini et al. [22], in their review of the literature on the relationship between occlusion and TMD, concluded that although several reports suggest a potential association, there is no basis for the hypothesis that occlusion plays a primary role in the pathophysiology of TMD. The authors emphasize the relevance of the biopsychosocial model in the development of such dysfunctions and highlight the slow adaptation of the stomatognathic system to pre-existing morphological malocclusions [22,70]. From a clinical perspective, this supports the recommendation of conservative, reversible treatment approaches—such as a well-designed occlusal splint, physiotherapy, and pharmacotherapy—as first-line options to control both subjective and objective symptoms of TMD [71].

According to some authors, abnormalities within the stomatognathic system may, through the activity of myofascial chains and the dura mater, influence the tension of adjacent and peripheral structures, gradually generating pain symptoms [72–74]. In light of this, the present study aimed to investigate whether individuals with malocclusions experience pain symptoms more frequently and report higher pain intensity in selected body regions. The first area analyzed in the proprietary questionnaire was the head and facial region. Headache is considered one of the primary symptoms of TMD and bruxism [24,75–77]. Some authors have suggested that certain malocclusions are significantly associated with an increased prevalence of headaches and partly overlap with malocclusions known to increase the risk of TMD, such as posterior crossbite, anterior

open bite, and Angle's Class II malocclusion [78–80]. Lambourne [78] and Al-Shorman and Shdeifat [81] reported that excessive overbite/overjet and posterior crossbite were associated with a higher likelihood of recurrent headaches in children and adolescents without clinical TMD. However, there is a lack of studies directly addressing the association between malocclusions and headache occurrence outside the context of TMD.

In our young adult cohort, we observed a somewhat different tendency. When analyzing pain in the occipital region in relation to the three occlusal classes, symptoms occurred more frequently in individuals with malocclusions and were reported with similar prevalence in those with skeletal Class II and skeletal Class III malocclusions. In contrast, pain in the left temporal region was most prevalent in individuals with Class III malocclusion and least frequent among those with normal occlusion, with a statistically significant association and a medium effect size. At the level of pain intensity, Class III participants also reported higher NRS scores in the temporal regions; however, only the global Kruskal–Wallis test for the left temple reached statistical significance, and Bonferroni-adjusted post hoc comparisons did not consistently confirm pairwise differences between classes. Together with medium effect sizes and NRS differences close to, but not clearly above, the ≈1-point MCID, these results are compatible with a less favorable temporal pain pattern in Class III, but warrant cautious interpretation in view of the partial loss of statistical significance after correction and the number of comparisons performed. Moreover, in the Class III group, pain was more frequently reported in the temporomandibular joints and temporal regions (right and left) compared with individuals with Class II malocclusion and normal occlusion. In turn, participants with Class II malocclusion more often reported pain in the left cheek region compared with the other groups.

The results obtained in our study are consistent with the observations of Wieczorek et al. [82] who used sEMG to assess differences in muscle activity and asymmetry indices across skeletal classes. In individuals with Class III malocclusion, they demonstrated dominance of the anterior temporalis muscles, corresponding anatomically to the temporal region, where in our study pain in this area (left temple) occurred more frequently in Class III participants compared with those in Class I. Conversely, in Class II subjects, the authors found dominance of the masseter muscles, which correspond anatomically to the cheek region. Based on the observations of Wieczorek et al. [82], it may be suggested that increased activity of specific muscles in individuals with Class II and Class III malocclusions, determined by skeletal occlusal type, combined with potential aggravating factors such as emotional stress, anxiety, or the presence of parafunctions, could contribute to heightened tension in these already more engaged muscles and may help to explain the pain patterns observed, although this cannot be verified within our cross-sectional design.

In our homogeneous cohort of university students and recent graduates, tension-pattern phenotypes associated with prolonged study/work posture and screen time—particularly sustained cervical flexion during computer and mobile device use—may interact with Angle class (I–III) to shape site-specific distributions of self-reported pain in the temporal/orofacial and cervical regions [3,83,84]. These occupational and behavioral factors represent important non-occlusal contributors to neck pain that were not directly measured and thus may confound or modify the observed associations. In parallel, trigeminocervical convergence and neuromuscular compensation linked to sagittal discrepancies (e.g., Class III) can increase cervical loading without necessarily meeting RDC/TMD diagnostic thresholds [85]. Within a biopsychosocial framework, bruxism and psychosocial stress may unmask small biomechanical asymmetries in susceptible individuals, whereas more adaptive subjects remain asymptomatic—thereby reconciling our site-specific findings with prior diagnostic-level null results [68]. Beyond these mechanisms, age-related patterns provide an additional explanatory layer. Epidemiological and clinical data show

that both TMD signs and broader musculoskeletal pain patterns shift from adolescence into early and middle adulthood, with younger individuals more often displaying fluctuating, predominantly myogenous and localized complaints, and older patients a higher burden of chronic, degenerative and psychosocially complex pain presentations [5,86,87]. Within this developmental continuum, a homogeneous young adult cohort with different sagittal occlusal classes may represent a phase in which neuromuscular adaptation still largely compensates for occlusal discrepancies at the diagnostic TMD level, thereby contributing to the absence of class–TMD associations in our data, while subtle, site-specific differences in craniofacial and cervical pain patterns between classes are already detectable.

Further analyses addressed the occurrence of pain symptoms in different spinal segments and limb regions across the studied occlusal groups. Most of the available literature in this area has focused on the coexistence of temporomandibular disorders with symptoms affecting the head, the spinal column, and even peripheral joints [15,88,89]. Bergamini [90], using surface electromyography, demonstrated that achieving neuromuscular balance of the occlusion reduced mean activation in key postural muscles, including the sternocleidomastoid, spinal extensors, and even the soleus. Valentino et al. [91] likewise employed electromyography to show a functional association between the masticatory system and lower-limb musculature under experimentally induced occlusal disturbances.

Our study identified differences among the examined groups regarding both the location and the overall burden of spinal pain. Cervical spine pain was more frequent in individuals with malocclusions (Classes II–III) than in those with normal occlusion, with small-to-medium effect sizes. Although post hoc pairwise tests for cervical pain intensity did not remain statistically significant after Bonferroni correction, the pooled contrast between malocclusion (Classes II+III) and Class I exceeded the prespecified $\approx$1-point MCID on the NRS, which may point to a clinically relevant increase in cervical pain burden in the malocclusion groups, but should be regarded as exploratory in light of the multiple comparisons and non-significant adjusted pairwise results. In addition, the overall number of currently painful body sites was higher in Class III than in Class I, with a medium-sized effect, supporting a greater global pain burden in Class III within this cohort, at an associative level rather than implying causality.

Fischer et al. [92] demonstrated a strong association between cranio-mandibular dysfunctions and hip joint mobility limitations and pain, which, according to the authors, may suggest a relationship between these body regions. In the analysis of our own results and malocclusion-related disorders, such observations were not confirmed. According to Fischer, the influence of the stomatognathic system on muscle tension and pain arises from central nervous system pathways transmitting nociceptive information between the TMJ and the rest of the body. Cuccia and Caradonna [15] explained that neural impulses from periodontal proprioceptors can influence shoulder girdle muscles via trigeminal sensory pathways and the accessory nerve, altering the tone of postural muscles. Occlusal imbalance may thus generate aberrant stimuli that could contribute to altered head and neck positioning and pain symptoms. This concept is consistent with our findings, in which pain symptoms in selected body regions were more frequently reported in individuals with malocclusions, particularly those with Class III, most commonly in areas located in close proximity to the stomatognathic system.

Finally, it is important to distinguish statistical from clinical significance. While some contrasts (e.g., cervical NRS in Classes II+III vs. I, number of painful sites in Class III vs. I) were statistically significant and showed medium-sized effects, with mean differences exceeding the prespecified MCID or indicating a clearly higher pain burden, others (e.g., left-temporal NRS in Class III) approached but did not clearly surpass that threshold and were accompanied by small-to-medium effect sizes. Such small effects, even if statistically

significant in some settings, are not necessarily clinically meaningful at the individual level and should be interpreted primarily as signals of potential risk patterns rather than as stand-alone treatment indications. Together with multiple-comparison control and the cross-sectional design, this argues for cautious clinical interpretation and replication in longitudinal cohorts [30,37,38].

The cross-sectional design does not permit causal inference; accordingly, our findings should be interpreted as evidence of co-occurrence rather than a causal relationship. Advanced imaging (e.g., MRI) was not performed and could have provided a more granular assessment of TMJ structures. We used RDC/TMD rather than DC/TMD, which may have affected case ascertainment; notably, DC/TMD shows excellent inter-examiner reliability for pain-related TMD ($\kappa \geq 0.85$) [67]. Our proprietary body-map pain questionnaire was not formally validated (e.g., test–retest reliability), introducing potential misclassification of pain location/intensity and bias in effect estimates. We also lacked control for side dominance/laterality (e.g., right/left) when analyzing pain asymmetry (such as left vs. right temple), which could influence side-specific patterns. Objective assessment of bruxism (e.g., nocturnal EMG) was not undertaken and might have masked or attenuated associations between occlusal class, bruxism and pain outcomes. In addition, some confounders—psychosocial stress, parafunctional habits, and lifestyle-related factors—were not fully controlled. Although participants were instructed to abstain from all analgesic medication before the examination, adherence to this recommendation could not be objectively verified, and some residual confounding by intermittent analgesic use cannot be entirely ruled out. Finally, we did not phenotype headaches (e.g., tension-type vs. migraine), which may have attenuated subtype-specific associations.

Despite these limitations, the present work provides unique interdisciplinary evidence by simultaneously examining occlusal type, temporomandibular disorders, and musculoskeletal pain symptoms within one study framework. To our knowledge, only a few studies have addressed these associations in a comparable way, particularly in a homogeneous young adult population. These findings therefore extend current knowledge and underline the need for integrated diagnostic protocols. Future research should build on this foundation by involving larger and more diverse cohorts, employing longitudinal designs, and incorporating standardized diagnostic tools across dental, physiotherapeutic, and psychological domains.

5. Conclusions

Although no significant association was observed between occlusal type and TMD occurrence, young adults with sagittal malocclusions—particularly Angle Class III—more frequently reported craniofacial and cervical spine pain and exhibited a higher overall number of painful body sites. These associations were characterized by small-to-medium effect sizes and, for key outcomes such as cervical pain intensity and the total number of painful sites, mean differences that reached or exceeded prespecified MCID thresholds, suggesting a potentially greater pain burden in the malocclusion groups. However, these findings are observational and may be influenced by unmeasured confounding factors; they should therefore be interpreted as patterns of co-occurrence rather than as evidence of a direct causal relationship between occlusal class and pain.

These findings highlight the importance of interdisciplinary assessment in patients with malocclusion, integrating both dental and musculoskeletal evaluation. Future studies with larger and more diverse cohorts, incorporating imaging and longitudinal designs, are warranted to confirm these associations and clarify their prognostic and therapeutic implications.

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Abbreviations

The following abbreviations are used in this manuscript:

TMD	Temporomandibular disorders
TMJ	Temporomandibular joint
ENT	Otolaryngology
RDC/TMD	Research Diagnostic Criteria for Temporomandibular Disorders
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
GCPS v1.0	Graded Chronic Pain Scale, version 1.0.
NRS	Numerical Rating Scale
MCID	Minimal Clinically Important Difference
CI	Confidence interval
STROBE	Strengthening the Reporting of Observational Studies in Epidemiology
ICMJE	International Committee of Medical Journal Editors
COPE	Committee on Publication Ethics
sEMG	Surface electromyography
MRI	Magnetic resonance imaging
pp	Percentage points
N	Sample size
C/Th/L	Cervical/Thoracic/Lumbar spine segments

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Article

Evaluation of Strain Values for Masseter Muscle Activity of Dentofacial Deformities Using Ultrasound Elastography

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Abstract

Background/Objective: This study aimed to evaluate the strain values (SVs) of masseter muscle activity in dentofacial deformities (DDs) using ultrasound elastography. **Methods**: The DD group consisted of 60 patients with dentofacial deformities with skeletal class II or III malocclusion, and the control group consisted of 26 volunteers with normal occlusion. The SVs and the cross-sectional area of the masseter muscle were measured using an ultrasonic elastography. These were measured at three functional positions: resting, mouth opening, and clenching. The SVs were statistically compared with the DD and control groups. Changes in the cross-sectional area and factors (patient status, skeletal morphology, and oral function) related to the SVs in the study group were statistically analyzed. **Results**: The SVs were significantly higher during clenching than in resting and mouth opening in both groups, although there was no correlation between the DD group and the control group. The cross-sectional area was larger during clenching, resting, and mouth opening. The resting SVs decreased as the masseter muscle cross-sectional area increased. The SVs of clenching increased with higher resting SVs and decreased with greater maximum mouth opening. **Conclusions**: The SVs measured by ultrasound elastography changed depending on functional mandibular movement and have the potential to evaluate the masseter muscle activity of dentofacial deformities.

Keywords: ultrasound elastography; strain ratio; dentofacial deformities; masseter muscle activity

1. Introduction

Dentofacial deformities are accompanied by abnormalities in dentofacial morphology and functional disorders due to abnormalities in the maxillo-mandibular skeletal morphology, position, and intermaxillary relationship between the maxilla and mandible. Evaluation of masticatory muscles is considered important in jaw movements, such as mouth opening and mastication. Functional evaluation is required, especially in dentofacial deformities where masticatory disorders are observed. Methods for evaluating masticatory muscles in dentofacial deformities include computed tomography (CT) and magnetic

resonance imaging (MRI) for morphological evaluation and electromyography for functional evaluation [1–3]. However, owing to radiation exposure and the complexity of the examination, a new evaluation method that can easily evaluate the function is required.

Ultrasound elastography is an emerging non-invasive imaging modality that provides information on tissue elasticity. Among its techniques, strain elastography allows for the semi-quantitative evaluation of muscle stiffness, which may reflect underlying muscle function and pathology [4,5]. Previous studies have shown the utility of ultrasound elastography in evaluating skeletal muscle injuries and chronic muscle diseases [6,7], but its application in the field of maxillofacial surgery remains limited. The masseter muscle plays a crucial role in jaw movement and masticatory performance. The differences in the masseter muscle between jaw deformities and healthy subjects and the stiffness of the masseter muscle during function have not been reported [8,9].

The relationship between postoperative recurrence and adaptation of masticatory muscles has also been discussed [10], and objective evaluation of masticatory muscles is considered important. If ultrasound elastography can be applied to the evaluation of masticatory muscles, an objective and more accurate diagnosis can be expected, but sufficient knowledge does not currently exist. The purpose of this study was to apply ultrasound elastography to investigate functional changes in the masseter muscle in patients with skeletal class II and III dentofacial deformities and the factors associated with these changes.

2. Methods

2.1. Ethics

This study complied with the principles stated in the Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects, adopted by the 18th World Medical Assembly, Helsinki, Finland, June 1964, and was amended most recently by the 64th World Medical Assembly, Fontaleza, Brazil, October 2013. This study was approved by the Kanazawa University Hospital Research Ethics Committee (Ref. No. 2963-1, date of approval: 20 February 2019).

2.1.1. Patients Informed Consent

All of the patients were informed of the research purpose and agreed to provide their clinical data for this study.

2.1.2. Inclusion Criteria

Patients with skeletal class II and III malocclusion were included. Skeletal class II malocclusion (n = 14) was defined as an ANB angle > 4° on lateral cephalometric analysis, whereas skeletal class III malocclusion (n = 46) was defined as an ANB angle < 1° or a Wits appraisal < −2 mm. All patients first visited the Department of Oral and Maxillofacial Surgery, Kanazawa University Hospital, between January 2019 and January 2022. The control group consisted of volunteers with normal occlusion (n = 26) recruited from hospital staff. All participants were aged 16–59 years and had complete permanent dentition excluding third molars.

2.1.3. Exclusion Criteria

Patients with congenital malformations (including cleft palate), temporomandibular disorders, pain, and trismus were excluded from this study.

2.2. Strain Values and Cross-Sectional Area Measurement of the Masseter Muscle by Ultrasound Elastography

The strain values (SVs) and cross-sectional area were measured using an ultrasonic elastography device (ultrasonic testing device Aplioi700, manufactured by TOSHIBA Med-

ical Systems Corporation, Tochigi, Japan). The measurement site was the point of greatest masseter muscle bulging during maximal clenching. Measurements were performed under three functional conditions: resting, mouth opening, and clenching. The patient was in the supine position with their head turned sideways, the probe was applied perpendicularly to the skin surface, and the masseter muscle region was selected when the compression and release became constant, and the SVs and cross-sectional area were measured (Figure 1). The SVs and cross-sectional area were measured at resting, mouth opening, and clenching on each side of the left and right masseter muscles at the maximally protruding part of the left and right masseter muscles at maximum clenching. The strain values were obtained using a no-manual-compression method. Therefore, no external pressure was applied during measurement. The strain was derived from subtle vibrations caused by involuntary muscle contractions of the operator's hand, the patient's own muscle activity, and respiration. The stability criterion was defined as a low-amplitude and stable strain graph with uniform color distribution on the elastographic image. All measurements were performed twice by the same operator on separate occasions, and the mean value was used for analysis. The intra-operator reliability of the strain value measurements was assessed in 10 randomly selected subjects, yielding an intraclass correlation coefficient (ICC) of 0.92, indicating excellent repeatability.

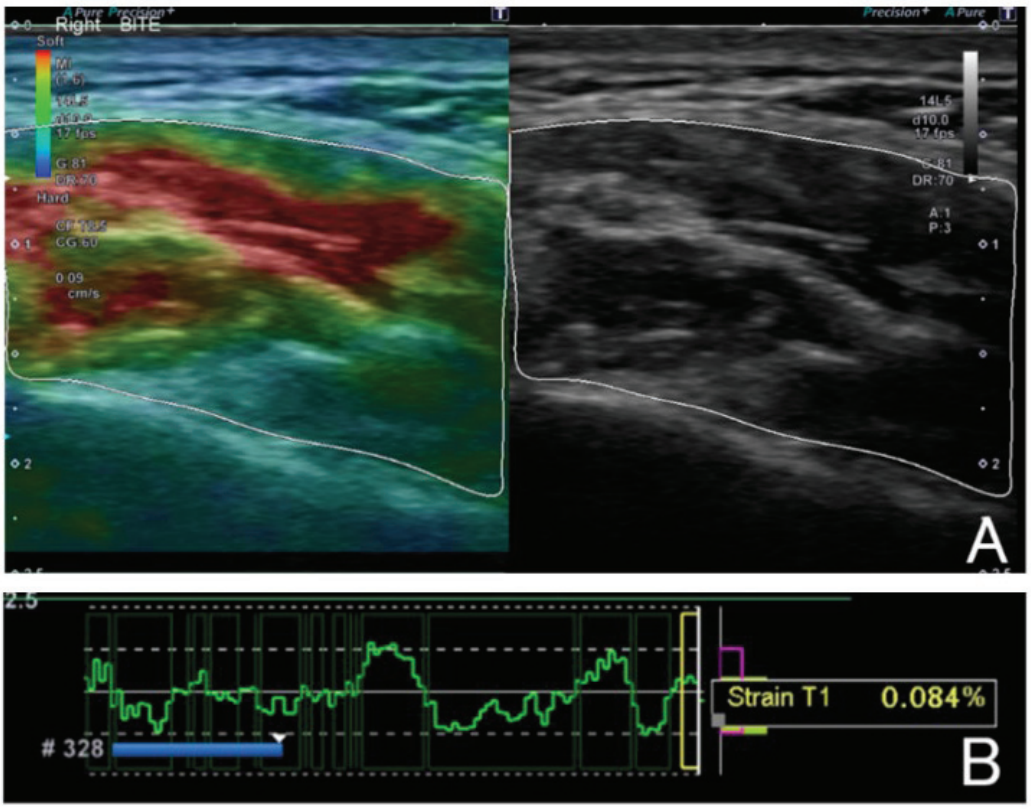

Figure 1. Ultrasound elastography image. Regions of interest (ROI) are indicated by white rectangles and were set to masseter muscle excluding fascia and fat. Color coded from red (high revel strain ratio) to blue (low level strain ratio) according to the hardness of tissue by B-mode images (**A**). There is a scale that shows the rate of compression and relaxation cycles, and the masseter muscle area is selected when it is constant (**B**).

2.3. Factors Related to Masseter Muscle Strain Values

Age, sex, and body mass index were measured as the patient factors. Overjet, overbite, SNA angle, SNB angle, ANB angle, GZN angle, SN-MP angle, and gonial angle by cephalometric analysis were measured as morphological factors (Figure 2). Maximum mouth

opening range, masseter muscle area, and SVs at resting, mouth opening, and clenching were measured as oral functional factors.

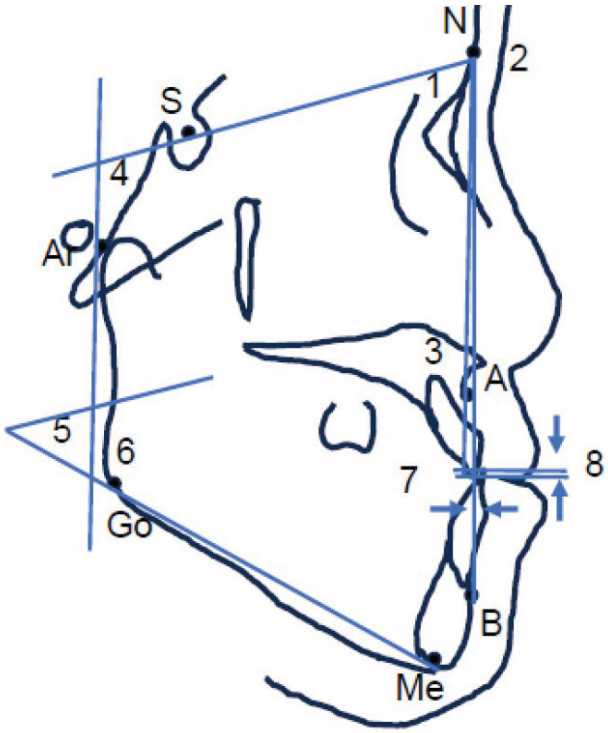

Figure 2. Lateral and frontal cephalometric analysis. Cephalometric landmarks: sella (S), nasion (N), pointA (A), pointB (B), menton (Me), gonion (Go), articulare (Ar), facial midline (FM). Angular measurements: 1. SNAangle; 2. SNB angle; 3. ANB angle; 4. GZN angle; 5. SN-MP angle; 6. Gonial angle. Distance measurements: 7. over jet; 8. over bite. Cephalometric landmarks and reference planes used for skeletal evaluation. Blue lines indicate reference planes (e.g., SN, mandibular plane, and vertical reference lines), and blue arrows represent the direction of horizontal and vertical displacement.

2.4. Statistical Analysis

The SVs of the normal occlusion group and skeletal class II or III dentofacial deformity groups were compared at resting, mouth opening, and clenching. The SVs of dentofacial deformity at resting, mouth opening, and clenching were compared. The cross-sectional areas of the masseter muscle between resting and mouth opening and clenching in patients with dentofacial deformities were compared. The relationship between the functional SVs and the factors was analyzed. For intergroup comparisons, the Kruskal–Wallis test was used, followed by post hoc pairwise comparisons with the Wilcoxon signed-rank test where applicable. Correlations were assessed using linear regression analysis. Statistical analyses were performed using Prism 9 (GraphPad Software, San Diego, CA, USA). A p value < 0.05 was considered statistically significant. A post hoc power analysis was conducted using G*Power 3.1 software. Based on the observed effect sizes (Cohen's d = 0.55) in the comparison of clenching versus resting strain values, the achieved statistical power was 0.83 at $\alpha = 0.05$, confirming that the sample size ($n = 86$) was adequate for detecting medium effect sizes.

3. Results

In total, 60 patients (45 women and 15 men) and 26 volunteers (14 women and 12 men) were included in this study. The average age of the included patients was 26 years (range, 18–59 years), and that of the volunteers was 32 years (range, 23–47 years).

3.1. Comparison of Strain Ratio Between Volunteers and Dentofacial Deformities

There were no statistically significant differences among volunteers, skeletal class III, and skeletal class II malocclusion of the SVs at any of the three functional points (Figure 3). Figure 4 shows that SVs at clenching were higher than that at resting ($p < 0.0001$ ****) and at mouth opening ($p < 0.0001$ ****) (A). In the strain elastography images, red represents soft areas, blue represents hard areas, and green represents areas between soft and hard areas. These images show that redness was recognized more prominently during clenching, with an increase in SVs (B).

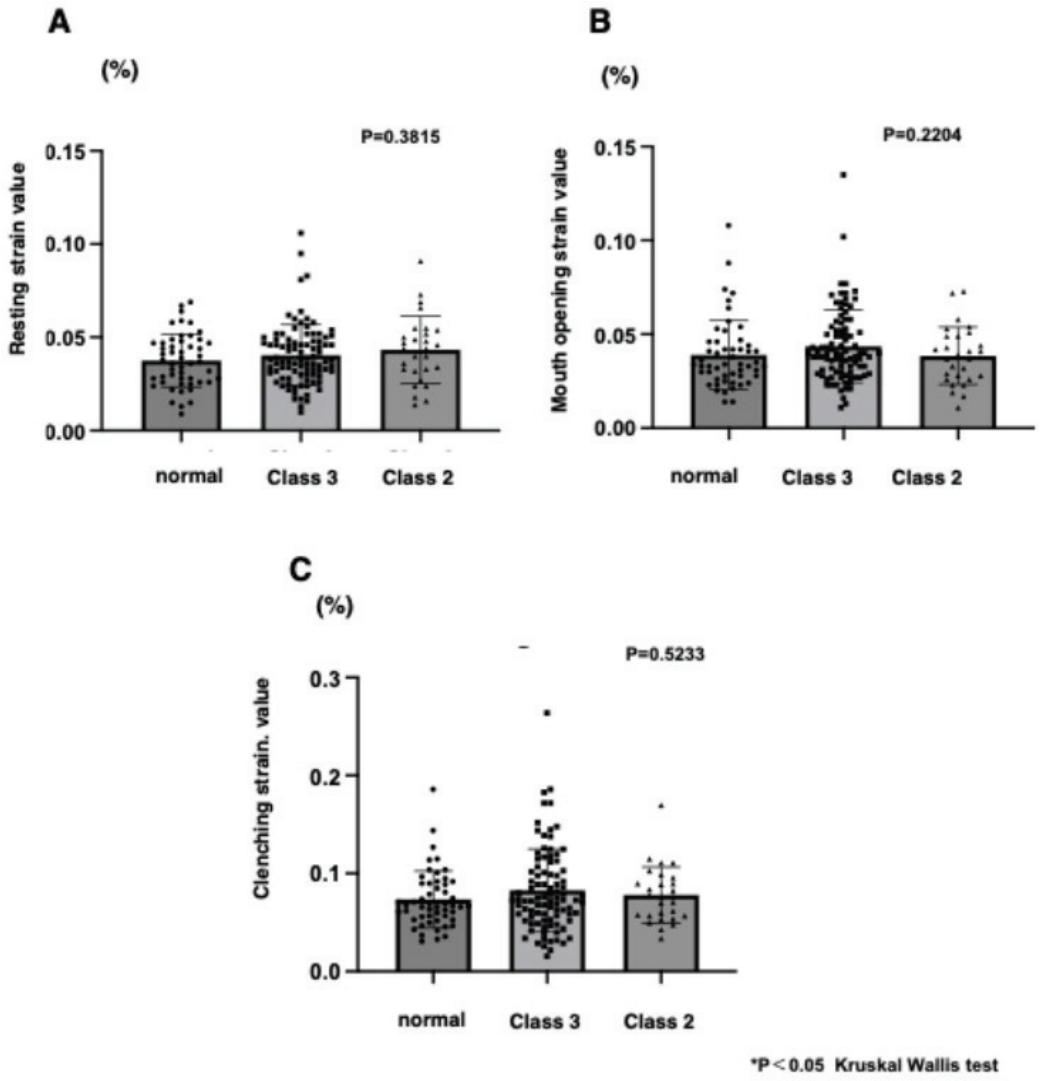

Figure 3. Comparison of masseter muscle strain values among normal and skeletal class III and skeletal class II at resting (**A**), mouth opening (**B**), and clenching (**C**).

3.2. Comparison of Cross-Sectional Area Among Resting, Mouth Opening, and Clenching in Dentofacial Deformities

There was a significant difference in the cross-sectional area of the masseter muscle at resting, mouth opening, and clenching. The cross-sectional area at clenching was the largest and that at mouth opening was the smallest among the three points in time (Figure 5).

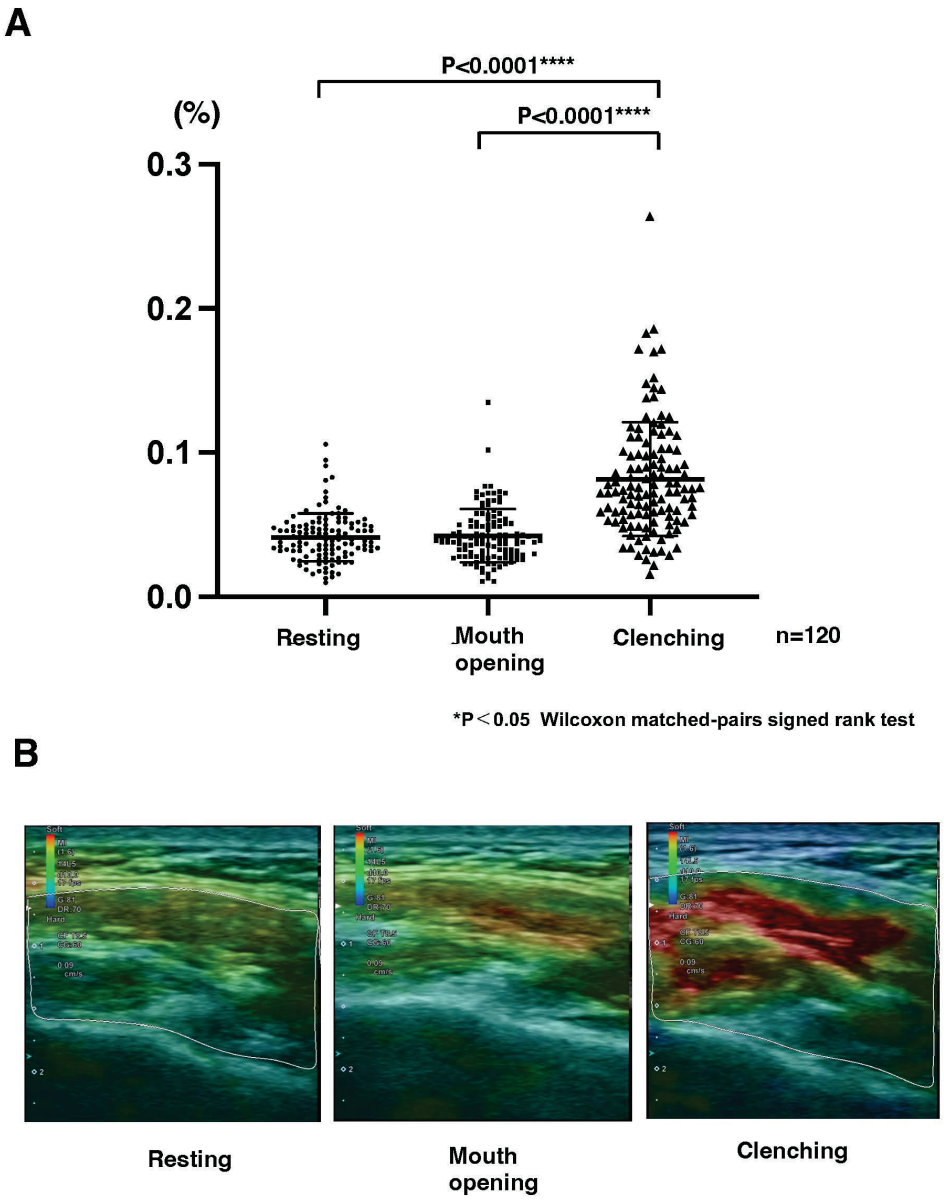

Figure 4. Comparison of masseter muscle strain values among resting, mouth opening, and clenching in patients with dentofacial deformity. (**A**) Strain values of the masseter muscle at rest, during mouth opening, and during clenching. Each dot represents one side of the muscle (n = 120). Strain values significantly increased from the resting state to mouth opening and further increased during clenching (**** $p < 0.0001$, Wilcoxon matched-pairs signed rank test) (**B**) Representative strain elastography images of the masseter muscle obtained at rest, during mouth opening, and during clenching. Warmer colors (red) indicate greater strain (softer tissue), whereas cooler colors (blue–green) indicate lower strain (stiffer tissue). The region of interest (ROI) of the masseter muscle is outlined in white.

3.3. Functional Factors Related to Strain Ratio in Dentofacial Deformities

Table 1 summarizes the correlations between functional SVs and factors associated with dentofacial deformities. Significant differences were found in the masseter muscle cross-sectional area, the mouth opening SVs and clenching in the resting SVs, the resting SVs with mouth opening, the mouth opening SVs, and the resting SVs with clenching. The resting SVs decreased as the masseter muscle cross-sectional area increased (Figure 6A). The SVs of mouth opening increased as the resting SVs increased (Figure 6B). The SVs of clenching increased as the SVs of resting increased (Figure 6C) and decreased according to mouth opening (Figure 6D).

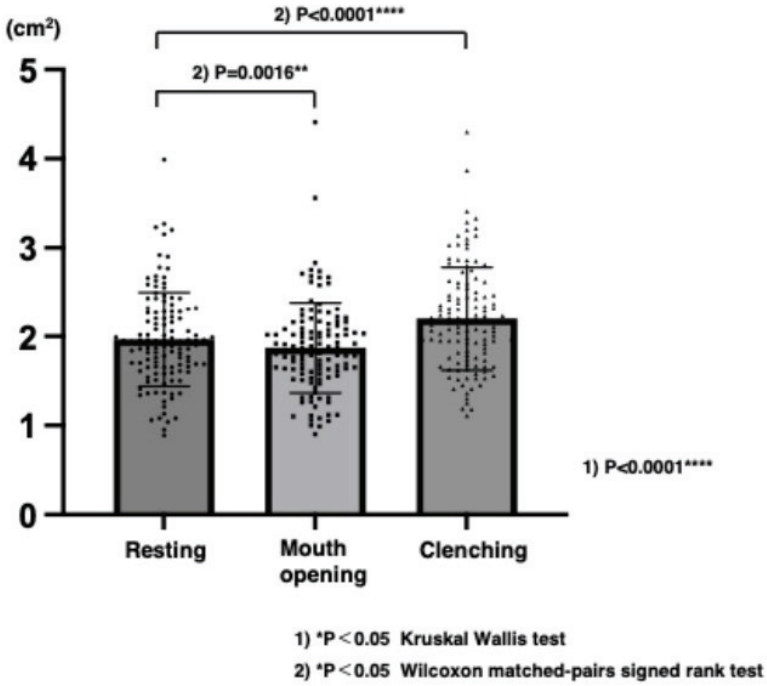

Figure 5. Comparison of masseter muscle cross-sectional area among resting, mouth opening, and clenching in patients with dentofacial deformity.

Table 1. Relationship between functional strain value and factors.

	Average (Range)	Resting SR		Mouth Opening SR		Clenching SR	
		R^2	*p* Value	R^2	*p* Value	R^2	*p* Value
(1) Patient factors							
Age	26 (16–59)	0.03	0.0807	0.02	0.1505	0.01	0.2428
Gender (male/female)	(15/45)	0.01	0.4127	-	0.7436	0.01	0.3326
Body mass index	21.0 (15.8-/31.5)	0.02	0.1601	0.01	0.2698	0.02	0.1209
(2) Morphological factors							
Over jet (mm)	−0.4 (−8.5~−12.0)	-	0.9382	0.01	0.2191	0.01	0.3971
Over bite (mm)	0.8 (−7.0~5.0)	-	0.3914	-	0.4405	0.01	0.2683
SNA angle (°)	81.3 (72.3~88.4)	-	0.2078	-	0.7193	-	0.2739
SNB angle (°)	80.9 (69.7~90.3)	0.02	0.1397	-	0.1298	0.02	0.173
ANB angle (°)	0.4 (−5.4~9.6)	0.02	0.1401	-	0.4408	-	0.4759
GZN angle (°)	91.4 (76.2~111.6)	0.02	0.1332	-	0.4434	-	0.5981
SN-MP angle (°)	39.8 (19.6~72.8)	0.03	0.0768	-	0.9733	-	0.4705
Gonial angle (°)	128.5 (107.7~143.7)	-	0.8129	-	0.4627	-	0.8557
(3) Oral functional factors							
MMO (mm)	47.3 (34.0–61.0)	0.01	0.0825	-	0.8366	0.03	0.0420 *
MM Area (cm^2)							
Resting	0.7 (−7.0~5.0)	0.03	0.0825	0.02	0.1726	-	0.2917
Mouth opening	80.0 (73.9~84.8)	0.05	0.0126 *	0.02	0.1451	-	0.397
Clenching	76.6 (67.2~86.7) 0.02	-	0.159	0.01	0.2393	-	0.8172
Strain ratio							
Resting	0.7 (−7.0~5.0)			0.1	0.0003 ***	0.06	0.0055 **
Mouth opening	80.0 (73.9~84.8)	0.1	0.0003 ***			-	0.8142
Clenching	76.6 (67.2~86.7)	0.06	0.0055 **	-	0.8142		

* $p < 0.05$ Linear regression.** $p < 0.01$; *** $p < 0.001$.

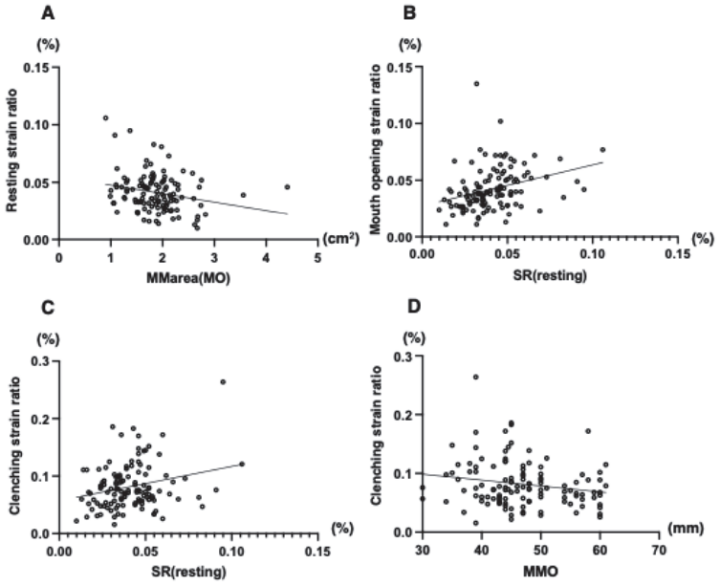

Figure 6. Incidence of masseter muscle strain value at resting (**A**), mouth opening (**B**), and clenching (**C**,**D**) in patients with dentofacial deformity.

4. Discussion

There were no statistically significant differences among the volunteers, the skeletal class III malocclusion, and the skeletal class II malocclusion of the SVs at any of the three functional points of resting, mouth opening, and clenching. The SVs of the masseter muscle did not change significantly during mouth opening; however, it increased significantly during clenching compared with resting and mouth opening in both dentofacial deformities and normal occlusal volunteers. Although there was no association with anteroposterior maxillofacial skeletal morphology, significant differences were observed during clenching than during resting and mouth opening. We believe that SVs would be useful for masseter muscle functional evaluation because SVs were significantly changed according to functional mandibular movement.

A method for evaluating masticatory muscles is performed using diagnostic imaging methods such as CT, MRI, or electromyogram (EMG) traditionally [11–14]. Many reports have evaluated the morphology of the masseter muscle in patients with dentofacial deformities using these methods [3,15–17], but it is not sufficient to evaluate the stiffness and functional changes in the masseter muscle. Another reason for choosing elastography as an examination method for the masseter muscle is that it can be measured more easily and less invasively than CT, MRI, or EMG, and the characteristics of the muscle during function can be distinguished in real time [7,18]. Ultrasound is a dynamic examination, superior to CT and MRI in lateral resolution and spatial resolution, and is a useful tool for assisting diagnosis. In previous reports, occlusal muscles had a significant difference between resting and clenching in normal occlusion populations, elasticity was increased during maximum contraction [18]. In this study, the SVs significantly increased during clenching, not only in normal occlusion subjects, but also in patients with dentofacial deformities.

Dentofacial deformity is characterized by a decrease in the ratio of type II fibers and atrophy of the masseter muscle fibers [14]. Therefore, we hypothesized that there would be some difference between patients with dentofacial deformities and those with normal occlusion. However, no significant differences were observed between the groups. Although skeletal class II and class III deformities have different biomechanical characteristics, the number of class II patients in this cohort was relatively small, and the subgroup comparison lacked sufficient statistical power. Therefore, both skeletal patterns were merged into one

dentofacial deformity group in this study, and this limitation should be considered when interpreting the findings.

After that, we examined the relationship between the masseter muscle cross-sectional area and three points of function; a statistically significant difference was observed during clenching and mouth opening compared to resting. We examined the correlation between the SVs and the cross-sectional area of the masseter muscle, but only the SVs at rest and the cross-sectional area of the masseter muscle when mouth opening was correlated.

This result indicates that the softer the masseter muscle at resting position, the smaller it is at mouth opening. Considering this, the SVs of the masseter muscle at rest may predict mouth opening function.

On the color map image of the masseter muscle, a red area was observed for both mouth opening and clenching. Both contracted and relaxed layers of the masseter muscle were observed at rest and during function. In particular, during clenching, large strains in the masseter muscle (shown in red) were found in the central part, and there was a tendency for the deep layer to have a larger strain than the shallow layer. Differences in muscle layers during function were correlated with the SVs. In a previous ultrasound evaluation of the masseter muscle, the maximum masseter muscle thickness was recorded in the central third of the contracted muscle, and it was greatest in the central region during both contraction and relaxation; it was reported to be thick and thinnest at the bottom [19]. These results are related to the anatomical features of the masseter muscle reported in previous studies. It has been reported that the muscle layer of the masseter muscle has a multi-layered structure, and many studies have shown a layered structure of the masseter muscle [5,20]. High and low strains coexist, and muscle contraction and relaxation differ depending on the layer. A study that analyzed the morphology of the mandible and masseter muscle demonstrated a correlation between the size of the masseter muscle and the size of the processus of the mandibule, and that the more curved the mandibular morphology, the larger the masseter muscle [21,22]. Although morphological factors and SVs in this study showed no correlation, further analysis is recommended after increasing the number of cases.

In the present study, a positive correlation was found between resting SVs and maximum mouth opening, whereas a negative correlation was observed between clenching SVs and maximum mouth opening. These findings suggest that lower resting muscle tension allows greater extensibility of the masseter during mouth opening, resulting in a larger range of motion. Conversely, higher SVs during clenching may reflect increased muscle stiffness or shortening, which could restrict the elongation of the muscle fibers and thereby limit maximum mouth opening. These results indicate that the static and dynamic properties of the masseter muscle may exert opposite influences on mandibular mobility.

Current reports on elastography in the field of maxillofacial and oral surgery include the evaluation of effects before and after treatment for temporomandibular disorders and the evaluation of masseter muscle hardness, thickness, and cross-sectional area before and after surgery [23,24]. However, there have been no reports evaluating changes in the masseter muscle during masticatory muscle function in subjects with jaw deformity and normal occlusion. To our knowledge, this is the first study to demonstrate changes in masseter muscle function during masticatory muscle function in patients with normal occlusion and dentofacial deformities.

Based on the present findings, an ultrasound-based assessment of the masseter SVs may serve as an objective indicator of muscle tension that correlates with mandibular mobility. This technique could be applied for screening patients with excessive muscle tension before orthognathic surgery and for monitoring changes in masticatory muscle stiffness during postoperative rehabilitation. Furthermore, integrating such quantitative muscle

assessment into a digital workflow may improve the accuracy of preoperative planning and postoperative follow-up. As demonstrated in the concept of a fully digital workflow for anterior segment repositioning devices [25], digital integration enables real-time functional feedback and patient-specific treatment adjustments. Therefore, combining SV-based muscle evaluation with digital treatment planning could facilitate a more functional approach to the management of jaw deformities.

There are several limitations to this study. First, the sample size was modest, particularly for patients with skeletal class II deformities, resulting in insufficient statistical power for subgroup comparisons. Therefore, class II and III cases were combined into a single dentofacial deformity group, and the results should be interpreted with caution. Second, volumetric or densitometric assessments such as Hounsfield units or grayscale intensity were not included, which may further improve characterization of masseter muscle properties in future studies. Third, the short-term cross-sectional design does not allow evaluation of postoperative adaptation or temporal changes in muscle stiffness. Finally, strain elastography is a semi-quantitative and operator-dependent technique, although standardized probe positioning and repeated average measurements were applied to minimize variability. Future longitudinal studies with larger and more balanced samples are warranted to confirm skeletal pattern-specific differences and to better clarify the functional role of the masseter muscle in dentofacial deformities.

In summary, ultrasound elastography is a simple examination that can evaluate masticatory muscles without radiation exposure and can be expected to provide an objective and more accurate diagnosis. As a result of this study, the SVs measured by ultrasound elastography changed depending on functional mandibular movement and have the potential to evaluate the masseter muscle activity of dentofacial deformities, masseter muscle stiffness, and masseter muscle cross-sectional area during function in patients with dentofacial deformities. Thus, ultrasound elastography may be an effective new tool for evaluating masticatory muscles.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Kanazawa University Hospital Research Ethics Committee (protocol code 1765-1, date of approval: 20 February 2019).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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Relationships Among Non-Functional Occlusal Habits, Temporomandibular Disorder Symptoms, and Skeletal Morphology in Patients with Dentofacial Deformities

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Abstract

Background/Objectives: Non-functional oral habits, such as unilateral chewing, bruxism, and clenching, may exacerbate temporomandibular disorder (TMD) symptoms and affect skeletal morphology in patients with dentofacial deformities. This study aimed to elucidate the relationships among these habits, TMD symptoms, and mandibular morphology, and to examine the association between non-functional habits and TMD symptom severity. **Methods:** A cross-sectional study was conducted in 141 patients with dentofacial deformities. At the initial consultation, participants completed a questionnaire assessing non-functional oral habits (unilateral chewing, bruxism, and clenching) and TMD symptoms, scored as follows: limited mouth opening (2 points), pain on opening (2 points), and joint sounds (1 point). Patients were stratified into three groups according to the number of habits ($\geq$2, 1, none). Total TMD scores were compared among groups, and the relationship between unilateral chewing and mandibular asymmetry was analyzed. **Results**: Unilateral chewing was reported by 82 patients (58%), bruxism by 28 (20%), and clenching by 29 (21%). Mean TMD scores were 1.94 (range: 0–5) in patients with $\geq$2 habits, 1.50 (0–5) in those with one habit, and 0.86 (0–3) in those without habits. TMD symptoms were significantly more severe in patients with multiple habits ($p < 0.05$). Among patients with mandibular asymmetry, 41 of 56 (73%) reported unilateral chewing, which was significantly higher than in those without asymmetry (42 of 85; 49%) ($p < 0.05$). **Conclusions**: In patients with dentofacial deformities, multiple non-functional oral habits were associated with greater TMD symptom severity, and unilateral chewing was significantly associated with mandibular asymmetry.

Keywords: non-functional oral habits; temporomandibular disorder; dentofacial deformity; mandibular asymmetry; unilateral chewing

1. Introduction

Oral habits include tongue thrusting, lip sucking, thumb sucking, mouth breathing, and resting the chin on the hand, among others. Non-functional occlusal habits have habit-

ual or psychological stress and depression causes, and examples include teeth grinding, clenching, and partial chewing. Functional occlusal habits have functional occlusion or muscular causes, and examples include functional mandibular prognathism and tongue thrusting due to functional occlusion problems. Among these, non-functional occlusal habits such as bruxism, clenching, and unilateral chewing have been reported to be significantly associated with temporomandibular disorders (TMD) [1–3]. Bruxism and TMD have a 17% prevalence worldwide, with significant differences between continents. The average prevalence of TMD among bruxism patients was reported to be 63.5% [4]. Non-functional occlusal habits, particularly bruxism, involve parafunctional activities such as grinding and clenching of the teeth [5], and their associations with TMD symptoms have been demonstrated in several studies [5–7]. Parafunctional habits such as bruxism are known to increase the risk of painful TMD in adolescents and adults, both cumulatively and synergistically [8]. Sleep bruxism, for instance, has been implicated in myofascial pain, temporomandibular joint (TMJ) pain, and intra-articular pathologies such as disk displacement and joint sounds [9,10]. Moreover, the interaction between sleep and awake bruxism has been associated with an increased risk of painful TMD [11].

Unilateral chewing is also regarded as a non-functional occlusal habit, similar to bruxism. However, little is known about the prevalence and clinical implications of these habits in patients with dentofacial deformities. Patients with dentofacial deformities, particularly those with mandibular retrognathia, open bite, or mandibular asymmetry, have been reported to present with higher rates of TMD symptoms [12]. Clinically, many patients with dentofacial deformities appear to have a history of TMD symptoms, which motivated the present investigation.

It has been hypothesized that non-functional occlusal habits during the growth period may affect mandibular morphology [13] and contribute to the development of dentofacial deformities, in addition to degenerative changes such as osteoarthritis. We hypothesized that patients with multiple non-functional occlusal habits exhibit higher TMD symptom severity and more frequent mandibular asymmetry. Bruxism, characterized by rhythmic activity of the masticatory muscles, is centrally regulated but also influenced by peripheral and psychosocial factors, including stress and anxiety [14]. Therefore, centrally mediated parafunctional habits may induce TMD symptoms, which in turn could influence mandibular growth and morphology, potentially contributing to the development of dentofacial deformities. This investigation was conducted as a retrospective observational study using preoperative clinical records and imaging data collected between 2015 and 2023 at Kanazawa University Hospital.

The aim of this study was to clarify the associations between non-functional occlusal habits and TMD symptoms in patients with dentofacial deformities.

2. Patients and Methods

2.1. Inclusion Criteria

This was a retrospective observational study that analyzed existing clinical records obtained at the initial consultation. All data were collected during the preoperative evaluation period between 2015 and 2023. This study included 141 patients (35 males and 106 females) who underwent orthognathic surgery for dentofacial deformities at Kanazawa University Hospital. The mean age of the patients was 24 years (range, 15–58 years).

Inclusion criteria for orthognathic surgery are skeletal and functional correction. Regarding skeletal classification based on ANB angle: 15 patients had skeletal Class I (ANB 2–4°), 25 patients had skeletal Class II (ANB > 4°), and 101 patients had skeletal Class III (ANB < 2°). Among the 141 patients, 38 presented with mandibular asymmetry and 57 with open bite.

Exclusion Criteria

Patients were excluded if they had:

- a history of systemic abnormalities, facial trauma, juvenile idiopathic arthritis, or idiopathic condylar resorption
- congenital anomalies
- pituitary adenoma
- unwillingness to provide informed consent

2.2. Methods

2.2.1. Questionnaire on Non-Functional Occlusal Habits and TMD Symptoms

A questionnaire was administered at the initial consultation.

The questionnaire used in this study was developed originally in our department as a simple screening tool to assess the presence of parafunctional habits and self-reported TMD symptoms during the initial consultation. Bruxism was assessed using a self-reported item: "*Do you grind your teeth?*". This question was designed to capture the overall tendency toward bruxism-like behaviors without distinguishing between awake and sleep conditions. Because sleep bruxism requires objective diagnostic methods such as polysomnography or electromyographic recordings, which were not feasible in this retrospective clinical setting, a simplified self-report approach was used to ensure consistency across all participants. The severity of self-reported TMD symptoms was evaluated using a simple categorical scoring system: pain on opening and limitation of mouth opening were scored as 2 points each, and joint sounds as 1 point. This simplified scale was designed as a screening index rather than a detailed Likert-type assessment, allowing consistent application across all participants at the initial consultation.

The survey items included:

1. Presence of non-functional occlusal habits (during waking hours only; sleep-related behaviors were not considered):
    - unilateral chewing
    - bruxism
    - clenching
2. History of TMD symptoms, scored as follows:
    - limited mouth opening (2 points)
    - TMJ pain (2 points)
    - joint sounds (1 point).

2.2.2. Evaluation of Skeletal Morphology

Skeletal classification (Class I, II, III), mandibular asymmetry, and open bite were evaluated using lateral cephalometric radiographs at the initial consultation. Skeletal classification was primarily determined based on the ANB angle, which reflects the relative anteroposterior relationship between the maxilla and the mandible. Participants with an ANB angle greater than 4° were classified as Skeletal Class II, and those with an ANB angle less than 2° were classified as Skeletal Class III, following previously established criteria [15]. To minimize possible misinterpretation due to mandibular rotation, SNA, SNB, and Wits appraisal were additionally evaluated as supporting parameters.

These indices were consistent with the ANB-based classification and confirmed the validity of the skeletal grouping used in this study. Mandibular asymmetry was defined as a menton deviation greater than 3 mm from the facial midline, measured on posteroanterior cephalometric radiographs. The facial midline was established as a perpendicular line drawn from the midpoint between the bilateral orbitale points to the menton. All

cephalometric measurements were performed by one calibrated examiner with more than 10 years of experience in orthodontic and dentofacial analysis. To assess intra-examiner reliability, 20 randomly selected radiographs were re-measured after a two-week interval, and the intraclass correlation coefficient (ICC) exceeded 0.90 for all variables. For inter-examiner verification, a second examiner independently reviewed all measurements, and any discrepancy greater than 1.0 mm or 1.0° was jointly re-evaluated until consensus was reached. This standardized procedure ensured excellent measurement reproducibility.

2.2.3. Statistical Analysis

Data were first tested for normality using the Shapiro–Wilk test. Patients were stratified into three groups according to the number of non-functional occlusal habits (≥2, 1, none). The total TMD symptom scores were compared among the three groups using a one-way ANOVA followed by Bonferroni's post hoc test for multiple comparisons. Effect sizes for the ANOVA were reported as Partial Eta Squared (η^2), with $\eta^2 = 0.01$ indicating a small effect, $\eta^2 = 0.06$ indicating a medium effect, and $\eta^2 = 0.14$ indicating a large effect. In addition, the association between unilateral chewing and mandibular asymmetry was statistically analyzed using the Chi-square test. $p < 0.05$ was considered statistically significant. The effect size for the Chi-square test was calculated using Cramér's V. All statistical analyses were performed using GraphPad Prism version 10 (GraphPad Software, San Diego, CA, USA).

These analyses ensured adequate statistical validity. A post hoc power analysis was performed using G*Power version 3.1.9.7 (Heinrich-Heine-University, Düsseldorf, Germany). For the one-way ANOVA comparing TMD scores among three groups, with a total sample size of n = 141, an alpha level of 0.05, and a medium effect size (f = 0.25), the statistical power ($1 - \beta$) was calculated as 0.92, indicating that the sample size was adequate to detect significant differences.

3. Results

A total of 99 patients (70%) reported awareness of non-functional occlusal habits. Among them, unilateral chewing was reported by 82 patients (58%: 95% CI, 49.6–66.0), bruxism by 28 patients (20%: 95% CI, 13.5–27.0), and clenching by 29 patients (21%: 95% CI, 14.2–27.7) (Figure 1). Skeletal morphology according to sagittal classification and the presence of open bite are shown in Table 1; no significant differences were observed in these categories. However, non-functional habits were significantly more prevalent in patients with mandibular asymmetry, being present in 46 of 57 patients (81%) ($p = 0.0249$ Chi-square test, Cramér's V = 0.22) (Table 2). Furthermore, unilateral chewing was significantly more frequent in patients with mandibular asymmetry (41 of 57; 72%) compared with those without asymmetry (42 of 85; 49%) ($p = 0.0049$ Chi-square test, Cramér's V = 0.27) (Figure 2). Regarding TMD symptoms, 87 of 141 patients (62%) reported a history of TMD symptoms. Specifically, joint sounds were present in 81 patients (57%), TMJ pain in 45 patients (32%), and limited mouth opening in 17 patients (12%) (Figure 3). Thus, more than half of the patients with dentofacial deformities had a history of TMD symptoms. According to skeletal classification, TMD symptoms were observed in 10 of 15 Class I patients (66%), 18 of 25 Class II patients (72%), and 59 of 101 Class III patients (58%), indicating that TMD symptoms were more prevalent in Class II patients ($p = 0.048$, Chi-square test) (Figure 4). The mean TMD symptom scores were 1.94 (range, 0–5) in patients with two or more non-functional habits, 1.50 (0–5) in those with one habit, and 0.86 (0–3) in those without habits. TMD symptom severity was significantly higher in patients with multiple non-functional habits ($p = 0.0108$ ANOVA test, $\eta^2 = 0.07$) (Figure 5).

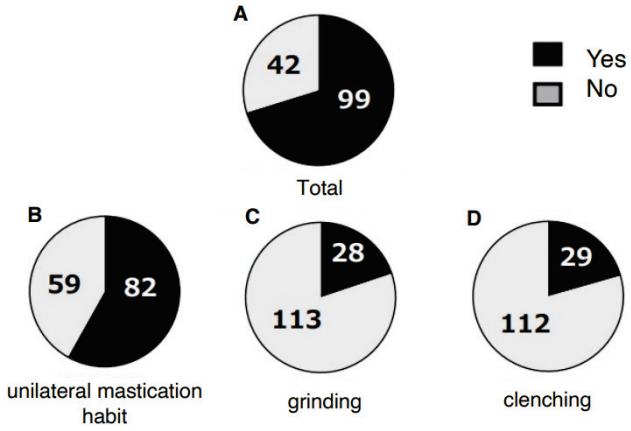

Figure 1. Subjective non-functional occlusal habits in patients with dentofacial deformities. The prevalence of unilateral mastication habit, grinding, and clenching is shown.

Table 1. Patients' characteristics of dentofacial deformities.

	Open Bite/Asymmetry				Total
	(−/−)	(+/−)	(−/+)	(+/+)	
Skeletal class I	0	7	10	2	15
Skeletal class II	12	8	6	1	25
Skeletal class III	48	23	41	11	101

(number: patients).

Table 2. Relationship between non-functional occlusal habits and skeletal morphology of dentofacial deformity.

Class of Non-Functional Occlusal Habits		Skeletal Morphology of Dentofacial Deformity				
		Class III	Class II	Class I	Open Bite	Asymmetry
NFOH group	Group A	22	6	5	13	14
	Group B	46	12	8	16	32
non-NFOH group	Group C	33	7	2	9	11
p value		0.2338	0.8294	0.1405	0.3358	0.0249 *

Statistical analysis was performed between the NFOH group and the non-NFOH group. $p < 0.05$ * Chi-square test (number). Group A: two or three non-functional occlusal habits. Group B: one non-functional occlusal habit. Group C: none. NFOH: non-functional occlusal habits.

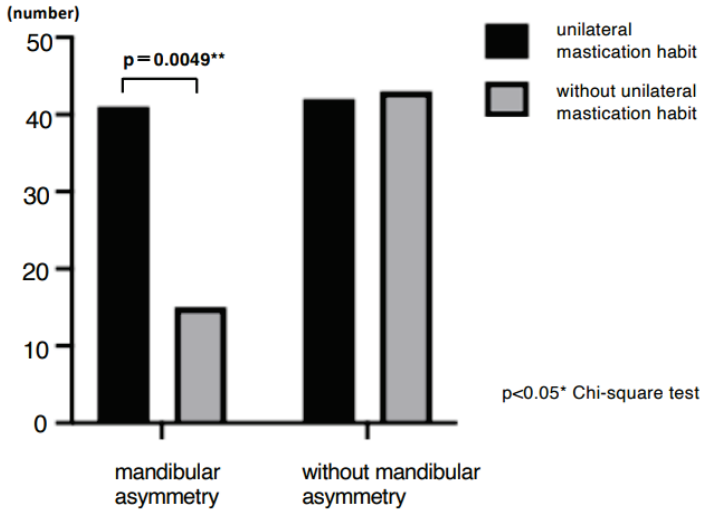

Figure 2. Relationship between unilateral mastication habit and mandibular asymmetry. The prevalence of unilateral mastication was significantly higher in patients with mandibular asymmetry than in those without (Chi-square test, * $p < 0.05$, ** $p < 0.01$).

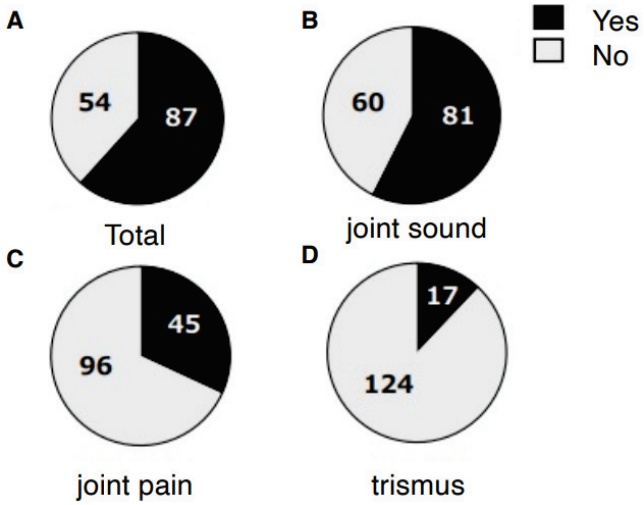

Figure 3. Subjective symptoms of temporomandibular disorder in patients with dentofacial deformities. The presence of joint sound, joint pain, and trismus is illustrated.

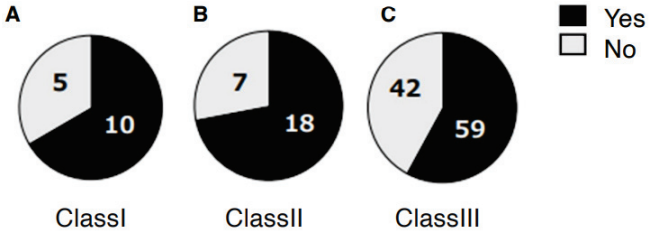

Figure 4. Total number of subjective temporomandibular disorder symptoms according to skeletal morphology. The prevalence of TMD symptoms is shown for skeletal Class I, II, and III patients.

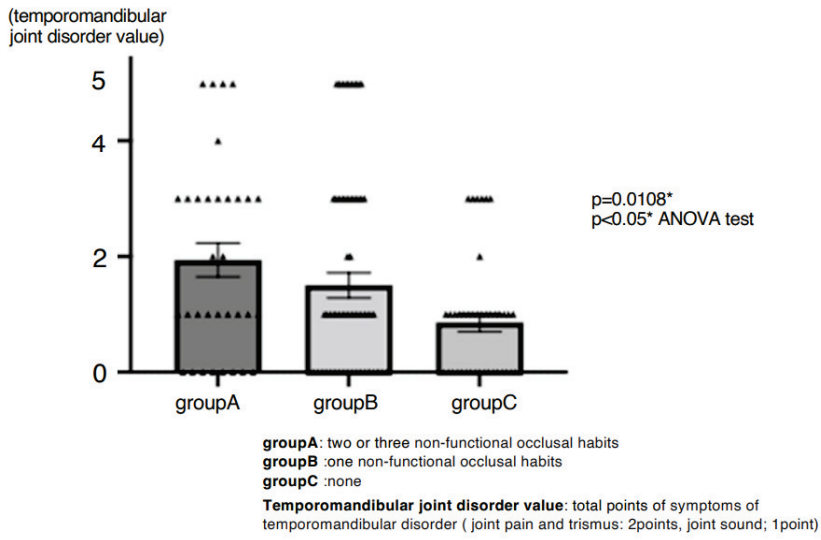

Figure 5. Relationship between non-functional occlusal habits and severity of temporomandibular disorder symptoms. TMD symptom scores (joint pain and trismus: 2 points each, joint sound: 1 point) were compared among patients with multiple NFOH (Group A), single NFOH (Group B), and none (Group C). Patients with multiple habits exhibited significantly higher TMD scores (ANOVA, * $p < 0.05$).

4. Discussion

This study investigated the associations between non-functional occlusal habits and temporomandibular disorder (TMD) symptoms in patients with dentofacial deformities. The principal findings were as follows: (1) non-functional oral habits were reported by 70%

of patients, with unilateral chewing being the most frequent; (2) unilateral chewing was significantly more common in patients with mandibular asymmetry; and (3) patients with multiple non-functional habits exhibited greater severity of TMD symptoms.

4.1. Prevalence and Impact of Parafunctional Habits

Our findings are consistent with epidemiological studies showing that awake bruxism has a prevalence of 23% in the general population [16], while sleep bruxism occurs in approximately 8% [17]. In the present cohort, bruxism and clenching were each observed in about 20% of patients, suggesting a higher frequency in dentofacial deformity patients compared to the general population. Bruxism, nail biting, and thumb sucking were found to be significantly associated with important oral/facial pain symptoms of clinical interest in the diagnoses of TMD indicating that those parafunctions are risk factors [18]. A significant association was observed between the presence of any dysfunctional oral habit and postoperative disk displacement with reduction [19].

Previous systematic reviews and clinical studies have consistently demonstrated significant associations between bruxism and TMD, including increased risk of myofascial pain, joint pain, and disk displacement [18,19]. Bruxer patients had more bony exostoses of the mandibular angle, smaller condyles, and morphological changes in cancellous and cortical mandibular bone compared to non-bruxer patients. Bruxism seems to induce morphological and anatomical changes in the different regions of the mandibular bone (condyles, mandibular angle, mandible body) [20]. Studies using CBCT and MRI have shown that patients with sleep bruxism have a higher prevalence of intervertebral disk deformation, intervertebral disk displacement, traumatic encephalopathy, and condylar bone changes [21].

CBCT revealed significant differences ($p < 0.05$) between patients with and without sleep bruxism in the right glenoid (AF)-axial plane (AP) and left glenoid-AP (B > NB), right submandibular angle (GA), left submandibular angle, saddle nose, and occlusal plane (B < NB), suggesting that bruxism may cause significant differences in the craniofacial morphology of the mandibular structure [13]. Furthermore, tooth contacting habit (TCH) has been identified as a behavioral factor prolonging chronic TMD pain [22]. Bruxism and dysfunctional oral habits were shown to be risk factors for the presence of TMD symptoms also after combined orthodontic and surgical treatment [19]. Importantly, preoperative parafunctional habits have also been shown to predict postoperative TMD symptoms even after orthognathic surgery [19], underscoring the importance of comprehensive functional assessment prior to treatment.

4.2. Unilateral Chewing and Mandibular Asymmetry

Unilateral chewing was associated with mandibular asymmetry in our patients.

It was reported that unilateral mastication might be an essential factor in the bilateral asymmetrical remodeling of the TMJ [23].

Population-based studies have demonstrated that chewing side preference is highly prevalent, with nearly half of individuals reporting a preference—most commonly for the right side [24]. Recent reviews have identified chewing side preference as a significant risk factor for TMD, with structural changes such as shorter condyles, increased articular eminence inclination, and altered fossa depth observed in patients with unilateral chewing [25].

During unilateral molar occlusion, mandibular deformity increases the pressure on the condyle and articular disk. Compared with mandibular protrusion or retraction, facial asymmetry will significantly increase the stress of the TMJ. Chewing on the non-deviated side will also lead to higher stress in the TMJ of patients with mandibular deviation [26].

As compared to the non-deviation side, the deviation side in the present class III patients with facial asymmetry showed a greater number of TMDs, such as condyle head deformity, disk displacement, and joint effusion [27].

Finite element stress analyses [26] and radiographic studies [27] have further confirmed that unilateral loading produces asymmetrical condylar deformation, disk displacement, and effusion, particularly on the deviated side. Clinical reports also show that patients with a unilateral chewing pattern present with significantly higher prevalence of TMD signs and symptoms [28]. Self-reported awake bruxism is highly associated with oral health-related quality of life in patients with temporomandibular joint osteoarthritis, while self-reported sleep bruxism and chewing-side preference are both moderately associated with oral health-related quality of life in patients with temporomandibular joint osteoarthritis [29].

Moreover, chewing-side preference and awake bruxism have been linked to reduced oral health-related quality of life in patients with TMJ osteoarthritis [29]. It has been suggested that pain caused by persistent clenching can cause damage to the articular disk, which in turn can lead to TMD [30]. Muscle asymmetry has been reported in patients with mandibular asymmetry [31], and muscle asymmetry has been reported to cause asymmetry of the condyle and result in morphological changes in the mandible [32,33]. It has been reported that the difference between the deflected and non-deflected condyles correlates with the development of facial asymmetry. CT scans of patients with mandibular asymmetry showed that the three-dimensional shape of the deflected condyle differed from that of the non-deflected condyle. This suggests a relationship between jaw asymmetry and joint remodeling [34]. It was reported that patients with TMD syndrome and unilateral chewing have abnormal changes in bilateral TMJ structure, showing medial and posterior displacement of the condyle on the unilateral chewing side and a compensatory increase in the pre-articular space on the non-unilateral chewing side [35]. Unilateral mastication affects the major compression sites in the left and right temporomandibular joints differently, suggesting that unilateral mastication may be an important factor in asymmetric remodeling of the TMJ [23]. A study using rats has shown that the condyles of growing humans become thinner while maintaining their length in the absence of occlusal stimulation [36]. It was reported that lateral imbalance of masseter muscle activity leads to inhibition of chondrogenesis and induces asymmetric formation of the condyle during the growth period [32]. In other words, this suggests that non-functional occlusal habits during the growth period cause asymmetry of the mandibular condyle and result in morphological changes in the mandible. These findings collectively support our observation that unilateral chewing is associated with both functional overload and skeletal asymmetry in dentofacial deformity patients.

4.3. Skeletal Morphology, Disk Displacement, and Joint Pathology

In addition to functional habits, skeletal morphology plays a crucial role in the pathophysiology of TMD. Previous studies have shown that skeletal Class II and hyperdivergent facial patterns are strongly associated with disk displacement and degenerative joint diseases [37]. When the temporomandibular joint disk displacement status was equal or bilaterally normal, the amount of mandibular deviation was not significant [38]. CBCT confirmed that a lesser condylar volume was also found on the deviation side in the asymmetric group. In the side with greater mandibular growth potential, the axis rotation in the axial plane would be greater [39].

In skeletal Class III patients with asymmetry, disk displacement has been found to correlate closely with mandibular deviation [38,39]. Our results, showing high prevalence of TMD symptoms in skeletal Class II patients, are in line with earlier reports by Ooi

and colleagues, who demonstrated that anterior disk displacement without reduction (ADDwoR) was more frequently observed in skeletal Class III and asymmetric Class II patients [40], as well as in anterior open bite patients [41]. Similarly, Chou et al. [39]. confirmed that condylar morphology differs between deviated and non-deviated sides in Class III asymmetry, highlighting the structural basis for functional imbalance. Thus, both morphological and functional factors act synergistically in shaping TMD pathology in dentofacial deformity patients.

4.4. Psychosocial and Neurophysiological Considerations

The underlying mechanisms may involve both central and peripheral regulation of masticatory muscle activity. Parafunctional behaviors—especially those involving chronic muscle tension or abnormal mandibular positioning—may meaningfully contribute to the risk of TMD in high-stress student populations [42]. The inhibitory neurotransmitter gamma-aminobutyric acid (GABA) plays an important role in the pathophysiology of anxiety behavioral disorders such as panic disorder and post-traumatic stress disorder, suggesting that oral behaviors such as teeth grinding and clenching, generally known as bruxism, may be associated with disturbances in brain GABAergic and glutamatergic systems [43]. Recent neuroimaging studies on teeth grinding have revealed involvement of the hypothalamic–pituitary–adrenal (HPA) axis, which is also associated with temporomandibular disorder (TMD) and post-traumatic stress disorder (PTSD). Currently, teeth grinding, PTSD, and other stress-related mental disorders are thought to stem from dysfunction in circuits involving the medial prefrontal cortex/anterior cingulate cortex region, dorsolateral prefrontal cortex (DLPFC), hippocampus, and amygdala. The precise neurochemical mechanisms by which certain selective serotonin reuptake inhibitors (SSRIs) induce sleep bruxism, as well as mechanisms involving important co-factors such as sleep regulation, endocrine systems, autonomic nervous function, stress/anxiety, and motor control, remain a focus of research. The efficacy of drugs such as gabapentin, tiagabine, gamma-hydroxybutyric acid (GHB), diazepam, and lorazepam in improving bruxism suggests that gamma-aminobutyric acid (GABA), a major neurotransmitter, plays a significant role in bruxism [43]. Bruxism is influenced by psycho-social and behavioral factors, which means that oromandibular parafunctional activities, temporomandibular disorders, malocclusion, high levels of anxiety and stress, among others, may precipitate the occurrence of bruxism. It is currently linked to orofacial pain; headaches; sleep disorders; sleep breathing disorders, such as apnea and hypopnea sleep syndrome; behavior disorders, or those associated with the use of medications [14]. Based on the above, it appears that bruxism caused by stress, etc., may prolong disorders caused by bruxism, such as orofacial pain and headaches and sleep disorders. Multivariate analyses revealed that anxiety was associated with TMD pain, TMJ sounds, and combined TMD, while autonomy was related to TMJ sounds [44].

Patients with TMDs may have an upregulated hypothalamic–pituitary–adrenal axis with higher cortisol secretion from the adrenal cortex. Anxiety/depression and pain catastrophizing scores were significantly higher in the TMD group, and psychological factors may contribute to chronic upregulation of the hypothalamic–pituitary–adrenal axis [45]. Muscle activity was greater among individuals with severe temporomandibular disorder and positive correlations were found among electromyographic activity, salivary cortisol and the degree of temporomandibular disorder severity [46]. Hormonal and muscle function studies have also shown that temporomandibular joint disorder and stress are related [45,46].

After long-term unilateral mastication, changes in the stress within the joint cause the imbalance of temporomandibular joint (TMJ) structural reconstruction, the transfor-

mation and even destruction of the fiber structure of the masticatory muscle, resulting in uncoordinated movement of bilateral muscles. The joint neurogenic diseases caused by the increase in neuropeptide substance P and calcitonin-gene-related-peptide (CGRP) released locally by TMJ may be the mechanism of TMD [25]. Chronic parafunctional activity can lead to repetitive joint overloading, neuropeptide release, and structural remodeling [25], thereby exacerbating TMD symptoms and potentially influencing mandibular growth and asymmetry.

4.5. Clinical Implications and Treatment Outcomes

From a clinical perspective, more than half of the dentofacial deformity patients in this study presented with TMD symptoms, particularly those with skeletal Class II morphology. These findings are consistent with previous studies reporting high preoperative prevalence of TMD symptoms in orthognathic surgery candidates [47]. Importantly, orthognathic surgery has been shown to reduce TMD prevalence from 60.9% preoperatively to 34.4% one year postoperatively [47], with long-term improvements in pain and masticatory function [27]. However, a minority of patients may experience postoperative worsening [47]. Nonfunctional occlusal habits are risk factors for the development of TMD after surgery. Therefore, identifying nonfunctional occlusal habits before surgery and correcting these habits can prevent the development of TMD after surgery [19]. Methods for assessing parafunctional habits include subjective evaluations such as questionnaires regarding opinions on non-functional habits, and objective evaluations such as electromyography and ultrasound elastography of the masticatory muscles. Although congenital anomalies are excluded in this study, it is thought to be useful for screening diseases that include facial asymmetry and mandibular and maxillary retrusion as characteristic features, such as OFDI syndrome [48]. By identifying dysfunctional occlusal habits during the initial consultation and correcting these habits before surgery, we believe we can prevent the development of temporomandibular joint disorders after surgery.

4.6. Limitations

This study has several limitations. First, the cross-sectional design precludes causal inference between non-functional occlusal habits, temporomandibular disorder (TMD) symptoms, and skeletal morphology. Second, the evaluation relied on self-reported questionnaires, which may be subject to recall bias. Third, advanced imaging modalities such as MRI or CBCT were not employed, limiting direct assessment of intra-articular pathology. Although age, sex, deformity type, and the number of parafunctional habits may influence TMD symptoms, the present study focused on bivariate associations rather than causal inference. Although a significant association was found between unilateral chewing and mandibular asymmetry, this cross-sectional study cannot establish a causal relationship. Future prospective studies should employ multivariate models to confirm these associations. Because the sample was predominantly female, the generalizability of the findings may be limited, and future studies with a more balanced sex distribution are warranted. In addition, as the study population consisted exclusively of Japanese patients treated at a single institution, caution is required when generalizing the findings to other ethnic or demographic groups. This study evaluates the relationship between nonfunctional occlusal habits and temporomandibular joint disorders in patients with dentofacial deformities. Since the impact on postoperative treatment outcomes was not assessed, no post-surgical follow-up information is available. As this study was retrospective in design, the analysis was limited to information available in the existing clinical records, which may reduce control over potential confounding variables.

In the future, evaluating the efficacy of habit-modification programs, behavioral therapy, or biofeedback may help clarify whether early intervention before and after orthognathic surgery contributes to postoperative functional and symptom resolution. Furthermore, postoperative changes in TMD symptoms were not evaluated because the present study focused exclusively on preoperative data. Future longitudinal studies should assess postoperative outcomes to determine the influence of habitual behaviors on recovery.

4.7. Future Perspectives

Future research should employ longitudinal and interventional designs to elucidate causal pathways linking non-functional occlusal habits, TMD symptoms, and skeletal deformities. The integration of multimodal assessments, including MRI, CBCT, and ultrasound elastography, will enable objective evaluation of structural and functional alterations in the masticatory system. Moreover, studies assessing the efficacy of habit-modification programs, behavioral therapy, or biofeedback—particularly before and after orthognathic surgery—could help clarify whether early intervention improves postoperative function and symptom resolution. Finally, interdisciplinary investigations combining biomechanical modeling, neuromuscular physiology, and psychosocial assessment are expected to deepen our understanding of how habitual loading patterns interact with skeletal morphology and joint health. Future studies with larger sample sizes should include multivariate analyses to adjust for these potential confounding factors.

4.8. Summary of the Discussion

In summary, this study demonstrated that non-functional oral habits—particularly unilateral chewing and bruxism—are significantly associated with TMD symptom severity and mandibular asymmetry in patients with dentofacial deformities. The integration of functional habit evaluation with skeletal and joint assessments is essential for accurate diagnosis and comprehensive management of these patients.

5. Conclusions

This study demonstrated that non-functional oral habits, particularly unilateral chewing and bruxism, are highly prevalent among patients with dentofacial deformities and are significantly associated with the severity of temporomandibular disorder (TMD) symptoms and mandibular asymmetry. Patients with multiple parafunctional habits exhibited greater TMD symptom scores, and unilateral chewing was strongly related to asymmetric mandibular morphology. These findings suggest that oral habits may contribute to both functional overload of the temporomandibular joint and the development or exacerbation of skeletal asymmetry. From a clinical perspective, comprehensive assessment of non-functional habits should be considered an integral part of diagnosis and treatment planning in patients with dentofacial deformities. Identifying and addressing such habits preoperatively may improve management of TMD symptoms, optimize surgical outcomes, and reduce postoperative risks. Future longitudinal studies incorporating objective functional and imaging evaluations are warranted to clarify the causal pathways linking oral habits, TMD symptoms, and skeletal deformities.

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Article

Sleep Bruxism and Occlusal Function: A Case–Control Study Based on Polysomnography in Young Colombians

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Abstract

Objectives: The objective of this study was to compare occlusal and articular characteristics between young adults with and without a confirmed diagnosis of sleep bruxism, through a case-control study based on polysomnography. **Methods**: We conducted a case–control study with probabilistic sampling, including 20 participants with a polysomnography-confirmed diagnosis of sleep bruxism and 20 age- and sex-matched controls. A clinical oral examination was conducted to identify wear facets, joint sounds, and soft tissue indentations. Occlusal relationships were analyzed using mounted models on a semi-adjustable articulator, evaluating interferences during working, balancing, and protrusive movements, premature contacts, attrition, and dental inclinations. **Results**: Sleep bruxism showed a higher frequency of temporomandibular joint sounds (35% vs. 5%; $p = 0.017$; w = 0.375) and left-side balancing interferences ($p = 0.04$; d = 0.723). Multivariate analysis revealed a moderate correlation between bruxism and the combination of joint sound and occlusal inclination (COR = 0.39; 95% CI: 0.19–0.57; $I^2 = 0.0\%$). Joint sound showed a weak association with REM-related bruxism (COR = 0.29; 95% CI: 0.05–0.51; $I^2 = 21.7\%$) and a moderate association with non-REM bruxism (COR = 0.41). The correlation with occlusal inclination was stronger during REM sleep (COR = 0.41) than during non-REM sleep (COR = 0.35; $I^2 = 0.0\%$), indicating consistent and clinically relevant associations. **Conclusions**: Occlusal and functional characteristics associated with sleep bruxism were identified, particularly joint sounds and dental inclinations, although no direct causal relationship was established. These findings suggest the presence of specific morphofunctional patterns that may play a role in the clinical expression of sleep bruxism.

Keywords: sleep bruxism; dental occlusion; temporomandibular joint; tooth wear; physical examination; adult; case–control studies

1. Introduction

Sleep bruxism is defined as a rhythmic, involuntary, and repetitive mandibular activity that occurs during sleep, typically accompanied by grinding sounds [1,2]. It is currently

understood as a complex, multisystemic physiological phenomenon with a multifactorial etiology, moving beyond the traditional mechanical paradigm [1–4].

This conceptual shift has redirected research toward the potential effects of bruxism on the stomatognathic system, particularly its role in the development of clinical dysfunctions that may require therapeutic intervention [4]. Several studies have reported associations between sleep bruxism, temporomandibular disorders (TMDs), and postural abnormalities [5,6]. This parafunctional activity can occur both during wakefulness and sleep, manifesting as involuntary clenching or grinding patterns [7–9].

For decades, various theories attributed bruxism to local factors, such as occlusal interferences or anatomical characteristics of the orofacial complex. However, these hypotheses have been increasingly questioned because of their limited empirical support and marginal clinical relevance [8,10]. In parallel, diverse etiological factors have been proposed, including systemic conditions (e.g., intestinal parasitosis, nutritional deficiencies, allergies, or endocrine disorders), psychological variables, and local factors such as malocclusion [3,8,11,12]. Specifically, the interaction of emotional stress, orofacial pain, and occlusal discrepancies has been suggested to promote the onset of bruxism [11–13]. More recent research, however, emphasizes the predominant role of psychopathological and neurophysiological mechanisms, relegating morphological factors to a secondary position [8,14]. While malocclusion has traditionally been considered a potential causal factor, there is no conclusive evidence to support this relationship [5,6,13]. Consequently, current approaches prioritize psychological, biological, and exogenous determinants, in alignment with the multifactorial nature of bruxism [3,8,14,15].

Today, sleep bruxism is recognized as a condition primarily of central origin, even though its most evident clinical manifestations appear within the stomatognathic system [8,16]. This paradigm shift—from an occlusion-centered to a neurophysiological model—has been supported by findings linking sleep bruxism to micro-arousals and alterations in D2 dopamine receptor expression in the striatum of affected individuals [17]. Its prevalence ranges between 20% and 40%, depending on the subtype (nonspecific, sleep-related, or awake bruxism), the diagnostic method used (self-report, clinical evaluation, or polysomnography), and population characteristics. It is especially prevalent among young adults; therefore, in the context of this study, diagnosis based on polysomnography was estimated at 43% [3,18].

Given its high prevalence and its potential association with functional disturbances in the stomatognathic system, it is relevant to explore its relationship with occlusal parameters. In this context, the present study aimed to compare occlusal and articular parameters in young adults with and without a confirmed diagnosis of sleep bruxism through a retrospective case–control study.

2. Materials and Methods

2.1. Design

This case–control study was conducted in accordance with the STROBE guidelines for observational research (Supplementary Material) [19]. The research protocol was approved by the Ethics Committee of the Autonomous University of Manizales (Protocol Code: GIN–GUN–001) and complied with Colombian Ministry of Health Resolution No. 8430 of 1993 and the ethical principles of the Declaration of Helsinki [20].

2.2. Context

This study was carried out in 2016 as part of the Oral Health Prevention Program at the Autonomous University of Manizales (Colombia). The target population included male and female university students aged 18 to 35 years.

The diagnosis of sleep bruxism was confirmed by nocturnal polysomnography (PSG), the gold standard for detecting rhythmic mandibular activity during sleep. This was complemented by a functional and morphological analysis of dental casts mounted on a semi-adjustable articulator, enabling detailed evaluation of both static and dynamic occlusal parameters, as well as associated clinical signs.

Participants were selected through probabilistic sampling, including only those with complete clinical records and valid diagnostic documentation. All participants were informed about the study objectives, selection criteria, and the retrospective nature of the research. Informed consent was obtained, authorizing the scientific use of their data for a period of up to ten years.

2.3. Participants

The final sample consisted of 40 university students, equally divided into two groups:

- Case group: 20 participants with confirmed sleep bruxism diagnosis via PSG.
- Control group: 20 participants without bruxism, matched by age and sex.

All participants were enrolled in the Oral Health Prevention Program and had complete clinical records, valid dental assessments, and PSG results.

Inclusion criteria: Students aged 18 to 35, actively enrolled in 2016, with complete clinical documentation including dental and PSG evaluations.

Exclusion criteria: Prior diagnosis of neuromuscular disorders or craniofacial malformations, ongoing orthodontic or prosthetic treatment, history of orthognathic surgery during the evaluation period, or technical inability to obtain functional articulator models.

2.4. Sleep Bruxism

Diagnosis followed a three-step protocol with increasing sensitivity and specificity, based on established guidelines (Supplementary Material) [21]:

Self-reported symptoms: Considered positive if the participant or a third party reported grinding sounds during sleep, accompanied by temporal or masseter muscle pain/fatigue upon awakening.

Intraoral clinical evaluation: Conducted by a certified oral rehabilitation specialist, screening for the following:

- Atypical dental wear facets (anterior or posterior).
- Masseter muscle hypertrophy during voluntary clenching.
- Morning muscle pain, discomfort, or fatigue not attributable to other causes.

Polysomnography: Positive cases in the first two levels were referred to the university laboratory, where a PSG was performed, recognized as the gold standard for identifying rhythmic mandibular activity and muscular events associated with sleep bruxism [22,23]. A physiatry specialist trained in PSG interpretation, blinded to participants' clinical profiles, used a Cadwell Easy III system with 10 mm stainless steel disc electrodes (Cadwell® 302139-200), following American Academy of Sleep Medicine (AASM) diagnostic criteria [24].

Electrodes were placed on the scalp using conductive gel after skin preparation to maintain impedance below 5 kΩ throughout the night. Neuroelectric activity was recorded with standard anatomical references using the 10–20 international system, and signals were amplified and digitized at $\geq$500 Hz, with 12–16-bit resolution [23,24].

Eye movements were tracked via electrooculography, placing electrodes on the outer canthi (1 cm above for the right eye, 1 cm below for the left), referenced to a mastoid electrode. This configuration enabled detection of vertical and horizontal eye movements through opposite-polarity signals, facilitating REM detection and transitions from wakefulness to light sleep. Slow eye movements were defined as those with <500 ms latency from initial deflection to peak amplitude [23,24].

Only cases confirmed through PSG were classified as sleep bruxism. For each positive case, an age- and sex-matched control was randomly selected from eligible candidates.

2.5. Functional Occlusal Assessment

Maxillary and mandibular models were mounted on a semi-adjustable articulator to analyze static and dynamic interocclusal relationships [25], following previous guidelines [26–28]. The assessment included the following:

- Premature contacts.
- Wear facets (attrition, abrasion, erosion).
- Occlusal interferences during work, balancing, and protrusive movements.

Dental morphology included Spee and Wilson curves, arch and palatal shape, gingival contours, malpositioned teeth, and the number of functionally absent units.

Temporomandibular joints were also examined for joint sounds, functional blockages, and muscle hypertrophy. Indirect signs of parafunction (e.g., cheek or tongue mucosa indentations) were noted as well [29].

2.6. Bias

As a case–control design, this study acknowledged potential biases [30].

- Selection bias may have arisen from the inclusion of only students with complete records and valid bruxism diagnostics, potentially limiting generalizability. This was mitigated through probabilistic sampling and strict inclusion criteria.
- Information bias, especially regarding self-reported symptoms, was minimized by employing a hierarchical, three-stage diagnostic protocol (self-report, clinical inspection, PSG), enhancing diagnostic accuracy.
- Observer bias was addressed by ensuring that PSG evaluations and clinical interpretations were conducted by blind professionals, using standardized and validated protocols.

2.7. Sample Size

The sample size was calculated based on the university's student population, aged 18–35, enrolled in the Oral Health Prevention Program in 2016. Using Epi Info v7 (StatCalc), and assuming 60% exposure prevalence in the bruxism group and 10% in controls, with a 1:1 case–control ratio, an expected odds ratio of 2.0, a 95% confidence interval, and 80% power, the required sample size was 40 participants. The 60% prevalence in the bruxism group is based on a previous study that documented a high prevalence of sleep bruxism in specific groups, such as young adults and individuals with sleep disorders, which show prevalence rates of up to 60% [31,32].

Thus, the final sample comprised 20 confirmed bruxism cases and 20 matched controls.

2.8. Statistical Analysis

Data analysis was conducted using SPSS v27 (IBM Corp., Armonk, NY, USA). Categorical variables were expressed as absolute and relative frequencies and compared using Pearson's chi-square test.

The normality of continuous variables was assessed with the Shapiro–Wilk test. For normally distributed variables, independent-samples t-tests were applied, reporting means, standard deviations (SDs), and standard errors (SEs). Odds ratios (ORs) with 95% confidence intervals (CIs) were also calculated.

The effect size was determined based on data type: Cramér's V (w) for categorical variables (interpreted as small < 0.1, moderate 0.1–0.3, large $\geq$ 0.3), and Cohen's d (d) for continuous variables (small $\geq$ 0.1, moderate $\geq$0.3, large $\geq$ 0.7) [33,34]. These met-

rics allowed the identification of clinically relevant differences, even in the absence of statistical significance.

To explore multivariable associations between sleep bruxism, occlusal conditions, and TMD symptoms, three linear regression models were developed. Model 0 included the total number of bruxism events as the dependent variable; Model 1 adjusted for the presence of joint sounds; and Model 2 additionally incorporated dynamic occlusal features (e.g., interferences, tooth inclination). Correlation coefficients (COR) with 95% confidence intervals (CIs) were reported, and a two-tailed significance level of $p < 0.05$ was applied.

All regression analyses were conducted under a random effects model to account for potential variability between subjects beyond sampling error. To evaluate heterogeneity, the I^2 statistic proposed by Higgins and Thompson was calculated. This measure estimates the proportion of total variability in effect sizes that cannot be attributed to sampling error (i.e., intra-group variability). I^2 values were interpreted using conventional thresholds: values below 25% indicated low heterogeneity, values below 50% indicated moderate heterogeneity, and values below 75% indicated substantial heterogeneity. In addition, T^2 (tau-squared) was computed to estimate the between-subject variance, providing a complementary indicator of unexplained heterogeneity in the models.

3. Results

The final sample consisted of 40 young adults, evenly divided between a sleep bruxism group (n = 20) and a control group (n = 20). The mean age was significantly higher in the sleep bruxism group (22.85 ± 3.67 years) compared to the control group (20.35 ± 1.57 years), with a statistically significant difference ($p = 0.009$) and a large effect size (d = 0.88). Regarding the sex distribution, no significant differences were found between the groups ($p = 0.705$), with a small effect size (w = 0.06). Other baseline variables, including smoking status, frequency of coffee consumption, self-reported stress, and the use of anxiolytic or sleep medication, showed no statistically significant differences between groups, with small to moderate effect sizes. No dropouts occurred during the course of this study (Table 1).

Table 1. Baseline characteristics of the analyzed sample (n = 40).

Sociodemographic Variables	Sleep Bruxism Group (n = 20)	Control Group (n = 20)	*p*-Value	Effect Size Classification	
Age (years)	22.85 ± 3.67	20.35 ± 1.57	0.009	0.88 (d)	Large
Male	5 (25%)	4 (20%)	0.705	0.06 (w)	Small
Female	15 (75%)	16 (80%)			
Daily smoker	0 (0%)	1 (5%)	0.310	0.95 (w)	Large
Coffee >4 times/week	0 (0%)	2 (10%)	0.146	0.90 (w)	Large
Self-reported stress	8 (40%)	6 (30%)	0.507	0.10 (w)	Moderate
Anxiety medication	1 (5%)	3 (15%)	0.292	0.17 (w)	Moderate
Sleep medication	1 (5%)	2 (10%)	0.548	0.09 (w)	Small

d: effect size determined by Cohen's d, w: effect size determined by Cramer's V.

3.1. Comparison of Signs, Symptoms, and Medical History

Table 2 presents a comparison of clinical signs, symptoms, and history between subjects with and without sleep bruxism. Although most of the analyzed variables did not show statistically significant differences between the groups ($p > 0.05$), moderate effect sizes

were observed for variables such as nocturnal clenching (w = 0.209), dental hypersensitivity (w = 0.154), the presence of occlusal impressions on buccal mucosa (w = 0.100), and temporomandibular joint (TMJ) locking (w = 0.284). Notably, the presence of joint sounds was significantly higher in the sleep bruxism group (35% vs. 5%), with a statistically significant difference (p = 0.017) and a large effect size (w = 0.375). This suggests a possible association between sleep bruxism and functional alterations of the TMJ.

Table 2. Comparison of signs, clinical symptoms, and history between subjects with and without sleep bruxism (n = 40).

Signs, Clinical Symptoms, and History	Presents Condition	Sleep Bruxism Group	Control Group	*p*-Value	df	w	Effect Size Classification
Fatigue or sore jaw	Yes	16 (80%)	15 (75%)	0.708	1	0.059	Small
	No	4 (20%)	5 (25%)				
Sore teeth or gums	Yes	9 (45%)	7 (46.15%)	0.516	1	0.102	Moderate
	No	11 (55%)	13 (53.85%)				
Headache in the temporal region	Yes	11 (55%)	12 (60%)	0.751	1	0.050	Small
	No	9 (45%)	8 (40%)				
Daytime grinding	Yes	7 (35%)	6 (30%)	0.740	1	0.052	Small
	No	13 (65%)	14 (70%)				
Nighttime grinding	Yes	8 (40%)	5 (25%)	0.310	1	0.160	Moderate
	No	12 (60%)	15 (75%)				
Nighttime clenching	Yes	9 (45%)	5 (25%)	0.184	1	0.209	Moderate
	No	11 (55%)	15 (75%)				
Wear facets	Yes	14 (70%)	15 (75%)	0.718	1	0.057	Small
	No	6 (30%)	5 (25%)				
Masseter voluntary hypertrophy contraction	Yes	8 (40%)	10 (50%)	0.527	1	0.101	Moderate
	No	12 (60%)	10 (50%)				
Discomfort in masticatory muscles	Yes	12 (60%)	12 (60%)	1	1	0	Null
	No	8 (40%)	8 (40%)				
Dental hypersensitivity	Yes	9 (45%)	6 (30%)	0.327	1	0.154	Moderate
	No	11 (55%)	14 (70%)				
Temporomandibular joint locking	Yes	0 (0%)	3 (15%)	0.071	1	0.284	Moderate
	No	20 (100%)	17 (85%)				
Occlusal impressions on buccal mucosa	Yes	11 (55%)	9 (45%)	0.527	1	0.100	Moderate
	No	9 (45%)	11 (55%)				
Dental impressions on lingual edges	Yes	4 (20%)	7 (35%)	0.287	1	0.168	Moderate
	No	16 (80%)	13 (65%)				
Temporomandibular pain on palpation	Yes	2 (10%)	4 (20%)	0.377	1	0.139	Moderate
	No	18 (90%)	16 (80%)				
Temporomandibular pain when opening or closing the mouth	Yes	4 (20%)	2 (10%)	0.377	1	0.139	Moderate
	No	16 (80%)	18 (90%)				
Presence of joint noise	Yes	7 (35%)	1 (5%)	0.017	1	0.375	Large
	No	13 (65%)	19 (95%)				

Table 2. *Cont.*

Signs, Clinical Symptoms, and History	Presents Condition	Sleep Bruxism Group	Control Group	*p*-Value	df	w	Effect Size Classification
Presence of functional anterior guidance	Yes	16 (80%)	16 (80%)	1	1	0	Null
	No	4 (20%)	4 (20%)				
Presence of premature contacts	Yes	19 (95%)	17 (85%)	0.292	1	0.166	Moderate
	No	1 (5%)	3 (15%)				

3.2. Dynamic Occlusal Evaluation

Table 3 presents the results of the dynamic articulator analysis, evaluating occlusal interferences and functional parameters during mandibular excursive movements. In general, no statistically significant differences were observed between the bruxism and control groups regarding right or left lateral interferences, protrusion, horizontal or vertical overbite, or premature contacts. However, a significant difference was found in balancing interferences on the left side ($p = 0.04$), being more pronounced in the bruxism group. This variable not only showed statistical significance but also had a large effect size (d = 0.723), suggesting a clinically relevant association between sleep bruxism and balancing interferences. Moderate to large effect sizes were also observed in other variables, such as right balancing interferences (d = 0.556), vertical overbite (d = 0.829), and premature contacts (d = 2.154), although these did not reach statistical significance. These findings may reflect subtle functional misalignments in bruxism subjects that warrant further clinical and biomechanical exploration.

Table 3. Summary of dynamic occlusal analysis by groups (n = 40).

Dynamic Variables	Groups	Statisticians					
		SD	SE	95% IC	*p*-Value	d	Effect Size Classification
Right lateral interferences	Bruxism	0.74	0.16	0.65 (0.30 a 0.99)	0.53	0.128	Small
	Control	0.82	0.18	0.55 (0.16 a 0.93)			
Left lateral interferences	Bruxism	0.75	0.16	0.45 (0.09 a 0.80)	0.22	0.374	Moderate
	Control	0.85	0.19	0.75 (0.35 a 1.14)			
Right balancing interferences	Bruxism	0.58	0.13	0.31 (0.03 a 0.59)	0.07	0.556	Moderate
	Control	0.91	0.20	0.75 (0.32 a 1.17)			
Left balancing interferences	Bruxism	0.75	0.16	0.45 (0.09 a 0.80)	0.04	0.723	Large
	Control	0.22	0.05	0.05 (−0.05 a 0.16)			
Protrusion interferences	Bruxism	0.97	0.21	0.70 (0.24 a 1.16)	0.98	0.085	Null
	Control	1.13	0.26	0.79 (0.24 a 1.34)			
Horizontal overbite (mm)	Bruxism	0.68	0.15	1.50 (1.17 a 1.82)	0.67	0.092	Null
	Control	0.83	0.19	1.57 (1.17 a 1.98)			
Vertical overbite (mm)	Bruxism	0.67	0.15	1.65 (1.33 a 1.96)	0.21	0.829	Large
	Control	0.84	0.19	1.04 (1.53 a 2.35)			
Premature contacts	Bruxism	0.32	0.07	1.00 (0.84 a 1.15)	0.48	2.154	Large
	Control	0.52	0.12	0.94 (0.69 a 1.20)			

3.3. Correlational Analysis

Figure 1 presents the results of the correlation analysis among the studied variables using random effects models. In Model 0, a moderate and statistically significant correlation was observed between the total number of bruxism events and two occlusal–functional parameters: TMJ noises and occlusal inclination (COR = 0.39; 95% CI: 0.19–0.57). Heterogeneity was absent (I^2 = 0.0%, τ^2 = 0, p = 0.7216), indicating consistent effects across both variables.

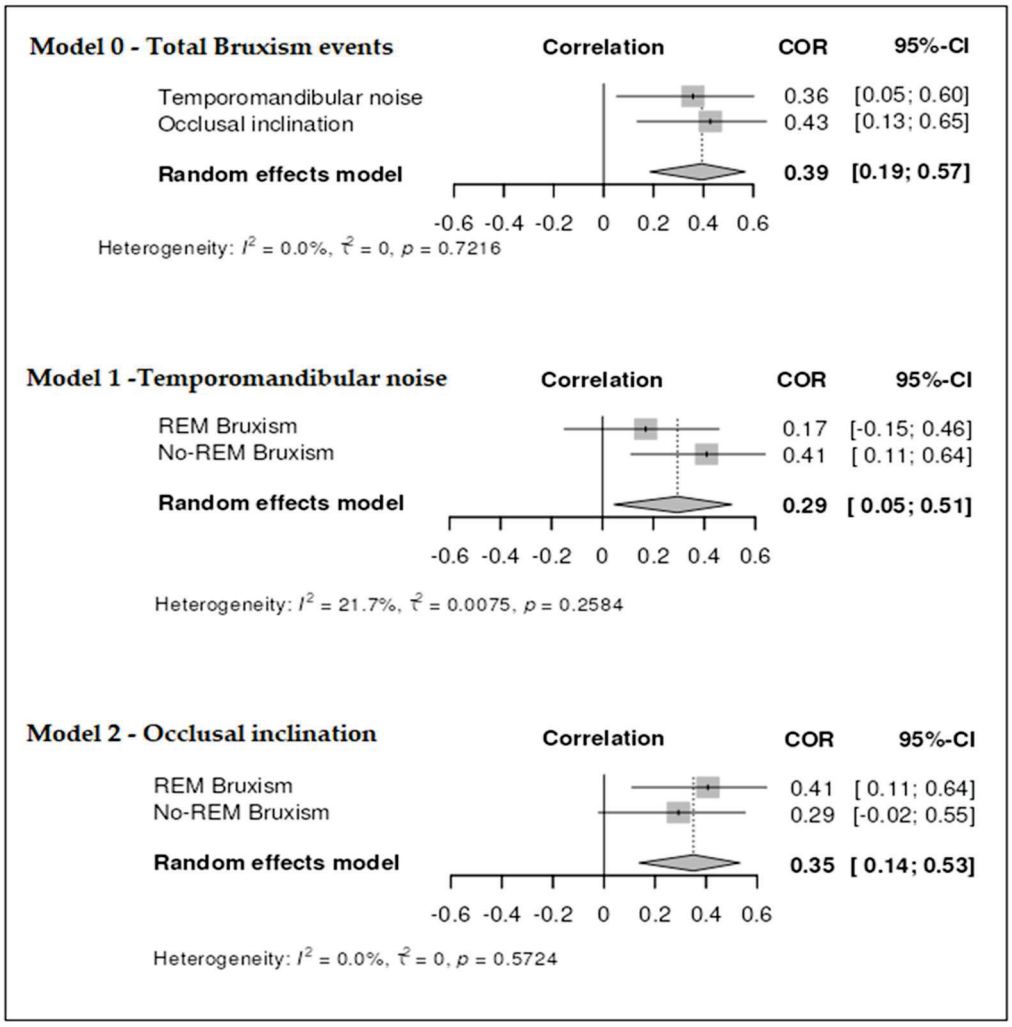

Figure 1. Multivariate associations between sleep bruxism, occlusal conditions, and temporomandibular symptoms.

In Model 1, a moderate correlation was found between TMJ noises and bruxism activity during REM and non-REM sleep phases (COR = 0.29; 95% CI: 0.05–0.51), with low and non-significant heterogeneity (I^2 = 21.7%, τ^2 = 0.0075, p = 0.2584), suggesting a slightly variable but still coherent association.

Model 2 revealed a moderate correlation between REM and non-REM bruxism phases and occlusal inclination (COR = 0.35; 95% CI: 0.14–0.53), with no heterogeneity observed (I^2 = 0.0%, τ^2 = 0, p = 0.5724), supporting the consistency of this relationship.

Overall, the absence or minimal presence of heterogeneity across models reinforces the robustness of the associations found.

4. Discussion

The main objective of this research was to compare occlusal and joint characteristics between individuals with a confirmed diagnosis of sleep bruxism and a matched control group, using a retrospective case–control design. One of the most relevant findings was the higher frequency of joint noises in the sleep bruxism group, a statistically significant difference supported by multivariate analysis, suggesting a possible functional association between this nocturnal parafunction and TMJ alterations. Previous studies have indicated that sleep bruxism may be related to repetitive microtrauma to the stomatognathic system, including elongation of capsular and discal ligaments, disc thinning, and muscular discoordination, which may contribute to condyle-disc displacement and the emergence of joint sounds [35,36]. This evidence supports the hypothesis that the TMJ is one of the structures most susceptible to the mechanical load associated with moderate to severe bruxism [37]. A significant association between bruxism and articular clicking has also been documented, especially when diagnosed through electromyography [38,39]. However, this relationship remains debated. Some authors suggest that bruxism patients may have greater subjective awareness of their symptoms, potentially overestimating the clinical relevance of this relationship, given that objective diagnostic methods tend to show less consistent correlations [40,41]. In this context, symptoms such as pain or joint sounds could reflect secondary muscular hyperactivity rather than true structural joint dysfunction. It has also been suggested that small changes in mandibular position could induce increased muscular activity and atypical mechanical loads on the TMJ, promoting inflammatory processes in retrodiscal or synovial tissues. Clinically, this may be present as joint sounds or disc dislocations in the presence of asymmetric occlusal contacts [42–44]. In this study, such findings were consistent with a higher frequency of joint sounds in the bruxism group, though without accompanying pain, possibly reflecting functional adaptation to chronic overload. However, it is crucial to highlight that despite the sample size calculation presented, several analyses yielded borderline results, which could indicate an insufficient sample size. Future studies should consider larger and more diverse samples to obtain more robust results. Additionally, it is important to emphasize that the inherent limitations of the obtained data, such as the absence of social variables like lifestyle, stress, and anxiety, among other comorbidities, were not addressed. These factors could have interfered with the observed results. Previous studies have reported that only a fraction of individuals with bruxism develop clinically significant orofacial pain [4,45,46].

Regarding occlusal variables, a higher frequency of interferences on the left balancing side was identified in individuals with sleep bruxism. This result aligns with findings by Tago et al. [47], who observed mediotrusive interferences in 96% of bruxism patients. However, despite this correlation, the correlation analysis performed in this study showed that while occlusal interferences have a moderate relationship with bruxism, the results may not have been sufficiently significant in all cases. The lack of a larger sample size could have influenced the borderline results observed. Additionally, the clinical relevance of these interferences remains controversial. Some studies suggest their contribution to the electromyographic pattern is limited and that their therapeutic removal may not be clinically justified [48]. Additionally, heterogeneity in the definition and classification of occlusal interferences complicates the establishment of consistent associations [38,49–51]. In contrast, no significant differences were observed between the groups regarding wearing facets, premature contacts, or working side interferences. These findings suggest caution when generalizing, as not all bruxism patients exhibit detectable occlusal alterations, and their presence does not necessarily imply a causal relationship. This aligns with studies that recommend a conservative approach to occlusal adjustments, reserving them for cases with clear clinical evidence of trauma, preferably combined with the use of occlusal

splints [1,52,53]. A higher frequency of inclined teeth was also reported in the sleep bruxism group, which is consistent with the literature suggesting that dental inclinations may alter occlusal load trajectories and increase functional load on periodontal and articular structures [54,55]. These altered trajectories may also be associated with excessive attrition, headaches, and joint noises [29,56,57]. It is important to note that although the correlation is significant, the results may not be conclusive because of the limitations of the sample size and the lack of consideration of other social variables that may have influenced the severity of bruxism.

An unexpected finding was the lower dental attrition in the sleep bruxism group. This observation is consistent with reports questioning the validity of dental wear as a diagnostic marker for bruxism, as no consistent relationship has been demonstrated between attrition and the intensity or frequency of this parafunction [58,59]. However, it should be highlighted that this study's limitations, especially regarding the sample size and the absence of factors such as stress and anxiety, may have influenced the results obtained. Overall, the results of this study support the hypothesis that sleep bruxism does not produce a uniform occlusal pattern. This variability may explain the lack of consensus regarding the intensity, clinical characteristics, and functional relevance of sleep bruxism, which seems to range between a physiological adaptive response and a pathological parafunction, even in the absence of evident articular or muscular manifestations [2,4,60].

5. Clinical and Practical Implications

The findings of this study provide relevant information for dental clinical practice, especially regarding the comprehensive diagnosis and functional assessment of sleep bruxism. The observed association between this parafunction and joint noises reinforces the usefulness of systematically including functional evaluation of the TMJ in patients presenting clinical signs of nocturnal parafunctional activity. The detection of occlusal interferences during balancing movements and dental inclinations should also be considered during clinical examinations, although these should not be assumed to indicate direct causality. In this context, a prudent and individualized clinical approach is recommended, avoiding invasive interventions, such as occlusal adjustments, unless clear evidence of dysfunction or trauma is present. Additionally, these findings may suggest a potential preventive role for orthodontics in the early correction of occlusal alterations that may increase functional load in predisposed patients. Overall, the need for interdisciplinary protocols is reinforced, integrating occlusal, functional, and psychosocial aspects to differentiate between physiological adaptations and pathological manifestations of sleep bruxism.

6. Study Limitations and Strengths

The case–control design limits the ability to establish causal relationships, as it does not allow for precise determination of the temporal sequence between occlusal characteristics and the presence of sleep bruxism. It is possible that some of the observed variables, such as balancing side interferences or dental inclinations, may function both as predisposing factors and as adaptive responses to parafunctional activity. These hypotheses warrant investigation in future longitudinal studies with clinical follow-up.

Additionally, the assessment of certain occlusal variables was based on subjective clinical criteria, which could introduce interobserver variability. However, standardized calibration procedures were implemented to minimize this potential bias and ensure consistency in data collection.

Despite these limitations, this study has several notable strengths. First, the sample was homogeneously distributed in terms of key sociodemographic factors, and no dropouts occurred. Second, the use of validated diagnostic criteria for sleep bruxism, combined with

a structured occlusal–functional examination, enhances the internal validity of the findings. Third, the statistical analysis incorporated effect size measures and heterogeneity indices, which strengthen the interpretation of associations and the reliability of the results. Finally, the absence or minimal presence of heterogeneity across the correlation models supports the consistency and robustness of the identified relationships.

7. Conclusions

This study identified morphofunctional differences between young adults with and without a confirmed diagnosis of sleep bruxism. In particular, participants with bruxism showed a higher frequency of joint noises, occlusal interferences on the balancing side, and abnormal dental inclinations. Additionally, statistical associations were found between the number of bruxism events recorded via polysomnography and two specific features: TMJ noises and dental inclination. These findings support the hypothesis that sleep bruxism is related to specific, albeit heterogeneous, occlusal patterns that may reflect adaptive functional mechanisms or biomechanical decompensations. However, because of the retrospective design of this study, causal relationships cannot be established. Longitudinal research is needed to clarify the directionality and clinical relevance of these associations for a better understanding of sleep bruxism and its impact on stomatognathic function.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/jcm14196733/s1, S1: STROBE checklist, bruxism self-report instrument, and intraoral clinical evaluation.

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Article

Polysomnographic and Electromyographic Evaluation of Sleep Bruxism in Young Colombian Adults: Case-Control Study

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Abstract

Background: Sleep bruxism (SB) is increasingly recognized not merely as a movement disorder but as a multifactorial condition in which physiological, behavioral, and contextual factors converge. **Objective**: To comprehensively characterize SB in young adults, integrating polysomnography (PSG) and surface electromyography (sEMG) to describe sleep architecture, periodic limb movements (PLMs), and masticatory muscle activity; compare these parameters with matched controls; and explore clinical correlations relevant to dental practice and individualized management. **Methods**: Forty university adults (20 PSG-confirmed SB; 20 controls) underwent PSG assessment of total sleep time, sleep stages, arousals, apnea, oximetry, and PLMs. EMG activity of the masseter and temporalis muscles was recorded in 37 participants (18 SB, 19 controls). Statistical analyses included *t*-tests, Mann–Whitney U tests, and multivariate logistic regression to identify independent predictors of SB. **Results**: SB participants exhibited higher bruxism event counts ($p \leq 0.001$; PS = 0.94), increased PLMs ($p \leq 0.01$; PS = 0.75), shorter REM sleep duration ($p = 0.04$; d = 0.69), and higher bruxism-related arousal indices ($p \leq 0.001$; PS = 83.4). Left masseter activity differed significantly ($p = 0.03$; d = 0.50), while other muscle measures showed no significant differences. Logistic regression identified age (OR = 0.59, $p = 0.02$), PLMs (OR = 0.96, $p = 0.03$), and REM sleep duration (OR = 0.98, $p = 0.05$) as independent predictors, explaining 58% of the variance. **Conclusions**: These findings provide a comprehensive profile of SB in young adults. Integrating PSG, sEMG, and oral assessments supports early diagnosis, personalized management, and interdisciplinary collaboration to prevent complications.

Keywords: sleep bruxism; temporomandibular joint; physical examination; adult; case–control studies

1. Introduction

Sleep bruxism (SB) has traditionally been classified as a sleep-related movement disorder characterized by repetitive, involuntary contractions of the masticatory muscles during nighttime rest. These manifestations are mainly expressed as rhythmic masticatory muscle activity or as sustained tonic activity [1,2]. However, in recent years, it has been proposed that SB should not be understood solely as a movement disorder, but rather as a condition with its own characteristics, in which physiological, behavioral, and contextual factors converge [3].

In this context, SB is clinically significant due to its high prevalence in the general population—estimated between 8% and 31% in children and young adults and its association with a spectrum of adverse orofacial outcomes, including abnormal tooth wear, masticatory muscle hypertrophy, temporomandibular disorders, myofascial pain, headaches, and reduced quality of life [4–7]. Despite extensive research, the precise etiology of SB remains multifactorial and incompletely understood, involving a complex interplay of central nervous system mechanisms, sleep microstructure alterations, autonomic dysfunction, and peripheral muscle activity [8,9].

Clinically, SB diagnosis has traditionally relied on a combination of self-reported symptoms, such as teeth grinding or clenching during sleep, bed partner observations, and clinical signs including dental wear facets and masticatory muscle hypertrophy [10]. However, these approaches are limited in sensitivity and specificity, potentially leading to misclassification or overdiagnosis. Consequently, polysomnography (PSG) combined with electromyographic (EMG) recordings of the masseter and temporalis muscles has emerged as the gold standard for objective SB diagnosis and quantification [5,6]. PSG enables simultaneous assessment of muscle activity, sleep stages, micro-arousals, and respiratory events, providing an integrated understanding of the neurophysiological underpinnings of the disorder.

Physiopathologically, SB is hypothesized to be closely linked to sleep fragmentation and arousals, during which brief cortical or autonomic activations trigger rhythmic masticatory muscle activity episodes [8,11,12]. These micro-arousals, particularly during Non- Rapid Eye Movement (N-REM) sleep, have been implicated in initiating SB events. Additionally, alterations in Rapid Eye Movement (REM) sleep duration and architecture may modulate SB occurrence and severity, although studies report heterogeneous findings [13–15]. Periodic limb movements during sleep (PLMs), commonly observed in restless legs syndrome and other sleep disorders, have also been found to cooccur with SB, suggesting shared neural circuits involved in sleep-related motor control [15,16]. The relationship between PLMs and SB remains incompletely elucidated, with some evidence indicating that increased PLMs may exacerbate sleep fragmentation and SB activity.

Electromyographic assessment during wakefulness and sleep provides crucial insights into neuromuscular function in SB patients. Surface EMG (sEMG) of the masseter and temporalis muscles allows quantification of activation levels and asymmetries, potentially reflecting underlying hyperactivity, neuromuscular imbalances, or compensatory mechanisms in response to chronic overuse [17–19]. However, research exploring these muscle characteristics in young populations with PSG-confirmed SB is limited, representing a significant gap in understanding the peripheral manifestations of this central sleep disorder.

Given the multifactorial nature of SB, integrative studies combining objective polysomnographic data, oral functional assessments, and electromyographic profiles are needed to unravel the complex interactions contributing to SB pathogenesis and clinical expression [5,8,16]. Identifying independent predictors of SB among neurophysiological and demographic variables could enhance diagnostic accuracy and inform personalized therapeutic approaches [8,13]. Moreover, clarifying the roles of age, REM sleep duration,

and PLMs in SB physiopathology may provide insights into modifiable factors and risk stratification [13–15].

From a clinical perspective, findings derived from PSG and electromyography EMG provide a valuable opportunity to enhance routine dental practice. Whereas traditional assessments rely on indirect signs such as tooth wear facets or muscle hypertrophy, the incorporation of these objective methods allows clinicians to identify specific patterns of masticatory activity, quantify their intensity, and relate them to sleep architecture. For dentists, this means the ability to distinguish clinically significant sleep bruxism from benign manifestations, thereby avoiding overdiagnosis and unnecessary treatments. Moreover, integrating PSG/EMG data into routine evaluations may support more personalized decisions, such as tailoring occlusal splints based on the patient's electromyographic profile, identifying risks of progression toward temporomandibular disorders, and making timely referrals to sleep medicine specialists when systemic alterations are detected.

For these reasons, this case–control study aimed to comprehensively characterize sleep bruxism in young adults, conceptualized as a sleep-related masticatory muscle activity rather than a disorder. Specifically, we sought to (i) integrate PSG and sEMG data to describe sleep architecture, periodic limb movements, and masticatory muscle activity; (ii) compare these parameters between PSG-confirmed sleep bruxism participants and matched controls; and (iii) explore potential clinical correlations relevant to dental practice and individualized management.

2. Materials and Methods

2.1. Study Design

This case–control study was conducted in accordance with the STROBE guidelines for observational research [20]. The protocol was initially approved by the Ethics Committee of the Autonomous University of Manizales (Protocol Code: 59-2016; approved on 14 September 2016). Subsequently, the same committee granted retrospective approval (Protocol Code: 292-210; approved on 25 August 2025), which corresponded to an administrative requirement to revalidate the secondary use of data already collected in 2016 for analysis and publication purposes. No new data collection or patient contact occurred after the original approval, and all procedures complied with the Colombian Ministry of Health Resolution 8430 of 1993 and the principles of the Declaration of Helsinki [21].

2.2. Context

The study was conducted within the Oral Health Prevention Program at the Autonomous University of Manizales (Colombia), focusing on a population of young adults aged 18–29 years. Sleep bruxism was assessed using overnight PSG, complemented by a functional oral analysis targeting static and dynamic occlusal parameters, as well as sEMG to evaluate masticatory muscle activity.

2.3. Participants

A total of 40 university students were enrolled and allocated as follows:

- Cases: 20 participants with PSG-confirmed SB.
- Controls: 20 participants without PSG evidence of SB.

2.4. Eligibility Criteria

Inclusion criteria: Students aged 18–29 years, enrolled since 2016 and 2025, with complete medical and dental records and PSG evaluation.

Exclusion criteria: Active dental treatment, more than four conservative prosthetic restorations, use of medications affecting sleep or motor function, neurological disorders,

more than two non-functional edentulous areas, use of removable prostheses, severe malocclusion, or diagnosed psychiatric or neurological conditions.

2.5. Sleep Bruxism Diagnostic Protocol

The diagnosis followed a three-level protocol developed by the Oral Health Prevention Program, based on sensitivity and specific criteria reported in previous studies [22]:

- Self-reported symptoms: Patient and/or bed partner reports of teeth grinding and morning temporal or masseter muscle pain or fatigue.
- Clinical intraoral assessment: Performed by a certified oral rehabilitator, identifying atypical dental wear facets and masseter hypertrophy during voluntary contraction.
- Polysomnography: Participants positive on the first two levels were referred to the sleep laboratory for overnight PSG, conducted by a physiatrist blinded to the clinical status [23].

2.6. Polysomnography

PSG recordings were obtained using the Cadwell Easy III system with 10 mm stainless steel electrodes (Cadwell® 302139-200, Cadwell Industries Inc., Kennewick, WA, USA), following the American Academy of Sleep Medicine guidelines [24,25]. Additionally, polysomnographic recordings (Cadwell Easy III, 2016 version; Cadwell Industries Inc., Kennewick, WA, USA) were included to control for sleep-related variables. The PSG protocol included electrooculography, electromyography, airflow measurement, respiratory effort, snoring, cardiac monitoring, oxygen saturation, and body position tracking. EEG channels were also recorded to identify sleep stages. Electrodes were applied with conductive gel, maintaining impedance <5 kΩ, and signals were digitized at ≥500 Hz with 12–16-bit resolution.

Ocular movements were monitored via EOG with mastoid-referenced electrodes in standard positions; movements with latency <500 ms were considered valid, enabling accurate REM sleep phase identification and transitions. Sleep bruxism was diagnosed if ≥2 RMMA episodes/hour or ≥4 muscle events/hour (phasic, tonic, or mixed) were observed, with a BEI >2 [24,25].

2.7. Masticatory Electromyography

sEMG was recorded using a Sierra® Wave® system (Cadwell®) at a 76.8 kHz sampling rate, with a 10–10,000 Hz band-pass filter and a 200 μV gain, employing 10 mm stainless steel Cadwell® electrodes (302139-200) with conductive gel (Cadwell® 202153-000) [19,26]. The ground electrode was positioned 2 cm above the nasion. A bipolar configuration was applied to evaluate variations in muscle activation [27].

Electrode placement was conducted as follows:

- Masseter muscles: Subjects were asked to close their teeth with maximal force. The active electrode was positioned on the motor point, and the reference electrode was placed 1 cm below the auricular lobe.
- Temporalis muscles: Electrodes were positioned over the anterior belly after maximal activation.

Although SENIAM guidelines were originally developed for limb muscles, the procedures adopted in this study are consistent with their general principles to ensure reproducibility in craniofacial sEMG [28]. Impedance values complied with international standards; values below 5 kΩ are considered acceptable for reliable sEMG recordings [28,29]. Participants were seated upright with the Frankfort plane parallel to the floor, as recommended for masticatory EMG protocols to minimize postural bias [30]. Participants were seated upright against the back of a chair with their arms relaxed, feet on the floor, eyes

open, and looking at a point in front of them. Prior to electrode placement, faces were cleaned with 95% ethanol, and conductive gel was applied to reduce low-conductance artifacts [28,31].

The protocol included voluntary contraction tasks, including lip compression, tongue thrust, masticatory contraction, and swallowing. Each measurement was repeated three times, with 30–60 s intervals to reduce fatigue [28,31]. Maximal voluntary contraction (MVC) of the orbicularis oris muscle was determined by 10 s of pursed lips. Nine swallows of 25 mL of water were requested (three per muscle), and participants were instructed to "swallow as usual" while holding the liquid in the mouth until resting. Total elapsed time during the sEMG process did not exceed 10 min. Force was recorded using a Pounds Myoescanner (Neilco Technology, USA), calibrated to 0.0 lb before each session; measurements $\geq$0.6 lb were considered normal.

Technical specifications of the recording system are summarized as follows:

- Sampling rate: 76.8 kHz;
- Bandwidth: 10–10,000 Hz;
- Gain: 200 μV;
- Input impedance: >100 MΩ for Cadwell® amplifiers;
- Common mode rejection ratio (CMRR): >100 dB;
- Input range: ±5 mV;
- Baseline noise: <1 μV RMS.

Signal acquisition and initial processing were conducted using the Cadwell® Sierra® Wave® software. Electrode and sensor application and verification were performed by a certified technologist, with all procedures logged in a standardized checklist.

Asymmetry indices were calculated as follows [32]:

Masseter Asymmetry (%):

$$((\text{Right Masseter} - \text{Left Masseter})/(\text{Right Masseter} + \text{Left Masseter})) \times 100$$

Temporal Asymmetry (%):

$$((\text{Right Temporal} - \text{Left Temporal})/(\text{Right Temporal} + \text{Left Temporal})) \times 100$$

The asymmetrical results of the masseter and temporal muscles can show positive values when activity is greater on the right side, and negative values when activity predominates on the left side. A value of 0 indicates balance between both sides [32].

2.8. Bias

Potential selection (complete records only), information (self-reported symptoms), and observer (clinical assessments) biases were minimized through; Probabilistic sampling; Blinded evaluators; Standardized protocols and strict inclusion criteria [33]. Nevertheless, a potential geographic bias must be acknowledged, as the sample was restricted to university students from a single urban region, which may limit the generalizability of the findings to broader or more diverse populations [34].

2.9. Sample Size

The sample size was estimated using Epi Info™ v7.2 (StatCalc, CDC, Atlanta, GA, USA), a validated software widely used for epidemiological and clinical research due to its robust statistical algorithms and accessibility [35]. The calculation was based on a target population of university students aged 18–29 years, aligning with the demographic profile most frequently associated with SB in Colombian adults is most frequently described [22]. Following recommendations for case–control studies, parameters were set considering

an expected prevalence of exposure of 60% in cases and 10% in controls, assuming a 1:1 case–control ratio, an odds ratio (OR) of 2, a 95% confidence interval (CI), and 80% statistical power [22,36–38].

This approach ensures adequate sensitivity to detect clinically meaningful associations while minimizing the risk of type II error, the required sample size was 40 participants, consistent with methodological standards that highlight the importance of balancing feasibility and statistical rigor in observational studies with restricted populations [33,34]. Moreover, the incorporation of a relatively high estimated prevalence in the case group was justified by previous reports documenting elevated rates of SB and parafunctional behaviors in young adults under academic stress, thereby increasing the plausibility of detecting group differences [22]. Thus, the final sample comprised 20 confirmed SB cases and 20 matched controls.

2.10. Statistical Analysis

Data were analyzed using SPSS v27 (IBM Corp., USA). Normality was assessed via the Shapiro–Wilk test; normally distributed variables were compared with *t*-tests, and non-normal variables with the Mann–Whitney U test. Means ($\bar{x}$), standard deviations (SD), odds ratios (OR), and 95% confidence intervals (CI) were reported. Effect sizes were estimated using the probability of superiority (PS) for non-parametric data (null $\leq$ 0.55; small > 0.56; medium > 0.64; large > 0.71; very large > 0.80) and Cohen's d for parametric data (small 0.1; medium 0.3; large $\geq$ 0.7) [39,40].

A binary logistic regression model was constructed to identify significant predictors of sleep bruxism. Independent variables included left masseter activity, REM sleep duration, and age, selected based on prior significant differences or trends. Variables directly defining bruxism events were excluded to avoid redundancy and collinearity. Regression coefficients (B), ORs with 95% CIs, and associated *p*-values were reported. Statistical significance was set at *p*-value < 0.05.

3. Results

Table 1 provides a descriptive and comparative summary of PSG variables, physiological activity, and specific events in participants with sleep bruxism (n = 20) and controls (n = 20). Participants SB exhibited several clinically relevant differences compared with matched controls. SB participants were slightly older (mean 22.85 vs. 20.35 years; p = 0.01, large effect size), which may reflect developmental or behavioral factors associated with sleep-related masticatory activity. REM sleep duration was significantly longer in the SB group (123.72 vs. 93.97 min; p = 0.04, moderate effect size), while Stage 1 sleep was reduced (9.45 vs. 18.10 min; p = 0.02, moderate effect size), suggesting alterations in sleep architecture that may facilitate the occurrence of bruxism episodes.

PLMs were notably higher in the SB group (84.20 vs. 49.70 counts; $p \leq 0.01$, moderate-to-large effect size), highlighting a possible shared central nervous system mechanism influencing both PLMs and SB. Most strikingly, bruxism events were markedly increased in SB participants across total, NREM, and REM sleep, as well as in arousals ($p \leq 0.001$, very large effect sizes >0.90), confirming the severity of masticatory muscle activity in this population.

Other sleep parameters—including total sleep time, NREM sleep duration, apneas, hypopneas, oxygen saturation, and heart rate—did not differ significantly, indicating that SB in young adults is primarily associated with altered sleep architecture, heightened motor activity, and increased bruxism events, rather than cardiorespiratory disturbances. These findings reinforce the clinical relevance of monitoring SB through PSG and EMG, allowing

early identification of patients at risk for dental wear, temporomandibular disorders, and other sequelae.

Of the initial 40 participants, 9 (23%) were men and 31 (77%) were women. Following attrition during follow-up (2 in the bruxism group and 1 in the control group), the bruxism group comprised 5 men (38.5%) and 13 women (61.5%), with a mean age of 22.72 ± 3.87 years. The control group included 4 men (21.05%) and 15 women (79.95%), with a mean age of 20.42 ± 1.57 years.

Table 1. Baseline characteristics of PSG variables in subjects with SB (n = 20) and controls (n = 20).

Variables	Groups	$\bar{x}$	SD	CI 95%	p-Value	Effect Size
Age (years)	SB	22.85	3.68	21.13 to 24.57	0.01 † *	0.88
	Control	20.35	1.57	19.62 to 21.08		
Total Sleep time (min)	SB	389.65	32.48	374.45 to 404.85	0.53 ^{U}	0.60
	Control	371.77	60.05	343.66 to 399.88		
REM Sleep time (min)	SB	123.72	45.76	102.31 to 145.14	0.04 † *	0.69
	Control	93.97	39.79	75.35 to 112.60		
N-REM Sleep time (min)	SB	265.95	49.53	242.77 to 289.13	0.53 †	0.17
	Control	278.15	85.85	247.33 to 308.97		
Stage 1 sleep (min)	SB	9.45	11.51	4.06 to 14.84	0.02 ^{U} *	0.67
	Control	18.10	15.31	11.9 to 25.26		
Stage 2 sleep (min)	SB	200.27	52.53	175.69 to 224.86	0.22 ^{U}	0.61
	Control	175.08	68.46	143.03 to 207.12		
Stage 3 sleep (min)	SB	56.23	25.80	44.15 to 68.30	0.42 †	0.28
	Control	63.50	25.64	51.49 to 75.50		
Total Arousals (count)	SB	30	23.22	18.63 to 40.37	0.37 ^{U}	0.63
	Control	20.60	14.68	13.73 to 27.47		
REM arousals index (arousals/hr)	SB	13.30	6.99	10.03 to 16.57	0.55 ^{U}	0.57
	Control	11.40	7.11	8.07 to 14.73		
N-REM arousals index (arousals/hr)	SB	11.15	7.87	7.47 to 14.83	0.37 ^{U}	0.62
	Control	8.3	4.51	6.19 to 10.41		
Central Apnea Episodes (count)	SB	0.65	1.31	0.04 to 1.26	0.38 ^{U}	0.62
	Control	0.20	0.52	−0.04 to 0.44		
Obstructive Apnea Episodes (count)	SB	1.40	3.79	−0.37 to 3.17	0.78 ^{U}	0.59
	Control	0.40	0.88	−0.01 to 0.81		
Mixed Apnea Episodes (count)	SB	0.75	1.48	0.06 to 1.44	0.34 ^{U}	0.64
	Control	0.20	0.41	0.01 to 0.39		
Hypopnea Episodes (count)	SB	28.95	33.18	13.42 to 44.48	0.25 ^{U}	0.59
	Control	19.40	25.72	7.36 to 31.44		
N-REM Oximetry (%)	SB	93.50	1.40	92.85 to 94.15	0.60 ^{U}	0.57
	Control	93.15	1.53	92.43 to 93.87		
REM Oximetry (%)	SB	93.85	1.31	93.24 to 94.46	0.84 ^{U}	0.59
	Control	89.60	19	80.71 to 98.49		
N-REM heart rate (beats/min)	SB	65.40	6.64	62.29 to 68.51	0.86 †	0.04
	Control	65	11.66	59.54 to 70.46		
REM heart rate (beats/min)	SB	66.80	7.13	63.46 to 70.14	0.83 †	0.06
	Control	66.25	12.30	60.49 to72.01		
Overall heart rate during sleep (mean)	SB	66.05	6.94	62.80 to 69.30	0.73 †	0.09
	Control	65.25	11.31	59.96 to 70.54		
Total PLMs (count)	SB	84.20	45.82	62.76 to 105.64	≤0.01 ^{U} *	0.75
	Control	49.70	20.35	40.18 to 59.22		

Table 1. *Cont.*

Variables	Groups	$\bar{x}$	SD	CI 95%	*p*-Value	Effect Size
PLMs in arousals (count)	SB	6.55	6.72	3.41 to 9.69	0.34 U	0.63
	Control	4.05	3.30	2.51 to 5.59		
Total Bruxism Events (count)	SB	260.50	119	204.80 to 316.20	≤0.001 U **	0.94
	Control	61.95	39.71	41.37 to 82.51		
N-REM Bruxism Events (count)	SB	135.45	77.81	99.03 to 171.87	≤0.001 U **	88.1
	Control	37.25	29.52	23.43 to 51.07		
REM Bruxism Events (count)	SB	120.20	90.21	77.98 to 162.42	≤0.001 U **	82.4
	Control	31.15	32.46	15.96 to 46.34		
Bruxism REM Index (events/hr)	SB	40.60	18.89	31.76 to 49.44	≤0.001 U **	93.7
	Control	10.14	6.08	7.29 to 12.98		
N-REM Bruxism Index (events/hr)	SB	30.58	15.88	23.15 to 38.01	≤0.001 U **	91.3
	Control	7.89	5.11	5.49 to 10.28		
Bruxism Events in arousals (count)	SB	86.75	57.03	60.06 to 113.44	≤0.001 U **	83.4
	Control	28.10	20.35	18.58 to 37.62		

†: *t*-test and Cohen's d effect size, U: Man's U test and effect size probability of superiority, $\bar{x}$: mean, SD: Standard deviation, CI: 95% confidence interval. *: significance *p*-value < 0.05, **: significance *p*-value < 0.001.

Table 2 provides EMG analysis of the masseter and temporalis muscles showed moderate differences between participants with SB and controls. While the average activity of the masseter and temporalis muscles did not differ significantly in most measures, the left masseter showed higher activity in the SB group ($p = 0.03$, moderate effect size = 0.50), suggesting a pattern of unilateral overuse in some patients.

Table 2. Comparison of Masticatory Muscle Activity and Asymmetry of the Masseter and Temporalis Muscles Between SB ($n = 18$) and Control ($n = 19$).

Variable	SB		Control		Inferential Statistics	
	$\bar{x}$ (CI 95%)	SD	$\bar{x}$ (CI 95%)	SD	*p*-Value	Effect Size
Right masseter muscle (lb)	0.04 (0.03 to 0.05)	0.03	0.06 (0.03 to 0.09)	0.05	0.28 U	0.34
Left masseter muscle (lb)	0.08 (−0.03 to 0.19)	0.23	0.07 (0.02 to 0.13)	0.10	0.03 U *	0.50
Asymmetry masseter muscle	0.31 (−0.19 to 0.26)	0.45	−0.16 (−0.37 to 0.05)	0.43	0.20 †	1.07
Right temporal muscle (lb)	0.06 (−0.01 to 0.13)	0.14	0.07 (0.3 to 0.11)	0.09	0.19 U	0.47
Left temporal muscle (lb)	0.08 (−0.03 to 0.19)	2.27	0.05 (0.03 to 0.08)	0.05	0.09 U	0.51
Asymmetry temporal muscle	0.13 (−0.03 to 0.30)	0.33	0.04 (−0.11 to 0.21)	0.32	0.41 †	0.25

†: *t*-test and Cohen's d effect size, U: Man's U test and effect size probability of superiority, $\bar{x}$: mean, SD: Standard deviation, CI: 95% confidence interval. *: significance *p*-value < 0.05.

Additionally, masseter muscle asymmetry tended to be greater in SB participants (very large effect size = 1.07), although it did not reach statistical significance. Clinically, this may reflect chronic neuromuscular imbalances associated with increased masticatory activity during sleep. Temporal muscle activity and asymmetry did not show relevant differences, indicating that peripheral changes in SB are primarily localized to the masseter, likely due to its central role in generating force during bruxism episodes.

These findings highlight the clinical importance of assessing muscle activity and symmetry in SB patients, as masseter alterations may predispose to hypertrophy, myofascial pain, or temporomandibular disorders, and guide individualized management strategies such as customized occlusal splints targeting patterns of muscular overuse.

Table 3 presents the mean resting electromyographic activity of the masseter muscle.

Analysis of the mean resting contractile force of the masseter muscles showed no statistically significant differences between participants with SB and controls ($p > 0.05$ for all comparisons), with effect sizes around 0.50 or lower. Both right and left masseters exhibited similar resting activity, and asymmetrical values were minimal in both groups.

Clinically, these findings suggest that resting masseter tone is not altered in young adults with SB, indicating that the peripheral muscular changes observed during sleep (e.g., increased EMG activity and asymmetry during bruxism events) do not persist at rest. This distinction is important for clinical evaluation, as it implies that interventions should focus on sleep-time muscle hyperactivity rather than baseline muscle tone, guiding decisions for occlusal splints, physiotherapy, or targeted biofeedback strategies.

Table 3. Mean Contractile Force of the Masseter Muscles in SB ($n = 18$) and Control ($n = 19$).

Variable	SB		Control		Inferential Statistics	
	$\bar{x}$ (CI 95%)	SD	$\bar{x}$ (CI 95%)	SD	*p*-Value	Effect Size
Right masseter muscle (lb)	0.48 (0.43 to 0.54)	0.12	0.49 (0.45 to 0.54)	0.10	0.89 ^{U}	0.50
Left masseter muscle (lb)	0.48 (0.42 to 0.53)	0.11	0.47 (0.42 to 0.53)	0.11	0.89 ^{U}	0.53
Asymmetry masseter muscle	−0.01 (−0.21 to 0.20)	0.41	−0.04 (−0.24 to 0.15)	0.39	0.78 ^{U}	0.08

U: Man's U test and effect size probability of superiority, $\bar{x}$: mean, SD: Standard deviation, CI: 95% confidence interval.

To identify predictors of sleep bruxism, a multivariate logistic regression analysis was performed (Table 4). Multivariate logistic regression analysis identified age, PLMs, and REM sleep duration as factors associated with SB in young adults. Higher age was a significant predictor of lower odds of SB (B = −0.53; OR = 0.59; 95% CI: 0.39–0.90; $p = 0.02$), suggesting that younger adults are more prone to develop clinically relevant bruxism.

Table 4. Logistic Regression Model Results for Predicting Sleep Bruxism in Young Adults.

Model	B	OR	CI 95%	*p*-Value	R^2	X^2	Sig Global
Total PLMs	−0.04	0.96	0.92 to 1.00	0.03	0.58	32.51	<0.001
REM Sleep time	−0.02	0.98	0.95 to 1.00	0.05			
Years	−0.53	0.59	0.39 to 0.90	0.02			
Constant	16.45	13,866,151		0.03			

B: Logistic regression coefficient (Beta), OR: Odds Ratio, CI: Confidence Interval (95%), *p*-value: Statistical significance level, R^2: Nagelkerke's R-squared, X^2: Chi-square statistic of the model, Global Sig: Overall model significance (Chi-square test *p*-value).

Interestingly, increased PLMs was slightly associated with reduced likelihood of SB (B = −0.04; OR = 0.96; 95% CI: 0.92–1.00; $p = 0.03$), indicating a subtle interplay between central motor activity and masticatory events during sleep. Longer REM sleep duration showed a similar trend, although marginally non-significant (B = −0.02; OR = 0.98; $p = 0.05$), implying that REM architecture may modulate bruxism expression, potentially through its effect on arousal thresholds and muscle activation.

The regression model demonstrated good fit (global $\chi^2 = 32.51$, $p < 0.001$; Nagelkerke $R^2 = 0.58$), explaining approximately 58% of the variability in SB occurrence. Clinically, these findings highlight that age and sleep-related motor patterns should be considered when assessing bruxism risk, supporting the use of PSG and EMG for indi-

vidualized evaluation and early identification of patients at higher risk for dental and temporomandibular complications.

4. Discussion

This case–control study, based on PSG and sEMG, provides robust evidence of the physiological and neuromuscular patterns that distinguish individuals with SB from healthy controls in a cohort of young adults. Our findings confirm that SB is associated with significant alterations in sleep architecture, a higher prevalence of PLMs, and a substantial increase in nocturnal masticatory activity, both in REM and N-REM phases. Independent predictors of SB were also identified, highlighting the role of age, REM sleep duration, and peripheral motor activity during sleep.

PSG data revealed a significantly higher frequency of SB events in the case group, with indices far exceeding the clinical threshold of $\geq$2 episodes of rhythmic masticatory muscle activity per hour as proposed by the American Academy of Sleep Medicine [25,26]. This nocturnal muscular hyperactivity, often accompanied by arousals, supports the hypothesis that SB represents a dysrhythmic sleep pattern in which brief autonomic and cortical events play a central role as triggers [8,11,12]. Consistently, our results showed an increase in stage 1 sleep—usually considered light and less restorative—and a relative reduction in total REM sleep, in line with previous studies linking SB to a fragmented and less restorative sleep architecture [13–15].

A particularly relevant finding was the higher frequency of PLMs in the SB group, suggesting a potential shared dysfunction in neuromotor mechanisms underlying motor control during sleep. While previous studies have proposed a coexistence of PLMs and SB, our analysis identified PLMS as a negative predictor of SB (OR = 0.96; p = 0.03), indicating that higher PLMs was slightly associated with lower odds of bruxism. This inverse relationship is intriguing and may reflect a neurophysiological competition between different motor circuits during sleep, where activation of leg motor pathways could transiently inhibit masticatory muscle bursts. Alternatively, PLMs might act as modulators of arousal thresholds, influencing the timing or intensity of bruxism episodes [16]. Further research using longitudinal designs, neuroimaging, and connectivity studies is warranted to clarify these mechanisms, which could provide valuable insights for individualized management and interdisciplinary collaboration between dentists, neurologists, and sleep specialists.

Regarding age, our results showed that SB was more prevalent among younger participants, consistent with prior literature indicating a progressive decline in bruxism activity with aging [4–6]. The multivariate logistic regression confirmed this pattern, revealing an inverse association between age and the likelihood of SB (OR = 0.59; p = 0.02), underscoring the need for early detection strategies in younger populations, particularly in university settings where psychosocial stress levels are high.

Electromyographic analysis revealed significant differences in left masseter activity during functional contraction, with a trend toward neuromuscular asymmetry, although this did not reach statistical significance. The observed unilateral predominance could reflect chronic functional adaptation or preferential lateralization in chewing and bruxism patterns, as previously reported in functional imaging and EMG studies [17–19,32]. However, masseter resting activity did not differ significantly between groups, suggesting that muscular hyperactivity in SB is predominantly nocturnal and does not persist during wakefulness.

From a methodological standpoint, the combined use of PSG and sEMG represents a major strength [19,41], enabling an objective and multidimensional characterization of SB. The inclusion of detailed polysomnographic variables, such as respiratory events, arousals, and oximetry, allowed us to control for potential confounding by sleep-disordered

breathing, which often complicates SB diagnosis in less rigorous studies. Furthermore, the estimation of effect sizes using probability of superiority and Cohen's d provided a quantitative appraisal of the clinical impact of the observed differences, beyond statistical significance [39,40].

5. Limitations and Clinical Implications

This study has several limitations that should be acknowledged. Although the sample size was statistically calculated, participants were restricted to university students, which may limit the generalizability of the findings to other populations. Moreover, while the case–control design is valuable for exploring significant associations, it does not allow for causal inferences [33]. Future longitudinal research could expand on these results by examining the progression of SB in relation to changes in sleep architecture, psychosocial factors, and neuroplasticity. In addition, integrating functional neuroimaging and cortical connectivity analyses may provide further insights into the neural circuits underlying the pathophysiology of SB.

A further limitation concerns the non-evaluation of psychological factors. Recent evidence indicates that the type of sleep bruxism activities can be influenced by psychological distress, and the omission of this assessment—particularly in a small sample—could have introduced an important bias [42]. Indeed, the Standardized Tool for the Assessment of Bruxism (STAB) recommends evaluating psychological parameters in conjunction with bruxism activity. Another limitation relates to the accuracy of sleep timing. Even a mismatch of 20 min determining when participants fell asleep can influence the total masticatory muscle activity [43]. This emphasizes the need for precise sleep onset monitoring in future studies. Finally, given the small sample size and the natural variation in electromyographic waveforms during sleep, the findings may have limited external validity. Larger cohorts are required in future research to capture the full range of SB-related activity [44].

The findings of this study have important clinical implications for the diagnosis, monitoring, and management of SB. First, our results reinforce the view of SB as a multifactorial condition with neurophysiological, respiratory, and musculoskeletal components [5,8,16,45]. The identification of age, PLMs, and REM sleep duration as independent predictors suggests that SB cannot be fully understood as a peripheral muscular phenomenon or a simple stress-related response, but rather as a complex disorder involving dysregulation of brain networks responsible for sleep architecture, motor control, and autonomic modulation [46].

The association between reduced REM sleep duration and SB further highlights the need to incorporate sleep architecture parameters into clinical assessment [13]. Given the essential role of REM sleep in emotional consolidation and neurovegetative homeostasis, its alteration in SB patients may contribute not only to motor events but also to psychological comorbidities such as anxiety and mood disorders [47,48]. This underscores the importance of providing more concrete clinical recommendations for dental and sleep practice, such as early referral for PSG/EMG assessment in patients with dental wear, morning masticatory discomfort, or muscle hypertrophy, and integrating findings into individualized patient management plans.

Furthermore, an interdisciplinary approach involving dentists, neurologists, clinical psychologists, and sleep medicine specialists is recommended to provide a comprehensive biopsychosocial evaluation, optimize treatment strategies, and facilitate early detection and monitoring of SB.

Moreover, our results emphasize the relevance of functional assessment of the stomatognathic system as part of routine dental examination, particularly in patients reporting

morning orofacial pain, dental wear, or muscle fatigue [49]. Early detection of signs such as joint noises or masticatory asymmetry may serve as indirect indicators of SB, enabling timely interventions ranging from patient education to occlusal, physiotherapeutic, or behavioral therapies [50,51].

In this context, the present study strengthens the evidence supporting the development of individualized assessment and management protocols for SB, based on the integration of clinical, functional, and polysomnographic markers. Such strategies not only optimize therapeutic outcomes but also improve patients' quality of life by preventing associated complications, including temporomandibular disorders, sleep impairment, and psychosocial consequences.

6. Conclusions

The findings of this case-control study demonstrate that sleep bruxism is significantly associated with functional alterations of the stomatognathic system, particularly the presence of joint noises and increased masseter muscle activity, as well as with modified sleep patterns, including reduced REM sleep duration and a higher frequency of periodic limb movements. These variables showed significant predictive capacity in the logistic regression model, suggesting a distinctive clinical and neurophysiological profile in individuals with sleep bruxism.

From a clinical perspective, these findings underscore the importance of a comprehensive evaluation that integrates polysomnographic parameters, electromyographic analysis, and functional clinical examination for the diagnosis and monitoring of sleep bruxism. They also highlight the relevance of an interdisciplinary approach, where dentists, neurologists, and sleep medicine specialists collaborate to design preventive and therapeutic strategies tailored to the patient's individual pathophysiology. Future longitudinal studies with more representative samples and sex-stratified analyses are needed to clarify the causal role of these factors and to establish more precise and sensitive diagnostic criteria for this highly prevalent condition with substantial functional impact.

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Abbreviations

The following abbreviations are used in this manuscript:

SB	Sleep bruxism
PSG	Polysomnography
EMG	Electromyographic
sEMG	Surface electromyographic
PLMs	Periodic limb movements during sleep
REM	Rapid eye movement
N-REM	Non-rapid eye movement

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Article

Association Between Occlusal Interferences, Temporomandibular Joint Dysfunction, and Bruxism in Romanian Adults

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Abstract

Background: Bruxism is a common parafunctional activity involving repetitive jaw muscle movements during wakefulness (awake bruxism) or sleep (sleep bruxism). While its multifactorial etiology is widely accepted, the roles of occlusal interferences, temporomandibular joint (TMJ) dysfunction, stress, and sleep-related breathing disturbances remain under investigation. **Objectives**: This cross-sectional study evaluated associations between bruxism and occlusal discrepancies, TMJ symptoms, stress, and sleep-related variables (snoring and obstructive sleep apnea, OSA) in Romanian adults. **Methods**: Ninety-eight adults (mean age: 30.4 ± 8.9 years) completed a structured questionnaire reviewed for content validity and pilot-tested for clarity but not formally validated. Participants were categorized into bruxism (n = 51) and control (n = 47) groups. Variables assessed included bruxism type, TMJ symptoms, occlusal interferences, stress, snoring, OSA, and parafunctional habits. Bivariate and multivariate logistic regression analyses were conducted. **Results**: Sleep bruxism was predominant (88%), with 59% classified as sleep-only bruxers. Occlusal discrepancies (46% vs. 14%, $p < 0.001$), TMJ symptoms (joint pain: 38% vs. 8%; fatigue: 44% vs. 10%), and habitual snoring (60% vs. 22%, $p < 0.001$) were significantly more common among bruxers. No significant difference was observed in OSA prevalence. Independent predictors of bruxism included occlusal interferences (adjusted OR = 4.7, $p = 0.009$), TMJ symptoms (adjusted OR = 6.5, $p = 0.002$), and habitual snoring (adjusted OR = 4.1, $p = 0.016$). **Conclusions**: Bruxism was significantly associated with occlusal interferences, TMJ dysfunction, and habitual snoring, supporting the need for multifactorial assessment and integrated clinical management. Limitations: This study relied on self-reported bruxism classification and a non-validated questionnaire instrument, which may limit generalizability and diagnostic accuracy.

Keywords: bruxism; sleep bruxism; awake bruxism; malocclusion; temporomandibular joint disorders; parafunctional habits; psychological stress; sleep apnea syndromes; self-reported questionnaire; cross-sectional analysis

1. Introduction

Bruxism is a prevalent oral parafunctional behavior characterized by repetitive jaw-muscle activity, including clenching, grinding, bracing, or thrusting of the mandible. It is typically categorized as either sleep bruxism (SB), which occurs during sleep, or awake bruxism (AB), which occurs during wakefulness. Recent consensus reports emphasize that bruxism is a centrally regulated behavior influenced by multiple biopsychosocial factors, with occlusion playing a contributory but not primary role [1–3]. This perspective is supported by recent systematic reviews that recommend cautious interpretation of occlusal factors in bruxism etiology [4,5].

Though traditionally considered a benign habit, bruxism has been associated with multiple clinical consequences, including abnormal tooth wear, restoration failure, tooth mobility, orofacial pain, and compromised masticatory efficiency. These outcomes may also impair quality of life and increase the risk of temporomandibular joint (TMJ) dysfunction and sleep disturbances [4,5].

Sleep bruxism has been classified by the International Classification of Sleep Disorders as a sleep-related movement disorder, believed to originate in response to sleep arousals [6], while awake bruxism is thought to be more closely associated with emotional states and behavioral patterns such as stress, anxiety, and concentration [7]. Epidemiological data indicate regional variability in bruxism prevalence, with higher rates observed in Europe and the Americas [8]. According to the International Classification of Sleep Disorders, 3rd edition (ICSD-3), sleep disorders are categorized into six major groups: (1) insomnia, (2) sleep-related breathing disorders, (3) central disorders of hypersomnolence, (4) circadian rhythm sleep-wake disorders, (5) parasomnias, and (6) sleep-related movement disorders [7]. Bruxism is classified under sleep-related movement disorders, while obstructive sleep apnea (OSA) falls under sleep-related breathing disorders [2,9,10]. Both conditions have been associated with disturbances in the stomatognathic system and may co-occur or share overlapping risk factors. In addition to OSA, central sleep apnea (CSA) is another major category of sleep-disordered breathing. Unlike OSA, which results from upper airway obstruction, CSA is characterized by a lack of respiratory effort due to instability in the respiratory control centers of the brain. While its direct implications on the stomatognathic system are less frequently studied, CSA may contribute to fatigue, arousals, or orofacial tension patterns that potentially influence conditions like bruxism. Recognizing the distinct pathophysiological profiles of these disorders is essential for accurately interpreting their associations with parafunctional behaviors.

The contribution of dental occlusion to bruxism has been long debated. Earlier studies suggested that premature contacts or occlusal interferences might initiate bruxism or exacerbate its severity [3]. However, subsequent research has largely refuted a direct causal relationship, emphasizing central nervous system mechanisms as the primary drivers of the condition [9,11]. Today, occlusion is considered a potential, but not primary, factor within a multifactorial etiology involving stress, sleep arousals, and genetic predisposition [2,4].

TMJ dysfunction is frequently reported among individuals with bruxism, likely due to sustained mechanical loading of the joint and surrounding musculature. Bruxism may lead to orofacial pain, joint sounds, limited jaw mobility, and morning jaw stiffness, and evidence supports a strong comorbidity with temporomandibular disorders (TMD) [12–15].

Whether TMJ symptoms are a cause or consequence of bruxism remains unclear, but their clinical overlap underscores the importance of dual assessment.

Psychological stress, particularly chronic stress, has been consistently linked to both forms of bruxism. It is believed to contribute via sympathetic nervous system activation, heightened muscle tone, and disturbed sleep patterns [6,16,17]. Although this relationship is well established, many studies rely solely on subjective stress measures, which may introduce bias.

Recent studies have also examined possible connections between bruxism and sleep-disordered breathing, particularly habitual snoring and OSA. While some suggest that micro-arousals from OSA may trigger bruxism as a compensatory mechanism to reopen the airway [18], others have found no significant independent association after adjusting for shared risk factors such as obesity or smoking [19,20].

Despite increasing recognition of bruxism's multifactorial nature, much of the existing research is based on subjective reports or non-standardized instruments, limiting comparability and generalizability [1,8,9,14]. Objective diagnostic tools such as polysomnography, electromyography, intraoral scanning, or TMJ imaging are not always accessible in large-scale studies. Thus, questionnaire-based data—while valuable—should be interpreted with appropriate caution.

Given these constraints, the use of a self-reported instrument in the present study was a pragmatic approach to allow for broad data collection in a general population sample. Although not a replacement for objective diagnostic tools, self-report methods remain widely used in bruxism research and can yield meaningful insights when carefully constructed and interpreted within their methodological limitations. Our questionnaire was developed with input from domain experts, reviewed for content validity, and pilot-tested to ensure clarity and thematic coverage. The results of the pilot study were not published separately.

To address these gaps, the present study investigated the association between bruxism and key potential contributors—occlusal discrepancies, TMJ-related symptoms, stress, and sleep-related breathing disturbances—in a Romanian adult population. Although based on a self-report instrument, the questionnaire was developed with expert input and pilot-tested to ensure thematic breadth and clarity. Our aim was to provide a preliminary but integrative view of bruxism's complex etiology in the general population, which may guide future research using objective assessments.

This study focused on Romanian adults due to the current lack of population-based data on bruxism and its potential correlates in this demographic. Given logistical and resource constraints, a self-reported method was selected to enable wide recruitment and preliminary exploration of relevant behavioral and clinical patterns. Although this approach has inherent limitations in diagnostic precision, it is well suited for hypothesis-generating research and helps address regional gaps in the bruxism literature.

Given the multifactorial etiology of bruxism and the scarcity of population-based studies examining its associations with occlusal interferences, temporomandibular joint (TMJ) symptoms, and sleep-related factors, this study aimed to explore these relationships in a sample of Romanian adults. While self-reported data present inherent limitations, they allow for broad, scalable assessments in non-clinical settings and can generate valuable hypotheses for future research. This investigation contributes to the growing body of evidence on the behavioral and structural correlations of bruxism and highlights the need for integrated, interdisciplinary approaches to its assessment.

Despite its methodological limitations, this study offers several strengths. It contributes to the contemporary literature by adopting a multifactorial approach to bruxism assessment, integrating self-perceived occlusal, musculoskeletal, and sleep-related parameters within a single analytical framework. The use of a structured, content-validated, and

pilot-tested questionnaire enabled broad data capture in a community sample, providing exploratory insights that may inform future research designs. Importantly, the findings emphasize the need for interdisciplinary investigation of bruxism-related complaints, which may have implications for both dental and sleep medicine practice.

Based on the current evidence suggesting multifactorial contributors to bruxism, we tested the null hypothesis that there are no significant associations between self-reported bruxism and occlusal interferences, TMJ symptoms, perceived stress, or sleep-related factors in Romanian adults.

2. Materials and Methods

2.1. Study Design and Participants

This cross-sectional observational study was conducted between March and June 2025 in accordance with the STROBE guidelines. This study was designed and reported in accordance with the STROBE checklist for cross-sectional studies. Efforts to mitigate potential sources of bias included anonymized data collection, the use of standardized survey items, and adjustments for key confounders in the multivariate analysis. Participants were recruited via an online questionnaire distributed through university and social media networks using a snowball sampling strategy. We acknowledge that snowball sampling via social media constitutes a non-probability sampling method and may introduce self-selection bias, potentially limiting the generalizability of the findings. This technique was chosen for its feasibility in recruiting a diverse adult sample during a defined study period and for its relevance in identifying individuals with specific behavioral traits such as bruxism. Eligible respondents were Romanian adults aged 18–60 years who provided electronic informed consent. The study protocol was approved by the Ethics Committee of the Vasile Goldiș Western University of Arad (Approval No. 17/19 March 2025), and all procedures complied with the Declaration of Helsinki. Anonymity and confidentiality were ensured.

This study was designed to explore potential associations between self-reported bruxism and contributing factors—including occlusal interferences, TMJ symptoms, stress, and sleep-related behaviors—in a general adult Romanian population. Given the lack of national data and limited access to objective diagnostic tools in large samples, a structured, self-reported approach was used to enable broad, hypothesis-generating analysis.

2.1.1. Inclusion Criteria

Participants were eligible for inclusion if they met all of the following criteria:

- Aged 18 years or older
- Romanian nationality and residence
- Ability to understand and complete the questionnaire in Romanian
- Consent to participate voluntarily in the study

2.1.2. Exclusion Criteria

Participants were excluded if they met any of the following criteria:

- Incomplete or inconsistent questionnaire responses
- Diagnosed psychiatric or neurological disorders that may affect perception or self-report accuracy (based on self-report)
- Previous maxillofacial surgery or conditions that could significantly alter occlusion or TMJ function

A total of 114 participants were enrolled; after exclusions, 98 complete responses were analyzed, 51 identified with bruxism and 47 without. The minimum required sample size (n = 46 per group) was calculated using Epidat 4.2 (α = 0.05, 80% power).

2.2. Survey Instrument and Variables

A 25-item structured questionnaire was developed by the research team to collect data relevant to the objectives of the study. The questionnaire was developed based on established bruxism assessment tools such as TMJ-related surveys and published observational studies in dental and behavioral sciences. Although the instrument was not previously validated, it underwent face and content validation by two subject-matter experts in prosthodontics and orofacial pain. A pilot study with five volunteers tested clarity, completion time, and item comprehensibility, leading to minor refinements to enhance clarity and consistency before distributing it to the full study sample. A structured questionnaire reviewed for content validity and pilot-tested for clarity was used.

Although the questionnaire was developed with domain expert input and pilot-tested for clarity, it was not formally validated through psychometric analysis. The internal consistency of items was not assessed, as the survey comprised distinct domains rather than coherent subscales. For perceived stress, only two items adapted from the PSS were included to minimize participant fatigue. However, we acknowledge that the full PSS-10 or PSS-14 is recommended for more robust assessment in future studies. The questionnaire was organized into four thematic sections: demographic data, bruxism characteristics, occlusal and TMJ-related factors, and behavioral or systemic variables. The key domains assessed are detailed below:

- Bruxism Status: Participants were asked if they experience tooth clenching or grinding during sleep or while awake, using lay descriptions. Bruxism status was determined based on self-report of symptoms (e.g., jaw discomfort, grinding noises, fatigue), third-party observation (e.g., partner's report), or prior professional diagnosis. Participants were categorized as having bruxism if they answered affirmatively or reported suggestive signs. Subtypes were classified as SB, awake bruxism (AB), or a combination of both (SB + AB).
- Occlusal Factors: Participants were asked whether a dentist had ever informed them of occlusal interferences, premature contacts, or malocclusion. They were also asked if recent dental restorations or malpositioned teeth were perceived to affect their bite. These self-reported occlusal issues were recorded as a composite variable representing the presence of occlusal interferences.
- TMJ Symptoms: Self-reported symptoms included jaw joint pain, joint noises (clicking, crepitus), and morning jaw stiffness or fatigue. Responses were dichotomized (yes/no) for each symptom, and the presence of any symptom was treated as indicative of TMJ dysfunction. Respondents were also asked if they had ever been diagnosed with a temporomandibular disorder (TMD) by a healthcare provider.
- Parafunctional Habits: Behavioral contributors such as nail biting, habitual gum chewing, or object chewing (e.g., pens, pencils) were assessed through yes/no questions. These behaviors were analyzed as potential confounding variables due to their known impact on masticatory activity and joint loading.
- Sleep and Respiratory Factors: Participants reported whether they or their bed partners observed habitual snoring. They were also asked whether they had been diagnosed with OSA or suspected of having it, based on a provided lay definition. Responses were categorized as none, suspected, or diagnosed OSA.
- Perceived Stress: Stress levels were evaluated using two adapted items from the Perceived Stress Scale (PSS), a widely used psychological instrument for measuring perceived stress developed by Cohen et al. [21] focused on daily life and work-related stress. Items were rated on a 5-point Likert scale (1 = strongly agree that life is stressful, 5 = strongly disagree). Lower scores indicated higher stress levels. These were treated as ordinal variables and also dichotomized for high-stress analyses (scores ≤ 2).

- Other Variables: Basic demographics included age (categorized: <20, 20–29, 30–39, 40–49, ≥50), gender (male/female), and occupational status (student, employed, unemployed). Bruxism participants were asked about treatment history (e.g., occlusal splint, medication, stress management) and perceived treatment effectiveness.

The questionnaire was developed specifically for this study based on existing literature and expert input, and it was pilot-tested for clarity and content validity. However, it was not subjected to formal psychometric validation or internal consistency analysis, which represents a methodological limitation. The questionnaire underwent content validation by a panel of five academic experts in dentistry and behavioral sciences. To assess clarity and usability, a pilot study was conducted over a two-week period using a convenience sample of 12 adult volunteers (aged 22–48) affiliated with the university. Eligible participants for the pilot study were fluent in Romanian, not involved in the main study, and willing to provide feedback. Respondents completed the questionnaire and offered comments on item clarity, relevance, and overall comprehension. Based on their suggestions, minor wording adjustments were made to improve the final version used in the main survey. The full questionnaire is provided in Supplementary Material S1.

2.3. Data Analysis

The minimum required sample size was calculated using *Epidat* version 4.2, assuming a confidence level of 95% ($\alpha = 0.05$), a statistical power of 80%, and an expected effect size (OR $\geq$ 3.0) based on previously reported associations between bruxism and TMJ symptoms [16]. The sample size was calculated based on an expected odds ratio (OR) $\geq$ 3.0, consistent with previous studies that reported moderate-to-strong associations between bruxism and TMJ symptoms in non-randomized populations [16]. This assumption also aligns with effect size interpretation guidelines proposed by Chen et al. [22]. Effect size interpretation for odds ratios followed thresholds proposed by Chen et al. [22] (small = 1.68, medium = 3.47, large = 6.71) and used here for illustrative purposes. However, we acknowledge that such thresholds are not standard in clinical studies and should be interpreted within the broader clinical context. A minimum of 46 participants per group was required to detect a statistically significant difference.

Data were entered into MedCalc v20.110 (MedCalc Software Ltd., Ostend, Belgium). Categorical variables were coded as binary (yes = 1, no = 0), Likert-scale items were treated as ordinal, and age categories were assigned midpoint values where needed. Incomplete responses were excluded. Descriptive statistics were calculated for the full sample and by bruxism status. Group comparisons used chi-square tests for categorical variables and independent *t*-tests or Mann–Whitney U tests for continuous/ordinal data, based on normality. Group comparisons used chi-square tests for categorical variables. For continuous variables with a normal distribution (e.g., age), independent *t*-tests were applied. For ordinal variables and continuous variables without a normal distribution (e.g., perceived stress scores), Mann–Whitney U tests were used.

Associations between bruxism and key variables (occlusal interferences, TMJ symptoms, snoring, OSA, stress, oral habits) were tested using 2 × 2 contingency tables. Odds ratios (OR) and 95% confidence intervals (CI) were computed; Fisher's exact test was used when applicable. A multivariate logistic regression model identified independent predictors of bruxism. Variables included occlusal interferences, TMJ symptoms (combined), high perceived stress, snoring, age, and gender. Adjusted odds ratios (aOR) and 95% CIs were reported. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test and Nagelkerke's R^2 coefficient in accordance with standard recommendations for logistic regression evaluation [23].

Effect size interpretation for odds ratios (ORs) followed established thresholds: small (OR = 1.68), medium (OR = 3.47), and large (OR = 6.71) as suggested by Chen et al. [22].

Statistical significance was set at $p < 0.05$. No correction for multiple comparisons was applied due to the exploratory nature of some analyses.

Given the exploratory nature of the study and the limited sample size, no correction for multiple comparisons was applied. We acknowledge that this may increase the risk of type I errors and the results should be interpreted with caution.

2.4. Outcome Measures

The primary outcome was the association between bruxism and occlusal interferences. Secondary outcomes included relationships between bruxism and TMJ symptoms, perceived stress, snoring, OSA, and oral habits. Exploratory outcomes included self-reported treatment use and perceived effectiveness among bruxers.

3. Results

3.1. Participant Characteristics

Out of 124 individuals who accessed the online questionnaire, 98 completed all of the mandatory items, yielding a completion rate of 79%. Incomplete responses were excluded from analysis. No imputation was performed for missing data, as all retained records were complete. A total of 98 adults were included in the final analysis. The final sample consisted of 98 adult respondents: 51 participants were assigned to the bruxism group and 47 to the control group. Ages ranged from 18 to 59 years, with the 20–29 age range representing the largest subgroup (approximately 45% of all respondents), reflecting the snowball sampling via academic and professional networks. The mean age was 29.8 years (SD = 8.5) in the bruxism group and 31.0 years (SD = 9.2) in the control group. This difference was not statistically significant ($p = 0.45$), indicating a similar age distribution across groups.

Gender distribution was also identical, with 28 females (55%) and 23 males (45%) in each group ($p = 1.0$). Most participants were university students or employed professionals, and no statistically significant differences in occupational status were observed between groups. Participant demographics are summarized in Table 1.

Table 1. Participant Characteristics.

Characteristics	Bruxism Group ($n = 51$)	Control Group ($n = 47$)	p-Value
Sample size	51	47	-
Mean age (SD)	29.8 (8.5)	31.0 (9.2)	0.45 ^{t}
Female (%)	28 (55%)	28 (60%)	1 $^{\chi 2}$
Male (%)	23 (45%)	19 (40%)	1 $^{\chi 2}$

Note: No statistically significant differences were found between groups in terms of age or gender distribution ($p > 0.05$), indicating comparability of demographic characteristics; t = independent samples t-test; χ^2 = chi-square test.

Among those with bruxism, the majority (88%, $n = 44$) reported symptoms consistent with SB, while 40% ($n = 20$) indicated awake bruxism (AB). Combined SB and AB was reported in 28% of cases. The most common presentation was SB-only (59%). A clinical diagnosis of bruxism had been established in 41% of participants, while the remaining were self-reported based on characteristic behaviors and symptoms. Four individuals in the control group reported occasional clenching or grinding during periods of stress but were not diagnosed with bruxism; these were retained in the analysis due to low frequency and minimal clinical impact.

To provide additional context, we conducted descriptive subgroup analyses. SB was more frequently reported by males, while AB was slightly more common among females. Younger participants (<30 years) reported higher rates of SB, whereas AB appeared more evenly distributed across age groups. Differences in reported TMJ symptoms, stress perception, and snoring frequency were observed across gender and bruxism subtypes.

However, due to the limited sample size, these findings were not tested for statistical significance and should be interpreted cautiously.

It should be noted that bruxism classification (sleep vs. awake) was based entirely on participants' self-reports and, where applicable, third-party observations. The absence of clinical examination or polysomnographic confirmation limits the diagnostic accuracy and introduces the potential for misclassification.

It is important to note that bruxism subtypes were determined based on participants' self-reported behaviors and, in some cases, third-party observations. This approach, while pragmatic for survey-based studies, relies on subjective recall and perceptions, which may limit the internal validity of subtype classification and introduce potential bias.

3.2. Occlusal Factors

Participants with bruxism reported a higher prevalence of occlusal disturbances compared to controls. These included perceived occlusal interferences or premature contacts. The association remained significant after adjusting for age, gender, stress, and snoring (Table 2).

Table 2. Prevalence of Occlusal Interferences and TMJ Symptoms.

Variable	Bruxism (n = 51)	Control (n = 47)	p-Value	Odds Ratio (95% CI)
Occlusal interference	23 (46%)	7 (14%)	0.0008	5.0 (1.9–13.0)
TMJ pain	19 (38%)	4 (8%)	0.0002	7.0 (2.2–22.2)
TMJ sounds	16 (32%)	3 (6%)	0.0014	7.4 (2.0–27.2)
Morning jaw fatigue	22 (44%)	5 (10%)	0.0001	6.8 (2.4–19.4)
Any TMJ symptom	30 (60%)	8 (16%)	<0.00001	7.5 (3.0–18.6)

Note: Bruxism was significantly associated with higher prevalence of occlusal interferences and TMJ-related symptoms ($p < 0.001$ for all comparisons), underscores a statistically significant association between bruxism-related parafunctions and self-reported TMJ symptoms.

3.3. TMJ Dysfunction Symptoms

TMJ-related symptoms—including joint pain, joint sounds, and morning jaw fatigue—were more frequently reported in the bruxism group. Overall, 60% of bruxers experienced at least one TMJ symptom, compared to 16% of controls (Table 2).

3.4. Perceived Stress

Although no statistically significant differences were found in mean stress scores, bruxism participants tended to report higher levels of perceived stress. Based on a 5-point Likert scale (where lower scores indicate greater stress), 44% of bruxers reported high daily stress (scores 1–2), compared to 30% of controls ($U = 1045.5$, $Z = 1.39$, $p = 0.16$). Similarly, high work- or study-related stress was noted by 36% of the bruxism group versus 24% of the controls ($p = 0.20$). Although high perceived stress appeared more frequent among participants with bruxism in univariate comparisons, this association was not statistically significant in the multivariate logistic regression model ($p > 0.05$). Therefore, its role as an independent predictor in this sample remains inconclusive. While these findings did not reach significance, they align with known psychological contributions to awake bruxism and were included in the multivariate analysis for completeness.

3.5. Sleep-Related Breathing

Habitual snoring was significantly more prevalent among participants with bruxism (60%) compared to those without (22%) ($\chi^2(1) = 15.38$, $p = 0.00009$; OR = 5.11, 95% CI: 2.1–12.4), indicating a possible co-occurrence. In contrast, no significant difference was observed for self-reported OSA, which was present in 22% of bruxers and 20% of controls ($p = 0.82$).

3.6. Parafunctional Habits and Dental Aesthetics

Parafunctional oral behaviors such as nail biting, chewing on pens, and excessive gum use were included as exploratory variables due to their potential—but not primary—relevance to bruxism. However, no statistically significant differences were observed between groups. Similarly, concerns related to dental aesthetics were presented for descriptive purposes only and were not central to the study's aims. Parafunctional oral behaviors were reported at similar rates in both groups. For instance, nail biting was present in 28% of the bruxism group and 24% of controls ($p > 0.3$). Likewise, concerns related to dental aesthetics—such as dissatisfaction with tooth alignment or appearance—were reported by approximately 30% of respondents in each group ($p = 0.95$), suggesting no direct association with bruxism status.

Although parafunctional oral behaviors such as nail biting, pen chewing, and excessive gum use were reported in both groups, no statistically significant differences were observed. One possible explanation is that these habits may have occurred at a low frequency or intensity insufficient to generate sustained masticatory strain or to overlap with the pathophysiological mechanisms underlying bruxism. Additionally, some of these behaviors may be more transient or context-dependent (e.g., stress-induced), and thus less likely to manifest as chronic, repetitive activities comparable to bruxism. This interpretation is consistent with prior literature indicating that occasional parafunctional behaviors do not necessarily translate into sustained muscular hyperactivity or clinical consequences.

3.7. Treatment and Self-Perceived Outcomes

Among bruxism participants, 52% ($n = 26$) reported having received some form of treatment, most commonly custom-fitted occlusal splints. Of those, 88% reported perceived improvements in symptoms such as pain, function, and sleep quality. These outcomes, however, were based solely on self-reported experiences and were not validated through clinical follow-up or objective assessment. As such, they should be interpreted as exploratory observations rather than evidence of treatment efficacy.

3.8. Multivariate Predictors of Bruxism

Logistic regression identified three independent predictors of bruxism: occlusal interference (adjusted OR = 4.7, $p = 0.009$; medium-to-large effect), any TMJ-related symptom (adjusted OR = 6.5, $p = 0.002$; large effect), and habitual snoring (adjusted OR = 4.1, $p = 0.016$; medium effect). Other factors—such as high daily stress (adjusted OR = 2.2, $p = 0.12$), age (aOR = 0.98, $p = 0.43$), and male gender (aOR = 1.1, $p = 0.85$)—were not statistically significant. The model demonstrated good fit (Hosmer–Lemeshow $p = 0.68$) and explained 58% of the variance in bruxism presence (Nagelkerke $R^2 = 0.58$) (Table 3). No significant interaction terms were identified.

Table 3. Multivariate Logistic Regression Predicting Bruxism.

Predictor	Adjusted OR	95% CI	*p*-Value
Occlusal interference	4.7	1.5–15.0	0.009
Any TMJ symptom	6.5	2.0–20.8	0.002
High daily stress	2.2	0.8–6.2	0.12
Snoring	4.1	1.3–13.2	0.016
Age (per year)	0.98	0.93–1.03	0.43
Male gender	1.1	0.4–3.0	0.85

Note: Occlusal interferences, TMJ symptoms, and snoring emerged as independent predictors of bruxism in the multivariate model. The model showed good overall fit (Hosmer–Lemeshow $p = 0.68$; Nagelkerke $R^2 = 0.58$); OR = odds ratio; CI = confidence interval; *p*-values from logistic regression.

4. Discussion

This study explored associations between self-reported bruxism and potential contributing factors in a sample of Romanian adults. Notably, participants with bruxism were more likely to report perceived occlusal interferences, TMJ-related symptoms, and habitual snoring. These findings underscore the multifactorial nature of bruxism while highlighting the need for cautious interpretation due to methodological constraints. Given the cross-sectional design of this study, causal inferences cannot be made. Although associations were observed between bruxism, TMJ-related symptoms, and occlusal interferences, the directionality of these relationships remains unclear. It is equally plausible that TMJ symptoms or occlusal discomfort may contribute to, rather than result from, bruxism. Longitudinal studies are necessary to clarify these temporal and causal dynamics. Individuals with bruxism were markedly more likely to report occlusal interferences, TMJ symptoms, and snoring, reinforcing a multifactorial model of bruxism pathogenesis that includes both peripheral and central contributors [1,2,5,10]. These findings highlight the multifaceted interaction among occlusal discrepancies, parafunctional activity, psychological stress, and airway-related disturbances in the pathophysiology of bruxism.

Several variables, including perceived stress, OSA, and parafunctional oral habits, did not show statistically significant associations with bruxism in this sample. These null findings should be interpreted cautiously. The limited number of stress items used (only two adapted from the PSS), reliance on self-reporting for OSA and habits, and the modest overall sample size may have reduced statistical power and construct validity. Additionally, the heterogeneity within subgroups may have obscured potential associations. Future studies employing validated tools, clinical screening, and larger stratified samples may better capture these complex relationships.

The role of occlusion in bruxism etiology has long been debated [8,9,24]. While previous reports emphasize the primacy of central nervous system mechanisms [8,25], others suggest that in certain individuals, occlusal interferences may trigger or exacerbate bruxism episodes as a neuromuscular response to disharmony [25,26]. In our study, occlusal discrepancies were independently associated with bruxism status in multivariate analysis. However, causality cannot be inferred from a cross-sectional design. While our findings indicate a potential association between perceived occlusal interferences and bruxism, these results are based on self-reports and should not be interpreted as conclusive evidence of clinical relevance. Future studies incorporating objective occlusal assessments are needed before recommending routine occlusal analysis in this context. Nonetheless, contemporary guidelines discourage irreversible occlusal adjustments unless supported by comprehensive diagnostic findings [24]. While some associations yielded moderate-to-high odds ratios, these effect sizes should be interpreted with caution. In the absence of objective clinical validation and given the exploratory nature of the study, the clinical meaningfulness of these associations remains uncertain. Future research is needed to determine whether these observed magnitudes translate into actionable clinical insights.

TMJ symptoms were significantly more prevalent among bruxers in our sample, particularly joint pain, joint sounds, and morning jaw fatigue. These findings are consistent with previous studies showing a strong overlap between bruxism and temporomandibular disorders (TMD), often attributed to chronic mechanical overload of the joint and masticatory musculature [12,27,28]. Although the direction of this relationship remains unclear, participant responses frequently indicated that bruxism preceded the onset of TMJ discomfort. This supports the hypothesis that bruxism can act as a precipitating factor in TMD development in susceptible individuals [12].

Psychological stress is widely acknowledged as a key driver of awake bruxism and a contributing factor to sleep bruxism [2,16,29]. While average stress scores did not differ

significantly between groups in our study, a higher proportion of bruxers reported elevated perceived stress levels. However, stress did not emerge as an independent predictor in multivariate modeling, possibly due to the limited single-item stress scale used. More nuanced assessment using validated instruments is recommended in future research.

The observed association between bruxism and habitual snoring—but not with OSA—corresponds with findings from recent systematic reviews [30]. It is hypothesized that sleep fragmentation and micro-arousals associated with snoring may act as triggers for sleep bruxism episodes via arousal-induced muscle activation [6,18]. Conversely, full-blown OSA may involve distinct pathophysiological pathways that do not consistently co-occur with bruxism. While habitual snoring was significantly associated with self-reported bruxism, this relationship may be influenced by unmeasured confounding factors such as body mass index (BMI), age, and gender, which are known to affect both snoring prevalence and sleep quality. As these variables were not fully adjusted for in the present analysis, the association should be interpreted with caution. Future studies incorporating objective sleep assessments and broader demographic controls are warranted to clarify the role of snoring in bruxism pathophysiology.

From a clinical perspective, these findings highlight the importance of a multidisciplinary diagnostic and therapeutic approach, integrating dental, psychological, and sleep medicine perspectives. Given the observed associations, future clinical investigations may explore the value of screening for TMJ symptoms and snoring in individuals with suspected bruxism, though our results alone do not support a change in practice without further validation, even when objective occlusal discrepancies are not evident. Clinical assessment protocols should include detailed a occlusal analysis, screening for TMJ dysfunction, psychosocial stressors, and sleep-related breathing disturbances. Although most of the treated participants in our study reported symptom improvement—particularly with the use of individually fabricated occlusal splints—optimal outcomes may require adjunctive behavioral and medical interventions tailored to each patient's risk profile [16,17,28].

This study has several important limitations that warrant emphasis. First, the structured questionnaire used to assess bruxism status, occlusal interferences, and TMJ symptoms was developed specifically for this study. Although it underwent expert review and was pilot-tested for clarity, it was not subjected to formal psychometric validation or internal consistency analysis (e.g., Cronbach's alpha), as the items addressed thematically diverse domains rather than unified constructs. Consequently, the instrument's internal reliability and construct validity remain unknown. Second, all variables, including bruxism subtype, occlusal factors, snoring, and TMJ symptoms, were based on self-report, which introduces potential recall bias and reporting bias. Participants may have inaccurately remembered or interpreted past experiences, or reported symptoms based on prior informal diagnoses or perceptions rather than objective evaluation. This increases the likelihood of misclassification, particularly for subjective domains such as occlusal discomfort or sleep-related behaviors. Third, the use of an online snowball sampling strategy may have introduced selection bias, resulting in a sample composed predominantly of young, educated adults, thereby limiting the generalizability of findings. These methodological constraints reduce internal validity and must be considered when interpreting the observed associations. Future studies should incorporate objective clinical assessments and validated instruments to confirm and expand upon these preliminary findings. Although we followed STROBE reporting guidelines, certain elements, such as the potential for response bias due to self-selection and the lack of imputation for missing data—remain inherent limitations. The use of self-reported data to assess bruxism, TMJ-related symptoms, and occlusal interferences introduces a substantial risk of misclassification and bias. Participants may misinterpret or underreport symptoms, especially in the absence of clinical

or polysomnographic confirmation. This limitation reduces the diagnostic precision of the study and should be considered when interpreting the observed associations. Future research should incorporate objective diagnostic criteria to validate self-reported findings and strengthen the evidence base.

Bruxism classification in this study relied on subjective self-perception and lay descriptions, without clinical or polysomnographic validation. This introduces a risk of misclassification, especially in differentiating between sleep and awake bruxism, and may affect the reliability of the reported associations. Stress assessment was limited to two adapted items from the PSS, which restricts the depth and validity of psychological evaluation. While this approach was chosen to minimize participant fatigue, it does not substitute for comprehensive validated instruments such as the full PSS-10 or PSS-14, which are recommended for future studies.

From a clinical perspective, these findings reinforce the multifactorial nature of bruxism and suggest potential avenues for further investigation, including the roles of occlusion, TMJ-related symptoms, and sleep-related factors. However, given the self-reported nature of the data and absence of clinical validation, recommendations regarding occlusal splints or TMJ screening should be made cautiously. Future longitudinal and clinically validated studies are needed to determine whether targeted assessments or interventions—such as occlusal therapy or TMJ evaluation—are warranted as part of a comprehensive bruxism management approach.

5. Conclusions

Within the constraints of its cross-sectional design and reliance on self-reported data, this study identified associations between bruxism and self-perceived occlusal interferences, TMJ-related symptoms, and habitual snoring in a Romanian adult population. While these findings support the multifactorial nature of bruxism, they should be interpreted as preliminary and hypothesis-generating rather than conclusive. The lack of objective diagnostic validation and the potential for misclassification or bias limit the ability to draw firm clinical inferences. Future research using validated instruments and clinical or polysomnographic assessments is warranted to confirm these associations and better inform multidisciplinary management strategies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm14165612/s1, Bruxism Questionnaire.

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Abbreviations

The following abbreviations are used in this manuscript:

AB	Awake Bruxism
CI	Confidence Interval
EMG	Electromyography
OR	Odds Ratio
OSA	Obstructive Sleep Apnea
SB	Sleep Bruxism
SD	Standard Deviation
TMJ	Temporomandibular Joint
TMD	Temporomandibular Disorders

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The Impact of Parafunctional Habits on Temporomandibular Disorders in Medical Students

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Abstract

Background: Temporomandibular disorders (TMD) are common musculoskeletal conditions affecting the temporomandibular joints, masticatory muscles, and associated structures. Their etiology is complex and multifactorial, involving anatomical, behavioral, and psychosocial contributors. Parafunctional habits such as clenching, grinding, and abnormal jaw positioning have been proposed as contributing factors, yet their individual and cumulative contributions remain unclear. This exploratory cross-sectional study aimed to evaluate the prevalence and severity of parafunctional habits and their association with TMD in medical students—a group exposed to elevated stress levels. Subjects were examined in Krakow, Poland, using the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) protocol. **Methods**: Participants completed a 21-item Oral Behavior Checklist (OBC) assessing the frequency of oral behaviors on a 0–4 scale. A self-reported total parafunction load was calculated by summing individual item scores (range: 0–84). Logistic regression was used to evaluate associations between individual and total parafunction severity scores and TMD presence. **Results:** The study included 66 individuals aged 19–30. TMD was diagnosed in 55 participants (83.3%). The most commonly reported habits were resting the chin on the hand (90.9%) and sleeping in a jaw-compressing position (86.4%). Notably, jaw tension (OR = 14.5; $p = 0.002$) and daytime clenching (OR = 4.7; $p = 0.027$) showed significant associations with TMD in the tested population. Each additional point in the total parafunction score increased TMD odds by 13.6% ($p = 0.004$). **Conclusions**: These findings suggest that parafunctional behaviors—especially those involving chronic muscle tension or abnormal mandibular positioning—may meaningfully contribute to the risk of TMD in high-stress student populations. Moreover, the cumulative burden of multiple low-intensity habits was also significantly associated with increased TMD risk. Early screening for these behaviors may support prevention strategies, particularly among young adults exposed to elevated levels of stress.

Keywords: temporomandibular disorders; DC/TMD; temporomandibular joint; parafunctional habits; oral behaviors; bruxism; medical students; jaw muscle tension; stress; young adults

1. Introduction

Temporomandibular disorders (TMDs) comprise a heterogeneous group of musculoskeletal and functional conditions involving the temporomandibular joint (TMJ), masticatory muscles, and related anatomical structures. Common clinical manifestations include pain, limited mandibular mobility, joint clicking, and sensations of jaw locking or deviation during movement [1–3]. Accurate diagnosis remains challenging due to the non-specific and often overlapping nature of clinical symptoms [4,5].

As one of the most prevalent musculoskeletal dysfunctions in the orofacial region [6,7], TMD can significantly impair patients' quality of life [8]. A recent meta-analysis reported a global prevalence of approximately 34%, with individual study estimates ranging from 5% to 88%, depending on diagnostic criteria and population characteristics. The highest rates were observed among individuals aged 18 to 60 years [7]. Notably, women are disproportionately affected, exhibiting both higher prevalence and greater symptom severity than men, along with more frequent episodes and less favorable recovery outcomes [9,10]. Although the relationship between oral behaviors and TMD has been widely explored, existing findings remain inconsistent and often inconclusive [6,11,12]. In particular, only a limited number of studies have addressed this issue in young adults exposed to chronic psychosocial stress, especially within Polish academic settings. Given its high prevalence and clinical complexity, a deeper insight into the various factors contributing to TMD is essential.

The etiology of TMD is multifactorial, encompassing anatomical, traumatic, systemic, behavioral, and psychosocial contributors [1,13,14]. Some studies have also explored systemic factors, such as vitamin D deficiency, which may affect musculoskeletal function and inflammatory regulation [15]. Among the various behavioral contributors, parafunctional behaviors have received particular attention due to their potential to exert excessive mechanical load on the masticatory system.

One of the key behavioral components implicated in the development and persistence of TMD symptoms is oral parafunction. These habits refer to non-functional, repetitive activities of the stomatognathic system that are unrelated to essential tasks such as chewing, swallowing, or speaking. Examples include tooth clenching, grinding, jaw bracing, resting the chin on the hand, and excessive gum chewing [1,11]. These behaviors may increase mechanical load on the TMJ and surrounding musculature, potentially resulting in microtrauma, inflammation, or chronic pain [16].

Bruxism, often discussed alongside general parafunctions, constitutes a distinct entity. It is typically defined as sustained or rhythmic clenching or grinding of the teeth, occurring during sleep (sleep bruxism) or wakefulness (awake bruxism), and is diagnosed using separate criteria [17,18]. While its etiopathogenesis may differ from that of other oral habits, bruxism can similarly contribute to excessive strain on the temporomandibular system [12].

Psychological stress is a well-recognized factor in the pathophysiology of TMD, influencing both muscular tension and the severity of parafunctional behaviors [19,20]. Stress has been shown to exacerbate behaviors such as clenching or bracing, possibly acting as a moderating or amplifying factor in the development and chronicity of TMD [20–22]. These mechanisms may explain the increased prevalence of TMD among populations experiencing chronic psychological strain, including individuals with anxiety or depression [23]. Taken together, stress may contribute to both the persistence of oral habits and the chronicity of TMD symptoms.

University students—particularly those in health-related academic programs—are frequently exposed to high levels of academic pressure, irregular sleep patterns, and increased cognitive and motor demands, which may predispose them to parafunctional

habits and TMD. Previous studies have identified this subgroup as being at elevated risk [23–25], though they remain underrepresented in the existing literature.

This study aimed to assess the prevalence of TMD and oral parafunctions in young adults under elevated stress and to examine their association with TMD presence. We hypothesized that both selected individual parafunctions and the cumulative parafunctional burden would be positively associated with the occurrence of TMD in this population.

2. Materials and Methods

2.1. Ethics Approval

The study protocol was reviewed and approved by the Bioethics Committee of the Jagiellonian University (decision no. 1072.6120.16.2024) on 17 April 2024. All procedures were conducted in accordance with the Declaration of Helsinki and Good Clinical Practice (GCP) guidelines. Written informed consent was obtained from all participants prior to data collection.

2.2. Study Population

This study was conducted among students enrolled in medical-related programs (medicine, dentistry, and physiotherapy) in Krakow, Poland. Recruitment was carried out through convenience sampling, primarily via online announcements posted in university-affiliated student forums. All eligible individuals were invited to participate, aiming to ensure the highest possible number of participants within the study's logistical and time constraints. However, this strategy may have introduced a degree of selection bias.

Inclusion criteria: Informed consent to participate, age between 18 and 30 years, and presence of a complete natural dentition (excluding third molars).

Exclusion criteria: Use of prosthetic restorations, previously diagnosed TMD, clinically significant malocclusion (Angle Class II and Class III), diagnosed musculoskeletal disorders (e.g., rheumatoid arthritis, degenerative joint disease, fibromyalgia), and Grade III tooth mobility (according to the Kantorowicz classification) [26–28].

2.3. Study Design

This study employed a cross-sectional observational design. Each participant underwent a standardized clinical examination and completed a structured questionnaire in accordance with Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [27,28], which includes both symptom-based screening and physical assessment components.

All clinical examinations were conducted at the Department of Prosthodontics, Jagiellonian University Medical College, by two trained and jointly calibrated examiners. Prior to data collection, both examiners underwent internal training and calibration to ensure consistency in diagnostic procedures. A subset of participants was examined jointly by both investigators to ensure procedural consistency between examiners.

All TMD diagnoses were made collaboratively by the two examiners, based on the integrated interpretation of clinical findings and questionnaire responses, in accordance with the DC/TMD Diagnostic Decision Tree [28,29]. The examiners were blinded to participants' questionnaire responses during the clinical examination, minimizing the risk of observer bias in the diagnostic process.

2.4. Assessment Tools

TMD diagnosis was established based on a clinical examination and a structured questionnaire, in accordance with the DC/TMD protocol, which provides standardized and validated guidelines for both clinical and research applications and is widely recognized as the reference standard for TMD diagnosis. According to the DC/TMD, TMD are

categorized into three major diagnostic groups: muscle disorders (Group I), joint disorders (Group II), and headaches attributed to TMD (Group III), with further subclassifications such as myalgia, disc displacement, and arthralgia [27,28,30].

To assess oral parafunctional behaviors, participants completed the self-report instrument Oral Behavior Checklist (OBC) [31], consisting of 21 items addressing both sleep-related and daytime oral habits (e.g., clenching, grinding, gum chewing, tongue pressing, jaw bracing, and object biting). Following the guidelines of the Scoring Manual for Self-Report Instruments, the frequency of each behavior was rated on a 5-point scale (0–4), with response options ranging from "never" to "4–7 times a week" or from "none of the time" to "all of the time", depending on whether the behavior occurred during the day or at night [29].

A total parafunctional intensity score was calculated by summing the individual item scores (range: 0–84), providing a quantitative measure of each participant's overall parafunctional burden. No categorical classification (e.g., low vs. high intensity) was applied, in accordance with the exploratory nature of the study.

2.5. Statistical Analysis

Statistical analysis was performed using R software (version 4.4.3; R Core Team, 2023) on a Windows 10 Pro 64-bit system (build 19045). No external R packages were required for the procedures conducted. Descriptive statistics were calculated for demographic variables, TMD diagnoses, and parafunctional scores. To evaluate associations between individual oral behaviors and the presence of TMD, univariate logistic regression models were applied. Each OBC item was analyzed in two forms: binary presence (yes/no) and intensity score (0–4). In addition, the total parafunctional intensity score was tested as a continuous predictor of TMD occurrence. Multivariate analysis could not be performed due to the limited sample size; the results are based solely on univariate models. Odds ratios (OR) with corresponding 95% confidence intervals (CI) were reported. A p-value below 0.05 was considered statistically significant. Effect sizes were interpreted according to thresholds proposed by Chinn (2000) [32], defining small (OR = 1.68), medium (OR = 3.47), and large (OR = 6.71) effects.

3. Results

3.1. Characteristics of the Study Group

A total of 66 participants met the eligibility criteria. The age range was 19 to 30 years, with a mean age of 23.44 $\pm$ 1.73 years. The sample included 41 females (62.12%) and 25 males (37.88%).

3.2. Prevalence of Temporomandibular Disorders

TMD was diagnosed in 55 participants (83.33%), while 11 individuals (16.67%) did not meet the diagnostic criteria. The most common subtype was a combined muscle–joint disorder (48.48%), followed by isolated joint disorders (21.21%) and isolated muscle disorders (13.64%).

3.3. Prevalence of Parafunctions

The most commonly reported parafunctional behaviors were leaning the head on the hand, such as cupping the cheek or resting the chin (90.91%); sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side) (86.36%); chewing gum (74.24%); maintaining tooth contact outside of eating (i.e., pressing or touching teeth together) (68.18%); and clenching teeth during waking hours (66.67%).

In contrast, the least frequently reported behaviors were playing musical instruments involving the jaw or mouth (e.g., woodwind, brass, or string instruments) (4.55%), grinding teeth during waking hours (28.79%), holding the phone between the head and shoulder (36.36%), placing the tongue between the teeth (37.88%), pressing the tongue forcibly against the teeth (39.39%), and singing (39.39%).

3.4. Severity of Parafunctional Behaviors

The highest reported intensity was noted for sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side), with 56.06% of participants indicating it occurred "all the time" and 24.24% "most of the time".

Sleep bruxism—defined as clenching or grinding teeth when asleep—was reported as occurring "all the time" by 16.67% of participants and "most of the time" by 15.15%.

For clenching teeth during waking hours, 27.27% reported it as occurring "sometimes," 16.67% "most of the time," and 1.52% "all the time."

Pressing, touching, or holding teeth together other than while eating was reported as "sometimes" by 27.27% and "most of the time" by 15.15%.

"Holding, tightening, or tensing jaw muscles without clenching or bringing teeth together" was reported as occurring "sometimes" (16.67%), "most of the time" (12.12%), and "all the time" (1.52%).

Other parafunctional habits were reported less frequently and with lower intensity overall. Detailed distributions of frequency and severity for each behavior are presented in Table 1.

Table 1. Frequency and intensity of parafunctional behaviors.

Activities During Sleep	Frequency				
	Never	<1 Night /Month	1–3 Nights /Month	1–3 Nights /Week	4–7 Nights /Week
Clenching or grinding teeth when asleep	32 (48.48%)	6 (9.09%)	7 (10.61%)	10 (15.15%)	11 (16.67%)
Sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side)	9 (13.64%)	2 (3.03%)	2 (3.03%)	16 (24.24%)	37 (56.06%)
Activities During Waking Hours	**Frequency**				
	None of the time	A little of the time	Some of the time	Most of the time	All of the time
Grinding teeth during waking hours	47 (71.21%)	12 (18.18%)	5 (7.58%)	2 (3.03%)	0 (0.00%)
Clenching teeth during waking hours	22 (33.33%)	14 (21.21%)	18 (27.27%)	11 (16.67%)	1 (1.52%)
Pressing, touching, or holding teeth together other than while eating (i.e., contact between upper and lower teeth)	21 (31.82%)	17 (25.76%)	18 (27.27%)	10 (15.15%)	0 (0.00%)
Holding, tightening, or tensing jaw muscles without clenching or bringing teeth together	28 (42.42%)	18 (27.27%)	11 (16.67%)	8 (12.12%)	1 (1.52%)
Holding or jutting the jaw forward or to the side	39 (59.09%)	17 (25.76%)	8 (12.12%)	1 (1.52%)	1 (1.52%)
Pressing the tongue forcibly against the teeth	40 (60.61%)	14 (21.21%)	7 (10.61%)	5 (7.58%)	0 (0.00%)
Placing the tongue between the teeth	41 (62.12%)	16 (24.24%)	7 (10.61%)	2 (3.03%)	0 (0.00%)
Biting, chewing, or playing with the tongue, cheeks, or lips	31 (46.97%)	11 (16.67%)	15 (22.73%)	6 (9.09%)	3 (4.55%)

Table 1. *Cont.*

Holding the jaw in a rigid or tense position, such as to brace or protect it	22 (33.33%)	24 (36.36%)	8 (12.12%)	8 (12.12%)	4 (6.06%)
Holding objects between the teeth (e.g., pipe, pencil, pens, fingers, fingernails)	39 (59.09%)	15 (22.73%)	8 (12.12%)	3 (4.55%)	1 (1.52%)
Using chewing gum	17 (25.76%)	20 (30.30%)	18 (27.27%)	9 (13.64%)	2 (3.03%)
Playing musical instruments that require use of the jaw or mouth (e.g., woodwind, brass, strings)	63 (95.45%)	2 (3.03%)	1 (1.52%)	0 (0.00%)	0 (0.00%)
Leaning the head on the hand, such as cupping or resting the chin	6 (9.09%)	11 (16.67%)	33 (50.00%)	13 (19.70%)	3 (4.55%)
Chewing food on one side only	24 (36.36%)	17 (25.76%)	14 (21.21%)	6 (9.09%)	5 (7.58%)
Eating between meals (i.e., food that requires chewing)	13 (19.70%)	19 (28.79%)	21 (31.82%)	10 (15.15%)	3 (4.55%)
Sustained talking (e.g., teaching, sales, customer service)	20 (30.30%)	23 (34.85%)	13 (19.70%)	7 (10.61%)	3 (4.55%)
Singing	40 (60.61%)	20 (30.30%)	2 (3.03%)	4 (6.06%)	0 (0.00%)
Yawning	17 (25.76%)	23 (34.85%)	19 (28.79%)	4 (6.06%)	3 (4.55%)
Holding the telephone between the head and shoulder	42 (63.64%)	19 (28.79%)	5 (7.58%)	0 (0.00%)	0 (0.00%)

Frequency and intensity of reported oral parafunctional behaviors. Values represent the number of participants and percentage (in parentheses) who selected each response option. The first two rows refer to nocturnal behaviors; the remaining items to behaviors during wakefulness.

3.5. Total Parafunction Intensity

The maximum possible score for parafunctional activity was 84, reflecting 21 items rated on a 0–4 scale. In the studied population, total scores ranged from 0 to 65. The mean total parafunctional intensity score was 22.98 ± 12.28, with a median of 22 and an interquartile range (IQR) of 15.25 to 30.00. These results indicate substantial interindividual variability in both the frequency and overall intensity of self-reported parafunctional behaviors.

3.6. Association Between Parafunction Presence and TMD

Certain parafunctional behaviors were significantly associated with increased odds of TMD. The strongest association was observed for "Holding the jaw in a rigid or tense position, such as to brace or protect it", which increased the odds of TMD more than 14-fold (OR = 14.538; $p = 0.002$).

Two main groups of statistically significant parafunctions were identified. The first group included behaviors related to chronic muscle tension, such as holding the jaw in a rigid or tense position, such as to brace or protect it (OR = 14.538; $p = 0.002$); holding, tightening, or tensing jaw muscles without clenching or bringing teeth together (OR = 8.526; $p = 0.010$); pressing, touching, or holding teeth together other than while eating (i.e., contact between upper and lower teeth) (OR = 8.615; $p = 0.004$); and clenching teeth during waking hours (OR = 4.667; $p = 0.027$).

The second group comprised behaviors involving abnormal jaw positioning, including holding or jutting the jaw forward or to the side (OR = 8.966; $p = 0.043$) and sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side) (OR = 5.714; $p = 0.026$).

Table 2 summarizes the univariate logistic regression results, detailing the associations between specific parafunctional behaviors and TMD. For improved clarity, odds ratios classified as large effect sizes (OR $\geq$ 6.71) have been highlighted in bold [32].

Table 2. Association between the presence of parafunctions and the occurrence of TMD.

Parafunction		N	n	OR	95%CI		$p < 0.05$
Clenching or grinding teeth when asleep	No	32	24	1	ref.		
	Yes	34	31	3.444	0.824	14.392	0.09
Sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side)	No	9	5	1	ref.		
	Yes	57	50	5.714	1.232	26.505	0.026 *
Grinding teeth during waking hours	No	47	37	1	ref.		
	Yes	19	18	4.865	0.577	40.992	0.146
Clenching teeth during waking hours	No	22	15	1	ref.		
	Yes	44	40	4.667	1.193	18.26	0.027 *
Pressing, touching, or holding teeth together other than while eating (i.e., contact between upper and lower teeth)	No	21	13	1	ref.		
	Yes	45	42	**8.615**	1.99	37.301	0.004 *
Holding, tightening, or tensing jaw muscles without clenching or bringing teeth together	No	28	19	1	ref.		
	Yes	38	36	**8.526**	1.671	43.509	0.01 *
Holding or jutting the jaw forward or to the side	No	39	29	1	ref.		
	Yes	27	26	**8.966**	1.073	74.894	0.043 *
Pressing the tongue forcibly against the teeth	No	40	31	1	ref.		
	Yes	26	24	3.484	0.688	17.643	0.132
Placing the tongue between the teeth	No	41	32	1	ref.		
	Yes	25	23	3.234	0.638	16.395	0.156
Biting, chewing, or playing with the tongue, cheeks, or lips	No	31	22	1	ref.		
	Yes	35	33	**6.75**	1.33	34.257	0.021 *
Holding the jaw in a rigid or tense position, such as to brace or protect it	No	22	13	1	ref.		
	Yes	44	42	**14.538**	2.782	75.967	0.002 *
Holding objects between the teeth (e.g., pipe, pencil, pens, fingers, fingernails)	No	39	30	1	ref.		
	Yes	27	25	3.75	0.741	18.978	0.11
Using chewing gum	No	17	14	1	ref.		
	Yes	49	41	1.098	0.255	4.724	0.9
Playing musical instruments that require use of the jaw or mouth (e.g., woodwind, brass, strings)	No	63	52	1	ref.		
	Yes	3	3	---	---	---	---
Leaning the head on the hand, such as cupping or resting the chin	No	6	4	1	ref.		
	Yes	60	51	2.833	0.45	17.829	0.267
Chewing food on one side only	No	24	17	1	ref.		
	Yes	42	38	3.912	1.009	15.164	0.048 *
Eating between meals (i.e., food that requires chewing)	No	13	11	1	ref.		
	Yes	53	44	0.889	0.168	4.715	0.89
Sustained talking (e.g., teaching, sales, customer service)	No	20	17	1	ref.		
	Yes	46	38	0.838	0.198	3.555	0.811
Singing	No	40	33	1	ref.		
	Yes	26	22	1.167	0.305	4.463	0.822
Yawning	No	17	12	1	ref.		
	Yes	49	43	2.986	0.775	11.499	0.112
Holding the telephone between the head and shoulder	No	42	34	1	ref.		
	Yes	24	21	1.647	0.393	6.911	0.495

p-values from univariate logistic regression. N—total in group; n—number of participants with TMD; OR—odds ratio; CI—confidence interval. Statistically significant associations ($p < 0.05$) are marked with an asterisk. Interpretation of effect sizes: small (OR $\geq$ 1.68), medium (OR $\geq$ 3.47), and large (OR $\geq$ 6.71). Large effect sizes have been highlighted in bold.

For better visual representation, the data from Table 2 were also presented as a forest plot (Figure 1), illustrating the strength and direction of associations between individual parafunctional habits and the presence of TMD.

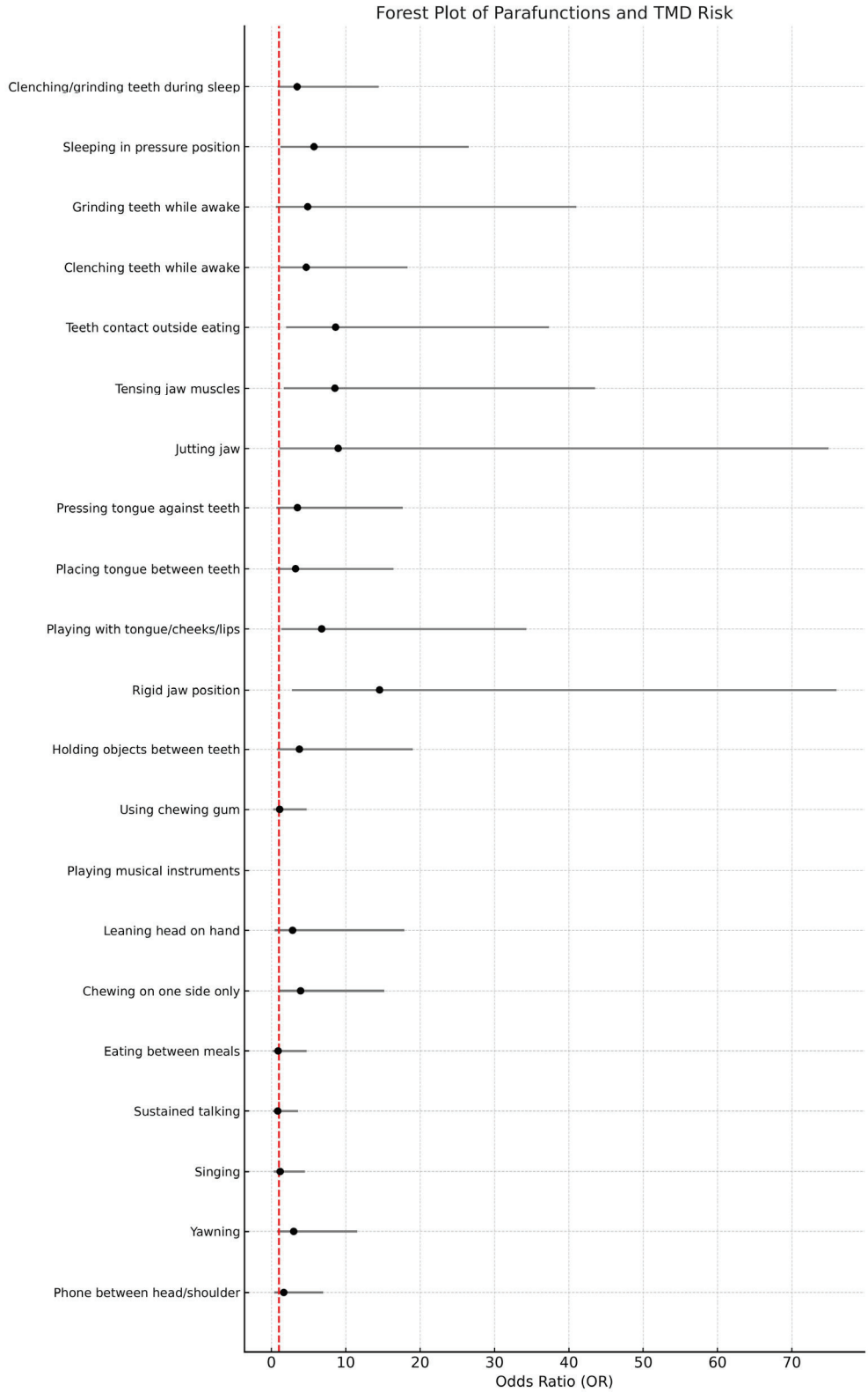

Figure 1. Forest plot displaying odds ratios (OR) and 95% confidence intervals for the association between individual parafunctional behaviors and TMD occurrence.

3.7. Association Between Parafunction Intensity and TMD

The analysis also showed significant associations between the severity of specific parafunctions and the presence of TMD. Notably, sleeping in a position that puts pressure on the jaw (e.g., on the stomach or side) was associated with TMD at both higher frequency levels: "most of the time" (OR = 12.00; $p = 0.044$) and "all the time" (OR = 5.12; $p = 0.048$). Interestingly, even participants who reported rarely holding the jaw in a rigid or tense position, such as to brace or protect it, had significantly increased odds of TMD (OR = 7.615; $p = 0.018$). Given the exploratory nature of the study, p-values were not adjusted for multiple comparisons and should be interpreted with caution.

3.8. Association Between Total Parafunction Intensity and TMD

A significant association was observed between the total parafunction score and the presence of TMD. Logistic regression revealed that each additional point on the parafunction severity scale increased the odds of TMD by 13.6% (OR = 1.136; 95% CI: 1.042–1.238; $p = 0.004$).

4. Discussion

4.1. Main Findings

The present study aimed to evaluate the association between parafunctional habits and the occurrence of TMD in a population of medical, dental, and physiotherapy students. TMD was diagnosed in 83.3% of participants. The most frequent subtype was a combined muscle–joint disorder (48.5%), followed by isolated joint (21.2%) and muscle disorders (13.6%). These findings align with prior evidence indicating elevated TMD rates in populations exposed to chronic stress.

A wide range of parafunctional behaviors was reported, with the most common including leaning the head on the hand and sleeping in a position that puts pressure on the jaw. The analysis revealed that certain behaviors—particularly those involving chronic muscle activation (e.g., clenching, pressing the teeth together, tensing jaw muscles) and improper mandibular positioning (e.g., jutting the jaw, side-sleeping)—were significantly associated with increased odds of TMD. Notably, even infrequent engagement in certain behaviors (e.g., "rarely" holding the jaw in a rigid position) was associated with elevated risk, underscoring the potential clinical relevance of low-grade, repetitive strain.

A significant association was also found between the total parafunction intensity score and TMD, with each additional point increasing the odds of TMD by 13.6% ($p = 0.004$). In some categories, full logistic regression was not feasible due to all participants endorsing a behavior being diagnosed with TMD, potentially reflecting a strong association but also highlighting statistical limitations due to sample size.

In comparison, the study by Cannatà et al. (2025) [23], conducted among a broader university population, reported a lower prevalence of TMD: 14.0% of students presented with pain-related symptoms, 28.0% with joint-related signs, 23.4% with both, and 34.6% with neither. Notably, parafunctional behaviors were significantly more prevalent among students enrolled in science-related programs—a group to which our participants belong. These findings further underscore the need for targeted monitoring and preventive strategies in academically stressed student populations.

4.2. Sample Characteristics

The composition of the study sample warrants careful consideration. All participants were medical, dental, or physiotherapy students, a population known to be particularly exposed to chronic psychological stress due to academic pressure and demanding schedules [23]. While the homogeneity of the sample may limit the generalizability of our

findings to the broader young adult population, it allows for focused analysis within a clearly defined subgroup. The decision to target healthcare students was intentional, as the prior literature indicates they are at elevated risk for both parafunctional behaviors and TMD symptoms [33,34].

It is important to discuss the relatively high prevalence of TMD identified in this sample (83.3%), which is elevated even for a student population. This may reflect both the elevated stress levels commonly reported among medical students and the high sensitivity of the DC/TMD criteria, which may identify mild or subclinical cases that would otherwise remain undiagnosed. Additionally, the majority of our study sample consisted of female participants, who, according to the well-established literature, are more likely to exhibit TMD symptoms [4].

4.3. Parafunctional Associations

The findings suggest that certain parafunctional behaviors are associated with the presence of TMD, particularly those involving chronic muscular tension and abnormal mandibular positioning. The strongest association was observed for holding the jaw in a tense or rigid position (OR = 14.538), which is consistent with previous studies highlighting sustained muscle tension as a major contributor to TMJ overload. Similarly, behaviors such as mandibular protrusion, lateral displacement, and maintaining tooth contact outside of functional mastication were also significantly associated with TMD development.

These observations support the hypothesis that not only bruxism but also other routine parafunctional activities may contribute to the etiology of functional disorders within the masticatory system [35].

A significant association was also observed between the total parafunctional score and the presence of TMD. Each additional point on the severity scale increased the odds of TMD by 13.6% (OR = 1.136; 95% CI: 1.042–1.238; $p = 0.004$), indicating that the cumulative effect of multiple mild parafunctions may play a meaningful role in TMD pathogenesis. Although no official norms have yet been established for this instrument, prior research using the OBC has indicated that a total score of 0–16 typically reflects normal behavior patterns, whereas scores of 17–24 and 25–62 occur two and seventeen times more frequently, respectively, in individuals with chronic TMD [29]. These findings reinforce the view that it is the cumulative burden of multiple parafunctions, rather than any single behavior, that may contribute to TMD development.

4.4. Role of Psychological Stress

An additional key consideration is the impact of psychological stress on the presence or exacerbation of TMD symptoms. Existing evidence indicates that stress may contribute to increased muscle tension and the development of unconscious parafunctional habits, such as clenching or prolonged mandibular positioning. Numerous studies have reported associations between elevated levels of stress, anxiety, or depression and a higher occurrence of TMD [18,19]. When analyzing the relationship between the Oral Behavior Checklist (OBC) score and other DC/TMD Axis II measures, Cannatà et al. found significant positive correlations between the frequency of oral behaviors and higher levels of anxiety, depressed mood, psychological distress, and somatization risk ($p < 0.001$). These findings reinforce the notion that parafunctional oral behaviors may not only reflect underlying psychological strain but also contribute to the maintenance and exacerbation of TMD symptoms.

Psychophysiological mechanisms are believed to play a central role in the etiology of TMD, particularly among young adults who are chronically exposed to emotional stress. This is especially relevant to our study population—medical students—who are recognized as being particularly vulnerable to academic and occupational stress and burnout [36].

4.5. Strengths and Limitations

This study has several important limitations. First, the homogeneity of the study population—comprising exclusively medical, dental, and physiotherapy students—limits the generalizability of the findings to broader young adult populations. Prior research, including the OPPERA study, has emphasized the influence of demographic variables such as age and sex on TMD prevalence, underscoring the need for more diverse samples [22]. While strict inclusion and exclusion criteria enhanced internal validity, they may have introduced selection bias by excluding individuals with more severe or atypical presentations.

Second, the study relied on self-reported parafunctional behaviors, many of which are unconscious or stress-related—such as jaw tension or clenching—which may have led to underestimation of their true frequency. Since these behaviors often occur outside of conscious awareness, participants may have inaccurately recalled or entirely overlooked them, resulting in potential misclassification. Furthermore, individuals experiencing symptoms or suspecting they had TMD may have been more motivated to participate in the study, potentially inflating the observed prevalence. Additionally, participants' awareness of being part of a study may have influenced their responses, introducing potential bias. [37].

Third, the absence of an a priori power analysis limits the ability to definitively evaluate the adequacy of the sample size. Nonetheless, the final number of participants (N = 66) was considered sufficient to detect large effects with approximately 90% statistical power, based on meta-analytic benchmarks for TMD and masticatory muscle research [38]. However, the limited number of TMD-free participants constrained the statistical analysis. Multivariate models could not be performed, preventing adjustment for confounding factors such as age, sex, or psychological stress, and contributing to wide confidence intervals for some odds ratios. Lack of statistical significance for certain habits may also reflect limited power to detect smaller effects. Unlike large-scale prospective studies such as OPPERA [39], this analysis was restricted to univariate comparisons.

The cross-sectional design constitutes another key limitation. While associations between parafunctional behaviors and TMD were observed, causality cannot be inferred. These findings should therefore be interpreted as correlational and hypothesis-generating rather than confirmatory. Moreover, no statistical correction for multiple comparisons (e.g., Bonferroni or false discovery rate) was applied, given the exploratory nature of the study.

Although stress levels were not formally assessed, the previous literature consistently identifies elevated levels of stress, anxiety, and maladaptive coping behaviors in medical student populations [33]. These psychosocial stressors may help explain the high prevalence of TMD symptoms and parafunctional habits observed in our sample. In the absence of a standardized psychometric tool (e.g., Perceived Stress Scale), our assumption of elevated stress levels remains speculative. This limits the ability to quantify emotional distress and its contribution to the observed outcomes.

To address these limitations, future research should include larger and more heterogeneous populations to enhance generalizability and allow for multivariate modeling. Longitudinal designs would enable assessment of temporal dynamics and potential causality between parafunctional habits and TMD development. Incorporating objective behavioral assessments (e.g., surface electromyography) and validated psychometric instruments could improve the precision of measurements and support more comprehensive statistical analyses.

4.6. Clinical Implications

This study contributes to the growing body of evidence indicating that everyday oral behaviors—beyond classic bruxism—may play a substantial role in TMD etiology.

Specifically, it identifies parafunctional habits such as prolonged jaw tension and abnormal mandibular positioning as potential contributors to TMD and emphasizes the cumulative effect of multiple low-grade oral behaviors. These insights highlight the clinical relevance of assessing behavioral factors in a medically educated, high-stress student population.

Importantly, not all individual behaviors showed statistically significant associations with TMD, possibly reflecting differences in mechanical sensitivity or psychological resilience. The broad variability in OBC scores observed in our cohort underscores considerable interindividual differences, supporting the need for further research to define diagnostic thresholds and predictive models in diverse populations. As a practical step, integrating OBC-based screening into student health programs may help identify at-risk individuals and guide targeted prevention.

From a clinical standpoint, these findings support the inclusion of behavioral and psychosocial screening into routine TMD diagnostics. Early identification of chronic jaw tension and maladaptive mandibular positioning may facilitate timely interventions. Furthermore, stress-reduction strategies and patient education on oral behaviors could become valuable components of comprehensive TMD prevention and management protocols, particularly in vulnerable populations such as students and young adults.

While the inclusion of a non-medical control group could have strengthened comparative analysis, this was beyond the scope of the present study. Future research should incorporate broader student populations to assess whether the observed associations are unique to healthcare students or generalizable across academic disciplines.

To build on these insights, future studies should aim to replicate and expand the current findings in larger, more heterogeneous cohorts. Longitudinal designs would be particularly valuable to clarify the temporal dynamics and potential causality between parafunctional habits and TMD onset or persistence. Incorporating objective behavioral assessments and validated psychometric tools would also enable more comprehensive statistical modeling and enhance the translational value of future research.

5. Conclusions

Despite its limitations, this study provides valuable insights into the relationship between parafunctional habits and TMDs. The results demonstrate a clear association between specific oral behaviors and the presence of TMD in young adults exposed to elevated psychosocial stress. These findings underscore the importance of early detection and routine monitoring of parafunctional habits—particularly in academic settings where chronic psychological burden is common.

Given that many of these behaviors are unconscious or subclinical, behavioral screening could serve as a useful component of early risk assessment. Clinicians should remain attentive not only to classic signs such as bruxism but also to subtle and cumulative behaviors like sustained jaw tension or habitual mandibular positioning, which may contribute to muscle overload and joint dysfunction.

Integrating behavioral assessment and targeted counseling into standard diagnostic and treatment frameworks may improve the early management of TMD, particularly in vulnerable populations. These findings provide a preliminary but compelling rationale for future longitudinal and interventional studies aimed at clarifying causality and informing preventive strategies.

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Informed Consent Statement: Informed consent was obtained from all participants.

Data Availability Statement: The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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Article

Association Between Gum Chewing and Temporomandibular Disorders

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Abstract

Background: Gum chewing is a common habit among young adults, often promoted for its oral health and psychological benefits. However, as a repetitive and non-functional activity, it is also considered a potential risk factor for temporomandibular disorder (TMD), particularly when practiced chronically. The aim of this study was to evaluate whether excessive gum chewing is associated with a higher prevalence of TMD among young adults presumed to be under elevated academic stress based on their demographic characteristics. **Methods**: Participants were examined in Krakow, Poland, using the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) protocol. Participants completed a structured questionnaire assessing gum-chewing frequency, duration, and chronicity. Associations between chewing behaviors and TMD presence were analyzed using univariate logistic regression ($\alpha = 0.05$). **Results**: This study included young adults 66 participants aged 19–30. TMD was diagnosed in 55 participants (83.3%), including muscular disorders (n = 9; 16.4%), articular disorders (n = 10; 18.2%), and combined muscular–articular disorders (n = 38; 57.6%). More than 70% of participants reported chewing gum for over five years. No statistically significant associations were found between TMD occurrence and the frequency, duration, or chronicity of gum chewing ($p > 0.05$). **Conclusions**: These findings suggest that, in the absence of other contributing factors, gum chewing may not independently contribute to TMD development. The elevated TMD prevalence may reflect confounding variables such as high academic stress, narrow age distribution, or female predominance. However, the limited sample size limits statistical power, particularly for detecting subtle effects potentially distorted by other variables. Additionally, the cross-sectional nature of this study precludes causal interpretation. Further studies in larger and more heterogeneous populations are recommended.

Keywords: temporomandibular disorders; temporomandibular joint; DC/TMD; gum chewing; parafunctional habits; oral behaviors; bruxism; stress; young adults; medical students

1. Introduction

1.1. Masticatory Function

Chewing is a fundamental function of the stomatognathic system, responsible for mechanical food breakdown and salivary stimulation. However, neuroimaging studies suggest

that its effects extend beyond digestion—mastication activates a widespread network of brain regions and enhances cerebral blood flow [1]. These activations intensify when chewing involves greater intensity and richer flavor, or occurs under emotional stress [1,2]. This evidence illustrates how both the mechanical and sensory aspects of mastication influence neural responses. Mastication also promotes the release of neurotransmitters involved in regulating attention, mood, and memory [3,4]. Regular chewing has been associated with preserved cognitive function through mechanisms that support neuroplasticity and reduce stress [5–7]. However, the long-term behavioral consequences of habitual chewing—particularly in the context of stress modulation or cognitive adaptation—remain unclear and warrant further longitudinal investigation.

1.2. Gum Chewing as a Parafunction

Chewing gum is a common habit among adolescents and young adults. Its widespread use has been attributed to its diverse applications—it may support oral hygiene by stimulating salivary production [8]. However, despite its potential benefits [9,10], chewing gum is classified as a parafunctional habit in the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [11,12], which raises concerns about its long-term effects on the stomatognathic system.

Parafunctional habits refer to repetitive non-functional oral behaviors that exceed normal physiological demands and may lead to musculoskeletal strain or joint overload. In the case of gum chewing, such effects are particularly relevant when mastication occurs excessively or without nutritional purpose. Repetitive chewing—especially when performed unconsciously or asymmetrically—may expose the masticatory system to sustained low-load mechanical stress, potentially contributing to myofascial pain, limited mandibular mobility, joint sounds, or tension-type headaches in individuals with predisposing factors such as stress or malocclusion [13].

Although it has been demonstrated that healthy individuals typically recover fully after prolonged chewing, chronic overuse may still induce microtrauma or exacerbate pre-existing dysfunctions [13,14]. These patterns can disrupt muscle coordination, overload the temporomandibular joints (TMJs), and lead to functional disturbances such as articular displacement or pain [13–15].

Recent evidence underscores the complexity of the relationship between gum chewing and temporomandibular disorder (TMD). Several studies have reported an association between gum chewing and increased jaw muscle discomfort [16,17]. In contrast, other studies described only transient symptoms that resolved after discontinuing gum use [13, 18]. These mixed findings highlight the need to better understand how habitual behaviors such as gum chewing relate to the broader context of TMDs.

1.3. TMD: Prevalence, Causes, and Diagnosis

Epidemiological studies indicate that TMDs are among the most prevalent musculoskeletal conditions affecting the craniofacial region. The newest research estimates the global prevalence of TMD at 34%, highlighting the substantial burden of this condition in the general population. However, the occurrence of TMD varies considerably across continents and age groups [19]. Women consistently demonstrate a higher prevalence and greater severity of TMD [20,21]. Research indicates that gender differences in orofacial pain not only persist but may widen over time, with females experiencing both increased incidence and less favorable recovery trajectories [21].

TMDs are widely recognized as multifactorial conditions influenced by anatomical, behavioral, and psychosocial factors [22]. Behavioral contributors—particularly oral parafunctions such as bruxism, clenching, and gum chewing—are consistently associated with

the onset and persistence of TMD symptoms [14,23]. These behaviors are significant predictors, especially when performed frequently or asymmetrically [14]. Their habitual nature may lead to microtrauma, muscular fatigue, and, over time, joint dysfunction in predisposed individuals [13,14]. Anatomical factors such as malocclusion have traditionally been considered risk factors; however, more recent studies suggest no strong correlation between malocclusion and TMD severity [24,25], underscoring the need for a broader multifactorial perspective. Psychosocial factors also play a critical role in TMD pathogenesis. High levels of stress, anxiety, and depression are associated with increased muscle tension, altered pain perception, and reduced coping capacity. These factors are particularly relevant in patients with myofascial pain [24]. Moreover, some findings suggest that the impact of oral habits on TMD may be mediated or amplified by psychosocial distress [26]. Additional factors under investigation include vitamin D deficiency, which may impair bone metabolism, muscle function, and inflammatory regulation. One study proposed a mechanistic link between low vitamin D levels and increased TMD risk [27]. Altogether, the current evidence reinforces the biopsychosocial model of TMD, in which biological predispositions, behavioral habits, and psychological stressors interact dynamically. Several authors emphasize that the effective management of TMD should address this complex interplay rather than focus solely on occlusal or isolated anatomical factors [28–30].

Diagnosing TMDs remains a clinical challenge due to their nonspecific, overlapping, and often diffuse symptoms [31]. Patients commonly report pain in the jaw, temples, or ears; joint noises; restricted jaw mobility; and headaches—manifestations that may resemble various orofacial or musculoskeletal disorders [32]. This symptom variability complicates differential diagnosis, particularly in non-specialist settings. Considering the high prevalence of TMD [19] and its negative impact on quality of life—such as sleep disturbances, reduced life satisfaction, and psychosocial burden [32,33]—timely and accurate diagnosis is essential [34]. Failure to recognize and manage TMD can lead to delayed treatment and increased risk of chronic symptoms. To improve diagnostic reliability, the DC/TMD protocol was developed as a standardized tool for use in both clinical and research settings [11,12]. The DC/TMD system categorizes TMD into three primary groups: muscle disorders, joint disorders, and headache attributed to TMD. Diagnosis is based on clinical examination and validated psychosocial assessment tools. Now considered the gold standard in TMD diagnostics, the DC/TMD framework improves diagnostic consistency, supports individualized treatment, and enhances our understanding of the multifactorial nature of TMD.

1.4. Aim of This Study

Most previous research has focused on short-term or experimental conditions, with limited data available on the long-term real-life impact of oral behaviors on TMD symptoms. Despite widespread gum use among young adults, studies employing standardized DC/TMD diagnostic protocols to assess its association with TMD are limited, and findings remain inconclusive. This study aims to address that gap by evaluating whether gum chewing is associated with the prevalence of TMD in a sample of young adults. Medical students were chosen as the study population primarily for convenience, but also due to their known exposure to elevated academic stress, making them a relevant group for TMD-related investigations [35,36]. Given the growing popularity of chewing gum as a lifestyle habit and stress coping mechanism, especially in academic settings, it is important to assess whether its chronic use poses a risk to the masticatory system [37]. Clarifying this relationship may support more accurate patient education and prevention strategies in clinical practice, particularly among younger individuals, where parafunctional behaviors often go unnoticed or underestimated [38]. Based on the previous literature, we hypoth-

esized that excessive gum chewing is associated with an increased prevalence of TMD among young adults.

2. Materials and Methods

2.1. Ethics Approval

Ethics approval was obtained from the Jagiellonian University Bioethics Committee (decision no. 1072.6120.16.2024) on 17 April 2024. This study was conducted in accordance with the Declaration of Helsinki and Good Clinical Practice (GCP) guidelines.

2.2. Study Population

This study included young adults (18–30 years) recruited from medical, dental, and physiotherapy faculties in Krakow. The age range was selected to reflect the typical age distribution of university students, which constituted the target population. Recruitment was conducted using a convenience sampling approach by posting announcements in student social media groups. Due to the observational cross-sectional design and logistical constraints, all eligible individuals available during the recruitment period were included, representing the maximum feasible sample size. All participants provided written informed consent prior to enrollment.

Inclusion criteria: Participants were eligible if they were aged 18–30 years, had complete dental arches, and provided informed consent

Exclusion criteria: Participants were excluded if they had prosthetic restorations, a previous diagnosis of TMD, significant malocclusion (Angle Class II or Class III), musculoskeletal disorders (e.g., rheumatoid arthritis, osteoarthritis, fibromyalgia), or pathological tooth mobility (Grade III according to Kantorowicz) [11,12,39].

2.3. Study Design

This study consisted of two stages. In the first stage, participants completed an original questionnaire assessing their gum-chewing habits, including frequency, duration, and chronicity. The questionnaire was developed specifically for this study and was pretested on members of our student research group prior to data collection. In the second stage, a clinical examination was conducted according to the DC/TMD protocol [11,12], including both questionnaire-based and physical assessment components. The clinical examinations were performed by two trained and jointly calibrated examiners at the Department of Prosthodontics, Jagiellonian University Medical College, Krakow, Poland. The examiners underwent internal training and calibration prior to data collection, sharing the same academic background and institutional environment. Although several patients were examined collaboratively to ensure consistency in diagnostic procedures, no formal assessment of inter-rater reliability was conducted. Diagnoses were established collaboratively based on the results of clinical examinations and questionnaires, ensuring a comprehensive assessment of each participant, according to DC/TMD protocol.

2.4. Questionnaire Content

Participants completed a structured questionnaire designed specifically for this study. The survey included items related to gum-chewing habits, with a focus on three key behavioral parameters: frequency, duration, and chronicity. Respondents were asked how often they chew gum (e.g., several times a day, once a day, several times a week, once a week, several times a month, once a month, or less frequently), how long a typical chewing session lasts (<10 min, 10–30 min, or >30 min), and how many years they have maintained the habit (<1 year, 1–3 years, 3–5 years, or >5 years). These questions allowed

for the categorization of participants into subgroups for further statistical analysis, as described below.

2.5. Variable Classification

Participants were categorized into analytical subgroups based on their self-reported gum-chewing behaviors collected via the original questionnaire.

Chewing frequency was classified into two main categories. Individuals who reported chewing gum several times a week, once a day, or several times a day were considered systematic users, whereas those who reported chewing once a week, several times a month, once a month, or less frequently were classified as non-systematic users.

Chewing duration was defined as the typical length of a single chewing session. Participants who reported chewing for less than 10 min were categorized as short-duration chewers, while those who chewed for 10 to 30 min or more than 30 min per session were grouped as long-duration chewers. This threshold was based on published data indicating that a typical meal for adolescents lasts approximately 10 min [40]

To assess the potential cumulative exposure to masticatory load, participants were also categorized according to habit chronicity. Those who had maintained the chewing habit for up to five years were considered to have a short-term habit, whereas those reporting more than five years of chewing history were categorized as long-term users.

2.6. Statistical Analysis

All statistical analyses were performed using the R statistical language (version 4.4.3; R Core Team, Vienna, Austria, 2023) on Windows 10 Pro 64-bit (build 19045). No additional R packages were used. Descriptive statistics were computed for all variables. For continuous data, results are presented as mean, standard deviation (SD), median, interquartile range (IQR), minimum, and maximum. For categorical variables, absolute and relative frequencies were reported.

To examine the association between gum-chewing behaviors and the presence of TMD, univariate logistic regression models were applied. The presence of any TMD—regardless of subtype—was treated as a binary outcome (TMD vs. no TMD). Overlapping diagnoses were included under the general "TMD" category. Each behavioral parameter—chewing frequency, duration, and chronicity—was analyzed independently. Results are expressed as odds ratios (ORs) with corresponding 95% confidence intervals (CIs) and *p*-values. A significance threshold of $\alpha = 0.05$ was adopted. Effect sizes were interpreted according to the thresholds: small (OR = 1.68), medium (OR = 3.47), and large (OR = 6.71), proposed by Chinn (2000) [41].

3. Results

A total of 66 participants met the inclusion criteria. They were aged between 19 and 30 years (mean 23.44 $\pm$ 1.72; median 23, IQR: 23–24), and the majority were female (n = 41; 62.1%). Characteristics of the study group are presented in Table 1.

TMD was diagnosed in 55 participants (83.3%) using the DC/TMD protocol. Muscle-related disorders were found in 9 participants (13.6%), joint-related in 14 (22.7%), and combined muscle-joint disorders in 32 (47.0%). Eleven individuals (16.7%) were classified as TMD-free.

A descriptive comparison by gender revealed a slightly higher prevalence of TMD among female participants (35 out of 41; 85.4%) compared with males (20 out of 25; 80.0%). Combined disorders were the most common diagnosis in both groups (48.8% in females, 48.0% in males). Muscle-related disorders such as myalgia were more frequent among females (n = 7) than males (n = 2), while joint-related TMD occurred with comparable

frequency (8 vs. 6 cases, respectively). The distribution of TMD subtypes by gender is summarized in Table 2.

Table 1. Characteristics of the study group.

Variable		Value
Total number of participants		66
Age [years]	Range	19–30
	Median (IQR)	23 (23–24)
	Mean (SD)	23.44 (1.73)
Sex	Female	41 (62.12%)
	Male	25 (37.88%)

Table 2. Distribution of TMD subtypes by gender.

Gender	Participants (n)	TMD Overall (n, %)	Muscle-Related TMD (n)	Joint-Related TMD (n)	Combined TMD (n)
Female	41	35 (85.37%)	7	8	20
Male	25	20 (80.00%)	2	6	12
Total	66	55 (83.33%)	9	14	32

A more detailed breakdown of bilateral TMD diagnoses is presented in Tables 3 and 4, covering muscle and joint disorders, respectively.

Table 3. Detailed results of muscle-related TMD diagnostics (bilateral assessment).

TMD Subtype	Diagnosis	N
Muscle disorders	Myalgia	18
	Arthralgia	1
	Other muscle-related diagnosis	57
No muscle disorder		56

Table 4. Detailed results of joint-related TMD diagnostics (bilateral assessment).

TMD Subtype	Diagnosis	N
Joint disorders	Disc displacement with reduction	19
	Disc displacement without reduction with limited opening	1
	Disc displacement without reduction without limited opening	6
	Degenerative joint disease	1
	Other joint-related diagnosis	39
No joint disorder		66

Clinical examinations were performed bilaterally for each participant, resulting in a total of 132 assessed sides. Among muscle-related disorders, myalgia was the most frequently diagnosed condition (n = 18), followed by a single case of arthralgia. In the domain of joint-related disorders, disc displacement with reduction was the most common finding (n = 19), while disc displacement without reduction was diagnosed in seven participants—one with limited opening and six without. Degenerative joint disease was observed in one

case. The category "other diagnosis" refers to cases where clinical signs and symptoms of TMD were observed but the findings did not fulfill the formal diagnostic criteria for specific DC/TMD categories (e.g., due to insufficient criteria or atypical presentation). It is important to note that multiple diagnoses were often present simultaneously, and the total number of reported diagnoses exceeded the number of participants due to bilateral assessment and overlapping conditions.

Based on responses to the original questionnaire on gum-chewing habits, participants were divided into subgroups by chewing frequency, duration per session, and chronicity of the habit. Systematic gum use was reported by 29 individuals (43.9%), while 37 (56.1%) were classified as non-systematic chewers. Regarding chewing duration, 29 participants (43.9%) reported sessions lasting less than 10 min, 33 (50%) chewed for 10–30 min, and 4 (6.1%) reported sessions exceeding 30 min. Long-term gum chewing, defined as more than 5 years of habit persistence, was reported by 47 participants (71.2%). The detailed distribution of participants is presented in Table 5.

Table 5. Distribution of participants by gum-chewing frequency, chewing duration per session, and chronicity of chewing habit.

Variable	Group	Answer	Number of Participants		
Chewing frequency	Non-systematic	Less often	4	37	56.1%
		Once a month	10		
		Several times a month	7		
		Once a week	16		
	Systematic	Several times a week	15	29	43.9%
		Once a day	3		
		Several times a day	11		
Chewing duration	Short chewing	<10 min	30	30	45.5%
	Long chewing	10–30 min	32	36	54.5%
		>30 min	4		
Habit chronicity	Short-term	<1 year	6	19	28.8%
		1–3 years	6		
		3–5 years	7		
	Long-term	>5 years	47	47	71.2%

Univariate logistic regression analysis revealed no statistically significant associations between chewing frequency, chewing duration, or chronicity of the habit and the presence of TMD ($p > 0.05$ for all parameters). Odds ratios and 95% confidence intervals for each variable are presented in Table 6. All odds ratios were below 1.68, indicating small effect sizes according to Chinn [41].

Table 6. Univariate logistic regression results.

Variable	Group	N	TMD	OR	95% CI	*p*
Chewing frequency	Non-systematic	37	31	1 (ref.)	-	-
	Systematic	29	24	0.929	0.253–3.412	0.912

Table 6. *Cont.*

Variable	Group	N	TMD	OR	95% CI	*p*
Chewing duration	Short chewing	30	24	1 (ref.)	-	-
	Long chewing	36	31	1.550	0.422–5.693	0.509
Habit chronicity	Short-term	19	17	1 (ref.)	-	-
	Long-term	47	38	0.497	0.097–2.549	0.402

Note: No statistically significant associations were found (all $p > 0.05$).

4. Discussion

4.1. Main Findings

The aim of this study was to investigate whether excessive gum chewing is associated with an increased prevalence of TMD among young adults. Although 83.3% of participants were diagnosed with TMD, univariate logistic regression analysis revealed no statistically significant associations between TMD diagnosis and any of the chewing-related variables—frequency, duration, or chronicity (all $p > 0.05$).

Moreover, based on the effect size thresholds proposed by Chinn (2000) [41], the observed odds ratios (ORs < 1.68) indicate only small effects, suggesting limited predictive value of these behaviors when considered in isolation. However, it is important to emphasize that the lack of statistical significance does not necessarily rule out a meaningful association. For example, the OR of 1.55 for prolonged gum chewing may indicate a subtle trend that did not reach significance, potentially due to the limited statistical power of the current sample.

4.2. High Prevalence of TMD

The prevalence of TMD in our study group (83.3%) was considerably higher than the global average of approximately 34% in the general population reported in a most recent meta-analysis [19]. However, the wide range of TMD prevalence reported in the literature—from 5% to 88%, depending on diagnostic criteria and population characteristics [42]—suggests that such a discrepancy is not unusual and requires careful interpretation.

Several factors likely contributed to the elevated rate observed in our study. First, the sample consisted exclusively of medical students aged 19–30, a demographic known to experience high levels of academic stress. Psychosocial stress has been repeatedly associated with muscular TMD symptoms, particularly myalgia. Academic pressure, irregular sleep, and performance-related anxiety may amplify parafunctional behaviors, such as clenching or gum chewing, which further increase susceptibility to TMD [43,44].

Second, sex-based differences may have influenced the results. Although no statistical analysis of sex-related differences was performed, descriptive data revealed a slightly higher TMD prevalence in females (85.4%) compared with males (80.0%). Previous studies have shown that women are more susceptible to TMD, often reporting greater pain intensity and poorer recovery outcomes [20,21]. This disparity may also be influenced by hormonal modulation of pain, as well as psychosocial and behavioral factors. The female predominance in our sample (62.1%) may therefore have slightly inflated the overall prevalence [45].

Third, individuals who suspected they had TMD and were interested in receiving a diagnosis may have been more likely to participate, further inflating the observed prevalence. Moreover, the DC/TMD protocol is characterized by high sensitivity and specificity, ensuring the reliable detection of TMD subtypes. However, its thoroughness may also partly explain the elevated number of positive diagnoses observed in our study [11,12]. All

of these factors should be taken into account when assessing the broader applicability of our findings.

4.3. Gum Chewing as a Modulating Factor

TMDs are acknowledged as conditions with multifaceted origins, involving a dynamic interaction between anatomical structures, behavioral patterns, and psychosocial influences [22]. In this multifactorial context, gum chewing may serve not as a primary cause but as a contributing factor—unlikely to provoke dysfunction in isolation, yet potentially relevant when combined with other risk modifiers such as elevated stress, bruxism, or occlusal discrepancies [28]. This interpretation is consistent with our findings, which showed no consistent dose–response association between gum use and TMD prevalence, despite widespread and prolonged chewing habits among participants. These observations suggest that, in otherwise healthy individuals, moderate chewing may be well tolerated or even advantageous, promoting masticatory muscle conditioning and neuromuscular resilience.

Nevertheless, the consequences of chewing appear to be shaped by its pattern and context. Chewing associated with meals tends to be symmetrical, deliberate, and temporally limited, whereas parafunctional activity—such as habitual or stress-induced gum use—can be prolonged, imbalanced, and unconscious, potentially resulting in repetitive strain to the masticatory apparatus. Such behaviors closely relate to bruxism, a common parafunctional activity involving repetitive clenching or grinding of the teeth, with a multifactorial etiology that includes psychological stress, anxiety, and adverse oral habits [46]. Recent meta-analyses estimate the global prevalence of sleep bruxism at 21% and awake bruxism at 23% [47].

Individuals with bruxism often exhibit increased thickness and activity of the masticatory muscles, which may result in pain, muscle fatigue, and overload of the temporomandibular joints [48]. A strong association has been established between bruxism and TMDs, with both conditions affecting the TMJ and masticatory muscles [49,50]. Shared contributing factors—particularly stress and parafunctional behaviors—may further reinforce this connection [23]. Neuroimaging studies have revealed that central nervous system mechanisms, including cortical and subcortical circuits, play a key role in the initiation and modulation of bruxism episodes [51]. In addition, ultrasonographic findings suggest that individuals affected by both bruxism and TMD often demonstrate significantly greater masticatory muscle hypertrophy compared with non-bruxers, underscoring the close interaction between bruxism and musculoskeletal adaptation [48].

Given this background, other common oral behaviors—such as chronic gum chewing—warrant closer investigation regarding their potential link to TMD development. Determining the threshold at which chewing behavior transitions from adaptive to maladaptive remains a key direction for future research. This nuanced view supports the integration of chewing behaviors into a broader biopsychosocial understanding of TMD pathogenesis, rather than evaluating them in isolation. This contextual interpretation may also help explain inconsistent findings in previous studies regarding the effects of habitual gum chewing.

Taken together, these insights indicate that, while gum chewing alone may not directly cause TMDs, its contribution as a parafunctional habit—particularly when combined with bruxism and psychosocial stressors—can amplify masticatory muscle load and joint strain, thereby increasing the risk of TMD development in susceptible individuals.

4.4. Study Limitations

This study has several limitations that should be considered when interpreting the findings. The limited sample size (N = 66) and the homogeneity of the population—consisting

solely of medical students from Krakow—limit the generalizability of the results to the wider population [45]. The narrow age range (19–30 years) and the high academic stress exposure may not be representative of other demographic groups. Additionally, the use of a convenience sampling approach may have introduced selection bias.

Chewing behaviors were assessed using a self-reported questionnaire. This introduces the potential for recall bias, especially in estimating frequency, duration, and chronicity of gum use. Another methodological limitation was the inability to conduct multivariate logistic regression due to the small number of TMD-free participants. Consequently, potential confounders such as sex, stress levels, and parafunctional intensity could not be statistically controlled. Finally, the cross-sectional design precludes causal inferences. Future longitudinal studies with larger and more heterogeneous populations are needed to evaluate whether excessive gum chewing contributes to the development or persistence of TMD symptoms over time.

5. Conclusions

The results of this study do not support a direct association between excessive gum chewing and the occurrence of TMDs in young adults. While TMD was highly prevalent in the study population, chewing-related behaviors alone did not appear to significantly influence its presence. However, given the cross-sectional design and limited statistical power, these findings should be interpreted with caution. They underscore the multifactorial nature of TMD and highlight the importance of considering broader behavioral and psychosocial factors. Further longitudinal and multi-center studies involving more diverse populations are needed to clarify the potential modulating role of gum chewing in the context of other risk factors such as stress, bruxism, and occlusal disturbances. Although definitive conclusions cannot be drawn, the present findings offer a meaningful contribution to the debate on gum chewing as a potential parafunctional behavior and underscore the complexity of TMD etiology.

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Article

Structural Features of the Temporomandibular Joint Evaluated by MRI and Their Association with Oral Function and Craniofacial Morphology in Female Patients with Malocclusion: A Cross-Sectional Study

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Abstract

Background/Objectives: Temporomandibular disorders (TMDs) are a group of musculoskeletal and neuromuscular conditions involving the temporomandibular joint (TMJ), masticatory muscles, and related anatomical structures. Although magnetic resonance imaging (MRI) is considered a noninvasive and highly informative imaging modality for assessing TMJ soft tissues, few studies have examined how TMJ structural features observed on MRI findings relate to oral function and craniofacial morphology in female patients with malocclusion. To investigate the associations among TMJ structural features, oral function, and craniofacial morphology in female patients with malocclusion, using MRI findings interpreted in conjunction with a preliminary assessment based on selected components of the DC/TMDs Axis I protocol. **Methods**: A total of 120 female patients (mean age: 27.3 ± 10.9 years) underwent clinical examination based on DC/TMDs Axis I and MRI-based structural characterization of the TMJ. Based on the structural features identified by MRI, patients were classified into four groups for comparison: osteoarthritis (OA), bilateral disk displacement (BDD), unilateral disk displacement (UDD), and a group with Osseous Change/Disk Displacement negative (OC/DD (−)). Occlusal contact area, occlusal force, masticatory efficiency, tongue pressure, and lip pressure were measured. Lateral cephalometric analysis assessed skeletal and dental patterns. **Results**: OA group exhibited significantly reduced occlusal contact area ($p < 0.0083$, $\eta^2 = 0.12$) and occlusal force ($p < 0.0083$, $\eta^2 = 0.14$) compared to the OC/DD (−) group. Cephalometric analysis revealed that both OA and BDD groups had significantly larger ANB angles (OA: 5.7°, BDD: 5.2°, OC/DD (−): 3.7°; $p < 0.0083$, $\eta^2 = 0.21$) and FMA angles (OA: 32.4°, BDD: 31.8°, OC/DD (−): 29.0°; $p < 0.0083$, $\eta^2 = 0.17$) compared to the OC/DD (−) group. No significant differences were observed in masticatory efficiency, tongue pressure, or lip pressure. **Conclusions**: TMJ structural abnormalities detected via MRI, especially osteoarthritis, are associated with diminished oral function and skeletal Class II and high-angle features in female patients with malocclusion. Although orthodontic treatment is not intended to manage TMDs, MRI-based structural characterization—when clinically appropriate—may aid in treatment planning by identifying underlying joint conditions.

Keywords: temporomandibular joint disorders; magnetic resonance imaging; DC/TMDs; female patients; occlusal function; craniofacial morphology; malocclusion; joint displacement; osteoarthritis

1. Introduction

Temporomandibular disorders (TMDs) are a group of musculoskeletal and neuromuscular conditions involving the temporomandibular joint (TMJ), masticatory muscles, and related anatomical structures. These conditions present with a range of clinical symptoms, including joint pain, joint sounds (e.g., clicking or crepitus), muscle tenderness, and restricted mandibular movement, which may significantly impair oral function and quality of life [1,2]. TMDs are widely recognized as multifactorial disorders involving structural, functional, psychological, hormonal, and behavioral components [3–6].

Epidemiological studies and meta-analyses report that TMDs affect approximately 10–15% of the general population, with a markedly higher prevalence in females and young adults [7]. Several biological and behavioral factors—including hormonal differences, psychological stress, and parafunctional behaviors—have been suggested as contributors to these demographic disparities [8]. For this reason, female participants are frequently prioritized in clinical studies of TMDs.

With respect to morphological characteristics, some observational studies have suggested a potential association between TMDs and specific craniofacial or occlusal features, such as skeletal Class II and III patterns, deep bite, and open bite [9–14]. However, recent systematic reviews have criticized earlier research for methodological limitations, including selection bias and insufficient control groups, and have emphasized that the causal relationship between malocclusion and TMDs remains inconclusive [15,16].

It is clinically intuitive that orofacial pain and joint dysfunction may contribute to reduced occlusal force and masticatory performance. Empirical studies have attempted to quantify these impairments using objective functional metrics, and their findings suggest that pain-related inhibition and altered muscle coordination may underlie decreased oral function in individuals with TMD [17–19]. However, due to heterogeneity in methodology and inconsistencies in outcome definitions across studies, these results should be interpreted with caution.

To account for the multifactorial nature of temporomandibular disorders (TMDs), the Diagnostic Criteria for Temporomandibular Disorders (DC/TMDs) was developed as a standardized system for both clinical and research purposes [20,21]. This framework consists of two complementary axes: Axis I focuses on physical diagnoses such as disk displacement, myofascial pain, and osteoarthritis, while Axis II assesses psychosocial factors, including pain-related disability and psychological distress. Despite its widespread adoption, the DC/TMDs protocol relies primarily on patient interviews and clinical examinations, which may have limitations in detecting specific structural conditions of the TMJ, especially in the absence of overt symptoms [22]. In this context, magnetic resonance imaging (MRI) may serve as a supplemental modality to characterize the structural features of the TMJ in research settings. However, it is not our intention to redefine asymptomatic individuals as patients based solely on imaging findings. Instead, we emphasize that MRI-based structural assessments should be interpreted independently of Axis I diagnoses and should not be equated with diagnostic categorization. Importantly, although the present study focuses on structural evaluation, recognition of Axis II factors remains essential in the comprehensive assessment of TMDs.

As a complementary tool, magnetic resonance imaging (MRI) is widely regarded as a noninvasive and informative modality for assessing both the soft and hard tissues of the TMJ, particularly the position and morphology of the articular disk, as well as joint effusion and osseous changes such as bone marrow edema and condylar deformation [23–26]. MRI-based three-dimensional assessment can provide detailed visualizations of TMJ structures, potentially enhancing our understanding of joint morphology and its variation among individuals with skeletal malocclusion. However, the presence of such findings does not necessarily indicate a pathological condition or a causal link to TMD symptoms, as similar structural variations have been observed in asymptomatic individuals [27,28]. Therefore, MRI-observed features should be interpreted cautiously and in conjunction with clinical findings, particularly to avoid misclassification or overtreatment.

Despite advances in diagnostic imaging, few studies have explored how structural features of the temporomandibular joint (TMJ) observed via MRI—when interpreted alongside a preliminary assessment based on selected components of the DC/TMD Axis I protocol—relate to craniofacial morphology in patients with malocclusion [27,28]. Moreover, to our knowledge, no previous study has simultaneously evaluated both craniofacial morphology and oral function in this population within a standardized clinical and imaging-based framework. Given the higher prevalence of TMDs among females [7], and in order to reduce sample heterogeneity, the present study focuses exclusively on female patients. This design choice was intended to improve internal validity by examining the potential associations between TMJ structural variation and the functional or morphological characteristics within the subgroup most commonly affected by TMDs. However, we fully recognize the importance of including male patients in future studies to assess sex-related differences in TMJ structure and function.

Therefore, the purpose of this cross-sectional study is to investigate the relationships among MRI-based structural features of the temporomandibular joint (TMJ), oral function, and craniofacial morphology in female patients with malocclusion. Structural conditions of the TMJ were assessed using magnetic resonance imaging (MRI), with imaging findings interpreted in parallel with a preliminary clinical screening based on selected components of the DC/TMDs Axis I protocol. This study specifically aims to compare oral function and craniofacial morphology across TMJ condition groups classified by DC/TMDs and supported by MRI, and to explore the potential associations between morphological and functional variables. By integrating MRI-based structural characterization, objective evaluations of oral function, and cephalometric analysis, we sought to obtain a comprehensive understanding of the structural and functional features that may accompany TMJ variation in this population. We hypothesized that patients with MRI-detected TMJ structural alterations would exhibit diminished oral function and distinct craniofacial morphology compared to those without such findings.

2. Materials and Methods

2.1. Subjects, Eligibility Criteria, and Group Setting

This observational study was conducted in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines [29]. Among 508 female patients aged 14 years or older who visited the Department of Orthodontics, Tsurumi University Dental Hospital, from August 2019 to April 2023, 120 female patients (mean age: 27.3 $\pm$ 10.9 years) who met the inclusion criteria and agreed to undergo MRI were included. The patient selection flow is shown in Figure 1.

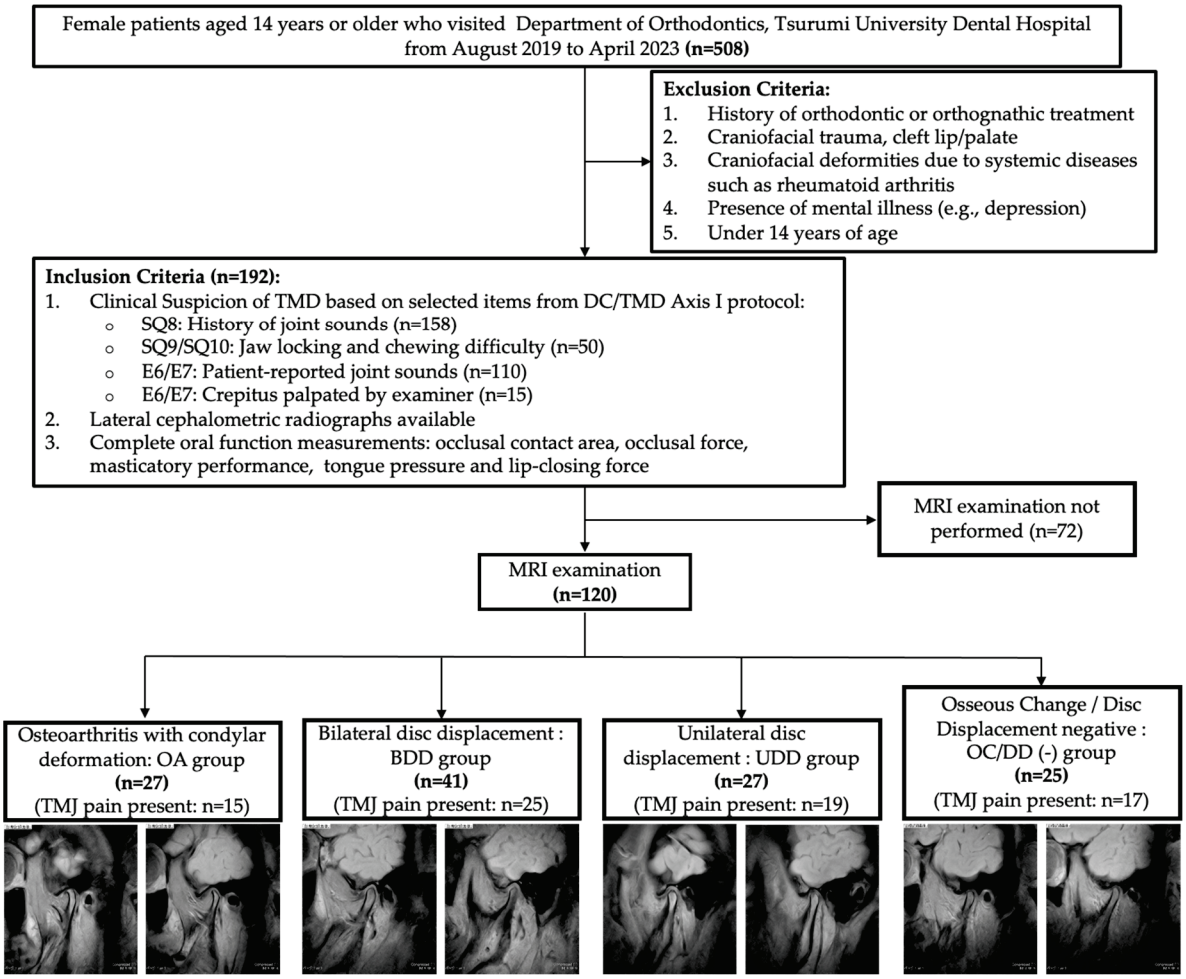

Figure 1. Flowchart illustrating subject recruitment and representative MRI images depicting typical structural features for each group.

Inclusion Criteria:

(1) Clinical suspicion of TMD based on selected items from the English version of the DC/TMDs Axis I protocol [20]. Specifically, patients were considered "suspected TMD" cases if they responded affirmatively to one or more of the following items:
   - SQ8: History of temporomandibular joint (TMJ) sounds (e.g., clicking).
   - SQ9 and/or SQ10: Episodes of jaw locking or difficulty in chewing.
   - E6 and/or E7: Patient-reported TMJ sounds and/or crepitus palpated by the examiner during mandibular movement.

This limited clinical screening was used as a preliminary assessment to identify candidates for MRI referral.

(2) Availability of lateral cephalometric radiographs.
(3) Complete oral function measurements: occlusal contact area, occlusal force, masticatory performance, tongue pressure, lip-closing force.

Exclusion Criteria:

(1) History of orthodontic or orthognathic treatment.
(2) Craniofacial trauma, cleft lip/palate.
(3) Craniofacial deformities due to systemic diseases such as rheumatoid arthritis.
(4) Presence of mental illness (e.g., depression).
(5) Age under 14 years.

Group classification (based on MRI findings):

OA group: Osteoarthritis with condylar deformation group.
BDD group: Bilateral disk displacement group.
UDD group: Unilateral disk displacement group.
OC/DD (−) group: Osseous Change/Disc Displacement negative group.

2.2. MRI Examination and Diagnosis

MRI scans were obtained as a supplemental imaging method, used when clinically indicated, and to confirm the diagnosis obtained with the DC/TMD, using a 0.4T open MRI system (APERTO Inspire, Fujifilm Medical, Tokyo, Japan) with a 10.0 cm TMJ surface coil. The MRI protocol for the temporomandibular joint included the following four sequences: (1) sagittal view at the intercuspal position (T2-star) with scanning parameters of repetition time (TR) = 400 ms, echo time (TE) = 14 ms, flip angle = 45°, bandwidth = 8.0 kHz, matrix size = 256 × 192, field of view (FOV) = 120 mm, slice thickness = 4 mm, number of slices = 9 (per side) and scan duration = 5 m 9 s (per side); (2) coronal view at the intercuspal position (T2-star) with TR = 400 ms, TE = 14 ms, flip angle = 45, bandwidth = 10.0 kHz, matrix size = 256 × 192, field of view (FOV) = 120 mm, slice thickness = 4 mm, number of slices = 9 (per side) and scan duration = 5 m 23 s (left and right, respectively); (3) sagittal T2 image with TR = 4400 ms, TE = 100 ms, flip angle = 90°, bandwidth = 12.5 kHz, matrix size = 192 × 192, FOV = 120 mm, slice thickness = 5 mm, number of slices = 6 (per side) and scan duration = 3 m 36 s (per side); and (4) sagittal view at the open-mouth position (T1) with TR = 1100 ms, TE = 30 ms, flip angle = 90°, bandwidth = 36.5 kHz, matrix size = 256 × 192, FOV = 120 mm, slice thickness = 5 mm, number of slices = 12 (in total) and scan duration = 3 m 33 s. All sequences were obtained with a field of view (FOV) of 120 mm, which ensured complete coverage of the temporomandibular joint region bilaterally. During MRI acquisition, patients were positioned in the supine position. For the closed-mouth position, patients were instructed to maintain their natural occlusion. For the open-mouth position, a bite block was used to support the mandible and maintain a stable open position during scanning.

These images were acquired by a certified radiologic technologist at the Department of Diagnostic Imaging (chief technologist: A.M), Tsurumi University Dental Hospital, and were interpreted to characterize disk position and condylar shape by a board-certified oral radiologist at the Department of Oral and Maxillofacial Radiology and Diagnosis (chief professor: C.I), Tsurumi University School of Dental Medicine, in accordance with established previously described MRI-based structural criteria [30–34]. Although the MRI examinations in this study were performed using a 0.4T open MRI system, this protocol has been used in previous clinical TMJ studies conducted at our institution and has shown acceptable diagnostic reliability for identifying disk displacement and osseous changes in the TMJ [34].

2.3. Evaluation of Oral Function

Evaluation methods of oral function have been described elsewhere [35]. Five parameters were assessed: occlusal contact area, maximum occlusal force, masticatory performance, tongue pressure, and lip pressure. Each was measured three times by trained examiners, and the average was used for analysis.

2.3.1. Occlusal Contact Area and Occlusal Force

Occlusal contact area and occlusal force were assessed using Dental Prescale II (GC Corporation, Tokyo, Japan) [36]. Subjects practiced biting on a training film inserted intraorally for 3 s with their molars. Subsequently, the actual measurement was conducted using the

Prescale film. A specialized scanner was used to analyze the film and calculate the contact area and maximum occlusal force.

2.3.2. Masticatory Performance

Masticatory efficiency was assessed using color-changeable chewing gum (Chew Check Gum, Oral Care Inc., Tokyo, Japan) [37]. After rinsing for 15 s, subjects chewed the gum for 60 cycles and then flattened it into a circular shape. The color change of the gum was used as an indicator of masticatory efficiency and measured using a colorimeter (CR-20, Konica Minolta Inc., Tokyo, Japan). Measurements were performed three times each in the order of free chewing, right-side chewing, and left-side chewing, with 3 min rest periods between each chewing trial. The mean value of free chewing was used for analysis.

2.3.3. Tongue Pressure

Tongue pressure was evaluated using the JMS tongue-pressure measuring device (JMS Co. Ltd., Hiroshima, Japan) [38]. Subjects were instructed to press their tongue firmly against the palate for 7 s with the probe placed on the tongue. After one practice attempt, three measurements were taken, and the average was recorded as tongue pressure.

2.3.4. Lip Pressure

Lip pressure was measured using the Ripple-Kun device (Shofu Inc., Tokyo, Japan) [39]. Subjects were instructed to insert the button into the oral vestibule and close their lips. The button was then pulled horizontally, and the force at which it exited the oral vestibule was measured. Following one practice trial, three measurements were taken, and the average was calculated as lip pressure.

2.3.5. Reliability

Calibration was performed before use, and tests were conducted by trained examiners. Intra-class correlation coefficients (ICC) were 0.73 for masticatory performance, 0.95 for occlusal force, 0.86 for contact area, 0.83 for lip pressure, and 0.96 for tongue pressure [35].

2.4. Evaluation of Craniofacial Morphology

Lateral cephalograms were taken with ear rods using a CX-150ST 8000C device (ASAHIROENTGEN IND. Co., Ltd., Kyoto, Japan). Settings: 150 kV; 250 mA; 0.32 s; FFD: 1650 mm. Tracings were digitized and analyzed using WinCeph ver.11.0 (Rise Co., Ltd., Miyagi, Japan). The anatomical landmarks, points, and angles used as endpoints in this study are shown in Table 1 and Figure 2. Linear measurements of overjet (OJ) and overbite (OB) were performed using dental models and calipers. The following 13 items are measured:

Antero-posterior skeletal patterns: ① SNA, ② SNB, ③ ANB, ④ Facial angle.

Vertical skeletal patterns: ⑤ FMA, ⑥ Y-axis, ⑦ Gonial angle.

Dental pattern: ⑧ FMIA, ⑨ IMPA, ⑩ U1 to SN, ⑪ Occlusal plane to FH, ⑫ Overjet, ⑬ Overbite.

All measurements were performed by a single orthodontist at Department of Orthodontics, Tsurumi University School of Dental Medicine (M.K). Intra-class correlation coefficients (ICCs) were confirmed by tracing data from 10 subjects twice with a 2-week interval, and ICC > 0.95 was confirmed. Measurement methods and reliability assessment followed the method of Xiong et al. (2020) [40].

Table 1. Anatomical landmarks, points, and angles.

Landmarks and Points	
S (sella)	Center of sella turcica
N (nasion)	The most anterior point of the frontonasal suture
Or (orbitale)	The lowest point on the average left and right inferior borders of the bony orbit
Po (porion)	The highest point on the superior surface of the soft tissue of the external auditory meatus
A-Point	The most posterior point on the anterior contour of the upper alveolar process
B-Point	The most posterior point on the anterior contour of the lower alveolar process
Me (menton)	The lowest point on the mandibular symphysis
Pog (Pogonion)	The most anterior point of the midline cross-sectional image of the mandibular miter
Gn (gnathion)	The midpoint of the nasolabial groove
Ar (articulare)	The intersection of the posterior margin of the mandibular branch and subnasal margin of the occipital bone
U1	The tip of the maxillary central incisor
L1	The tip of the mandibular central incisor
Mo	The central point of the cuspid fit of the upper and lower first molars
Angles	
① SNA (°)	The angle between the SN plane and NA line
② SNB (°)	The angle between the SN plane and NB line
③ ANB (°)	The angle formed by point A, nasion, and point B
④ Facial angle (°)	The angle between the Frankfurt (FH; Or-Po) plane and N-Pog plane
⑤ FMA (°)	The angle the between Mandibular inferior margin plane (Mp) and the FH plane
⑥ Y-axis (°)	The angle between the Frankfurt (FH; Or-Po) plane and S-Gn plane
⑦ Gonial angle (°)	The angle the between Mandibular inferior margin plane (Mp) and the ramus plane
⑧ FMIA (°)	The angle between the Frankfurt (FH; Or-Po) plane and the long axis of the L1
⑨ IMPA (°)	The angle between the long axis of the L1 and the Mandibular inferior margin plane (Mp)
⑩ U1 to SN (°)	The angle between the long axis of the U1 and the SN plane
⑪ Occlusal plane to FH (°)	The angle between the line connecting Mo and midpoints of U1 and L1 and the FH plane

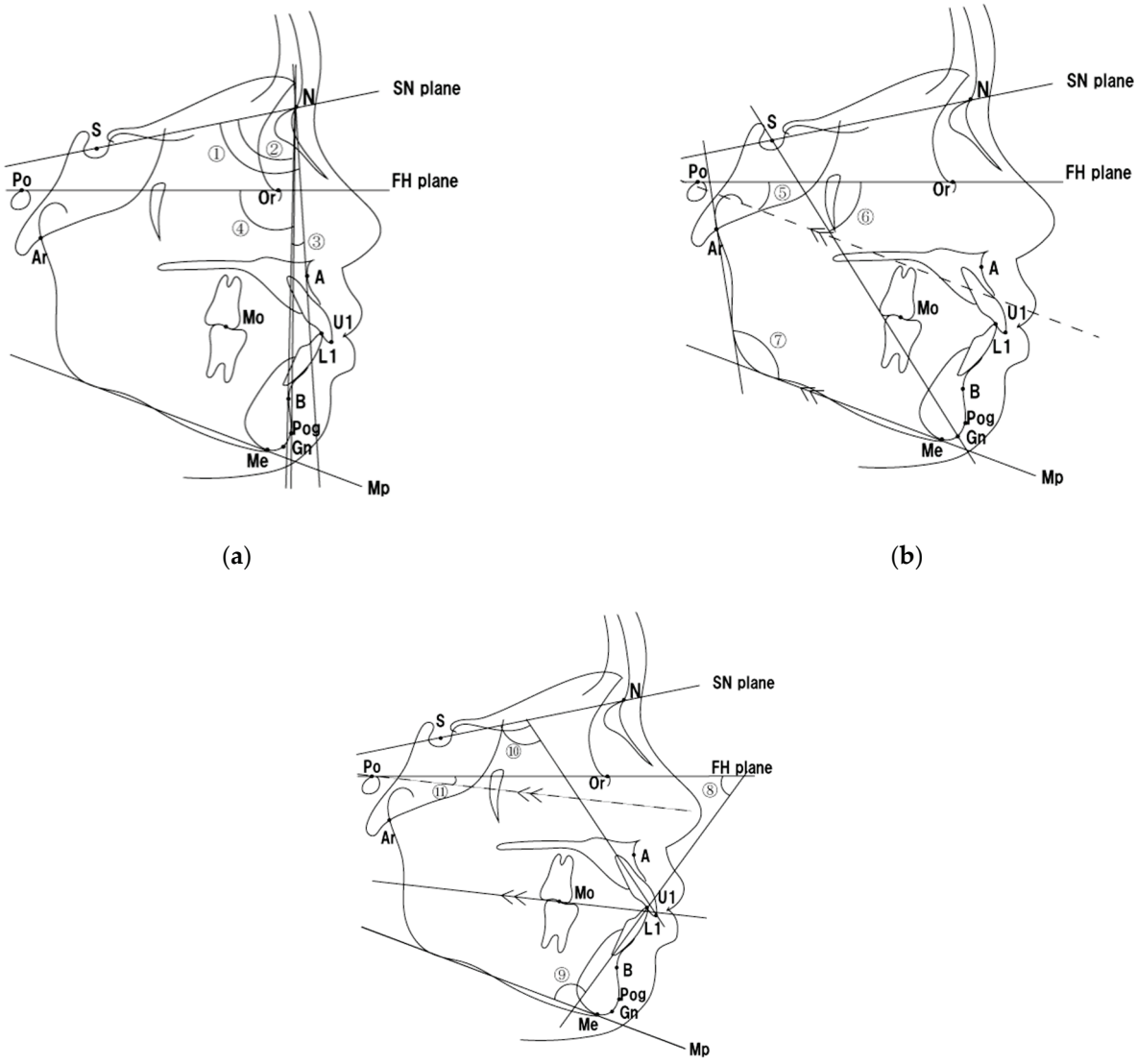

Figure 2. Anatomical landmarks, points, and angles: (**a**) antero-posterior skeletal pattern; (**b**) vertical skeletal pattern; (**c**) dental pattern.

2.5. Sample Size Calculation

Sample size estimation was performed using G*Power (version 3.1.9.7) for one-way ANOVA with four independent groups. Based on effect size benchmarks specific to temporomandibular joint (TMJ) research, as proposed by Zieliński and Gawda (2025) [41], a large effect size was anticipated. According to their study, comparisons involving joint structural differences and masticatory function typically yield large effect sizes (Hedges' $g \approx 0.70$), which corresponds to Cohen's $f \approx 0.40$. Assuming an alpha level of 0.05, power of 0.90, and effect size $f = 0.40$, the required sample size was calculated to be 96. To account for potential data exclusions, a total of 120 participants were enrolled. This sample size is considered sufficient to detect clinically meaningful differences among the groups.

2.6. Statistical Analysis

Normality was confirmed using the Kolmogorov–Smirnov test, Shapiro–Wilk test, and histogram inspection (Table S1 and Figure S1). As the data were assumed to be normally distributed, one-way ANOVA was used to compare variables among the four groups. To control for type I error due to multiple comparisons, Bonferroni correction was applied

in the post hoc analysis [42]. Accordingly, the threshold for statistical significance was adjusted to $p < 0.0083$ (0.05/6), based on six pairwise group comparisons (OA vs. BDD, OA vs. UDD, OA vs. OC/DD (−), BDD vs. UDD, BDD vs. OC/DD (−), UDD vs. OC/DD (−)). For each ANOVA, effect sizes were calculated using Eta squared (η^2). Effect sizes were interpreted as follows: $\eta^2 = 0.01$ (small), $\eta^2 = 0.06$ (medium), and $\eta^2 = 0.14$ (large). While some comparisons reached statistical significance, those with small effect sizes ($\eta^2 < 0.06$) were not considered clinically meaningful in accordance with established interpretation criteria [43]. All analysis were performed using SPSS Statistics ver27.0 (IBM, Tokyo, Japan).

3. Results

3.1. Demographic and Clinical Characteristics

Figure 1 shows the number of subjects in each group: 27 subjects in the OA group, 41 subjects in the BDD group, 27 subjects in the UDD group, and 25 subjects in the OC/DD (−) group, along with representative MRI images illustrating the structural characteristics typically observed in each group. No significant differences in age were found among the four groups (Table 2).

Table 2. Median age and prevalence of TMJ pain across groups classified by MRI-observed structural features.

Group	Age	TMJ Pain Present (n)	TMJ Pain Absent (n)	Total (n)	Pain Prevalence (%)
OA	24 (17.5–30.5)	15	12	27	55.6
BDD	25 (18–32)	25	16	41	61
UDD	22 (14.5–29.5)	19	8	27	70.4
OC/DD (−)	22 (17–27)	17	8	25	68

Age is presented as median and interquartile range (IQR) due to non-normal distribution. Differences in age were primarily analyzed using the Kruskal–Wallis test (non-parametric). For robustness, a confirmatory ANOVA (parametric) was also performed, which yielded consistent results. TMJ pain prevalence was compared using the chi-square test. Kruskal–Wallis test p-value = 0.814; ANOVA test p-value = 0.81; Chi-square test p-value = 0.66.

3.2. TMJ Pain Prevalence

Table 2 shows the prevalence of TMJ pain in each group. No significant differences were observed in the prevalence of pain among the four groups ($p > 0.05$). Notably, a high proportion of TMJ pain was also reported in the OC/DD (−) group (68%), suggesting that TMJ pain may not always be associated with identifiable structural characteristics in MRI.

3.3. Comparison of Oral Function

Table 3 shows the results of intergroup comparisons of oral function. Occlusal contact area was significantly lower in OA (10.36 ± 4.39 mm^2) compared to OC/DD (−) (18.63 ± 10.6 mm^2) group ($p < 0.0083$). Additionally, maximum occlusal force was significantly lower in the OA (429.1 ± 151.77 N) compared to the OC/DD (−) (708.52 ± 368.55 N) group ($p < 0.0083$). No significant differences were observed among groups for masticatory performance, tongue pressure, or lip pressure.

Table 3. Comparison of oral function across four groups.

Parameter	OA (n = 27)	BDD (n = 41)	UDD (n = 27)	OC/DD (−) (n = 25)	*p*-Value	η^2	OA vs. BDD	OA vs. UDD	OA vs. OC/DD (−)	BDD vs. UDD	BDD vs. OC/DD (−)	UDD vs. OC/DD (−)
Occlusal Contact Area (mm^2)	10.36 ± 4.39	13.11 ± 5.97	15.49 ± 6.59	18.63 ± 10.6	<0.001	0.12	n.s.	n.s.	*	n.s.	n.s.	n.s.
Maximum Occlusal Force (N)	429.1 ± 151.77	536.05 ± 235.96	602.3 ± 239.12	708.52 ± 368.55	0.002	0.14	n.s.	n.s.	*	n.s.	n.s.	n.s.
Masticatory Efficiency (ΔE)	41.7 ± 5.43	41.18 ± 6.06	37.89 ± 8.6	41.30 ± 6.51	0.142	0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Tongue Pressure (kPa)	29.77 ± 9.28	28.99 ± 6.81	27.49 ± 10.26	33.39 ± 10.9	0.134	0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Lip-closing Force (N)	11.85 ± 6.43	10.48 ± 3.67	10.03 ± 2.66	11.17 ± 3.73	0.425	0.02	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Data are presented as mean ± standard deviation. Statistical comparisons were performed using one-way ANOVA and Bonferroni's post hoc tests. Statistical significance: $p < 0.0083$ (0.05/6) (*); n.s., not significant.

3.4. Comparison of Craniofacial Morphology

3.4.1. Antero-Posterior and Vertical Skeletal Patterns

Table 4 shows the results of cephalometric analysis across four groups. The OA and BDD groups had significantly larger ANB angles (OA: 4.43 ± 2.85°, BDD: 3.27 ± 3.73°, OC/DD (−): 0.31 ± 2.83°) and significantly smaller SNB angles (OA: 76.73 ± 4.7°, BDD: 77.41 ± 5.05°, OC/DD (−): 81.67 ± 3.93°), suggesting a skeletal Class II tendency ($p < 0.0083$). FMA angles were significantly larger in the OA and BDD groups (OA: 34.81 ± 7.44°, BDD: 32.79 ± 8.0°, OC/DD (−): 25.71 ± 7.31°), suggesting a high-angle tendency ($p < 0.0083$). Other parameters, such as Facial angle and Y-axis, also tended to indicate a skeletal Class II tendency in the OA group.

Table 4. Comparison of cephalometric measurements across four groups.

Parameter	OA (n = 27)	BDD (n = 41)	UDD (n = 27)	OC/DD (−) (n = 25)	*p*-Value	η^2	OA vs. BDD	OA vs. UDD	OA vs. OC/DD (−)	BDD vs. UDD	BDD vs. OC/DD (−)	UDD vs. OC/DD (−)
① SNA (°)	81.16 ± 3.68	80.67 ± 2.79	81.53 ± 3.87	81.34 ± 2.86	0.726	0.01	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
② SNB (°)	76.73 ± 4.7	77.41 ± 5.05	80.16 ± 4.88	81.67 ± 3.93	<0.001	0.15	n.s.	n.s.	*	n.s.	*	n.s.
③ ANB (°)	4.43 ± 2.85	3.27 ± 3.73	1.37 ± 3.64	0.31 ± 2.83	<0.001	0.21	n.s.	*	*	n.s.	*	n.s.
④ Facial angle (°)	83.2 ± 4.73	85.07 ± 4.88	87.83 ± 4.2	88.57 ± 3.6	<0.001	0.18	n.s.	*	*	n.s.	n.s.	n.s.
⑤ FMA (°)	34.81 ± 7.44	32.79 ± 8.0	30.41 ± 5.07	25.71 ± 7.31	<0.001	0.17	n.s.	n.s.	*	n.s.	*	n.s.
⑥ Y-axis (°)	67.47 ± 4.95	66.10 ± 5.35	63.92 ± 4.48	62.87 ± 4.41	0.003	0.11	n.s.	n.s.	*	n.s.	n.s.	n.s.
⑦ Gonial angle (°)	124.77 ± 6.81	126.27 ± 6.47	126.29 ± 6.27	122.11 ± 8.83	0.098	0.05	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
⑧ FMIA (°)	53.19 ± 11.21	56.6 ± 11.86	61.71 ± 10	62.52 ± 10.32	0.007	0.1	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
⑨ IMPA (°)	92.01 ± 9.36	90.61 ± 8.39	87.89 ± 9.39	91.76 ± 10.65	0.357	0.03	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
⑩ U1 to SN (°)	104.56 ± 6.39	108.84 ± 7.85	108.54 ± 8.42	113.06 ± 9.25	0.003	0.11	n.s.	n.s.	*	n.s.	n.s.	n.s.
⑪ Occlusal plane to FH (°)	20.06 ± 4.91	18.43 ± 4.96	17.24 ± 4.77	14.78 ± 4.61	<0.001	0.13	n.s.	n.s.	*	n.s.	n.s.	n.s.

Table 4. *Cont.*

Parameter	OA (n = 27)	BDD (n = 41)	UDD (n = 27)	OC/DD (−) (n = 25)	*p*-Value	η^2	OA vs. BDD	OA vs. UDD	OA vs. OC/DD (−)	BDD vs. UDD	BDD vs. OC/DD (−)	UDD vs. OC/DD (−)
⑫ Overjet (mm)	5.04 ± 2.77	5.22 ± 4.15	2.48 ± 3.37	1.88 ± 3.52	<0.001	0.15	n.s.	n.s.	n.s.	n.s.	*	n.s.
⑬ Overbite (mm)	0.17 ± 3.05	1.55 ± 3.15	1.15 ± 3.31	1.07 ± 2.39	0.33	0.03	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Data are presented as mean ± standard deviation. Statistical comparisons were performed using one-way ANOVA and Bonferroni's post hoc tests. Statistical significance: $p < 0.0083$ (0.05/6) (*); n.s., not significant.

3.4.2. Comparison of Dental Morphology

As shown in Table 4, the OA group showed significantly smaller U1 to SN angles compared to the OC/DD (−) group (OA: 104.56 ± 6.39°, OC/DD (−): 113.06 ± 9.25°) and significantly larger Occlusal plane to FH angles compared to the OC/DD (−) group (OA: 20.06 ± 4.91°, OC/DD (−): 14.78 ± 4.61°) ($p < 0.0083$). The BDD groups showed significantly larger Overjet compared to the OC/DD (−) group (BDD: 5.22 ± 4.15 mm, OC/DD (−): 1.88 ± 3.52 mm) ($p < 0.0083$).

4. Discussion

This cross-sectional study examines the relationship between temporomandibular joint (TMJ) structural features observed via MRI and oral function and craniofacial morphology in female patients with malocclusion. Patients were categorized into four groups based on MRI-identified structural conditions, interpreted in conjunction with DC/TMD-based clinical screening. Our findings indicate that patients with osteoarthritis (OA)-like structural changes exhibit significantly reduced occlusal contact area and occlusal force compared to those without observable structural abnormalities (OC/DD (−) group). These results suggest that TMJ structural abnormalities, particularly condylar deformities, may be associated with diminished occlusal support function.

This observation is in line with prior studies. For example, Bavia et al. reported associations between facial morphology and occlusal force in patients with TMD [44]. The current findings extend this knowledge by linking MRI-based joint features to functional and morphological outcomes. Interestingly, patients with unilateral disk displacement (UDD group) did not show significant reductions in oral function, aligning with reports by Sato et al., who found no marked decrease in occlusal force or masticatory performance in cases of unilateral joint abnormalities [45]. This emphasizes the potential functional impact of bilateral TMJ involvement. In our study, MRI served as a supplementary imaging modality and was not employed as a standalone diagnostic tool. Interpretation of the findings was guided by previously validated imaging protocols [23–28]. While TMJ pain was assessed, we did not evaluate pain intensity or disability using validated Axis II instruments. Furthermore, variables such as masseter muscle thickness, which may influence occlusal function, were not assessed. These limitations should be addressed in future investigations.

Notably, no significant differences were found among the groups in terms of masticatory efficiency, tongue pressure, or lip pressure. The chewing efficiency test used in this study, which relies on the color change in chewing gum, mainly evaluates mixing ability rather than crushing performance. Previous research by Sasaki et al., Lepley et al., and Mizokami et al. suggested that mixing ability and crushing ability represent distinct muscle activities [35,46,47]. Tomonari et al. also reported that muscle activity varies according to the hardness of the test food [48]. These insights imply that the soft chewing gum used in this study may not detect subtle functional differences. Furthermore, Schimmel et al. found no clear correlation between occlusal force and masticatory efficiency [49],

supporting our results. Moreover, Sasaki et al. reported significant correlations between masticatory performance and both tongue and lip pressure [35], indicating that soft tissue functions significantly influence mixing ability. While the color-changeable chewing gum test provides an accessible method for assessing mixing ability, its correlation with occlusal force is limited. Solid food-based tests (e.g., carrots or almonds) may provide more accurate evaluations of masticatory efficiency, particularly with respect to crushing ability.

Tongue and lip pressure are produced by the tongue and orbicularis muscle, respectively, and differ from occlusal support muscle activity. Additionally, these tests measure static maximal strength, not dynamic aspects such as endurance or coordination during mastication and swallowing. Hence, further studies using electromyography (EMG) and foods with different textures may provide more comprehensive assessments of specific oral motor functions relevant to mastication.

Cephalometric analysis revealed that the OA and BDD groups exhibited features suggestive of skeletal Class II and high-angle morphology, including significantly larger ANB and FMA angles and smaller SNB angles, compared to the OC/DD (−) group. The OA group also showed dental compensations, such as lingual inclination of the maxillary incisors, as indicated by a significantly smaller U1 to SN angle than both the OC/DD (−) group and previously reported Japanese female norms (approximately 107.8°) [50]. While these findings suggest structural variation in mandibular position and vertical dimension, the cross-sectional design limits causal inferences. Although no control group without malocclusion was included, reference values from Japanese females with Class I malocclusion (e.g., ANB ~ 3.3°) indicate that the mean ANB value in the OA group (4.43°) reflects a Class II tendency beyond typical malocclusion norms [50]. Previous observational studies have reported similar associations between TMJ symptoms and craniofacial morphology [19,51–54], although the directionality and clinical implications remain uncertain. These findings may support the hypothesis that underlying craniofacial patterns and TMJ structural findings often coexist in malocclusion cases, rather than indicating a direct causal relationship.

In terms of joint pain, there were no significant differences in prevalence among the four groups. This may reflect limitations in the DC/TMD Axis I assessment of pain, which focuses on pain history within the past 30 days and provoked responses [20], without capturing the broader psychosocial context of pain. In contrast, validated pain intensity and disability instruments, such as the Visual Analog Scale (VAS), Numerical Rating Scale (NRS), Jaw Functional Limitation Scale (JFLS), and Quantitative Sensory Testing (QST), offer more nuanced assessments of pain experience and functional impact [55–58]. The absence of such Axis II-oriented measures in this study limits our interpretation of the pain-related findings. Notably, the relatively high prevalence of TMJ pain in the OC/DD (−) group underscores that joint pain may occur in the absence of structural abnormalities, and could reflect psychosocial or neuromuscular contributors. Future studies should incorporate comprehensive Axis II assessments to clarify the multifactorial nature of TMJ pain and its interaction with structural and functional parameters. Furthermore, experimental studies have shown that induced orofacial pain does not always reduce occlusal force or masticatory efficiency, supporting the need for a multidimensional framework in interpreting these relationships [59–61].

While our findings suggest that certain TMJ structural features, particularly osteoarthritic changes and bilateral disk displacement, may be associated with reduced occlusal function and high-angle skeletal morphology in female patients with malocclusion, these observations should not be interpreted as evidence of causality or diagnostic necessity. MRI can serve as a supplemental tool in complex cases, but its role in routine orthodontic

treatment planning remains limited and must be considered alongside clinical symptoms and psychosocial factors.

However, some limitations should be noted. As a cross-sectional study, causal relationships cannot be inferred. The sample consisted only of females and included only patients suspected of TMD, which may introduce selection bias. Furthermore, we did not include a control group of individuals without malocclusion, which limits our ability to determine whether the observed TMJ findings are exclusive to malocclusion. Importantly, this study focuses only on MRI-detectable TMJ structural features and does not incorporate assessments of myofascial or psychosocial contributors to TMD. Interestingly, a high pain prevalence was observed even in the OC/DD (−) group (68%), which lacked apparent structural abnormalities. This underscores that TMJ pain can arise in the absence of structural changes, likely due to multifactorial influences including psychosocial stress, central sensitization, or muscle-related dysfunction. As this study did not assess Axis II (psychosocial) components, potential confounding factors could not be evaluated. Future studies should incorporate DC/TMDs Axis II assessments, longitudinal designs, and CBCT-based three-dimensional evaluations to clarify the contribution of psychosocial and non-structural factors to the multifactorial nature of TMDs.

A key limitation of this study is the use of a 0.4T open MRI system, which may have lower sensitivity compared to higher-field systems (e.g., 1.5T or 3T) for detecting subtle structural changes, particularly in early-stage TMDs. Although the imaging protocol was based on prior research conducted at our institution, caution is warranted in interpreting findings where fine detail may be diagnostically significant. Additionally, the slice thickness used in this study (4–5 mm) may have limited spatial resolution, potentially leading to the underdetection of small lesions or subtle TMJ abnormalities. This parameter was determined based on the technical capabilities of the 0.4T MRI system used, but we acknowledge that thinner slices would provide better anatomical detail. Moreover, 3D sequences were not employed, which may have limited diagnostic precision in detecting complex disk displacements. These imaging limitations may partially explain the challenges of detecting early-stage structural changes in Axis I diagnoses and underscore the need for multimodal assessment strategies.

Although Bonferroni correction was applied to control for multiple-group comparisons per variable, no global adjustment was conducted across the 13 cephalometric variables. As such, the possibility of inflated Type I error due to multiple-endpoint testing cannot be entirely excluded. Additionally, cephalometric parameters such as ANB showed statistically significant differences across groups, but the clinical significance of relatively small angular differences (e.g., 2–3°) should be interpreted with caution. These findings, while statistically significant, should not be taken as evidence for diagnostic categorization or treatment indication without further clinical validation. Future studies comparing against normative clinical thresholds may help clarify their relevance for treatment planning.

The method used for assessing masticatory efficiency, based on color-changeable chewing gum, has not been validated against gold-standard techniques such as sieving or spectrophotometry. Furthermore, the ICC value of 0.73 for this test indicates moderate reliability, which may have introduced variability in the measurements. Masticatory performance was evaluated using a color-changeable chewing gum, which may not reflect crushing ability or masticatory performance for solid foods. Tongue-pressure and lip-closing force measurements in this study focused on static muscle strength and did not reflect dynamic functional tasks such as swallowing, speech, or continuous oral coordination. This may limit the interpretation of oral function in real-life conditions. The lack of differences in tongue and lip pressure among groups may be due to methodological constraints. Static measurements may not capture dynamic function, such as atypical swallowing. Sasaki

et al. (2023) reported correlations between tongue pressure and malocclusion [35], suggesting that further studies using dynamic tests or EMG are warranted. These functional assessments should be viewed as exploratory tools to characterize physiological trends, rather than as definitive clinical indicators.

5. Conclusions

The MRI-observed structural features of the temporomandibular joint (TMJ)—particularly condylar deformities and bilateral disk displacement—were associated with reduced occlusal function and a skeletal Class II high-angle pattern in female patients with malocclusion. These findings suggest that TMJ morphology may contribute to variations in oral function and craniofacial form. However, due to the multifactorial etiology of temporomandibular disorders, structural changes should be interpreted in conjunction with clinical findings and psychosocial assessments. MRI may serve as a supplemental tool in complex cases, but its routine use in orthodontic diagnostics warrants careful consideration. Further longitudinal multi-dimensional studies incorporating the DC/TMDs Axis II and 3D imaging are essential to elucidate the clinical significance of these structural findings and their implications for orthodontic treatment planning.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm14144921/s1, Table S1: Results of tests on normality of data, Figure S1: Histogram for each evaluation item, File S1: All the data analyzed in this study.

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Article

The Rainbow and the Umbrella of Temporomandibular Disorders—Total Antioxidant Capacity and Total Oxidant Status in Patients with Myofascial Pain with Referral

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Abstract: Background: Temporomandibular disorders (TMDs) represent an umbrella term encompassing various musculoskeletal dysfunctions, including those affecting the masticatory muscles. This study aimed to compare the salivary levels of non-enzymatic antioxidants and redox balance between patients with temporomandibular myofascial pain with referral and matched healthy controls. **Methods**: The sample consisted of 44 individuals diagnosed with temporomandibular myofascial pain with referral and a matched control group. The procedure included a clinical examination based on the Diagnostic Criteria for Temporomandibular Disorders and saliva collection. Biochemical analysis included the assessment of reduced glutathione (GSH) levels, total antioxidant status (TAC), total oxidant status (TOS), and the oxidative stress index (OSI). **Results**: Patients with temporomandibular myofascial pain with referral exhibited higher levels of total oxidant status and glutathione. The mean value of total antioxidant capacity was lower, although the median was higher compared to the control group. No statistically significant differences were observed in the oxidative stress index between the two groups. **Conclusions**: Patients with temporomandibular myofascial pain with referral exhibit oxidative imbalance, reflected by increased salivary levels of non-enzymatic antioxidants, elevated total oxidant status, and significant differences in antioxidant capacity compared to healthy controls. Individually tailored physical activity, proper nutrition, and targeted supplementation may be necessary to maintain oxidative-antioxidant balance in this patient population.

Keywords: antioxidants; myofascial pain with referral; oxidative stress; oxidative stress index; temporomandibular disorders; total antioxidant capacity; total oxidant status

1. Introduction

Temporomandibular disorders (TMDs) are an umbrella term concerning many musculoskeletal dysfunctions that involve the masticatory muscles, the temporomandibular

joint, and other associated structures [1]. In the whole group of disorders, it is possible to distinguish those of muscle or joint origin. The treatment usually requires an interdisciplinary approach from various medical specializations [1]. One of the most frequent temporomandibular myogenic dysfunctions is myofascial pain with referral [2,3].

Myofascial pain with referral is characterized by the pain experienced at the site of palpation and beyond the boundary of the palpated muscles [3]. The diagnosis criterion is familiar pain induction by provocation tests, including palpation, jaw function, and jaw movement [3]. Myofascial pain reflects overlapping autonomic, motoric, and sensory symptoms that interact with both the muscles and the surrounding connective tissue, which means fascia [4]. Myofascial pain is associated with the presence of a trigger point within a taut muscle band [4]. The presence of trigger points is associated with pain, muscle spasm, sensitivity, limited range of movement, weakness, and autonomic dysfunction [5]. According to the criteria for temporomandibular disorders, myofascial pain with referral is demonstrated by simultaneous pain within masticatory muscles and referred pain, and is modified by jaw movement, function, or parafunction [2]. According to Travel and Simons, there are major and minor criteria of myofascial pain [4,6]. The major criteria include regional pain symptoms, referred pain, palpable taut muscle band, limited movement, or gentle muscle weakness. The minor criteria concern pain and local twitching response during palpation of the trigger points, and pain relief through muscle therapy [4,6]. The referred pain is modulated by central sensitization and contributes to the complexity of the disease [4].

The pathophysiology of pain is not fully understood [7]. The literature emphasizes the role of nitrosative and oxidative stress, cation signaling, and the inflammatory response [7]. Oxidative stress demonstrates excessive production of reactive oxygen and nitrogen species (ROS and RNS) that counteract the physiological role of antioxidants. The resulting oxidative imbalance is involved in the pathophysiology of many pain-related conditions [7]. The source of oxidative stress in the masticatory system is mechanical stress associated with repeated jaw movement and overuse/misuse of the muscles [8]. Excessive reactive oxygen formation at the myofascial trigger point influences pain-related TRP (transient receptor potential) channels [4]. Only TRPV1-4, TRPA1, and TRPM8 link with pain [4]. TRPV channels are sensitive to capsaicin and vanilloids [9,10]. They maintain electrolyte homeostasis and play a crucial role in various pain stimuli such as heat, pH, and pressure [9,10]. In turn, TRPA1 is prone to external factors, including severe cold, mechanical influences, noxious compounds, reactive chemicals, and endogenous cellular damage [9]. TRPM8 is involved in the sensation of cold temperatures and pain signaling [9]. ROS fluctuations in sensory neurons affect pain intensity or hyperalgesia and neuronal plasticity by modulating the excitability of respective neurons [11]. There is some evidence that oxidative stress within the trigeminal nucleus is involved in orofacial pain in rats [11]. This is gaining importance due to the fact that the trigeminal sensory nuclei complex is associated with peripheral and central mechanisms, ascending and descending pain-related pathways, and neuromodulation [12].

The original purpose of the research was to compare the salivary content of selected non-enzymatic antioxidants and oxidative-reductive balance parameters between patients with temporomandibular disorders—myofascial pain with referral and matched healthy controls. It was hypothesized that in patients with myofascial pain with referral, concentrations of non-enzymatic antioxidants and total antioxidant capacity would be lower than in the control group. In connection with this, increased total oxidant status and oxidative stress index were expected in the group with myofascial pain with referral. Bearing in mind the modern design of TMDs management, it was supposed that dietary behavior, supplementation, lifestyle factors, and physical activity may be paramount in oxidative stress

modulation. It was also suggested that conscious regulation of glutathione levels based on personalized antioxidants supplementation with respect to the hormesis curve could be a novel strategy in OS management. Nevertheless, these processes may be suppressed by the antioxidant paradox.

2. Materials and Methods

2.1. Ethical Issues

The research was performed upon obtaining the consent of the Bioethics Committee of the Medical University of Bialystok, Poland (permission number: R-I-002/322/2016, date: 29 September 2016, study group sample collection; APK.002.175.2023, date: 30 March 2023, control group sample collection and biochemical determination; APK.002.248.2024, date: 18 April 2024, study group biochemical determination), in line with the tenets of the Declaration of Helsinki of the World Medical Association (WMA) and the Guidelines for Good Clinical Practice (GCP). The participation in the study was voluntary. All subjects received comprehensive information about the nature, scope, and course of clinical procedures. Each subject expressed written consent to participate in the research. At every phase of the study, the patients could decide to leave the experiment without any consequences.

2.2. Subjects and the Sample Size

The research was performed in the Department of Prosthodontics at the Medical University of Bialystok, Poland. The study group consisted of 44 patients (32 females, 12 males) with temporomandibular disorder—myofascial pain with referral. The subjects were diagnosed with respect to Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [13]. The average age was 23.6 $\pm$ 1.9 and ranged from 18 to 25 years. The age frame of the patients was determined by the fact that the aging process begins around the age of 30 [14], and that there exists a relationship between oxidative stress and aging [15].

Inclusion criteria:

- Diagnosis of myofascial pain with referral with respect to DC/TMD;
- Pain within the craniofacial and/or craniomandibular area (Visual analogue scale—VAS $\geq$ 8 points);
- Full natural dentition, class I of Angle's Molar Classification and canine position—all considered as a criteria of normal physiological occlusion;
- No current history of orthodontic treatment or retention status above three years after completion of treatment.

Exclusion criteria:

- Injuries within the craniofacial and/or craniomandibular area;
- Any surgical treatment within the craniofacial and/or craniomandibular region;
- Any occlusal splint therapy;
- Any prosthetic treatment;
- Any physiotherapy within the craniofacial and/or craniomandibular area;
- Any diseases associated with the activity of the masticatory muscles;
- Metabolic disorders;
- Any medications, regardless of whether they have been used chronically in the past or present;
- Any individually tailored diet and taking supplements in the last six months.

The control group enrolled 44 matched healthy people (22 females, 22 males), ranging from 18 to 25 years. The average age was 22.3 $\pm$ 2.2. The subjects demonstrated a lack of pain within the craniofacial and/or craniomandibular area, including myofascial pain with referral. The subjects fulfilled all exclusion criteria.

2.3. Saliva Collection

The spitting method was used to collect non-stimulated saliva [16]. The material was obtained after an overnight rest, always between 8.00 and 9.00 a.m. No food or drinks were consumed by the patients. The exception was pure water drunk at least 2 h before taking saliva. All hygiene procedures in the oral cavity were also abandoned. To ensure comfortable, non-stressful conditions, the saliva was collected in the Department of Prosthodontics at the Medical University of Bialystok, Poland, in the same room where the clinical examination was conducted. Sampling was preceded by rinsing the mouth twice with distilled water at room temperature, and after at least 5 min of adaptation to environmental conditions. The patient was sitting in the dental chair. The head was slightly tilted down, with limited movement of the face and mouth. Secreted saliva was collected directly into a sterile Falcon® tube (BD Biosciences, San Jose, CA, USA) and then placed in an ice bucket. The time of collection was 10 min to a maximum volume of 5 mL, with the saliva spat out in the first minute being omitted. The method was described in a previous publication [8].

A calibrated pipette with an accuracy of 100 µL was used to determine the volume of saliva, and the flow of non-stimulated saliva was obtained by dividing the saliva volume by the time of secretion. After sampling, the saliva was immediately centrifuged in constant conditions (20 min., 3000× *g*, +4 °C, MPW 35; MPW Med. Instruments, Warsaw, Poland). To protect the samples from oxidation due to their processing and storage, butylated hydroxytoluene was added to the supernatants (BHT, Sigma–Aldrich, Saint Louis, MO, USA; 10 µL 0.5 M BHT per 1 mL of saliva). For biochemical tests, saliva samples were frozen at—80 °C and then stored under these conditions until the time of analysis [8].

2.4. Biochemical Determination

2.4.1. Non-Enzymatic Antioxidants

The concentration of reduced glutathione (GSH) was determined in duplicate samples using a colorimetric method. The measurement was based on the reduction of 5,5′-ditiobis-2 nitrobenzoic acid to 2-nitro-5-mercaptobenzoic acid under the influence of GSH contained in the assayed sample. By the wavelength of 412 nm, absorbance variations were measured, and the concentration of 2-nitro-5-mercaptobenzoic acid was calculated from a calibration curve specified for GSH solutions [17].

2.4.2. Oxidation-Reduction Balance Parameters

The total oxidant status (TOS) was determined by the bichromatic method (560/800 nm) in triplicate samples. The measurement was based on the oxidation of Fe^{2+} ions to Fe^{3+} ions in the presence of oxidants in the sample. The detection of Fe^{3+} was carried out using xylenol orange. The TOS was measured from the hydrogen peroxide calibration curve and expressed as 1 µmol H_2O_2 Equiv, per mg protein [18].

The total antioxidant capacity (TAC) was evaluated in triplicate using a colorimetric method. The measurement is based on the neutralization of the $ABTS^{\pm}$ (2,2-azino-bis-(3-ethylenbenzothiazoline-6-sulfonate cationic radical) solution surrounded by antioxidants contained in the test sample. Absorbance was measured at a wavelength of 660 nm. To determine total antioxidant capacity, the standard curve for Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) was used [19]. Results were presented in Trolox mmol/mg of total protein. The oxidative stress index (OSI) was determined as the quotient of TOS to TAC (OSI = TOS/TAC) and was expressed in %.

2.5. Statistical Analysis

Statistical analysis was performed using GraphPad Prism 8 software (GraphPad Software, La Jolla, CA, USA) and G Power v.3.1.9.6 (Kiel University, Kiel, Germany). The Shapiro–Wilk test was applied to check whether the dataset is distributed along a normal distribution curve. The measures of central tendency related to the median were estimated and provided on a graph simultaneously with individual biomarker concentrations. The arithmetic mean and standard deviation were presented in the Table 1. The Mann–Whitney U test was applied to compare significant differences in the concentrations of individual biomarkers and saliva flow rate between the study group and control group, as well as in groups divided by gender. Post-hoc power analysis was conducted (*t*-test, means: Mann–Whitney test, two-tailed). Cohen's d was used to assess the effect size. For conventional Cohen's d, the following effect size cutoffs were accepted: 0.2 (small), 0.5 (medium), 0.8 (large). For adapted Cohen's d, the following thresholds were recommended: 0.1 (small), 0.3 (medium), 0.7 (large) [20]. Statistical power (1-β) was calculated based on the relation of the effect size α and sample size (n). The sample size required to report statistically significant differences between relevant groups (at the 0.05 level) with a probability of 0.8 (80%) was specified. To evaluate interdependence between salivary biomarkers and saliva flow rate, Spearman's correlation coefficient was used. A p-value of <0.05 was considered statistically significant.

3. Results

The findings from this study revealed statistically significant differences in salivary concentrations of GSH, TAC, and TOS between patients who suffered from temporomandibular disorders and healthy controls ($p < 0.05$) (Table 1) (Figure 1).

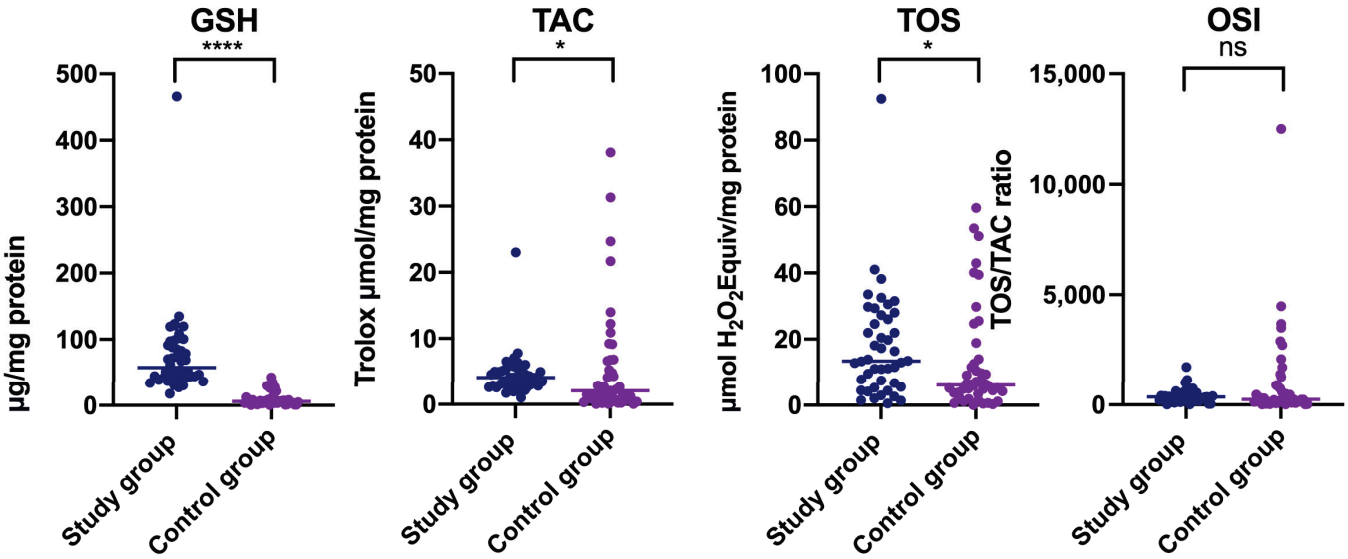

Figure 1. Concentrations of non-enzymatic antioxidants (GSH), total antioxidant capacity (TAC), total oxidant status (TOS), and oxidative stress index (OSI) in non-stimulated saliva in patients with temporomandibular disorder—myofascial pain with referral (n = 44) and control group (n = 44). The mean value and line at the median are given. Statistical significance: * < 0.05, **** < 0.0001, ns—nonsignificant.

Table 1. Concentrations of non-enzymatic antioxidants (GSH), total antioxidant capacity (TAC), total oxidant status (TOS), and oxidative stress index (OSI) in non-stimulated saliva and saliva flow rate in patients with temporomandibular disorder—myofascial pain with referral (n = 44) and control group (n = 44). The mean value, standard deviation, and median are given. With respect to post-hoc power analysis 1-β (statistical power for sample size used in present study), Cohen's d (effect size) and n (sample size needed in future research for 80% test power) are presented.

Biomarkers and Saliva Flow Rate	Gender	Study Group Patients with Myofascial Pain with Referral n = 44			Control Group n = 44			Mann–Whitney U-Test	Power	Effect Size	Sample Size for 80% Test Power
		Mean	± SD	Median	Mean	± SD	Median	p	1-β	*Cohen's d*	n
GSH	Women	71.610	31.810	69.380	11.280	12.060	6.231	<0.000 ****	1.000	2.508	9
	Men	86.240	122.000	45.550	8.966	9.169	5.974	<0.000 ****	0.654	0.893	47
	Women + Men	75.600	67.670	57.380	10.120	10.650	6.231	<0.000 ****	1.000	1.355	21
TAC	Women	4.329	1.625	4.202	6.061	10.080	1.502	0.056	0.132	0.240	594
	Men	4.857	5.805	3.022	5.020	6.699	2.457	0.403	0.051	0.026	53,221
	Women + Men	4.473	3.253	4.069	5.541	8.474	2.049	0.027 *	0.117	0.166	1190
TOS	Women	17.060	11.580	15.770	12.390	15.080	6.690	0.045 *	0.225	0.347	284
	Men	19.370	24.940	12.250	13.210	16.820	5.618	0.179	0.119	0.290	432
	Women + Men	17.690	16.030	13.350	12.800	15.790	6.130	0.015 *	0.286	0.307	351
OSI	Women	424.900	339.800	363.300	1329.000	2775.000	307.300	0.841	0.353	0.457	165
	Men	387.900	257.500	355.700	717.400	1005.000	235.700	0.763	0.220	0.449	180
	Women + Men	414.800	317.000	361.700	1023.000	2085.000	247.900	0.633	0.455	0.408	200
Saliva flow rate	Women	0.593	0.305	0.600	0.427	0.126	0.400	0.040 *	0.692	0.711	70
	Men	0.675	0.415	0.500	0.498	0.183	0.525	0.375	0.309	0.554	120
	Women + Men	0.616	0.335	0.550	0.463	0.159	0.400	0.039 *	0.752	0.583	99

Statistical significance: * < 0.05, **** < 0.0001; Cutoffs for Cohen's d: conventional Cohen's d: 0.2 (small), 0.5 (medium), 0.8 (large); adapted Cohen's d for findings in temporomandibular joint research: 0.1 (small), 0.3 (medium), 0.7 (large) [20].

Higher contents of GSH and TOS were noted in patients with temporomandibular disorder—myofascial pain with referral (Median $_{\text{GSH Study group}}$ = 57.380, Median $_{\text{GSH Control group}}$ = 6.231; Median $_{\text{TOS Study group}}$ = 13.350, Median $_{\text{TOS Control group}}$ = 6.130) (Table 1). The mean value of TAC was lower in people with temporomandibular dysfunction (Mean $_{\text{TAC Study group}}$ = 4.473, Mean $_{\text{TAC Control group}}$ = 5.541), but median was higher compared to the control group (Median $_{\text{TAC Study group}}$ = 4.069, Median $_{\text{TAC Control group}}$ = 2.049) (Table 1) (Figure 1). With respect to the OSI, reported differences were not statistically significant between both groups ($p > 0.05$) (Figure 1) (Table 1).

In relation to gender, statistically significantly higher concentrations of GSH were noted both in women and men who suffered from temporomandibular disorder compared to relevant healthy controls (Median $_{\text{GSH Study group of women}}$ = 69.380, Median $_{\text{GSH Control group of women}}$ = 6.231) (Table 1) (Figure 2).

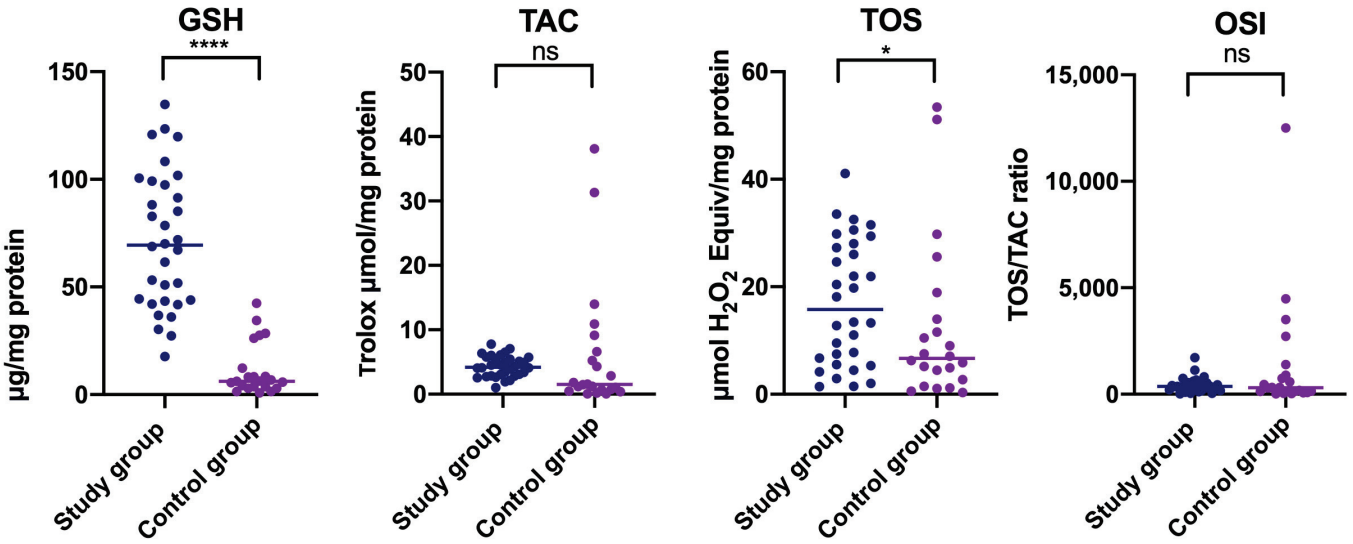

Figure 2. Concentrations of non-enzymatic antioxidants (GSH), total antioxidant capacity (TAC), total oxidant status (TOS), and oxidative stress index (OSI) in non-stimulated saliva in women with temporomandibular disorder—myofascial pain with referral (n = 32) and control group (n = 22). The mean value and line at the median are given. Statistical significance: * < 0.05, **** < 0.0001, ns—nonsignificant.

A similar trend was observed in men (Median $_{\text{GSH Study group of men}}$ = 45.550, Median $_{\text{GSH Control group of men}}$ = 5.974) (Table 1) (Figure 3).

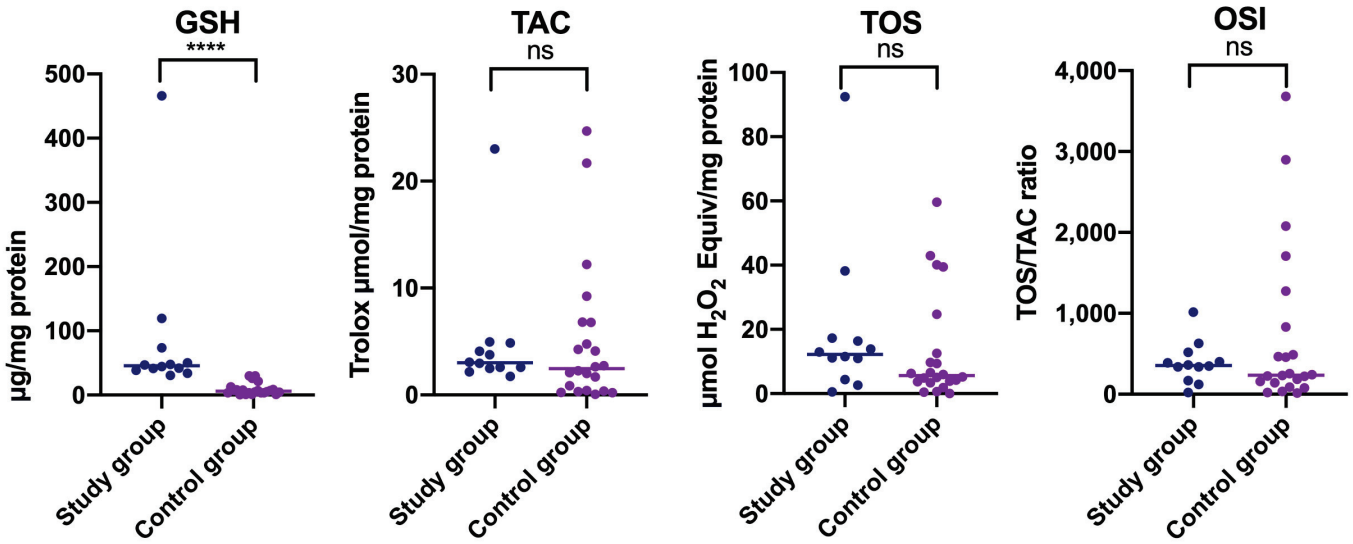

Figure 3. Concentrations of non-enzymatic antioxidants (GSH), total antioxidant capacity (TAC), total oxidant status (TOS), and oxidative stress index (OSI) in non-stimulated saliva in men with temporomandibular disorder—myofascial pain with referral (n = 12) and control group (n = 12). The mean value and line at the median are given. Statistical significance: **** < 0.0001, ns—nonsignificant.

In the case of TOS, statistically significant differences were observed only in women (Table 1) (Figures 2 and 3). Higher TOS was noted in women with myofascial pain with referral compared to relevant healthy controls (Median $_{\text{TOS Study group of women}}$ = 15.770, Median $_{\text{TOS Control group of women}}$ = 6.690) (Table 1) (Figure 2). No statistically significant differences in OSI and TAC levels were reported between study and control groups divided by gender (p > 0.05) (Table 1) (Figures 2 and 3).

Statistically significantly higher saliva flow rate was noted in the study group compared to healthy controls (Median $_{\text{Saliva flow rate Study group}}$ = 0.550, Median $_{\text{Saliva flow rate Control group}}$ = 0.400) (Table 1, Figure 4). A similar trend was observed in women compared to the relevant control group (Median $_{\text{Saliva flow rate Study group of women}}$ = 0.600, Median $_{\text{Saliva flow rate Control group of women}}$ = 0.400) (Table 1, Figure 4). No statistically significant differences in saliva flow rate were noted between the study and control groups of men ($p > 0.05$) (Table 1) (Figure 4).

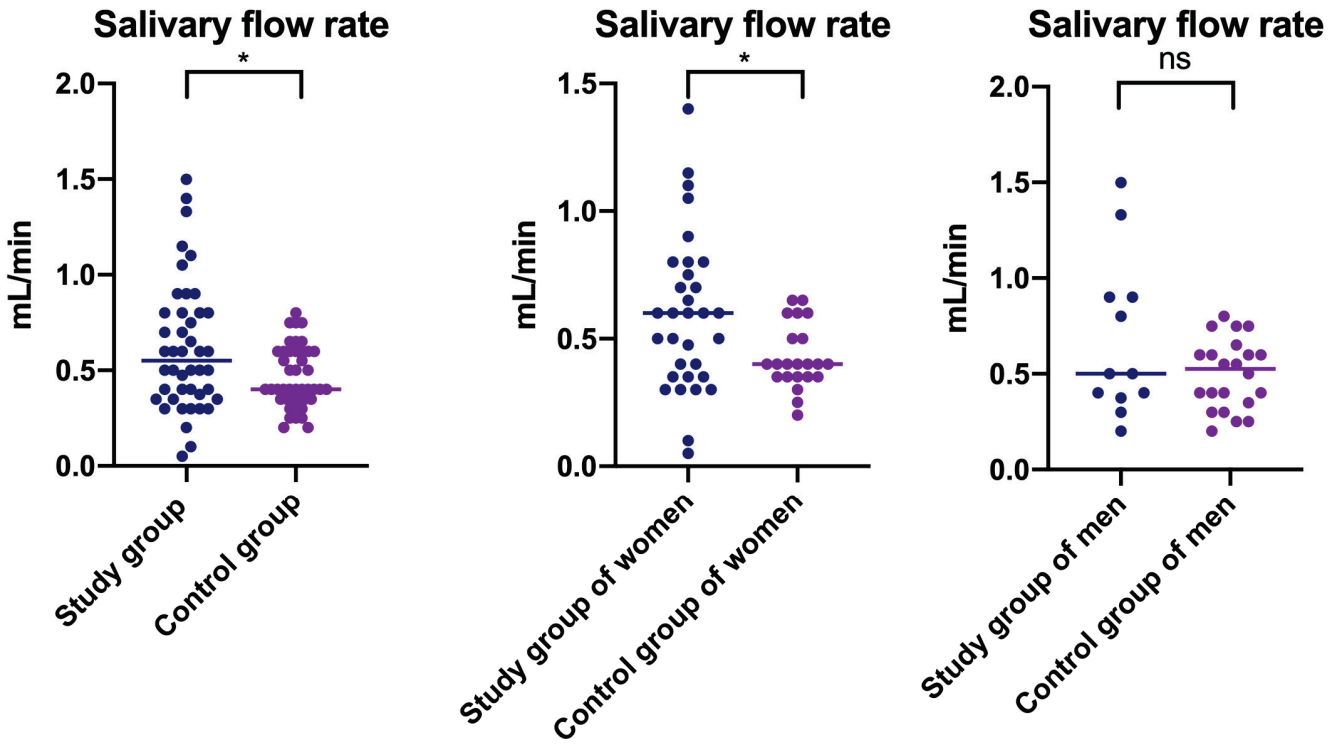

Figure 4. Salivary flow rate in patients with temporomandibular disorder—myofascial pain with referral (n = 44) and matched control group (n = 44) as well as in subgroup divided based on gender—group of women with myofascial pain with referral (n = 32), group of men with myofascial pain with referral (n = 12), control group of women (n = 22), and control group of men (n = 22). The mean value and line at the median are given. Statistical significance: * < 0.05, ns—nonsignificant.

In patients with myofascial pain with referral, a direct proportional relationship was noted between the saliva flow rate and the salivary concentrations of GSH and TAC (r = 0.432, p = 0.003; r = 0.490, $p < 0.001$, respectively) (Figure 5). Statistically significant correlation was noted between TOS and TAC (r = 0.396, p = 0.008) (Figure 5). In the case of the control group, TOS revealed a statistically significant link with GSH, TAC, and OSI (r = 0.497, p = 0.001; r = 0.458, p = 0.002; r = 0.413, p = 0.005, respectively) (Figure 5).

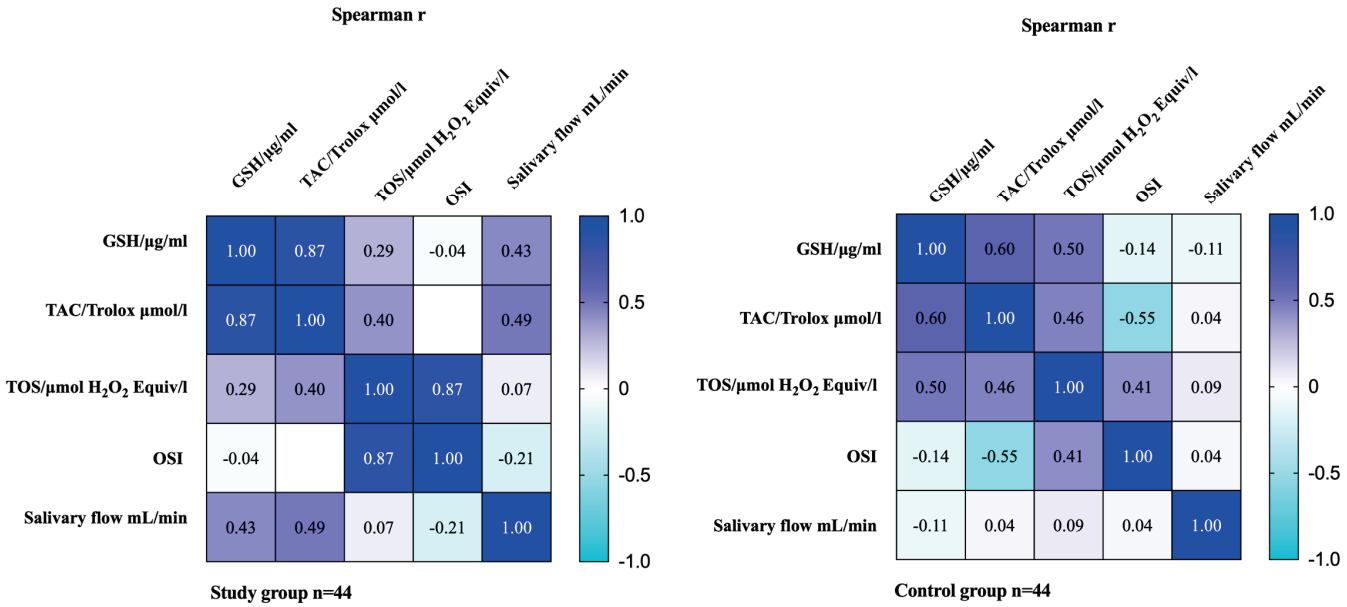

Figure 5. Heatmap of intercorrelations between salivary GSH, TAC, TOS, OSI, and salivary flow rate in patients with temporomandibular disorder—myofascial pain with referral (n = 44) and matched control group (n = 44). The Spearman's correlation coefficients are given.

4. Discussion

Oxidative stress links with many human diseases, including aging, cancer, diabetes, vascular disease, as well as dysfunction of the central and peripheral nervous system, including chronic pain [7,21–23]. However, there is still a literature gap regarding the role of oxidative stress in temporomandibular disorders. There are limited studies concerning the impact of oxidative stress on TMDs [24]. Current clinical and preclinical insights focus on the identification and modulation of oxidative/nitrosative stress biomarkers, which align with a patient-centered approach embracing personalized TMDs management. Temporomandibular disorders are the most common chronic orofacial pain conditions, and the ROS formation is one of the causes of TMDs [7]. Understanding the role of oxidative/nitrosative stress in TMDs pathology is of great assistance in TMDs guidance.

One of the interesting biomarkers of oxidative stress considered in this study is reduced glutathione (GSH). Glutathione is a tripeptide composed of three amino acids, such as cysteine, glutamic acid, and glycine [21,25,26]. This is the most abundant intracellular antioxidant in the body, which plays a crucial role in health and disease [25]. The concentration of GSH varies and depends on the type of tissue [26]. The average content is from 1 to 10 mM, with an increased level found in the brain from 0.5 to 3.4 µmol/g. In the central nervous system, the highest concentration of GSH occurs in glial cells of the cortex [26]. Considering different brain structures, the great absorption of GSH is found in the retina compared to the hypothalamus, spinal cord, midbrain, hippocampus, cerebellum, and cerebral cortex [26]. In the case of the retina, sun exposure leads to an excessive formation of reactive oxygen/nitrogen species, and GSH plays an important homeostatic role in these processes [27]. The brain and other tissues favor a common pathway for GSH synthesis [26]. The main functions of GSH include strengthening the immune system, prevention of cell damage caused by oxidative stress, participation in apoptosis, prostaglandin synthesis inhibition, transport facilitation of reactive metals and amino acid across membranes, metal homeostasis, DNA repair, enzyme activation, metabolism of toxins and carcinogens, myelin maturation, neuronal differentiation, and support for embryonic mammalian development [26]. Furthermore, GSH serves as a supply of extracellular cysteine and neuronal glutamate [26]. Probably, it has a binding site for glutamate receptors and may play a role as

a neuromodulator/neurotransmitter [26]. GSH intensifies NMDA receptor responses and neuronal activation [26]. In vivo and in vitro decreased concentration of GSH leads to an impairment of motor neurons [26], which may potentially implicate the pathophysiology of myofascial pain.

Imbalance in GSH levels results in accelerated ageing processes and neurodegeneration [22,26]. Reduced content of glutathione is observed in autism, Alzheimer's disease, Parkinson's disease, schizophrenia, bipolar disorder, amyotrophic lateral sclerosis, and multiple sclerosis [22,26]. Other related pathologies concern the circulatory system, the immune system, the lungs, liver, gastrointestinal system, and metabolism [22]. Due to the fact that decreased GSH contributes to the onset and progression of neurological and neurodegenerative diseases, it may be considered as a marker for diagnostic screening for these disorders [26]. Jafri highlighted that muscle overuse seems to be the potential mechanism leading to a decrease in glutathione levels and an increase in ROS production and the appearance of myofascial trigger points [28]. This is extremely important in the context of the pathophysiology of myofascial pain and the potential tendency to clenching and grinding of the teeth. Furthermore, coexisting decreased content of GSH, exaggerated oxidative species formation, and excessive mechanical overload contribute to synovial hyperplasia within the temporomandibular joint (TMJ) [29]. TMJ inflammation also links with oxidative stress. It can be assumed that reduced GSH concentration may increase the susceptibility to TMD [29].

It should be noted that one of the causes of oxidative stress is ischemia [5]. Local ischemia can be considered as a co-player of the redox balance in patients with myofascial pain with referral. Koca et al. stressed that these processes may resemble a vicious cycle in which ischemia initiates oxidative stress, which in turn causes ischemia [5]. Local ischemia within the myofascial tissue facilitates muscle spasms and the formation of trigger points [5]. Excessive physical stress does not lead to the formation of trigger points in every individual [5]. Travel and Simons hypothesized that overloading a muscle initiates the rupture of the sarcoplasmic reticulum and increased concentration of calcium at the tissue level [5]. It promotes vasoconstriction and, consequently, ischemia [5]. In connection with this, ischemia-reperfusion phenomenon leads to local and systemic inflammatory response, leucocyte-endothelial cell adhesion, transendothelial leucocyte migration, increased platelet-leucocyte aggregation, elevated microvascular permeability, and reduced endothelium-dependent relaxation [30]. Ischemia tends to cause free radical-mediated damage [30]. The leucocytes that appeared during reperfusion promote the inflammatory cascade [30]. The role of the above-mentioned GSH in the antioxidant defense mechanism seems to be paramount [30]. These findings gain importance when considering the pathophysiology of myofascial pain with referral that overlaps stress, anxiety, depression, muscle overuse/misuse, chronic microtraumas, and vitamin and mineral deficiencies [5,31]. It should be stressed that vitamin D deficiency negatively impacts skeletal muscles through oxidative stress and mitochondrial dysfunction [32,33]. As a neuroactive steroid, vitamin D triggers neuronal excitability in the pain pathway. It means that vitamin D deficiency contributes to central neuronal hypersensitivity linked with chronic pain. Vitamin D insufficiency is considered a precipitating factor of myofascial pain syndrome [32]. In conclusion, in the case of myofascial pain, the oxidative stress seems to be both the cause and effect of the disorders.

Ege et al. revealed a lower concentration of GSH in a group with internal derangement of the temporomandibular joint ($n = 70$) compared to healthy controls ($n = 70$) [24]. Observed differences were not statistically significant ($p = 0.069$) [24]. Demir et al. reported statistically significantly lower serum levels of GSH in patients with temporomandibular joint disorders than in healthy controls [34]. Rezazadeh et al. showed statistically significant

reduced salivary content of glutathione reductase in people with temporomandibular joint disorder compared to healthy controls [35]. Our study revealed the opposite results to those expected. GSH content was significantly higher in patients who suffered from myofascial pain with referral compared to the control group. This tendency was also observed in the subgroups divided based on gender (Figures 1–3) (Table 1). Increased GSH may suggest an adaptive response to oxidative stress [21]. At this point, it should be mentioned that the causal link between glutathione levels and the occurrence of disease requires explanation. One of the confounding factors is the "antioxidant paradox" [21,36]. Besides antioxidant properties, GSH may trigger prooxidant hormesis activity and contribute to hormesis, affecting the body to reinforce its endogenous antioxidant defenses. In connection with this, redox balance may be the cause or consequence of the disease [21]. Hormesis represents a biological phenomenon characterized by an adaptive biphasic dose-response, which is based on stimulation that is beneficial at low doses, and inhibition or toxicity at high doses [37]. Exposure to low doses of stressors may promote or modulate physiological homeostasis, while higher doses may lead to physiological imbalance and adverse effects [37]. These dynamics are typically represented by a bell-shaped hormesis curve [38]. Hormesis may modulate biological processes at multiple levels, including the cellular, organ, individual, and population levels [37]. The most common hormetic models include dietary restriction, fasting, cold exposure, radiation, energy deficiency, chemical stress, biological factors, and nutritional hormetins [37,39,40]. All triggers can be categorized as deleterious, neutral, or beneficial stressors [41]. These contribute to the activation of hermetic mechanisms, impacting glutathione levels and mitochondrial biogenesis [41]. The glutathione system is one of the most well-established models of hormesis, initially observed in bacteria [39]. In this model, oxygen exposure and the resulting oxidative stress lead to the upregulation of nuclear factor erythroid 2-related factor 2 (Nrf2), which is associated with the synthesis of glutathione [39]. In the context of the conducted research and the observed discrepancy in GSH levels, the following questions arise: At what point on the hormesis curve are patients suffering from myofascial pain with referral located—on the ascending or descending phase? How do potential dietary hormetins, physical activity, and the biopsychosocial component of Axis II in the DC/TMD protocol influence the observed GSH levels? Do these triggers produce an additive effect, or do they interact synergistically? At which phase of the hormesis curve should antioxidant supplementation be introduced to achieve a beneficial, non-toxic effect [38]? Should patients be monitored through repeated biochemical testing in order to determine their individual position on the hormesis curve? Identifying this position may help explain the differences in glutathione levels observed between the study and control groups. Repeated biochemical assessments over time might be useful. However, an individually tailored oxidative stress profile may complicate this approach. Further research involving the implementation of controlled stressors under specific conditions is needed. Nevertheless, it should be remembered that sometimes "less is more" [39].

Achieving personalized stability in glutathione status is one of the proposed modern strategies for health promotion and disease prevention [21,39]. Minich et al. highlighted that the causal dependence between glutathione levels and the risk of illness/treatment still needs clarification [21]. This author emphasized that vitamins, minerals, and food can significantly affect circulating glutathione, which may influence clinical benefits [21]. Current strategies involve the application of food and nutrients that may elevate or maintain optimal glutathione levels [21]. Nutritional interventions focus on the role of N-acetylcysteine as a supplement for glutathione support, intake of dietary protein as the source of amino acids, omega-3 fatty acids, vitamins such as B2, B5, B12, C, E, alpha-lipoic acid, selenium, curcumin, and green tea [21,27]. Special role may be attributed to the plant foods that

contain glutathione, e.g., asparagus, avocado, cucumber, brassica vegetables, green beans, spinach, and papaya [21,27]. The art of eating is gaining importance. Plant-based food and practical strategies for "eating the rainbow" seem to be paramount [42]. The rainbow strategy is distinguished by nutrition criteria: red foods and inflammation (I), orange foods and reproductive health (II), yellow foods and digestion (III), green foods and cardiovascular health (IV), blue-purple foods and cognition (V) [42]. Bearing in mind the pathophysiology of temporomandibular myofascial pain described in previous [8,31,43] and current publications, all these groups of plant-based foods should be incorporated in an individually tailored novel approach in TMD management. Nevertheless, it should be mentioned that the rainbow strategy may be associated with certain limitations. Immediate painful response associated with compression of the periodontal ligament and delayed painful response determined by hyperalgesia—both linked with orthodontic force application [44], and analogously with teeth "overclenching"—may limit the rainbow strategy implementation, especially in the case of eating hard, raw plant-based food. The help of dieticians may be essential in developing a nutritional strategy. Summarizing, dietary behavior focused on antioxidant-rich foods may reduce the risk of noncommunicable disease by elevating total antioxidant capacity (TAC). Studies on subjects suffering from oxidative stress conditions revealed that 70% of interventions associated with plant foods and supplements resulted in elevated plasma/serum TAC levels [45]. Lifestyle factors affecting the salivary TAC levels include exercise, smoking habits, alcohol dependence, as well as occupational exposure to toxicants [45]. Oral behavior also seems to be important. Bearing in mind the fact that in a healthy person the contact of the teeth should be about 17.5 min per day [46], and that probably in people with temporomandibular disorders this time is prolonged [47], it can be assumed that the TAC level will simultaneously decrease as a response to repetitive mandibular movements associated with clenching or grinding of the teeth. This is a kind of analogy to the excessive overload of the muscles mentioned above. More research is needed. Special attention in TAC modulation may be attributed to cellphones associated with exposure to radio frequency radiation and watching TV [45]. It was found that emotional and psychological factors may influence salivary TAC levels. In connection with this, watching a cheerful, comical video for 30 min contributes to an increase in salivary TAC levels [45].

Our study revealed that mean TAC levels in people with temporomandibular myofascial pain with referral were lower than in matched healthy controls, but the median value was conversely higher (Table 1) (Figure 1). The lower average TAC in the study group was caused by the presence of outliers in the control group (Figure 1). With respect to gender, declared differences were not statistically significant (Table 1) (Figures 2 and 3). Statistically significant increased TOS was observed in people who suffered from temporomandibular dysfunction compared to the control group (Table 1) (Figure 1). A similar tendency was observed in a subgroup of women (Table 1) (Figure 2). Elevated TOS was reported in women with myofascial pain than in relevant healthy controls. No statistically significant differences were stated with respect to OSI between the study group and control group, and in subgroups divided based on gender, respectively. Statistically significant correlation was noted between TOS and TAC in patients with myofascial pain with referral (Figure 5). In the case of the control group, TOS correlated with GSH, TAC, and OSI (Figure 5).

Lawaf et al. reported no statistically significant differences in salivary TAC between people who suffered from TMDs with and without pain, and healthy controls [48]. In turn, plasma TAC was significantly lower in both TMD patients compared to the control group [48]. Ozcan-Kucuk et al. revealed that TAC levels in patients with sleep bruxism were lower than those of matched healthy controls. The TOS and OSI were higher in people with sleep bruxism than in the control group [49]. Madariaga et al. reported statistically

significantly lower content of TOS in people with myogenous temporomandibular disorder than in healthy subjects [50]. TAC levels were higher in the TMD group compared to the control group. There were no statistically significant differences in TAC and TOS levels between a group of myalgia and a group of myofascial pain [50]. Ege et al. reported statistically significantly lower TAC and higher TOS in people with internal derangement compared to matched controls [24]. The latest research highlighted interdependence between sleep bruxism intensity and low TAC, high AOPP (advanced oxidative protein products), and TBARS (thiobarbituric acid-reacting substances) serum levels [51].

Koca et al. revealed a statistically significant inversely proportional relationship between the visual analogue scale concerning VAS and TAC in people with general myofascial pain in the body [5]. Simultaneously, a direct proportional link was reported between VAS and TOC as well as the OSI [5]. This interdependence between TAC, TOS, OSI, and pain scores may be integrated to specify the severity of the dysfunction, including antioxidant system depletion, as well as to monitor antioxidant treatment [5]. It should be noted that in our study, one of the many inclusion criteria was craniofacial/craniomandibular pain equal to and above 8 points of the VAS. Other studies revealed an inversely proportional relationship between TAC and TOS in patients with general myofascial pain dysfunction and direct proportional dependence between TAC and pressure pain thresholds (PPT) [52]. This study also revealed the opposite results to those expected with respect to VAS. There was no correlation between VAS scores and TAC, so pain evaluation with respect to PPT seemed to provide more sensitive data [52].

Our study revealed a direct proportional relationship between the saliva flow rate and the salivary concentrations of GSH and TAC in people with myofascial pain with referral. These connections were not reported in the case of the control group (Figure 4). Salivary flow rates change depending on the circadian cycle, individual hydration, food stimulation, and oral hygiene [53]. It should be noted that a higher saliva flow rate was observed in the study group as well as in women with myofascial pain with referral compared to the healthy controls (Figure 5).

Similarly to the abovementioned GSH, TAC levels may be modulated by nutritional and supplement interventions. Caffeinated or alcoholic antioxidant beverages elevate salivary TAC by 50% and urinary TAC by 40% in the intervention [45]. Vitamin C and vitamin E may also influence the salivary and urinary TAC [45]. Red wine extract contributes to an increase in salivary TAC within 30 min [45]. A significant role may be attributed to blackberry juice, spinach, strawberries, and fruit-based drinks [45]. In turn, physical stress reduces salivary TAC [45].

Buczko et al. revealed that orthodontic treatment may modify the oxidant-antioxidant balance in the saliva of clinically healthy subjects [54]. This author reported that 2 years after orthodontic intervention, the total antioxidant status was lower as compared to the values noted before and one week after the treatment [54]. OSI and TOS were the highest after one week of the treatment. Similar values of OSI were reported before and after 2 years of interventions. With respect to TOS, the lowest values were observed after 2 years of treatment [54]. According to this, it would be extremely interesting to assess the impact of occlusal splints on the oxidative stress biomarkers profile in patients with TMDs. Vrbanovic et al. stated that in women, occlusal splint contributes to elevating the capacity to remove free radicals. This author emphasized that data concerning TAC levels in TMDs are inconsistent. Many studies reported lower TAC levels in patients with TMDs compared to the control group. Vrbanovic et al. suggest that TAC levels may be related to the chronicity of the disorder [55]. It means that chronic pain lasting 6 months or more provides an opportunity to adapt to potentially high oxidant levels, resulting in higher TAC levels. It reflects a compensatory reaction to a distorted oxidative balance [55].

Oxidative stress and associated changes in signaling pathways have multiple pathophysiological consequences at different stages of life [56]. To mitigate the negative effects and toxicity of oxidative stress on health, systematic physical activity should be implemented to reduce the noxious effects of free radicals. Exercises contribute to ROS formation and affect the level of muscle contraction. Modest ROS accumulation increases muscle strength [56]. However, during intense exercises, its excessive production leads to acute muscle fatigue [56]. Bearing in mind the pathophysiology of myofascial pain with referral, a necessity to provide proper hygiene of the circulatory system with respect to the discharge muscle metabolites as well as due to oxidative-antioxidant balance, individually tailored physical activity and modern eating behavior should be implemented as a novel strategy in TMDs management.

Bearing in mind the literature gap, our study contributes to the expansion of knowledge concerning oxidative stress biomarkers in the TMD umbrella evolvement. The main advantage of this research is a strictly defined protocol that remains in line with Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [57]. Once again, we highlighted the role of nutrition and supplementation as a key to understanding the oxidative-antioxidative balance disorders, the pathophysiology and etiology of TMDs, including myofascial pain with referral. We stressed the importance of individually tailored eating behavior in TMD patients exposed to oxidative stress. Based on the literature, we pointed out the risk of lifestyle and diet-related diseases associated with oxidative stress, which may also affect our study group. The main limitation was the inequality of the study group in terms of gender, with the predominance of the number of women, with an associated imbalance in the number of men. Therefore, it is advised to be cautious with the results of this study. More research is needed. The next restriction was limiting the interpretation of the results due to the lack of consideration of the exact nutritional profile of the patients and people from the control group. Future research should take this into account.

5. Conclusions

1. Patients with temporomandibular myofascial pain with referral exhibit oxidative imbalance, as evidenced by increased salivary concentrations of the non-enzymatic antioxidant glutathione, elevated total oxidative status, and statistically significant differences in total antioxidant capacity compared to the control group.
2. Despite the observed alterations in individual markers of oxidative stress (TAC, TOS), no statistically significant differences were found in the oxidative stress index between patients with temporomandibular myofascial pain with referral and the control group.
3. Patients with temporomandibular disorders—specifically myofascial pain with referral may benefit from individually tailored physical activity, proper nutrition and eating behaviors, as well as targeted supplementation, in order to maintain oxidative-antioxidant balance. The "rainbow strategy" could play a key role in this approach.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The article contains complete data used to support the findings of this study.

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Abbreviations

The following abbreviations are used in this manuscript:

TMDs	Temporomandibular disorders
ROS	Reactive oxygen species
RNS	Reactive nitrogen species
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
VAS	Visual analogue scale
GSH	Reduced glutathione
TOS	The total oxidant status
TAC	The total antioxidant capacity
OSI	The oxidative stress index

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Gender Differences in Mouth Opening on Temporomandibular Disorder Patients—Implications for Diagnosis

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Abstract: Background/Objectives: Temporomandibular disorder (TMDs) patients often present limited mouth opening (LMO). A key diagnostic cutoff is a mouth opening threshold >40 mm. However, this universal cutoff may not accurately reflect gender anatomical variations. This study investigates gender-specific differences in maximum mouth opening (MMO) to propose revised diagnostic criteria for LMO. **Methods:** A five-year prospective study was conducted from 1 August 2019 to 1 May 2024 in a Portuguese TMDs department. The patients' gender, MMO, and LMO complaints with clinical validation were recorded. Statistical analyses, including Generalized Additive Models (GAMs) and Generalized Linear Models (GLMs), assessed the relationship between MMO and LMO, with gender-stratified comparisons. **Results:** In this study 1045 patients were included. The median (accompanied by the interquartile range [25th percentile–75th percentile]) MMO was lower in females (40 mm [34–45]) than in males (44 mm [40–48]). Patients presenting LMO complaints exhibited significantly reduced MMO values compared to those without LMO complaints ($p < 0.001$). Gender-specific thresholds emerged: for females, LMO was observed when MMO was $\leq$35 mm, while in males, LMO symptoms appeared when MMO was $\leq$38 mm. A "gray zone" of diagnostic uncertainty was identified between 36 and 37 mm for females and 38 and 42 mm for males. **Conclusions:** In this study we observed the gold standard cutoff for diagnosing MMO in female should be <35mm and for male <38mm. These findings suggest that a single LMO threshold does not account for gender-related anatomical differences, potentially leading to underdiagnosis in females and misclassification in males. Revising diagnostic criteria to incorporate gender-specific thresholds could enhance accuracy, improve early diagnosis, and promote personalized treatment strategies for TMDs patients. Further research incorporating additional variables such as age, dental occlusion, craniofacial structure, and body mass index is recommended to refine these diagnostic guidelines.

Keywords: temporomandibular disorders; limited mouth opening; gender; diagnostic thresholds; personalized medicine

1. Introduction

Temporomandibular disorders (TMDs) are a group of conditions affecting the temporomandibular joint (TMJ), masticatory muscles, and associated structures, often resulting in pain, joint noises, and limited mouth opening (LMO). TMDs can significantly impact an individual's quality of life by interfering with basic functions like chewing, speaking, and oral hygiene maintenance [1]. The estimated global prevalence of TMDs is approximately 34%, based on a recent meta-analysis, with regional variation across populations [2]. In Europe, the overall prevalence is 29%, with age-specific rates of 18% in individuals under 18 years old, 41% in adults aged 18–60, and 32% in individuals over 60 years old [2]. These figures underscore the widespread nature of TMDs and their clinical relevance across the lifespan.

LMO is one of the primary diagnostic criteria for TMDs, and it is typically assessed through a measurement of the interincisal distance during active mouth opening. The Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) define LMO as an interincisal distance of less than 40 mm as the "cutoff" [3,4]. Despite the robustness of this threshold, it was established based on a study of over 20,000 individuals, which was conducted exclusively on healthy children aged 4–17 years. Other authors have suggested a cutoff of 35 mm [5,6]. These discrepancies indicate that relying on a fixed cutoff may lead to under- or overdiagnosis in certain subpopulations, emphasizing the need for personalized diagnostic criteria.

An emerging area of interest in the field of TMDs is the role of kinesiophobia, or fear of movement, in limiting mouth opening. Recent studies suggest that individuals with TMDs may reduce their range of jaw movement not only due to pain but also due to anticipatory fear of exacerbating symptoms, which contributes to a self-limiting behavioral pattern [7,8]. In this context, maximum mouth opening (MMO) is not solely a biomechanical measure but also a reflection of the patient's psychological state. This fear-avoidance model has been linked to other musculoskeletal pain conditions and may have important implications for the interpretation of LMO in TMDs diagnosis.

Another critical dimension to consider is the influence of gender on MMO values. Numerous anatomical studies have documented significant gender-based differences in craniofacial morphology and muscle strength, with men typically exhibiting greater MMO due to larger jaw structures and more robust masticatory musculature [9–12]. Physiological factors such as hormonal differences and the increased prevalence of bruxism in women may also contribute to variations in MMO [13,14]. Bruxism, although not classified as a TMDs, is more prevalent among women and may contribute to increased muscle tension, fatigue, and joint overload [14,15]. This parafunctional activity can indirectly exacerbate or amplify TMDs-related symptoms, particularly in individuals with predisposing anatomical or psychological factors [16,17]. Psychological differences, including pain sensitivity, coping strategies, and the prevalence of anxiety-related disorders, may further modulate how TMDs presents and is perceived between genders [18,19].

Despite this well-established fact, the current 40 mm threshold is uniformly applied across genders. This uniform approach raises several concerns. Women, who naturally tend to have smaller MMO, may be underdiagnosed, for clinically significant limitations in mouth opening, leading to delays in treatment. Conversely, men may be overdiagnosed if their baseline MMO substantially exceeds the diagnostic threshold, resulting in unnecessary

interventions or misclassification. The implications for clinical practice are substantial, suggesting that a one-size-fits-all model may not accurately identify and manage TMDs-related functional impairments.

This study argues that a single LMO threshold cannot capture gender differences in normal and pathological jaw function. The aim of this study is to analyze interincisal distances in male and female TMDs patients from a single-center clinical database, to evaluate whether gender-specific diagnostic thresholds for LMO are warranted. We hypothesize that gender differences in MMO are significant enough to justify the use of sex-specific thresholds for diagnosing LMO. Alternatively, if no significant gender-related differences are observed, this would support the continued use of a universal diagnostic threshold.

2. Materials and Methods

2.1. Study Design and Data Collection

A 5-year prospective study was conducted in a Portuguese TMDs department from August 1, 2019 to May 1, 2024. The Instituto Português da Face ethics committee approved this study (PT/IPFace/RCT/0525/19), and all of the enrolled patients provided their written informed consent in accordance with the current legislation. The inclusion criteria were as follows: (1) age $\geq$ 18 years; (2) recorded gender and MMO and LMO complaint during the first TMDs consultation; and (3) capacity to provide informed consent and participate in the clinical interview and examination (Figure 1). The exclusion criteria were as follows: (1) other facial problems that could potentially cause LMO (e.g., irradiation, cancer, trauma); (2) neuromuscular disorders or systemic conditions affecting mandibular function (e.g., Parkinson's disease, multiple sclerosis); (3) severe psychiatric illness impairing communication or cooperation; and (4) any dental or prosthetic condition impeding an accurate MMO measurement. All eligible patients with inclusion criteria over these five years were included. Descriptive data and clinical outcomes were registered in the EUROTMJ database (https://eurotmj.org/tmj, accessed on 1 May 2025). At the first consultation, patients were instructed to answer questions regarding their complaints, namely LMO. To assess the presence of LMO, patients were asked a direct question during the initial consultation: "Do you feel that you have limited mouth opening?". Those who responded affirmatively were further evaluated through a standardized clinical examination by the same experienced clinician (D.F.A) [4]. In clinical evaluation, the patients were instructed to perform a series of mouth-opening movements to observe jaw movement. LMO status was confirmed when the clinician verified a restricted mandibular range of motion consistent with the patient's complaint. MMO (mm) was also registered. MMO was accessed using a certified ruler between the incisor teeth (TheraBite ® Jaw ROM Scale). All clinical evaluations were performed by the same clinician to ensure consistency (D.F.A).

2.2. Statistical Analysis

Analyses were conducted using the R Statistical language (version 4.3.3; R Core Team), on macOS (Apple M1 chip, 8-core CPU, 2020), using the packages likert (version 1.3.5; [20]), dplyr (version 1.1.4; [21]), reshape2 (version 1.4.4; [22]), ggstats (version 0.9.0; [23]), ggplot2 (version 3.5.2; [24]), GGally (version 2.2.1; [25]), caret (version 7.0-1 [26]), car (version 3.1-3; [27]), rpart (version 4.1.23; [28]), randomForest (version 4.7-1.2; [29]), pROC (version 1.18.5; [30]), pastecs (version 1.4.2; [31]), and rpart.plot (version 3.1.2; [32,33]). An exploratory analysis was conducted on the following variables by gender: LMO (–): absence of limitation or LMO (+): presence of limitation, and MMO. For these variables, appropriate measures of central tendency and dispersion, as well as frequency (both absolute and relative), were determined by gender. The sample mean accompanied by the standard deviation was used for approximately symmetric distributions, presented

as the mean (standard deviation). For asymmetric distributions, the median accompanied by the interquartile range was reported, in the format of the median [P25; P75]. Skewness was assessed through a hypothesis test on the population skewness coefficient.

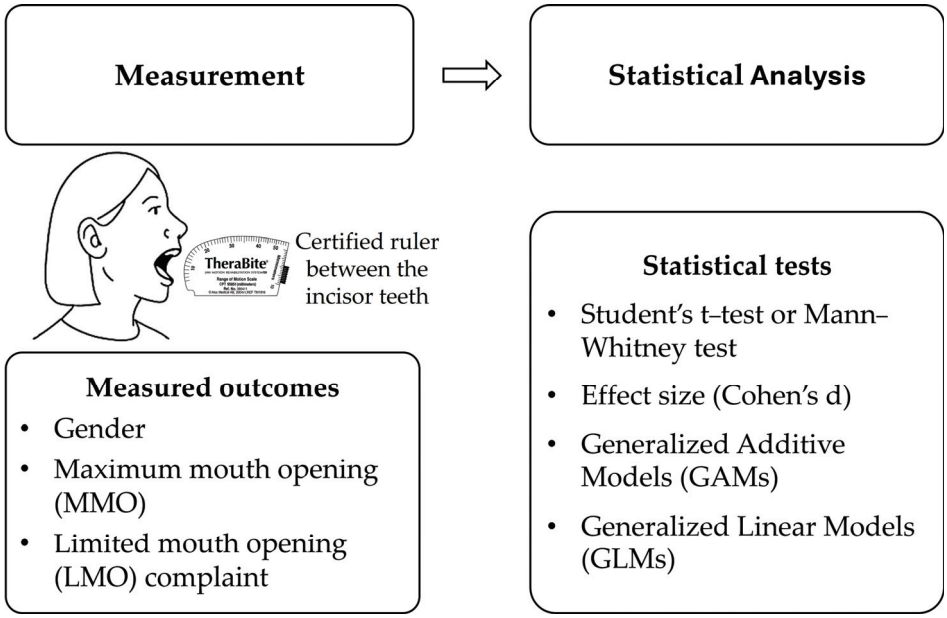

Figure 1. Flowchart illustrating the measurement of maximum mouth opening (MMO) using a certified ruler, and the main outcomes and statistical analyses included in this study.

The normality of MMO distribution was assessed using the Shapiro–Wilk test. Homoscedasticity was tested using Bartlett's test upon confirming normality in the MMO distribution across LMO categories. If both conditions were met, Student's parametric t-test was applied. In cases where homoscedasticity was violated, Welch's parametric test was used. The absence of normality led to the choice of the non-parametric Mann–Whitney test.

Effect size was measured using Cohen's d to compare MMO between female and male participants, between LMO (–) and LMO (+), and within each gender group (female and male). Cohen's d quantifies the magnitude of the difference between groups in terms of the pooled standard deviation. A larger d value indicates a greater difference, with conventional thresholds for interpretation: small (0.1), medium (0.3), and large (0.7) [34]. This approach helps to assess the practical significance of differences in MMO both between genders and within each gender group based on LMO status.

After completing the exploratory analysis, a study of the functional relationship between MMO and LMO by gender was conducted using Generalized Additive Models (GAMs). In this class of models, the logistic link function was used due to the response variable (LMO) following a Bernoulli distribution. Where the functional form appeared to be approximately linear, the association was modeled using Generalized Linear Models (GLMs) with the same link function as in the GAMs. From the GLMs, the respective odds ratios of MMO by gender were estimated. An alpha significance level of 5% was set.

3. Results

A total of 1045 patients were analyzed using records from the EUROTMJ database. The exploratory analysis results are summarized in Table 1. In this table, the MMO measures account for the fact that the distributions by gender are asymmetrical (female 80%; male 20%).

Table 1. Demographic data by gender according to maximum mouth opening (MMO) and limited mouth opening (LMO).

Variables		N (%) or Median [P_{25};P_{75}]
Number of patients		1045
Gender	Female	836 (80%)
	Male	209 (20%)
MMO (mm)		41.0 [34.0;45.0]
	Female	40.0 [34.0;45.0]
	Male	44.0 [40.0;48.0]
LMO (+)		633 (60.6%)
	Female	529 (63.3%)
	Male	104 (49.8%)
LMO (–)		412 (39.4%)
	Female	307 (36.7%)
	Male	105 (50.2%)
MMO (mm)		
	LMO (–)	43.0 [39.0;47.0]
	LMO (+)	38.0 [32.0;43.0]

A comparison of MMO values between patients who were positively and negatively diagnosed with LMO was conducted. Figure 2A shows that the MMO medians are different. This evidence is supported by comparing the difference in median values ($p < 0.001$). The corresponding Cohen's d value was 0.645, which indicates a medium effect size. The median MMO values in the LMO (–) group were 43.0 mm [39.0;47.0], and in the LMO (+) group, they were 38.0 mm [32.0;43.0]. Subsequently, a GAM was applied to describe the functional form of the association between the MMO and LMO. Due to the number of observations being lower outside the MMO interval [20;50] mm, we will consider only values belonging to it. Patients present a risk of LMO symptoms in cases where MMO < 36 mm. In cases where the MMO is >39 mm, the risk of not having LMO symptoms increases. Given the near linearity of the functional form, a GLM with a logistic link function was then applied to model the association between MMO and LMO. This model indicates that the MMO has statistical significance ($p < 0.001$) regarding the Wald test application. Additionally, the GLM provided a 95% confidence interval for the odds ratios [0.903; 0.935], indicating that for each additional 1 mm increase in MMO, the odds ratio of LMO decreases by 1.065; 1.097.

Subsequently, a comparative analysis was conducted on MMO values regarding gender. The median MMO values were compared considering the presence or absence of LMO for females. It was found that the median of MMO in LMO (−) was 42.0 mm [37.5; 46.0], whereas in the LMO (+), the value was 36.0 mm [32.0;43.0] (Figure 3A). Statistical significance was observed when comparing MMO in the two groups ($p < 0.001$). The corresponding Cohen's d value was 0.555, which indicates a medium effect size. For males, the median of MMO in the LMO (−) group was 46 mm [42;49], while in the LMO (+) group, the value was 43 mm [36;47] (Figure 3B). Statistical significance was also observed when comparing the two groups ($p < 0.001$). The corresponding Cohen's d value was 0.623, which also indicates a medium effect size.

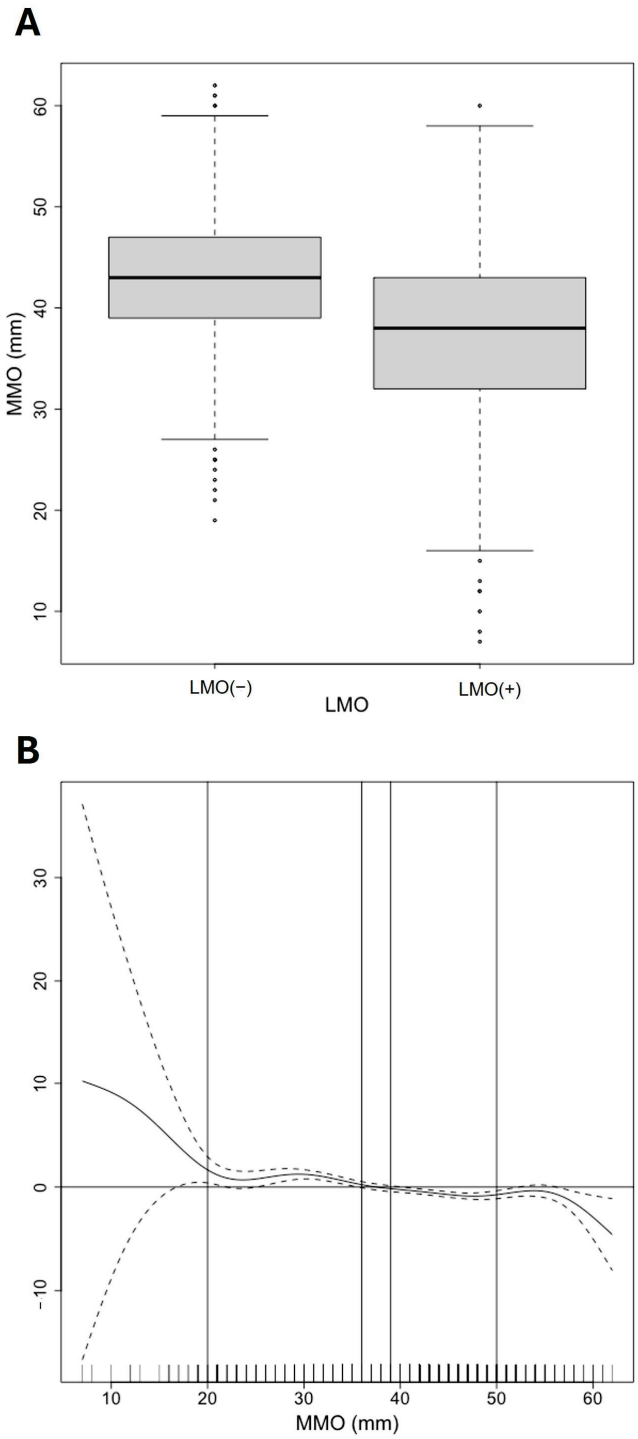

Figure 2. Maximum mouth opening (MMO) values among patients with limited mouth opening (LMO) complaints. (**A**) The boxplot represents the distribution of MMO between each category of LMO. (**B**) Generalized Additive Model (GAM) for describing the functional form of the association between the MMO and LMO variables. For statistical analysis, only the MMO values limited by the vertical lines 20 and 50 mm, respectively, were considered given the low number of cases outside this range. The risk of LMO (+) for MMO values between the 36 and 39 mm vertical lines, respectively, is undefined since the confidence bands include the zero value of the ordinate. Values below 36 mm correspond to a risk of LMO (+). Values greater than 39 mm correspond to LMO (–).

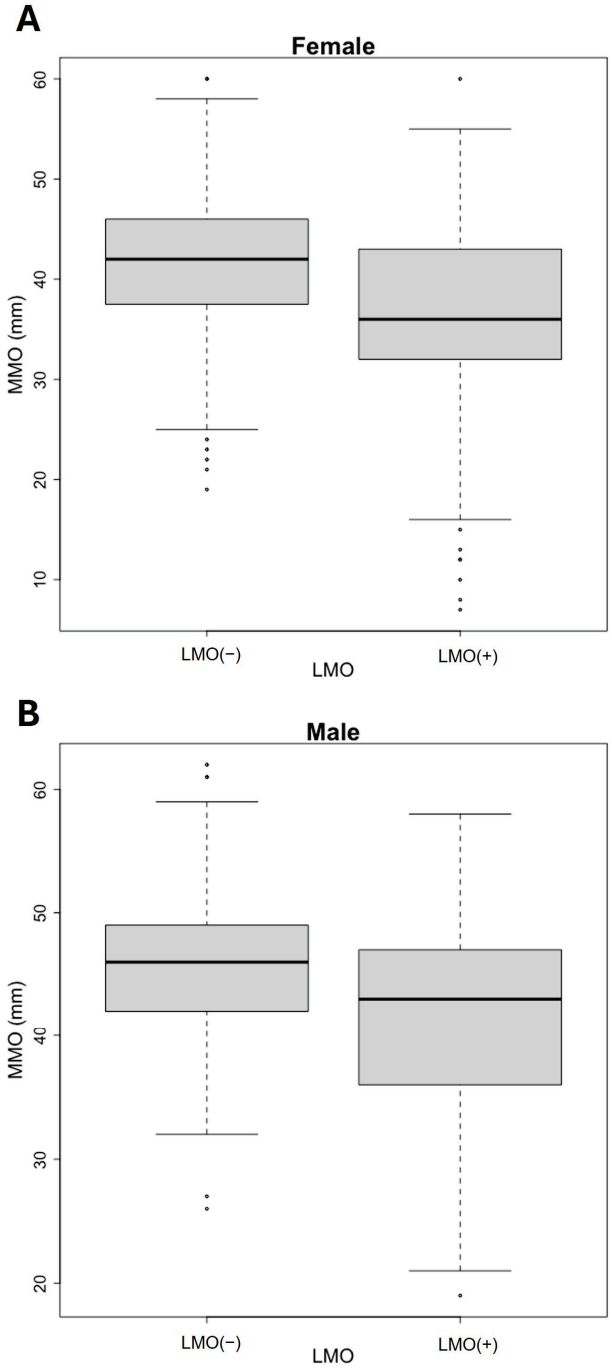

Figure 3. Maximum mouth opening (MMO) values among female (**A**) and male (**B**) patients with limited mouth opening (LMO (+) and without LMO (−)). The boxplot represents the distribution of MMO between each category of LMO.

The GAM was then applied to describe the functional form of the association between the MMO and LMO for both genders (Figure 4A,B). For females, LMO (+) is present if the MMO is ≤35 mm. When the MMO is >38 mm, the risk of LMO decreases. The GLM provided a 95% confidence interval for the odds ratios [0.901; 0.938], indicating that for each additional 1 mm increase in MMO, the odds ratio of LMO (+) decreases by 1.061; 1.099. For males with LMO (+), the symptoms are present if the MMO is less than 38 mm. The risk of LMO decreases when the MMO is >45 mm. The GLM provided a 95% confidence interval for the odds ratios [0.889; 0.963], indicating that for each additional 1 mm increase in MMO, the risk of LMO (+) decreases by 1.037; 1.111. In a univariate logistic regression model using MMO as the sole predictor of LMO status, the area under the ROC curve

(AUC) was 0.69 for both males and females. This indicates a moderate discriminatory ability, suggesting that MMO alone can partially distinguish between patients with and without perceived LMO.

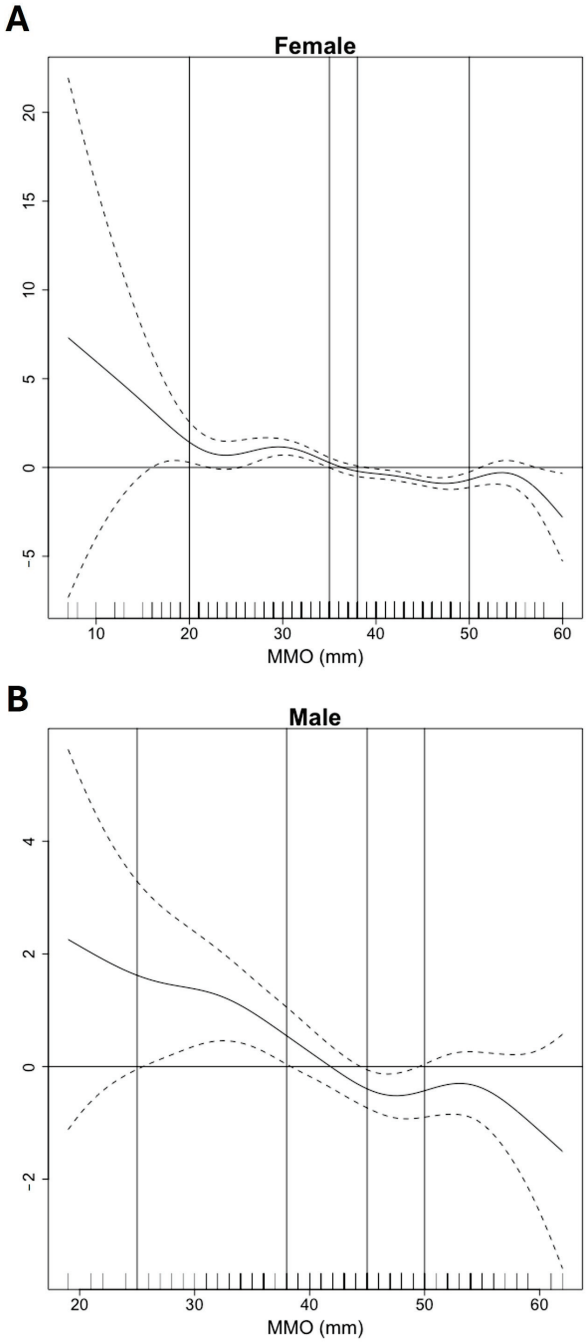

Figure 4. Functional distribution of maximum mouth opening (MMO) values among female (**A**) and male (**B**) patients with limited mouth opening (LMO (+) and without LMO (−)). Generalized Additive Model (GAM) for describing the functional form of the association between MMO and LMO variables. For statistical analysis, only the MMO values limited by the vertical lines 20 and 50 mm, respectively, were considered given the low number of cases outside this range. The risk of LMO (+) for MMO values between the 36 and 39 mm vertical lines, respectively, is undefined since the confidence bands include the zero value of the ordinate. Values below 35 and 38 mm correspond to a risk of LMO (+) for females and males, respectively. Values greater than 38 and 45 mm correspond to LMO (−) for females and males, respectively.

4. Discussion

This study emphasizes the potential for gender-specific thresholds in diagnosing LMO associated with TMDs, as it uncovers significant differences in MMO capacities between males and females. By examining MMO variations in male and female TMDs patients using flexible statistical models, this article demonstrates consistent sex-based differences that question the validity of a universal diagnostic threshold. Specifically, females displayed significantly lower MMO values, justifying a diagnostic threshold of 35 mm, while for males, 38 mm was more appropriate. Diagnostic gray zones—ranging from 36 to 37 mm for women and 38 to 42 mm for men—further reflect natural inter-individual variation and emphasize the limitations of applying a single cutoff point across all patients.

Well-established differences in craniofacial morphology and biomechanics support the biological underpinnings of these findings [35]. Males generally possess larger mandibular structures, wider condylar heads, and longer ramus lengths, contributing to a greater mandibular excursion capacity and, consequently, higher MMO values [36,37]. Women, in contrast, exhibit more gracile facial bone structure, reduced muscle cross-sectional area, and different TMJ geometry, all of which may contribute to narrower physiological ranges for mouth opening [10,36–38]. Additionally, hormonal differences influence soft tissue behavior and pain perception. Estrogen, for example, is known to increase ligament laxity and may sensitize nociceptive pathways, potentially influencing both joint mobility and pain reporting in female patients [39,40]. Beyond anatomical factors, neurophysiological and psychosocial influences are increasingly recognized as contributors to sex differences in TMDs [41]. Women are more likely to experience chronic pain syndromes and often score higher on psychological distress measures, including anxiety, depression, and somatization, all of which are linked to increased TMDs severity and functional limitation [40]. Kinesiophobia, the fear of movement due to the anticipation of pain, may limit voluntary jaw opening and perpetuate dysfunction [7,8]. This behavioral pattern, more commonly observed in women, reinforces the argument for gender-sensitive diagnostic tools [7,8]. Recent studies have highlighted the significant impact of psycho-emotional factors on TMDs. For instance, a pilot study utilizing a specialized questionnaire found that TMDs patients exhibited higher levels of psychological distress compared to healthy controls, emphasizing the need for psychological counseling in TMDs management [42]. Recently, our investigation group showed significant correlations between clinical satisfaction and factors such as patient expectations and post-treatment pain levels. Notably, the presence of depression was associated with an increased need for further TMJ treatment, highlighting the importance of addressing psychological factors in TMDs management [18]. Additionally, stress has been shown to influence TMJ status and salivary cortisol levels, particularly during high-stress periods such as exams, suggesting a direct link between stress and TMDs symptoms [43]. Another key factor is the higher prevalence and severity of bruxism among women [15]. Although bruxism is not classified as a TMDs, bruxism can result in chronic hyperactivity of the masticatory muscles, leading to fatigue, pain, and reduced MMO [44,45]. Studies have shown that women who brux are more likely to develop myofascial pain and muscle guarding, which can further restrict jaw function [15,46]. In combination with higher pain sensitivity and greater stress reactivity, this suggests a feedback loop that disproportionately affects female patients and contributes to lower MMO measurements. This study reflects the clinical reality where bruxism often coexists with TMDs, particularly in patients with myofascial pain or functional limitations.

From a clinical standpoint, the debate over threshold values for diagnosing LMO has long been contentious. MMO is typically measured as the interincisal distance, which is the space between the upper and lower central incisors when the mouth is fully opened, and used to define LMO. The DC/TMD, established by the International RDC/TMD

Consortium Network and the Orofacial Pain Special Interest Group, set the threshold for diagnosing LMO at an interincisal distance of less than 40 mm [3,4]. This value is derived as a clinical standard for identifying significant restrictions in mouth opening that may indicate TMDs, specifically in cases where disc displacement without reduction is present. According to the DC/TMD guidelines, if passive mouth opening (with assistance) remains below this 40 mm threshold, it strongly suggests the presence of LMO, making it a critical diagnostic marker for TMDs [4]. However, LMO should not be interpreted in isolation; its diagnostic value is enhanced when considered alongside other clinical findings such as joint pain, joint sounds, muscle sensitivity, and functional limitation. The support for using 40 mm in this criterion was based on a study of around 20,000 children/adolescents [3,4]. In contrast, other diagnostic systems, such as the Dijkstra classification for trismus, recognize a wider spectrum of functional limitation: mild (30–35 mm), moderate (15–30 mm), and severe (<15 mm) [6]. Mild trismus corresponds to a mouth opening of 30 to 35 mm, moderate trismus is defined by 15 to 30 mm, and severe trismus involves a mouth opening of less than 15 mm. Our findings align more closely with this graded classification and suggest that rigid dichotomous cutoffs may be clinically limiting, especially when applied without consideration of patient sex. The accuracy of MMO measurements is crucial for proper diagnosis. A recent study evaluated the reproducibility and validity of various MMO measurement techniques, highlighting the importance of standardized methods to ensure consistent and reliable assessments across different patient populations [47].

Methodologically, the use of GAMs and GLMs in this study provides strong statistical support for individualized threshold modeling. These models accommodate non-linear relationships and allow for the better estimation of probability curves across MMO values. The finding that each millimeter increase in MMO is inversely associated with the likelihood of LMO—and that this relationship is stronger when stratified by sex—supports the need for personalized diagnostic criteria. Such individualized cutoffs may help clinicians identify early-stage TMDs in male patients whose MMO remains above 40 mm, and more accurately diagnose LMO in women whose MMO, while below 40 mm, may still be within their normal range. The analysis revealed an area under the curve (AUC) of 0.69 for both males and females, indicating moderate discriminatory power. This suggests that MMO alone has some ability to distinguish between patients with and without LMO, performing better than random chance but falling short of high diagnostic accuracy. These findings reinforce the idea that MMO, while informative, may be more valuable as part of a multivariable diagnostic model that incorporates additional anatomical, functional, or psychosocial variables. The moderate AUC also supports our rationale for not relying on a single fixed threshold for diagnostic classification but instead exploring flexible, sex-specific cutoffs tailored to individual patient characteristics.

The implications of these findings extend across diagnostic, rehabilitative, and educational domains. Clinically, applying gender-specific thresholds could significantly reduce underdiagnosis in women and prevent overdiagnosis in men, enhancing diagnostic accuracy. The more accurate identification of LMO can also inform tailored rehabilitation plans, including physiotherapy, occlusal therapy, and behavioral interventions such as biofeedback or cognitive behavioral therapy (CBT) for kinesiophobia. Furthermore, patient education can be improved when normative values are presented within a personalized, gender-informed framework, fostering trust and engagement in the therapeutic process. Moreover, this approach aligns with the principles of personalized medicine, which prioritize individualized assessment and treatment planning over population-based generalizations. Future clinical guidelines for TMDs assessment may benefit from incorporating sex-specific diagnostic algorithms, especially in multidisciplinary settings involving dentists, physiotherapists, and orofacial surgeons.

This study does have limitations that impact the generalizability of its findings. Notably, the cross-sectional design restricts the ability to track the progression of MMO and LMO in TMDs patients over time, which would provide more comprehensive insight into the role gender plays in TMDs onset and prognosis. One of the limitations of this study is the inclusion of patients with various types of TMDs, including both arthrogenous (e.g., disc displacement, osteoarthrosis) and myogenous (e.g., myofascial pain) conditions. These subtypes may affect MMO through different pathophysiological pathways—structural restriction versus muscular guarding—potentially introducing clinical heterogeneity into the dataset. While this reflects the real-world diversity of TMDs presentations, future studies should consider stratifying participants by diagnostic category to allow for more specific and reliable conclusions regarding sex-based diagnostic thresholds. Another limitation is that this study included patients with self-reported or clinically suspected bruxism, which, although not classified as a TMDs, may influence masticatory muscle activity and confound the assessment of MMO. While this reflects real-world clinical presentations, it may limit the specificity of findings related solely to TMDs pathophysiology. Additionally, while this study's sample size is robust, confounding variables like age, craniofacial structure, dental occlusion, BMI, and ethnicity—which can significantly affect MMO—were not controlled. Although age was recorded, it was not incorporated into the statistical models as a covariate. These variables may influence baseline mandibular mobility and the clinical response to intra-articular interventions, particularly in relation to MMO. Their omission limits the ability to perform stratified analyses or identify subgroups with differential treatment responses. A longitudinal study approach, incorporating these factors, could offer a more nuanced understanding of MMO variations and refine gender-specific thresholds for broader populations.

Although our study did not directly evaluate the influence of age, BMI, occlusal status, or craniofacial structure on maximum mouth opening (MMO) outcomes, these factors are known to influence mandibular kinematics and are functional limitations in patients with TMDs. Age-related changes in joint elasticity, muscle tone, and intra-articular degeneration may restrict the mandibular range of motion and affect responsiveness to treatment [48]. Similarly, elevated BMI has been associated with systemic inflammation and increased mechanical load on joints, potentially limiting mandibular excursion [48,49]. Occlusal discrepancies and craniofacial morphology, including Class II or III skeletal patterns, deep bite, or mandibular retrognathism, have been shown to alter the biomechanics of the TMJ and may predispose patients to hypomobility or disc interference [50–52]. Stratifying analyses or incorporating these variables into multivariable or interaction-based models could provide a more refined understanding of patient-specific risk factors for LMO and improve the accuracy of individualized diagnostic thresholds. These variables were not fully explored in the current analysis; their potential confounding or moderating roles merit consideration in future studies. From a statistical standpoint, future studies should consider incorporating these patient-specific characteristics as covariates or interaction terms in linear mixed-effects models or ANCOVA designs. This would allow for the more refined analysis of treatment effects on MMO, helping to determine whether specific subgroups (e.g., younger patients, normo-weight individuals, or those with balanced occlusion) respond more favorably to HA+PRP interventions. Stratified analysis could also support the development of more personalized treatment algorithms in TMJ rehabilitation.

5. Conclusions

In conclusion, this study provides compelling evidence for revisiting and refining the diagnostic criteria for TMDs through a gender-specific lens. Identifying distinct thresholds for LMO in men and women highlights the limitations of a universal diagnostic cutoff

and underscores the value of incorporating anatomical, physiological, and behavioral differences into clinical assessment protocols. In this study we observed the gold standard cutoff for diagnosing MMO in female should be <35mm and for male <38mm.

While these findings are promising, they also reveal the need for more comprehensive research to validate and expand upon this work. Future studies should adopt longitudinal, multicenter designs to evaluate changes in MMO over time and across treatment stages. Tracking hormonal fluctuations, especially in relation to menstrual cycle phases and menopausal status, may provide deeper insights into the role of sex hormones in TMDs symptom expression and MMO variability. Incorporating psychometric assessments—such as measures of anxiety, depression, and kinesiophobia—can further elucidate the interplay between psychological stress and functional limitation in TMDs patients. Additionally, machine learning techniques hold potential for developing predictive models that integrate demographic, anatomical, psychological, and behavioral data to establish personalized diagnostic thresholds.

By advancing toward individualized diagnostic criteria, healthcare professionals can improve diagnostic accuracy, avoid misclassification, and deliver more effective, targeted interventions. These refinements enhance clinical outcomes and align with broader healthcare trends prioritizing precision and patient-centered care.

Applying gender-specific thresholds for LMO can improve diagnostic accuracy, reduce misclassification, and lead to more tailored treatment planning for TMDs patients. Recognizing that men and women differ in their physiological mandibular capacity allows clinicians to avoid underdiagnosis in females and overtreatment in males. These findings can directly inform clinical protocols for diagnosis, rehabilitation, and patient education, contributing to more precise and individualized care in orofacial pain management.

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Abbreviations

AUC: area under the curve; BMI: Body Mass Index; CBT: cognitive behavioral therapy; DC/TMD: Diagnostic Criteria for Temporomandibular Disorders; GAM: Generalized

Additive Model; GLM: Generalized Linear Model; IQR: interquartile range; LMO: limited mouth opening; MMO: maximum mouth opening; ROC: receiver operating characteristic; TMDs: temporomandibular disorders; TMJ: temporomandibular joint.

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Double-Puncture Arthrocentesis in Arthrogenous TMJ Disorders: Bioviscosupplementation vs. Viscosupplementation a Randomized Controlled Trial

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Abstract: Background/Objectives: Intra-articular injections of hyaluronic acid (HA) or platelet-rich plasma (PRP) have been used in the treatment of temporomandibular joint (TMJ) arthrocentesis to improve lubricative properties and influence regenerative processes. This study aimed to evaluate the potential clinical benefits of complementary bioviscosupplementation with hyaluronic acid (HA) and platelet-rich plasma (PRP) in patients undergoing double-portal TMJ arthrocentesis. **Methods:** A total of forty-six patients (33 females, 13 males; mean age of 45.83 ± 20.62 years) with arthrogenous temporomandibular disorders, identified through clinical and imaging examinations, were randomized into HA+PRP (23 patients) or HA-alone (23 patients) groups. The primary outcome variable was TMJ arthralgia; the secondary outcome was maximum mouth opening (MMO). All the outcome variables were assessed preoperatively (T0) and at several follow-ups (T1—1 month, T2—3 months, T3—6 months, T4—12 months follow-up). **Results:** The HA+PRP group presents lower TMJ arthralgia levels than the HA group at every follow-up moment ($p < 0.05$, r ≈ 0.3). At T3 and T4, the HA+PRP group presented a higher MMO average than the HA group ($p = 0.03$ and $p = 0.02$; r ≈ 0.3). At T4, the HA group's success rate was lower than the HA+PRP group (65% vs. 96%), and a higher number of postoperative reinterventions were observed (35% vs. 4%). **Conclusions:** In this study, complementary intra-articular bioviscosupplementation (HA+PRP) following double-portal TMJ arthrocentesis was associated with better clinical outcomes regarding TMJ arthralgia reduction, MMO improvement, and reduced risk of future TMJ reintervention.

Keywords: hyaluronic acid; platelet-rich plasma; temporomandibular joint; arthrocentesis; osteoarthritis; regenerative medicine; pain management

1. Introduction

Temporomandibular disorders (TMDs) are defined as diseases and disorders related to alterations in the structure, function, or physiology of the masticatory system and that

may be associated with other systemic and comorbid medical conditions [1]. Recent meta-analytic evidence suggests that TMDs affect approximately 34% of the global population, although prevalence rates vary by region and age group. In Europe, for example, the prevalence is around 29%, with the highest rates observed among adults aged 18–60 years (41%) compared to younger (<18 years, 18%) and older (>60 years, 32%) populations, underscoring its significance as a public health concern [2].

TMDs are frequently characterized by structural changes in articular disc–condyle coordination, including disc displacements (with or without reduction), sometimes associated with inflammatory or degenerative changes in the synovia/cartilage and surrounding tissues, such as osteoarthrosis (OA) [3]. Common symptoms and signs include joint pain, mandibular movement restriction, impaired mastication, and reduced quality of life.

Treatment approaches for TMDs include pharmacological treatment, physical therapy, splint therapy, arthrocentesis with medication injection, arthroscopy, or open surgery. TMJ arthrocentesis is a minimally invasive treatment option that has emerged as a valuable technique to manage intra-articular symptoms [4]. Double-portal arthrocentesis enables effective TMJ lavage through the application of hydraulic pressure, reducing pain levels by washing out pro-inflammatory proteins and increasing mandibular mobility by releasing adhesions in synovial fluid [5]. However, while effective for symptom control, this technique alone lacks TMJ regenerative potential [6].

To address this limitation, intra-articular injections of hyaluronic acid (HA) and platelet-rich plasma (PRP) have been used with arthrocentesis to improve patient outcomes [5,7,8]. HA is a polysaccharide glycosaminoglycan found in cartilage and synovial fluid and is largely responsible for the lubricative properties in humans [9]. Chondrocytes and synoviocytes produce it and play a vital role in elasticity and viscosity, contributing to synovial fluid's elasticity and shock-absorbing function [10]. In degenerative conditions, such as TMJ OA, a reduction in lubrication was detected due to a decrease in the concentration and molecular weight of HA [10,11]. HA injections have been proven to be effective in reducing TMJ pain [12,13]. However, some studies have shown that viscosupplementation with HA did not have a beneficial effect compared to other treatments, such as corticosteroid injections [14,15]. PRP is an autologous blood product rich in platelets and growth factors, including PDGF, TGF-β, VEGF, and IGF, which stimulates cell proliferation, differentiation, and angiogenesis [16]. These regenerative processes are crucial in modulating inflammation, supporting chondrocyte viability, and restoring extracellular matrix composition [17]. Intra-articular PRP has shown promise in promoting cartilage repair and synovial healing, especially concerning early TMJ osteoarthritic changes [18].

While PRP and HA have been independently studied in TMJ therapy, recent studies have investigated them as a combination therapy (HA+PRP) for their potential synergistic effects. In a study by Wenxing Yu et al., HA and PRP were used in the treatment of knee osteoarthritis, resulting in improved outcomes in terms of pain, function, and stiffness at 52 weeks [19]. While the knee and TMJ differ in regard to their anatomical structure and mechanical function, they share common degenerative features, such as cartilage degradation, synovial inflammation, and reduced intra-articular lubrication. These parallels provide a rationale for examining whether similar biologic therapies may benefit patients with TMJ disorders. Emerging data in the TMJ area suggest that combining HA with PRP may yield enhanced outcomes in terms of pain reduction, joint sounds, and mastication efficiency [20,21].

The combined use of HA and PRP following TMJ arthrocentesis remains underexplored in the literature, and only a few randomized trials have systematically evaluated its long-term effectiveness. Recent systematic reviews have examined the benefits of PRP and PRF (platelet-rich fibrin) in TMJ intra-articular therapy, confirming their safety and efficacy

in regard to pain reduction and functional improvement [21,22]. Despite the growing interest in autologous biologics for TMDs, there remains a lack of high-quality randomized controlled trials directly comparing HA+PRP combination therapy to HA alone, following double-portal arthrocentesis. Most existing studies either evaluate these agents in isolation or without a rigorous methodological framework, often lacking control groups, long-term follow-up, or standardized outcome measures. This trial is among the first to address these gaps, employing a randomized, controlled design to evaluate the synergistic effects of HA and PRP on pain, joint function, and the potential for reducing reinterventions. Our study, therefore, contributes important clinical evidence that may inform and optimize minimally invasive treatment protocols for patients with arthrogenous TMDs.

The present clinical study investigates the efficacy of intra-articular infiltration of combined HA+PRP therapy, following double-portal TMJ arthrocentesis. The study's primary objective is to compare the clinical effectiveness of HA+PRP versus HA alone (viscosupplementation) in reducing the pain intensity in patients with arthrogenous TMDs. The secondary objectives include evaluating improvements in mandibular function (maximum mouth opening) and the need for reintervention during the follow-up period. It is hypothesized that arthrocentesis combined with HA+PRP infiltration will produce superior clinical outcomes across these domains compared to HA alone.

2. Materials and Methods

2.1. Study Design

A controlled randomized parallel-group clinical trial (clinicaltrials.gov, code NCT06457698) was conducted at the Instituto Português da Face from 1 June 2022 to 1 February 2024. The study adheres to the current legislation, and the principles outlined in the Declaration of Helsinki, with approval given by the Instituto Português da Face ethics committee (PT/IPFace/RCT/0245/14). All the patients signed an informed consent form.

The study was initially designed to include 50 patients (25 in each group). During the study, 4 patients did not conform with the follow-up visits (drop-out rate = 8%). Patients of both genders with a TMD diagnosis and indication for TMJ arthrocentesis were recruited. The inclusion criteria included: (1) age > 18 years; (2) history of conservative treatment for TMDs without significant improvement for at least three months; (3) clinical diagnosis (persisting daily TMJ pain VAS $\geq$ 4, TMJ sounds, limited mouth opening, painful chewing) and imaging of unilateral or bilateral arthrogenous disorder; (4) radiological findings that most components of the joint were salvageable (assessed by D.F.A) [23]; and (5) magnetic resonance imaging (MRI) and computed tomography (CT) documenting TMJ internal derangement early osteoarthritis alone or combined with other disorders (arthralgia, disc displacement with reduction (DDwR), disc displacement without reduction (DDwoR), disc perforation, bony osteophytes, condylar resorption). The exclusion criteria included: (1) any history of previous TMJ surgical interventions or any facial trauma within the last 4 weeks before the study [24,25]; (2) concomitant surgery on the contralateral TMJ at the time of the study intervention (note, prior contralateral TMJ surgery was not an exclusion criterion if the joint was clinically stable and asymptomatic); (3) severe systemic medical conditions that could interfere with joint healing or the inflammation response, including uncontrolled diabetes mellitus, autoimmune diseases (e.g., rheumatoid arthritis, lupus), bleeding or coagulation disorders, and active malignancy [25,26]; (4) a documented psychiatric illness, including major depressive disorder, bipolar disorder, or schizophrenia, based on the patient's medical records or self-reported [24]; and (5) pregnancy [27]. No conservative treatment was applied during the follow-up period.

2.2. Outcome Evaluation

A diagnosis of TMDs was established according to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), using the validated English version [24,28]. All clinical examinations and diagnoses were performed by D.F.A, an experienced clinician trained in the DC/TMD protocol. All the outcomes were assessed preoperatively (T0) and postoperatively (T1—1 month, T2—3 months, T3—6 months, T4—12 months follow-up).

The primary outcome was TMJ arthralgia (VAS, 0–10) [29]. The level of TMJ arthralgia was registered according to the level of pain experienced during palpation of the lateral pole or around the lateral pole or the level of pain on maximum unassisted or assisted mouth opening, right or left lateral movements, or protrusive movements, following the DC/TMD guidelines [24,28]. The patient selected a score for each side, using a 10-point VAS, from 0 representing no pain to 10 representing severe pain. Arthralgia was reported if verified according to (1) a history of pain in the TMJ area and (2) pain modified with jaw movement, function, or parafunction [24,28]. The secondary outcome evaluated was the maximum mouth opening (MMO, mm). MMO was measured, using a certified ruler, between the incisal edge of the maxillary and mandibular central incisors (TheraBite® Jaw ROM Scale). At the end of the study, how many patients relapsed and needed a new intervention was recorded. The success rate of the procedure was graded as successful or a failure, according to Table 1, as described by Eriksson, et al. [30].

Table 1. Criteria for classification of treatment success rate.

Criteria	Description
Successful	No pain or only mild pain level (0–2 on a 0–10 VAS) and MMO $\geq$ 35 mm
Acceptable	No pain or only mild pain level (VAS $\leq$ 2 on a 0–10 scale) and MMO $\geq$ 30 mm and < 35 mm
Failure	Pain constant or moderate (3–10 on a 0–10 VAS) and/or MMO $\leq$ 30 mm

2.3. Randomization

The subjects were randomly assigned to two groups: HA injection or HA injection + PRP. Codes were prepared and distributed in regard to the two groups for the allocation. The treatment assignment was made by an independent person (nurse), who was not involved in performing any other procedures in the study, such as the preoperative injection or the TMJ arthrocentesis. An envelope containing a code was selected and assigned to the patient. The surgeon (D.F.A) was unblinded because he could distinguish between the color of the two viscosupplements (crystalline for HA alone, amber yellow for HA+PRP).

2.4. Treatment Protocol

2.4.1. Double-Puncture TMJ Arthrocentesis Under Local Anesthesia

Local anesthesia was administered, using lidocaine with epinephrine (1:80,000), to block the auriculotemporal nerve. The first puncture involved carefully palpating the lateral rim of the glenoid fossa. A 5 cc syringe was prepared, with a mixture of 3 cc of Ringer lactate and 1.8 cc of lidocaine with epinephrine. A 21 G needle connected to the syringe was gently inserted into the TMJ skin area. Once the needle tip made contact with the posterior slope of the eminence of the upper joint compartment, it was oriented vertically to access the upper compartment, allowing the surgeon to perform a validation step, namely performing a pumping action and observing active and passive pumping, which is crucial for patient safety. For the second puncture, the joint was maintained at maximum distention with continuous inflow through the first portal, while the surgeon felt the insufflation/distention in the anterior joint area. Subsequently, the second portal was established using a 21 G needle, with successful fluid outflow. After completing an

effective circuit, joint washing was carried out using intra-articular hydraulic pressure, with at least 150 mL of Ringer lactate solution.

2.4.2. Hyaluronic Acid and Platelet-Rich Plasma Preparation

The protocol was followed according to the guidelines for the use of Endoret® (BTI Biotechnology Institute, Vitoria-Gasteiz, Álava, Spain). Briefly, 32 mL of venous blood per joint was collected and added to four 8ml collection tubes, containing sodium citrate (Endoret®, BTI Biotechnology Institute). Then, the blood was centrifugated (Endoret System V Centrifuge®, BTI Biotechnology Institute) at 800 rpm for 8 min at room temperature. After centrifugation, 3 layers were perceptible: (1) a layer with platelet-rich plasma and growth factors; (2) a layer with white blood cells; and (3) a layer corresponding to red blood cells. Then, the total plasma volume was calculated, and the plasma corresponding to the first fraction (the low platelet fraction) was carefully aspirated. The second fraction of the first layer corresponding to PRP, above the white blood cell layer, was carefully removed and transferred into new tubes.

2.4.3. Hyaluronic Acid and Platelet-Rich Plasma Administration

Both groups received viscosupplementation (HA group)/bioviscosupplementation (HA+PRP) after completing the articular lavage, using the first portal to access the joint. In the HA+PRP group, ten minutes before mixing with HA, a calcium chloride-rich activator (Endoret®, BTI Biotechnology Institute, Vitoria-Gasteiz, Álava, Spain) was added to the PRP. The mixture of activated PRP with HA was then carried out at a ratio of 1 cc of low molecular weight HA (Suplasyn®, 20 mg/mL, Inverin, County Galway, Ireland) + 1 cc of PRP and introduced in the joint through the first portal [31–35].

2.5. Statistical Analysis

All the statistical procedures were performed using IBM SPSS Statistics 26.0.0 (IBM Co., Armonk, New York, NY, USA) and GraphPad Prism v. 10.0 software (GraphPad Software). The sample size calculation was performed using G*Power v. 3.1.9.7. An effect size of d = 0.80 (large), $\alpha = 0.05$, and power = 0.95 were assumed, resulting in a required total sample size of 54 participants (27 per group). A final sample of 46 participants (23 per group) was included, yielding an estimated statistical power of 91.4%, which was considered acceptable for the study objectives. Given the non-normal distribution of the variables, as assessed by the Shapiro–Wilk test, non-parametric statistical tests were applied. The Friedman test was used to assess the within-group differences over time. To compare differences between the two groups (HA vs. HA+PRP) at each time point, the Mann–Whitney U test was used. The effect sizes were calculated using Cohen's *r* (continuous variables) or *Cramér's V* (categorical variables), computed as small ($r \approx 0.10$), medium ($r \approx 0.30$), or large ($r \geq 0.50$) effect sizes, according to relevant guidelines [36,37]. Statistical significance was set at $p < 0.05$.

3. Results

Forty-six patients with a mean age of 45.83 ± 20.62 years old (range 18–88) completed the study, resulting in 83 operated joints. Thirty-three patients were females (71.74%) (Table 1). The preoperative arthrogenous TMD diagnoses were: (1) osteoarthrosis (n = 83 joints); (2) arthralgia (n = 40 joints); (3) disc displacement with reduction (DDwR) (n = 32 joints); (4) disc displacement without reduction (DDwoR) (n = 29 joints); (5) osteophytes (n = 5 joint); (6) disc perforation (n = 3 joint); and (7) condylar resorption (n = 3 joints) (Table 2). There were no significant differences in the baseline characteristics between the HA and HA+PRP groups (Table 2). For all the diagnoses and demographic variables,

the effect sizes (*Cramér's V* and Cohen's r) were negligible, except for the DDwoR, which showed a small effect size ($V = 0.124$).

Table 2. Baseline characteristics of the patients. HA: hyaluronic acid; PRP: platelet-rich plasma; *p*: *p*-value. The Mann–Whitney U test was used for continuous variables; Fisher's exact test was used for categorical variables. The effect sizes are reported as Cohen's r for non-parametric comparisons and *Cramér's V* for categorical associations. Confidence intervals (95%) are provided where applicable. A significance level of $p < 0.05$ was considered statistically significant.

	Total (n = 46) (83 Joints)	**HA (n = 23) (38 Joints)**	**HA+PRP (n = 23) (45 Joints)**	***p*, *Cramér's V or Cohen's r [95% CI] r or V***
Demographic data				
Age M ± SD	45.83 ± 20.62	46.87 ± 23.12	44.78 ± 18.25	0.84, 0.03 [−0.26, 0.32]
Sex (F)	33 (71.74%)	15 (65.22%)	18 (78.26%)	0.51, 0.15 [−0.15, 0.42]
Diagnosis				
Osteoarthrosis	83 (100.00%)	38 (100.00%)	45 (100.00%)	1.00, 0.00 [0.00, 0.00]
Arthralgia	40 (48.19%)	19 (50.00%)	21 (46.67%)	0.83, 0.01 [−0.21, 0.22]
DDwR	32 (38.55%)	15 (39.47%)	17 (37.78%)	0.99, 0.01 [−0.21, 0.22]
DDwoR	29 (34.94%)	16 (42.11%)	13 (28.89%)	0.25, 0.12 [−0.09, 0.33]
Osteophytes	5 (6.02%)	2 (5.26%)	3 (6.67%)	0.99, 0.05 [−0.17, 0.26]
Disc Perforation	3 (3.61%)	2 (5.26%)	1 (2.22%)	0.51, 0.08 [−0.14, 0.29]
Condylar Resorption	3 (3.61%)	2 (5.26%)	1 (2.22%)	0.51, 0.08 [−0.14, 0.29]

The mean visual analogue scale (VAS) for TMJ arthralgia before the treatment was 4.46 ± 2.32 in the HA group and 5.63 ± 2.78 in the HA+PRP group. The mean MMO was 40.10 ± 10.48 mm in the HA group and 42.45 ± 7.02 mm in the HA+PRP group. There were no significant differences between the two groups in regard to the preoperative outcomes (Figures 1 and 2).

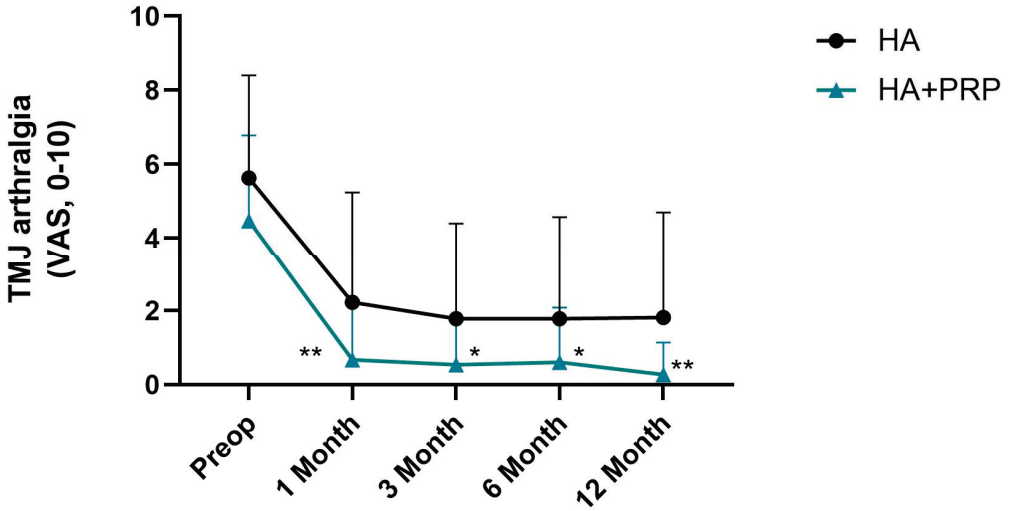

Figure 1. Statistical test results for temporomandibular joint (TMJ) arthralgia comparing the hyaluronic acid (HA) and HA + platelet-rich plasma (PRP) groups. TMJ arthralgia was assessed using the visual analog score (VAS, 0–10). Error bars indicate mean (M) ± standard deviation (SD); the Mann–Whitney U test was used to compare each time frame; * $p < 0.05$, ** $p < 0.01$ when compared to the HA group. HA: hyaluronic acid; PRP: platelet-rich plasma.

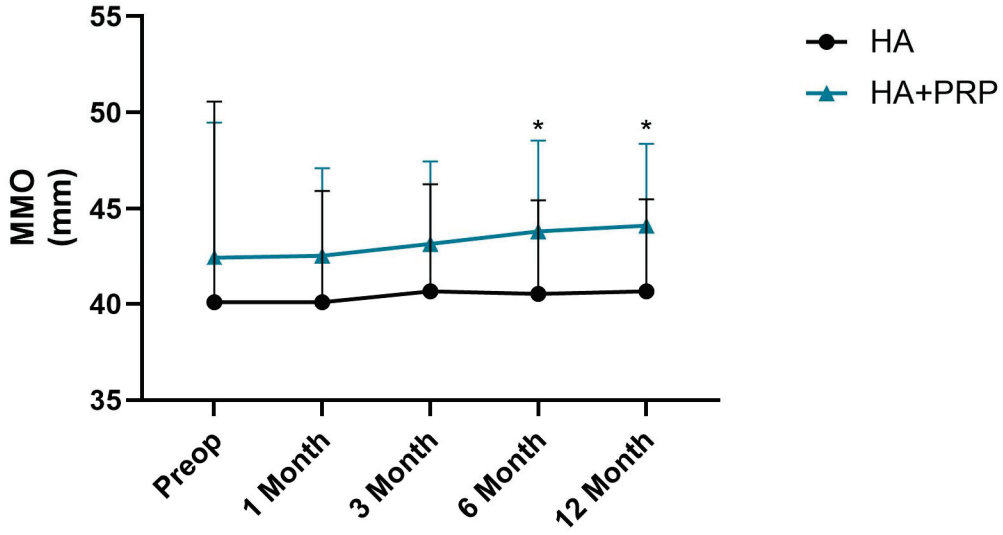

Figure 2. Statistical test results for maximum mouth opening (MMO) comparing the hyaluronic acid (HA) and HA + platelet-rich plasma (PRP) groups. Error bars indicate mean (M) ± standard deviation (SD); the Mann–Whitney U test was used to compare each time frame; * $p < 0.05$, when compared to the HA group. HA: hyaluronic acid; PRP: platelet-rich plasma; MMO: maximum mouth opening.

Significant differences were found within both the HA and HA+PRP groups across the time points (preoperative, 1 month, 3 months, 6 months, and 12 months) in regard to pain (VAS) ($\chi^2(4) = 46.51$, $p < 0.001$. and $\chi^2(4) = 87.25$, $p < 0.001$). These results suggest that the pain (VAS) experienced changed significantly over time in both groups, indicating that both interventions had an effect on pain over the follow-up period.

In postoperative phase (T1), a significant reduction in the VAS for TMJ arthralgia was observed in both groups (Figure 1). At T1, the HA+PRP group presented a lower TMJ arthralgia score compared to the HA group (Figure 1, 0.67 ± 1.51 vs. 2.22 ± 3.01; U = 291.50, Z = −2.21, $p = 0.03$). Cohen's r was 0.29 [0.03, 0.51], indicating a medium effect. At T2 and T4, the statistically significant differences remained similar to T1 between the two groups (Figure 1, U = 296.00, Z = −2.11, $p = 0.03$; U = 287.50, Z = −2.56, $p = 0.01$, respectively). Cohen's r was 0.280 [0.02,0.50] and 0.339 [0.09,0.55], respectively, indicating a medium effect.

In regard to the MMO outcome, no significant differences between the HA and HA+PRP groups were observed across the time points ($\chi^2(4) = 1.40$, $p = 0.84$ and $\chi^2(4) = 5.16$, $p = 0.27$). Comparing the different follow-up moments, no statistical differences were seen at T1 and T2 between the two groups (Figure 2). At T3 and T4, the HA+PRP group presented a significantly higher MMO average compared to the HA group (Figure 2, 43.83 ± 4.72 and 44.13 ± 4.25 vs. 40.52 ± 4.92 and 40.67 ± 4.83, U = 151.00, Z = −2.13; $p = 0.03$ and U = 150.00, Z = −2.16; $p = 0.03$). Cohen's r was 0.32 [0.03,0.56] for both comparisons, indicating a medium effect.

At the end of the study, the global success rate was 65.22% (n = 15) in the HA group, while it was 95.65% (n = 22) in the HA+PRP group (Table 3, $p = 0.047$). After 12 months (T4), eight patients (34.78%) had an indication for a new intervention. Seven patients were in the HA group, and one patient was in the HA+PRP group (Table 3, $p = 0.047$). The effect size was moderate (*Cramér's V* = 0.32), favoring the HA+PRP group in both analyses. No harm or unintended effects were observed in either group. Moreover, no adverse events or complications related to TMJ arthrocentesis and the intra-articular injections were observed or reported throughout the study period.

Table 3. Success rate and need for reintervention in terms of double-puncture TMJ arthrocentesis with hyaluronic acid (HA) compared to HA + platelet-rich plasma (PRP). Fisher's exact test was used for the categorical variables. Effect size is reported as *Cramér's V*. Confidence intervals (95%) are provided where applicable. A significance level of $p < 0.05$ was considered statistically significant. HA: hyaluronic acid; PRP: platelet-rich plasma; *p*: *p*-value.

	Success Rate			**Need for Reintervention**	
	Success: Acceptable N (%)	**Failure N (%)**	***p*, *Cramér's V***	**N (%)**	***p*, *Cramér's V***
HA	15 (65.22%)	8 (34.78%)	0.047, 0.32	8 (34.78%)	0.047, 0.32
HA+PRP	22 (95.65%)	1 (4.35%)	[0.24–0.33]	1 (4.35%)	[0.24–0.33]

4. Discussion

The primary objective of this randomized clinical trial was to compare the clinical efficacy of bioviscosupplementation (HA+PRP) versus viscosupplementation with HA alone, following double-portal TMJ arthrocentesis, in reducing pain and improving mandibular function in patients with arthrogenous TMDs. Our hypothesis was that the combination therapy would produce superior clinical outcomes across all the assessed domains. The results of the study confirmed this hypothesis: patients in the HA+PRP group demonstrated significantly greater reductions in TMJ arthralgia, improved MMO at long-term follow-up, and a lower incidence of postoperative reintervention compared to the HA-only group. Recent developments in regenerative medicine have led to exploring PRP and HA as potential adjunctive therapies in TMJ arthrocentesis. The combination of PRP and HA holds promise due to their complementary mechanisms of action. The term HA "viscosupplementation" indicates the restoration of viscoelastic properties, such as lubrification, elasticity, and anti-inflammatory effects. The term "biosupplementation" refers to the use of biological agents to stimulate tissue repair and regeneration. Clinical studies have demonstrated that PRP is a novel therapeutic agent with several "biosupplementation" therapeutic advantages in treating TMDs, such as joint restoration, cartilage repair, and normalization of endogenous HA synthesis, slowing down OA progression [38]. Marmotti, et al. [39] found that adding HA to PRP could effectively promote chondrocyte proliferation and improve cartilage repair. Similarly, Anitua [40] revealed that PRP may have therapeutic effects in attenuating joint pathology, regarding cartilage healing, chondrogenesis enhancement, and the stimulus of cell proliferation, migration, and differentiation, making it a promising procedure for repairing and replacing damaged articular tissues. HA preparations have relatively short intra-articular half-lives due to rapid clearance and enzymatic degradation by hyaluronidases [38]. However, when combined with PRP, evidence suggests that their therapeutic impact can be extended through synergistic mechanisms. In some studies, the clinical benefits of PRP are maintained for one year after intra-articular injections in patients with knee pain [41]. Previous studies have shown that PRP may enhance HA's protective effects by improving chondrocyte viability and stimulating extracellular matrix synthesis, thereby contributing to prolonged joint lubrication and anti-inflammatory action [6,38]. Furthermore, this study states that HA lubrification and anti-inflammatory actions might facilitate the distribution and persistence of PRP healing factors within the joint space, concluding that this synergistic interplay between PRP regenerative and anti-inflammatory properties and HA lubricating effects can lead to long-term pain relief and functional improvements [6].

Other studies have also explored the role of platelet-rich fibrin (PRF) in the management of TMJ disorders. Both PRP and PRF reduced pain and improved mandibular mobility in TMJ osteoarthritis [22,42]. Additionally, studies, such as those by Harba, et al. [21,43], confirm the safety and regenerative potential of intra-articular injections of autologous

blood products in TMD treatment. These findings support our approach and emphasize the growing interest in biological therapies for TMJ conditions.

The benefits of adjuvant medications, such as HA and PRP, following TMJ arthrocentesis, remain controversial. It is worth mentioning that the literature reveals controversy regarding the superiority of arthrocentesis with supplementation therapy compared to arthrocentesis alone [20]. While increasing evidence supports the use of PRP combined with HA in the treatment of knee osteoarthritis [19,44], their efficacy and mechanisms of action in regard to the TMJ may differ due to joint-specific anatomical, functional, and biochemical environments. Therefore, TMJ-specific evidence is essential before generalizing findings across joints. A recent meta-analysis by Simental-Mendìa et al. revealed that activated PRP was more effective than non-activated PRP in improving pain and function in patients with osteoarthritis (primarily knee OA), but not specifically in regard to TMDs [45]. Platelet activation with calcium chloride ($CaCl_2$) induces a less compact fibrin matrix, facilitating a gradual release of growth factors over a seven-day period. This promotes cell migration and wound healing. This effect can be harnessed in autologous gels or scaffolds to ensure the sustained release of growth factors in surgical wound repair. To simplify, activating platelets with calcium chloride stabilizes the release of growth factors, increasing the duration of their effects [46].

Arthrocentesis has long been established as a conservative and minimally invasive approach to the treatment of TMDs. Double-puncture arthrocentesis is a highly safe and effective procedure, facilitating the removal of inflammatory tissue degradants, and its effectiveness in improving TMD outcomes is reported in several articles [5,47]. According to previous studies, the lavage of inflammatory mediators and the lysis of fibrous adhesions between the disc and the glenoid fossa make it a widely accepted and clinically effective treatment in managing TMDs [5,20,48]. Diraçoğlu, et al. [48] compared arthrocentesis with non-surgical treatment modalities, demonstrating that although non-surgical treatment can be beneficial in managing internal derangements, arthrocentesis was proven to have better results regarding the reduction in TMJ pain levels. Gurung, et al. [32] compared arthrocentesis alone with arthrocentesis, followed by HA infiltration. The authors observed that the use of combined therapy was found to be promising and superior to arthrocentesis alone. Al-Moraissi, et al. [49] concluded that minimally invasive procedures deserve to be implemented as efficient first-line treatments or should be considered early on, in other words, as soon as the patient does not show a clear benefit from the initial conservative treatment.

Applying combined supplementation to arthrocentesis in managing TMJ internal derangements has generated increasing interest in recent years. From 2017 to 2023, HA was the most common topic in scientific publications focused on injectables administered into TMJ cavities. However, in the same period, there was a significant upward trend in published primary studies focused on infiltration with PRP preparations in treating TMDs [50]. Cömert Kiliç, et al. [51] conducted a study comparing intra-articular infiltration with PRP with the infiltration of HA, independently, following TMJ arthrocentesis. A group of 49 patients suffering from TMJ OA were divided randomly into two groups, treated with arthrocentesis, followed by intra-articular infiltration with PRP or HA, independently. The outcomes evaluated included VAS pain and MMO. The authors concluded that although both treatment techniques resulted in significant clinical improvements in the VAS and MMO, no statistically significant difference was observed between both groups, suggesting that arthrocentesis plus PRP infiltration was not superior to arthrocentesis plus HA [51].

In our study, we observed statistically significant improvements in TMJ arthralgia (VAS) in both groups; however, the HA+PRP group consistently outperformed the HA-only group in the long term. While the differences were statistically significant, the observed effect sizes (r between 0.28–0.33) indicate moderate clinical relevance. These results suggest

that the advantage of HA+PRP, though meaningful, may be modest in magnitude at the individual level. In regard to the MMO outcome, no significant differences were seen in the early postoperative stages. Nevertheless, in the latter stages (6 and 12 months post-operation), the HA+PRP group presented higher MMO averages. The effect size for these comparisons was also moderate ($r = 0.32$), supporting a clinically relevant, although not dramatic, benefit. This study corroborates previous studies, as it shows that HA has promising and reliable short-term clinical efficacy in treating TMDs, the postoperative efficacy decreased compared to HA+PRP in combination. In contrast, 6 and 12 months after treatment with the combined therapy, HA+PRP remains significantly effective, with a clear advantage over using HA independently. Additionally, after 12 months (T4), eight patients (34.78%) had an indication for a new intervention, (eight vs. one patient from the HA and HA+PRP group, respectively). This can be explained by PRP's capacity to promote tissue repair and regeneration, reducing the likelihood of recurrent symptoms and diminishing the need for frequent interventions [51]. At the end of our study, treatment was considered to be successful in 15 patients (65.22%) in the HA group, while in the HA+PRP group, in 22 patients (95.6%). Likewise, the significant reduction in reintervention rates and increased success rate in the HA+PRP group (*Cramér's V* = 0.321) suggests a meaningful reduction in long-term treatment failure. Our study emphasizes that viscosupplementation with HA alone versus bioviscosupplementation (HA+PRP) has positive effects regarding improvements to functional impairments, MMO, and pain reduction, and a reduced risk of reintervention in patients suffering from intra-articular TMDs. Based on our knowledge, Asadpour, et al. [20] were the first to publish an investigation regarding the clinical efficacy of such treatment and a comparison in terms of arthrocentesis, followed by intra-articular infiltration of PRP, HA, and a combined therapy with HA+PRP, in TMD patients. A total of 30 patients were assessed at six months post-treatment. The established results indicated that although there was an improvement in the clinical outcomes in all the groups, the authors concluded that combined HA+PRP infiltration following arthrocentesis was shown to be more effective than infiltration with HA or PRP independently in the management of TMJ OA. Accordingly, our findings support the hypothesis that combined therapy with HA+PRP infiltration following arthrocentesis can have a significant effect on pain reduction and an increase in the function and MMO in patients with a diagnosis of internal derangements. A study conducted by Hegab, et al. [52] concluded that arthrocentesis with PRP injection exhibits better long-term results, whereas HA injections yield better short-term results. Similarly, Harba, et al. [21] corroborated our results and showed that combined HA+PRP treatment significantly improves the symptoms for patients with TMDs compared to HA alone. Although it was proven that HA was independently effective in alleviating TMJ symptoms in all the follow-up periods, including long-term follow-ups, the combined therapy provided better results regarding the decrease in the mean pain score, improvement in the MMO, and better masticatory efficiency. Taking all the previous findings together, it seems that the regenerative effects associated with PRP enhance the long-term improvements in TMJ health and function. Furthermore, combined HA+PRP has been shown to obtain highly satisfactory long-term clinical outcomes compared to HA independently.

One of the significant limitations of our study is the absence of a group treated with PRP alone following arthrocentesis, as well as the lack of a control group undergoing arthrocentesis alone. However, based on recent studies [20,51,53], which have already demonstrated the efficacy of alone therapy (HA and PRP) compared to arthrocentesis alone, the inclusion of these control groups was deemed non-essential for the primary aim of our trial. Another limitation is the absence of a needle-only (sham or dry-needling) control group, which could have helped isolate the mechanical or neuromodulatory effects of joint

injection itself, effects known to occur via local stimulation, similar to dry needling or acupuncture. The decision to exclude a placebo group was based on ethical considerations, as intra-articular penetration without therapeutic intent would involve unnecessary risk. Future studies may consider a three-arm design, including HA, PRP, and placebo/sham groups, to further clarify the independent contributions of the biological and mechanical components in TMJ treatment. Large sample sizes and long-term effects are equally significant in establishing evidence of the long-lasting benefits of combined therapy. Hereupon, incorporating a more extended follow-up period and enrolling a more significant number of patients will be beneficial in evaluating the efficacy of combined therapy in managing and treating intra-articular TMDs. The potential synergy between PRP and HA warrants further investigation through clinical studies that assess their combined effects on pain relief, functional outcomes, and patient satisfaction.

Taken together, these findings align with our results, supporting the view that combination therapy offers both statistical and clinically relevant benefits in pain relief, joint mobility, and a reduction in the need for reinterventions. However, the effect sizes observed in our study were moderate, highlighting the importance of tempered interpretation and the need for further high-quality trials, with larger sample sizes.

5. Conclusions

In this study, intra-articular bioviscosupplementation (HA+PRP) injection, following double-puncture TMJ arthrocentesis, had better clinical outcomes regarding TMJ pain reduction, MMO improvement, and functional improvement than HA only. Although statistically significant differences were observed, the corresponding effect sizes were generally moderate, indicating a clinically relevant, but not intense, benefit at the individual level. A reduced risk of future TMJ reintervention was observed in the bioviscosupplementation group. Bioviscosupplementation aims to utilize biological mechanisms to stimulate tissue regeneration. Furthermore, these techniques aim to regenerate damaged tissues, rather than merely alleviating the symptoms, as conventional analgesic pharmacology does. This combined therapy can play an important role in long-term clinical efficacy managing intra-articular TMDs. While the findings are encouraging, they should be interpreted cautiously due to the sample size and the absence of a PRP-only or placebo group. This study contributes to the growing body of evidence supporting the combined use of PRP and HA in managing arthrogenous TMDs and may inform future clinical guidelines. However, larger, multicenter trials with longer follow-up periods and broader outcome assessments are needed to confirm the long-term clinical significance of this approach.

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Informed Consent Statement: Informed consent was obtained from all the subjects involved in the study. Written informed consent was obtained from the patient(s) to publish this paper.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare that there are no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Clinical Manifestations of Temporomandibular Disorders and Their Relationship with Sleep Disturbances and Emotional Disorders in a Spanish Pediatric Population: A Cross-Sectional Study

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Abstract: The etiology of temporomandibular disorders (TMDs) has been linked to various factors, including functional and psychological factors, which makes it difficult to identify associations between a single etiological factor and the signs and symptoms of TMDs. **Objectives**: This study aimed to describe the presence of TMD symptoms and their relationship with sleep disturbances and emotional disorders in children and adolescents. **Methods**: This observational study included Spanish children aged between 8 and 13 years. The measurement instruments consisted of the BRUNI survey for sleep disorders and the Educational-Clinical Questionnaire: Anxiety and Depression (CECAD) survey. A clinical examination was subsequently performed following the DC/TMD guidelines for diagnosing TMDs. Frequencies, means, and standard deviations were applied, along with the prevalence ratio as a measure of association and the chi-square test. The significance level was set at 5%. **Results:** A total of 128 participants participated in the study with a mean age of 10.89 (±2.15) years. The prevalence of TMDs was 54%, while the most common symptoms were muscle pain at 26%, joint pain at 14%, and a combination of both at 14%. Children who presented muscle pain had a mean anxiety score of 44.87 (±11.85), whereas those without symptoms had a mean score of 36 (±10.78, and 0.03 *p*-value). The BRUNI index revealed that 78.13% of patients with TMDs had difficulty initiating and maintaining sleep, with a prevalence ratio (PR) of 3.57 (*p*-value 0.041). **Conclusions**: The present study reveals that temporomandibular disorders are common in children and adolescents, with 54% presenting at least one clinical sign or symptom. Emotional disturbances and sleep problems were also prevalent, affecting 41% and 56% of participants, respectively. Early interdisciplinary screening is essential to manage the co-occurrence of TMDs, emotional distress, and sleep problems in children.

Keywords: temporomandibular disorders; adjustment sleep disorders; emotional aspects; pediatric dentistry

1. Introduction

The term temporomandibular disorders refers to disorders characterized by pain in the preauricular area and/or masticatory muscles, the presence of sounds in the TMJ during

mastication, and deviations or restrictions of mandibular movements [1]. TMDs comprise a diverse range of terminology that encompasses a group of clinical problems related to the muscles of mastication, the temporomandibular joint, and associated structures. They represent the most common cause of non-dental orofacial pain and are due to multifactorial etiologies that are still under investigation [2,3]. TMDs have been linked to various factors, including functional and psychological factors, which makes it difficult to identify the association between a single etiological factor and the signs and symptoms of TMDs [4].

There are numerous epidemiological studies in the scientific literature regarding TMDs which report that they represent a condition that frequently affects adults; however, in the child and adolescent population, existing studies are insufficient. Moreover, research reflects an increase in the prevalence of this disorder with increasing age [5–7].

When addressing temporomandibular disorders (TMDs) in the developmental age, it is essential to employ internationally recognized diagnostic criteria that consider both somatic and psychosocial dimensions of the disorders. The most widely accepted diagnostic framework is the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), developed by the International Network for Orofacial Pain and Related Disorders Methodology. The DC/TMD employs a dual-axis approach: Axis I includes physical diagnoses such as myalgia, arthralgia, and disc displacement, while Axis II assesses psychological factors and pain-related disability [8,9].

Parafunctional habits are defined as repetitive, involuntary behaviors involving the masticatory system that are not related to normal functions like chewing, speaking, or swallowing. Common examples include awake bruxism (clenching or grinding teeth while awake), sleep bruxism (involuntary grinding during sleep), nail biting, lip or cheek chewing, and pencil biting [10,11].

These behaviors are particularly frequent during childhood and adolescence, and are considered contributing factors to the development and persistence of TMD symptoms [12,13].

Sleep disorders, especially sleep bruxism, are masticatory muscle activities that occur during sleep and are classified as sleep-related movement disorders [14]. Sleep bruxism in children has been associated with arousals, stress, and psychosocial factors, and may co-occur with TMDs in certain cases. These disturbances can exacerbate jaw pain, fatigue, and joint noises, and are important to consider in both diagnosis and treatment planning for TMDs [12,13].

Signs and symptoms of TMDs can be observed with a wide frequency range. Valesan et al. report a prevalence in young adults of 31% and in children and adolescents of 11% [5]. De Sena et al. described a general prevalence of TMDs in children ranging from 16% up to 68% [1]. Without being able to reach a consensus, the interpretation of signs and symptoms of TMDs in children comes from the understanding of these disorders as variations within the normal pattern, as preclinical characteristics, or as manifestations of a disease [5].

In addition, TMD and bruxism share a multifactorial etiology [15,16]. According to a recent meta-analysis, the estimated worldwide co-occurrence of bruxism and TMDs is 17%, with significant differences observed between geographical continents, being as high as 70% in North America and as low as 9% in Asia. In Europe this co-occurrence is 14%. A previous study demonstrated that sex was a significant factor, as the risk of co-occurrence of TMDs and bruxism was higher in females. In addition, the analysis revealed that the mean prevalence of TMDs among subjects with bruxism was 63.5%, with the highest frequency found in North America (98.3%) and the lowest in Asia (53.9%). However, the meta-analysis revealed that temporal factors and the average age of subjects did not significantly contribute to observed variability across investigations [17].

The variability in these reports may be attributed to the diversity of diagnostic criteria, different examination protocols, and the diversity of the sample [15,16]. Valesan et al. concluded that the frequency of TMDs was 11.3% in children and adolescents. In addition, the most frequent clinical manifestation was the displacement of the articular disc (8.3%), followed by the degeneration of the joint (0.4%). The displacement of the disc with reduction was the most prevalent (25.9%) TMD in young adults, with a 7.4% prevalence in children and adolescents [5]. According to a meta-analysis conducted by Zielinski et al., the prevalence of TMDs worldwide is high and affects around 34% of the population. However, the prevalence of TMDs in children and adolescents is 27% and differs depending on geographic location, varying by continent: 37% in North America, 33% in South America, 18% in Europe, and 32% in Asia [17]. It occurs in a wide age range, although, according to recent research, it most commonly develops in subjects between 20 and 40 years old [18].

In a study conducted with Brazilian adolescents, Aravena et al. reported that pain located in areas close to the temporomandibular joint was the most frequent clinical manifestation of TMDs (41%), followed by the sensation of dental clenching (32%) and joint noise (25%) [7]. Other studies in non-Caucasian populations such as Marpaug et al. showed a higher percentage of signs such as joint noises (15%) [12]. However, according to Aravena et al., the symptomatology associated with TMDs was lower (30%) [7]. However, De Sena et al. reported that in developing populations, the presence of signs can reach 68%, while only 41% experience symptoms [1].

Marpaug et al. reported that the prevalence rates of TMDs related to joint and muscle pain in children and adolescents were 23.4% and 36.9%, respectively. They also described psychological factors and sleep disorders as potential risk factors for TMDs [12]. Corroborating this, Yap et al. stated that psychological factors and the presence of bodily pain in developing patients are strongly associated with TMDs, as are oral habits that are most common in children, such as sleep bruxism, and wake bruxism in adolescents [11,13].

Al-Khotani et al. reported that 27.2% of children are diagnosed with at least one TMD symptom, with myofascial pain being the most common diagnosis (15%), followed by disc displacement with reduction, arthralgia, myofascial pain with limitation of mouth opening, and osteoarthritis. Children diagnosed with myofascial pain more frequently report orofacial pain, headaches, and teeth clenching, whereas those with arthralgia more frequently report orofacial pain and grinding compared to those without a TMD diagnosis. Self-reported orofacial pain and headache, as well as bruxism, are therefore associated with a diagnosis of disc pain and displacement [19]. In children and adolescents, TMD symptoms have been associated with certain orofacial conditions, particularly neck pain. In contrast, TMD symptoms have only been weakly associated with anxiety. Postural imbalance is not significantly related to TMD symptoms, although habitual daytime clenching significantly affects the manifestation of TMD symptoms [20].

However, despite the copious scientific literature in this area, there is no conclusive data in this regard for the Spanish child and adolescent population. The associations between TMDs and sleep disorders and psychological factors such as stress and anxiety are still not addressed. Based on the above, the objective of this cross-sectional study was to describe the frequency of clinical manifestations linked to temporomandibular disorders and their association with sleep disturbances and emotional disorders. The null hypothesis is therefore that clinical manifestations cannot be linked to temporomandibular disorders and there is no association between TMDs and sleep disturbances and emotional disorders.

2. Materials and Methods

2.1. Design and Ethical Aspects

A multicenter, observational, cross-sectional, pilot study was designed and conducted in the provinces of Guadalajara and Toledo, both in the Autonomous Community of Castilla-La Mancha. It was approved by the Ethics Committee of the Hospital Clínico San Carlos in Madrid (internal code: 21/376-E) and complied with Spanish Organic Law 3/2018 on Personal Data Protection and the Guarantee of Digital Rights.

Participants were informed about the purpose of the study, and their parents authorized their participation by signing a consent form. All data were encrypted and hidden from anyone outside the research group. The principal investigator was responsible for retaining the data and ensuring data security.

2.2. Study Population

The study population consisted of children between 8 and 13 years of age who attended routine dental check-ups and growth and development control appointments at public health centers and private dental clinics in the areas of Azuqueca de Henares, Alovera, and Seseña. These patients had no recent history of dental caries treatment and were invited to participate in the study as part of their regular dental visits.

2.2.1. Eligibility Criteria

Children and adolescents who agreed to participate in the study and whose reading ability allowed them to complete questionnaires were included. Those with a mental disability, a degenerative systemic disease that could affect the muscular or joint system, or a history of congenital developmental disorders involving the maxillofacial complex were excluded. Likewise, patients with uncooperative behavior or a history of orthodontic or orthopedic treatment were not included in the study.

2.2.2. Sample Size

The sample size was calculated using the formula for a finite population. To determine the size of the potential participating population, the corresponding number was extracted from the Spanish National Institute of Statistics website (children aged 10 years), considering the mean age of the target population. A prevalence of 21.83% reported in the study by Macrì et al. [21] was used. In addition, a significance level of 0.05, a type II error (β) of 80%, and a power of 20% were established. With these parameters, the sample calculation resulted in a sample size of 157 participants.

2.2.3. Data Collection System

Informed consent was obtained from the parents and verbal assent from the patient at the research center. Each child's guardians subsequently completed the questionnaires in the waiting room. The patient was then invited to a clinic alone to complete the emotional disturbance questionnaire so that their responses would not be influenced by the presence of a parent or legal guardian.

In the next phase, an experienced dentist conducted a clinical examination to identify signs and symptoms associated with TMDs. This process is diagramed and presented in Figure 1.

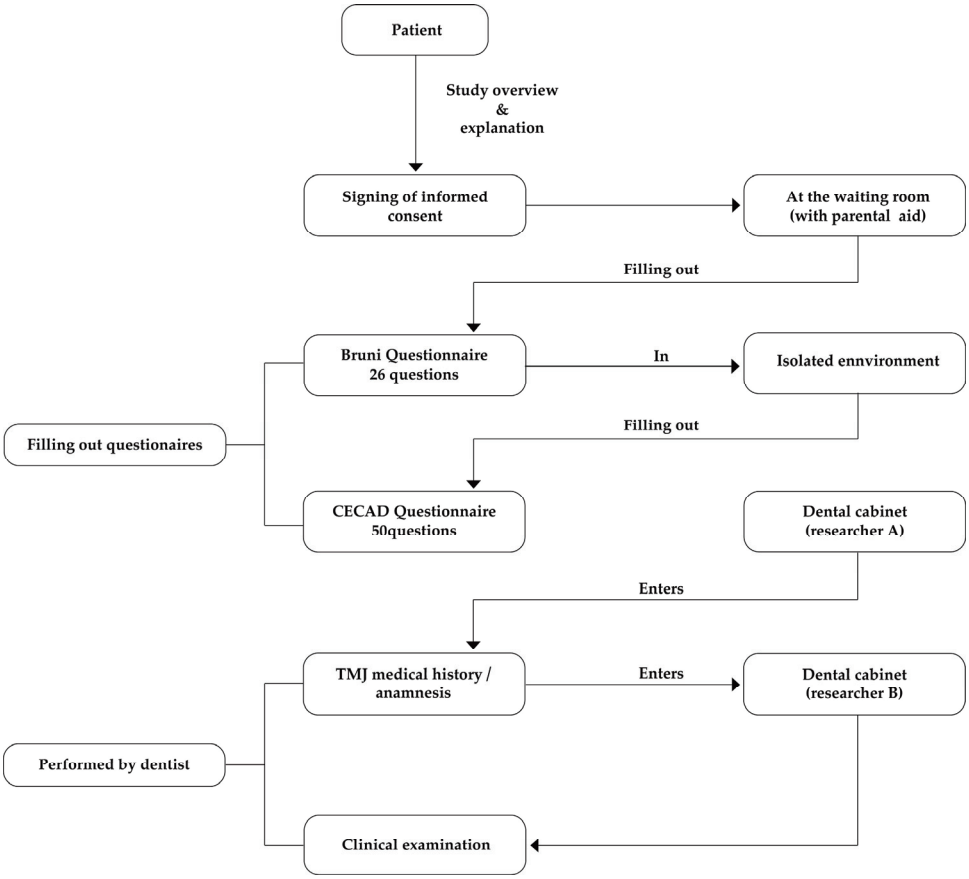

Figure 1. Data collection process.

Questionnaires

Information on sleep and emotional disorders was collected using two validated instruments: the Sleep Disturbance Scale for Children (SDSC), also known as the BRUNI index [22], and the Educational-Clinical Questionnaire: Anxiety and Depression (CECAD) [23].

- Sleep Disorders:
  The SDSC/BRUNI index is a validated questionnaire designed to assess sleep disturbances in children [22]. This questionnaire consists of 26 questions that assess the following parameters: initiating and maintaining sleep, sleep breathing disorders, arousal/nightmare, sleep/wake transitions, excessive somnolence, and sleep hyperhidrosis. All questions are answered along with the parent or guardian and scored on a 5-point Likert scale (1 = never; 5 = always), with higher scores indicating greater clinical severity. Scores exceeding the normal range, as described in Table 1, are considered indicative of a sleep disorder.

Table 1. Normal sleep disorder scores.

Disorders	Normal Range
Initiating and Maintaining Sleep	9.9
Sleep Breathing Disorders	3.8
Arousal/Nightmare	3.3
Sleep/Wake transitions	8.1
Excessive Somnolence	7.1
Sleep Hyperhidrosis	2.9
Global Score	39

- Emotional Disorders:
  The Educational-Clinical Questionnaire: Anxiety and Depression (CECAD) is a validated instrument designed to assess emotional disorders in children and adolescents aged 7 to 18 years. Due to its robust psychometric properties and widespread use in early screening, it is commonly applied to identify symptoms of anxiety and depression in pediatric populations. It consists of 50 questions that assess the presence of depression (29 questions), anxiety (20 questions), worthlessness (8 questions), irritability (6 questions), cognitive disturbances (7 questions), and psychophysiological symptoms (16 questions) and 1 question assessing clinical aspects, scored using a 5-point Likert scale (never, almost never, sometimes, almost always, always) [23]. The CECAD has demonstrated good reliability and validity and enables early detection of individuals at psychological risk, facilitating timely interventions [24]. The survey responses were processed through the virtual analysis platform recommended by the authors [24], ensuring standardized interpretation of results. Scores above the normative mean were classified as a risk factors for emotional disorders (Figure 2).

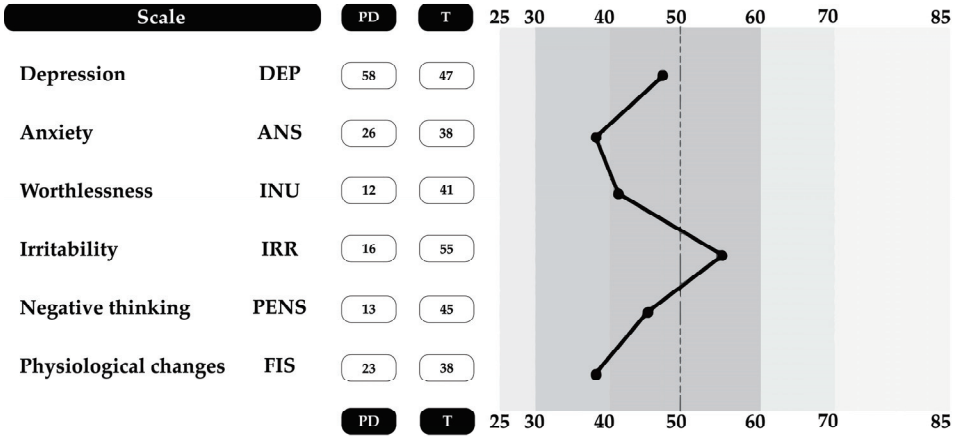

Figure 2. Results processed using CECAD survey virtual platform.

In both questionnaires, the timeframe for completion depended mostly on the participant and whether they had the option to ask questions about any issues that arose.

1. History Taking/Anamneses:
2. Each patient underwent a structured clinical interview conducted by a trained researcher in a dental office setting. The interview lasted approximately 35 min and included questions regarding the following:
   - Jaw pain:
     Discomfort located in the temporal region, preauricular area, or around the ear, as well as the presence of headaches. Patients were asked about the onset, duration, and activities that aggravated or relieved the pain.
   - Joint noises:
     The presence of clicking, popping, or crepitus during mandibular movements, including questions about their frequency, duration, and specific jaw movements that provoked them.
   - Jaw locking or limited movement:
     Episodes of mandibular blockage during opening or closing, including duration and how the patient resolved the restriction.
   - Clinical examination:
     A calibrated examiner assessed the clinical presence or absence of temporomandibular dysfunction signs. This included joint sounds detected via ausculta-

tion or palpation during lateral and protrusive movements, muscle tenderness upon firm bilateral digital palpation of the masseter and temporalis muscles, mandibular deviations during opening and closing (corrected or uncorrected), and restricted jaw opening. Pain intensity upon palpation was recorded using a six-point visual analog scale, ranging from 0 (no pain) to 5 (very intense pain), with 3 indicating a moderate pain response.

In accordance with the DC/TMD diagnostic criteria, a definitive diagnosis of temporomandibular disorders was established only when the discomfort reported during the anamnesis could be reproduced during clinical examination. Muscle or joint pain was considered positive for TMDs if the same area elicited similar discomfort upon palpation or functional testing, thus ensuring consistency between subjective reports and objective findings.

- Clinical examination system:

  The exam was performed by a different investigator to the researcher recording patient history. Each patient was seated in a dental chair (Sinius Sirona®) at a 45° angle and the clinical examination was divided into two parts: extraoral and intraoral.

  This examination determined the clinical presence or absence of joint sounds, pain, mandibular deviation, or limited jaw opening. Joint sounds were diagnosed by audible sound or palpation of the TMJ, while joint pain was identified through child-reported discomfort during joint palpation. Muscle pain was assessed by applying firm bilateral digital pressure over the largest portion of each masticatory muscle. Mandibular deviation was noted when the jaw deviated from the midline during opening and closing. A maximum interincisal opening of less than 35 mm was considered limited opening. Each alteration was recorded as present or absent on the standardized study form, which was based on the official Spanish-language version of the DC/TMD assessment instruments, translated and validated by the International Network for Orofacial Pain and Related Disorders Methodology (INfORM) [9]. To avoid confounding effects from dental intervention, all clinical evaluations were performed at least four weeks after dental treatment, ensuring that findings reflected true temporomandibular dysfunction rather than transient postoperative effects.

2.2.4. Reliability and Reproducibility

Data collection was conducted by two experienced researchers. To ensure diagnostic consistency and minimize inter-observer variability, the two clinicians responsible for performing the examinations underwent a structured calibration process prior to initiating data collection. This process consisted of two phases. First, both examiners participated in a theoretical–practical training session based on the official Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) protocol, during which the key diagnostic steps were standardized, and consensus was reached on interpretation criteria for muscle tenderness, joint sounds, and mandibular movement patterns.

Subsequently, in the second phase, both researchers independently examined a pilot group of 10 pediatric patients not included in the final study sample. Their results were compared using Cohen's kappa coefficient to determine the level of inter-examiner agreement for each variable assessed. A kappa value of 0.85 or higher was considered acceptable for proceeding with data collection. The calibration process was supervised by two senior clinicians with expertise in orofacial pain and TMD diagnosis. Additionally, periodic meetings were held throughout the study to re-evaluate procedures and resolve any discrepancies in the interpretation of clinical signs.

Twenty percent of the patients who participated in the study were randomly recalled to repeat the tests.

2.2.5. Statistical Analysis

The analysis was carried out using IBM SPSS® version 26. Frequencies and percentages were applied to summarize qualitative variables, while measures of central tendency were used for quantitative variables. The prevalence ratio was calculated as a measure of association, and its statistical significance was assessed using the chi-square test. The significance level was set at $p < 0.05$. A 95% confidence interval was computed for the analysis. The effect size was calculated using Cramér's V, where 0 indicates no association between emotional and sleep disorders and the signs and symptoms of TMDs, whereas a value of 1 indicates a maximum association between these variables [25].

3. Results

3.1. Population Description

The population comprised children with a mean age of 10.89 ± 2.19 years who attended different dental clinics in a population belonging to the province of Guadalajara in the Community of Castilla-La Mancha during the period 2023–2024.

TMD prevalence was 54%. Among these cases, 26% presented muscle pain, 14% joint pain, and 14% both types of pain. Of the patients diagnosed with TMDs, 75% exhibited joint clicks, 11.1% experienced joint locking, and 81% showed corrected deviation during mouth opening and closing.

3.2. Relationship Between Sleep Disorders and Temporomandibular Disorders

The data from the Bruni et al. questionnaire showed that difficulties in initiating and maintaining sleep were significantly related to both muscle and joint pain. Specifically, patients with muscle pain had a mean score of 26.53 (SD = 30.06), while those with joint pain had a mean score of 12.14 (SD = 2.79), with a significant *p*-value of 0.017 and a 95% confidence interval, indicating that children with sleep initiation and maintenance problems are significantly more likely to report painful TMD symptoms. These comparative values between groups are reflected in Table 2, which details the distribution of sleep disturbance scores by clinical manifestation.

Table 2. Sleep disturbance scores and presence of symptoms.

Factors	Absence of Manifestation Mean ± SD	Pain Muscle Mean ± SD	Pain Joint Mean ± SD	Pain Both Mean ± SD	*p*-Value
Initiating and Maintaining Sleep	11.33 ± 3.53	26.53 ± 30.06	12.14 ± 2.79	26.00 ± 33.69	***0.017***
Sleep Breathing Disorders	4.22 ± 2.10	4.33 ± 2.47	3.57 ± 0.79	6.14 ± 4.06	*0.449*
Arousal Disorders	3.56 ± 0.70	4.93 ± 2.25	4.14 ± 1.46	4.29 ± 2.36	*0.053*
Sleep/Wake Transition Disorders	9.17 ± 2.41	12.07 ± 6.31	8.71 ± 2.87	12.86 ± 7.01	*0.375*
Excessive Somnolence	7.94 ± 3.83	10.13 ± 5.05	8.57 ± 2.94	9.14 ± 3.53	*0.154*
Hyperhidrosis	2.78 ± 1.11	4.53 ± 3.50	2.29 ± 0.76	3.71 ± 2.93	*0.336*
Sleep Disturbance	39.00 ± 10.10	57.73 ± 23.75	39.43 ± 8.50	56.14 ± 26.39	***0.020***

In addition, corrected mandibular deviation during mouth opening was also influenced by sleep onset and maintenance disturbances, with a mean score of 18.71 (SD = 21.06) and a *p*-value of 0.047 with a 95% confidence interval, further supporting the link between sleep quality and functional mandibular alterations. This comparative analysis including symptomatic and asymptomatic participants is detailed in Table 3.

Table 3. Sleep disturbance scores and presence of signs.

Factors	Absence of Manifestation Mean ± SD	Click Mean ± SD	*p*-Value	Joint Blockage Mean ± SD	*p*-Value	Corrected Deviation Mean ± SD	*p*-Value
Initiating and Maintaining Sleep	11.33 ± 3.53	19.79 ± 22.97	*0.119*	33.20 ± 37.01	0.158	18.71 ± 21.06	***0.047***
Sleep Breathing Disorders	4.22 ± 2.10	4.43 ± 2.74	*0.318*	4.00 ± 1.73	*0.738*	4.41 ± 2.58	*0.504*
Arousal Disorders	3.56 ± 0.70	4.11 ± 1.91	*0.482*	5.20 ± 3.35	*0.476*	4.00 ± 1.76	*0.223*
Sleep/Wake Transition Disorders	9.17 ± 2.41	10.61 ± 5.12	*0.836*	14.40 ± 3.58	***0.016***	10.85 ± 4.59	*0.086*
Excessive Somnolence	7.94 ± 3.83	8.93 ± 4.45	*0.890*	12.60 ± 3.29	***0.012***	9.47 ± 4.53	*0.138*
Hyperhidrosis	2.78 ± 1.11	3.36 ± 2.56	*0.637*	3.60 ± 3.58	*0.564*	3.29 ± 2.34	*0.905*
Sleep Disturbance	39.00 ± 10.10	48.64 ± 21.27	*0.618*	64.80 ± 25.19	***0.017***	48.29 ± 19.40	*0.102*

In contrast, other sleep disorders such as sleep breathing disorders, arousal disorders, and hyperhidrosis do not show statistically significant associations with the presence of temporomandibular disorders, as evidenced by *p*-values above 0.05 in most comparisons, as shown in Tables 2 and 3.

3.3. Impact of Emotional Disorders on TMJ

The analysis of the relationship between the CECAD (Depressive Affect Quality Assessment Questionnaire) and the presence of temporomandibular disorders indicates that anxiety plays an important role. Patients with muscle pain had a mean anxiety score of 44.87 (SD = 11.85), whereas those without symptoms had a mean of 36 (SD = 10.78), with a significant *p*-value of 0.03. Furthermore, physiological changes resulting from stress showed a statistically significant relationship with the presence of muscle and joint pain, with *p*-values of 0.008 and 0.007, respectively. This reinforces the hypothesis that psychological stress can exacerbate TMJ symptoms.

On the other hand, other psychological factors such as negative thinking, worthlessness, and irritability did not show a statistically significant relationship with the presence of clicking, joint locking, or corrected deviations (Tables 4 and 5).

Table 4. CECAD scores and presence of symptoms.

CECAD		Absence of Manifestation Mean ± SD	Click Mean ± SD	Joint Blockage Mean ± SD	Corrected Deviation Mean ± SD	*p* [1]
Depression	Ptj [2] Pm [3]	52.78 ± 16.01 44.94 ± 9.13	66.88 ± 19.75 51.47 ± 10.40	55.14 ± 15.64 46.14 ± 9.58	58.43 ± 12.18 49.71 ± 6.02	*0.055* *0.091*
Anxiety	Ptj [2] Pm [3]	36.00 ± 10.78 45.33 ± 8.58	44.87 ± 11.85 53.73 ± 9.00	34.43 ± 12.46 44.00 ± 9.66	44.57 ± 12.54 52.14 ± 10.85	***0.030*** ***0.016***
Worthlessness	Ptj [2] Pm [3]	14.50 ± 3.97 46.78 ± 7.70	19.00 ± 6.40 52.67 ± 9.69	14.86 ± 4.71 46.86 ± 9.92	14.71 ± 4.23 47.71 ± 6.13	*0.093* *0.098*
Irritability	Ptj [2] Pm [3]	11.78 ± 5.25 47.28 ± 9.94	14.73 ± 5.71 52.53 ± 10.70	12.57 ± 3.60 49.57 ± 7.09	16.14 ± 4.49 56.86 ± 7.22	***0.043*** ***0.032***

Table 4. *Cont.*

CECAD		Absence of Manifestation Mean ± SD	Click Mean ± SD	Joint Blockage Mean ± SD	Corrected Deviation Mean ± SD	p [1]
Negative Thinking	Ptj [2]	13.61± 5.41	68.87 ± 5.95	16.71 ± 11.32	14.14 ± 4.30	*0.203*
	Pm [3]	46.22 ± 9.49	51.87 ± 10.32	45.86 ± 7.86	48.00 ± 7.30	*0.183*
Physiological Changes	Ptj [2]	29.17 ± 7.96	37.73 ± 9.19	28.43 9.90	35.29 ± 8.65	***0.008***
	Pm [3]	44.89 ± 8.13	54.07 ± 8.71	43.57 9.52	51.14 ± 8.99	***0.007***

[1] p-value for clicks, joint blockage, and correlation deviation. [2] Established score in this investigation. [3] Normal value.

Table 5. CECAD scores and presence of signs.

CECAD		Absence of Manifestation Mean ± SD	Pain Muscle Mean ± SD	p [1]	Pain Joint Mean ± SD	p [1]	Pain Both Mean ± SD	p [1]
Depression	Ptj [2]	52.78 ± 16.01	57.75 ± 20.25	*0.907*	69.40 ± 26.39	*0.201*	55.03 ± 17.57	*0.248*
	Pm [3]	44.94 ± 9.13	46.46 ± 11.25	*0.740*	51.60 ± 13.52	*0.308*	45.85 ± 10.25	*0.275*
Anxiety	Ptj [2]	40.14 ± 13.01	44.87 ± 11.85	*0.531*	44.00 ± 15.60	*0.391*	38.00 ± 11.37	*0.454*
	Pm [3]	49.07 ± 10.71	53.73 ± 9.00	*0.564*	51.00 ± 12.19	*0.549*	47.35 ± 9.49	*0.441*
Worthlessness	Ptj [2]	16.00 ± 6.54	19.00 ± 6.40	*0.906*	20.00 ± 8.97	*0.256*	15.09 ± 5.91	*0.136*
	Pm [3]	47.36 ±11.10	52.67 ± 9.69	*0.829*	52.80 ± 13.03	*0.331*	46.62 ± 10.10	*0.156*
Irritability	Ptj [2]	12.93 ± 4.68	14.73 ± 5.71	*0.969*	15.40 ± 6.07	*0.299*	12.59 ± 4.57	*0.326*
	Pm [3]	49.29 ± 8.86	52.53 ± 10.70	*0.953*	54.40 ± 10.50	*0.315*	49.18 ± 8.84	*0.416*
Negative Thinking	Ptj [2]	13.79 ± 5.83	68.87 ± 5.95	*0.255*	16.60 ± 8.26	*0.661*	13.50 ± 5.33	*0.073*
	Pm [3]	46.25 ± 10.83	51.87 ± 10.32	*0.378*	52.00 ± 12.47	*0.582*	46.06 ± 9.90	*0.128*
Physiological Changes	Ptj [2]	33.50 ± 10.05	37.73 ± 9.19	*0.318*	35.00 ± 12.79	*0.650*	31.44 ± 8.72	*0.441*
	Pm [3]	49.21 ± 10.05	54.07 ± 8.71	*0.337*	49.60 ± 11.80	*0.709*	47.29 ± 9.20	*0.472*

[1] p-value for pain scores. [2] Established score in this investigation. [3] Normal value.

3.4. Associations Between the BRUNI Sleep Quality Index and TMD

The results obtained from the BRUNI index reveal that 78.13% of patients with TMDs experience difficulty in initiating and maintaining sleep, with a prevalence ratio (PR) of 3.57 and a significant p-value of 0.041. It was also observed that 65.63% of patients had a high score on the BRUNI index, suggesting that poor sleep quality could be associated with TMJ dysfunction (Table 6).

Table 6. Association between sleep disorders and TMDs.

Sleep Disorders	% *	PR	p-Value	95% CI Lower	95% CI Upper	Cramer's V
Initiating and maintaining sleep	78.13	3.570	***0.041***	1.026	12.43	0.289
Sleep breathing disorders	25.00	1.167	*0.825*	0.290	4.590	0.031
Arousal disorders	62.50	2.083	*0.217*	0.640	6.730	0.175
Sleep/wake transition disorders	40.63	0.855	*0.793*	0.270	2.750	0.037
Excessive somnolence	37.50	2.100	*0.266*	0.560	7.880	0.157
Hyperhidrosis	34.38	1.830	*0.368*	0.490	6.930	0.127
Sleep disorders	65.63	2.390	*0.145*	0.730	7.780	0.206

* The percentage of participants that presented x sleep alteration and DTM.

3.5. Association Between Emotional Disorders and TMDs

The data in Table 7 on the association of the CECAD with the TMJ also reveal that patients with high scores for emotional stress tend to report more TMJ symptoms, with a statistically significant difference compared to those with less emotional distress. p-values less than 0.05 indicate that the impact of stress not only affects pain perception but also mandibular function in general.

On the other hand, other psychological factors such as negative thinking, worthlessness, and irritability do not show a statistically significant relationship with the presence of clicking, joint locking, or corrected deviations.

Table 7. Association between emotional disorders and TMDs.

CECAD	%	PR	*p*-Value	95% CI Lower	95% CI Upper	Cramer's V
Anxiety	50.00	2.600	*0.126*	0.750	9.008	0.216
Depression	46.87	1.765	*0.320*	0.531	5.865	0.13
Worthlessness	46.87	1.765	*0.352*	0.531	5.865	0.132
Irritability	59.73	2,297	*0.164*	0.710	7.490	0.197
Negative thinking	37.50	1.560	*0.483*	0.450	5.470	0.099
Physiological changes	53.13	5.667	***0.012***	1.370	23.46	0.357
TOTAL	47.87	3.088	*0.085*	0.833	11.44	0.244

4. Discussion

TMDs represent a term that encompasses a myriad of signs and symptoms affecting the masticatory muscles, the temporomandibular joint, or both [26] and are often accompanied by psychological factors such as stress, anxiety, and irritable bowel syndrome (IBS) [27]. Therefore, we have identified the prevalence of these disorders and their association with sleep disturbances, stress, and anxiety in children.

The results obtained in this study reveal a high prevalence of clinical manifestations of temporomandibular disorders (TMDs) in children and adolescents, reaching 54%, a value notably higher than that reported by Rentsch et al. (18.8%), Al-Khotani et al. (27.2%), Mara de Paiva et al. (34.9%), Ebrahimi et al. (34.7%), and Restrepo et al. (40%) [2,19,28–30]. Díaz et al. reported a 43.4% prevalence of TMJ problems, citing that 72.3% of the cases presented a single disorder, 20.4% two TMDs, and 7.3% more than two TMDs, in similar populations. This coincides with the values reported by Eraslan et al. (66.8%) in a young adult population [31,32], and those reported by Jie Lei et al. (61.4%) in Asian adolescents [33]. While the study by Taneja et al. in an Indian adolescent population used both the FAI and the CD/TMD questionnaire, it reported a 51% prevalence of signs and symptoms [34]. The discrepancies observed between these studies and the present one may be due to key methodological differences, such as the diagnostic criteria used, the size and demographic characteristics of the populations studied, and the environment in which the studies were conducted. For example, the study by Al-Khotani et al. and the study by Eraslan used less strict questionnaires (self-test) for the identification of TMDs [19,32]; this could explain the lower percentage of prevalence reported in those studies.

Supporting this trend at the population level, a comprehensive global meta-analysis estimated the overall prevalence of TMDs at 34%, with significant geographic variability: 47% in South America, 33% in Asia, and 29% in Europe. In children and adolescents, the worldwide prevalence is approximately 27%, with notable differences between regions—North America showing the highest (37%) and Europe the lowest (18%) [17]. These disparities underscore the importance of developing geographically contextualized screening strategies and highlight how regional, cultural, and demographic factors may influence the identification and reporting of TMDs.

In contrast, the percentage of patients who presented joint sounds in our study (75%) is more consistent with the findings of Pimenta et al. (68% in women and 67% in men) [35]. This fact suggests that, regardless of the differences in the methodologies used, certain clinical signs, such as joint sounds, seem to remain a frequent and relatively constant marker among different studies.

The study by Aravena et al. reported that four out of ten adolescents reported some type of temporomandibular pain or discomfort, the majority of whom were female, a finding that agrees with our results regarding the higher prevalence of TMDs in females.

Furthermore, Aravena et al. used the CD/TMD questionnaire for the assessment of TMDs, finding a prevalence of 26.88% and a male/female ratio of 1:1.27 (p = 0.24) [7]. In comparison, our study reported a slightly higher proportion, which could be due to cultural factors or differences in pain perception.

A meta-regression study analyzing global data—including European cohorts—reported a 13.7% pooled co-occurrence of bruxism and TMDs in Europe and found that a higher proportion of female participants was significantly associated with increased co-occurrence rates [36]. These results support our findings on gender differences and the influence of psychosocial factors in TMDs.

It is obvious that the instruments used for the detection of TMDs influence the prevalence results; therefore, when discussing data from different studies, this aspect must be taken into account. In this regard, the study by Mendiburu-Zavala found that 74.3% of adolescents presented some degree of TMDs [37]. On the other hand, a study conducted by Torul et al. in a Turkish pediatric population found that 19.7% of participants presented symptoms of TMDs according to the Fonseca Anamnestic Index (FAI), while 38.8% showed at least one symptom on clinical examination [38].

Some researchers note that parafunctional habits significantly increase the risk of TMDs (OR = 4.24; 95% CI 1.64–10.93), as do anxiety symptoms (OR = 1.09; 95% CI 1.02–1.16) [38]. These results are consistent with our findings on the impact of parafunctional habits and psychological factors on the development of TMDs in pediatric populations.

A study conducted by Mendiburu-Zabala et al., which compared two Mexican populations of young adults, found a moderately significant correlation (0.316) between poor quality of sleep and perceived stress [37].

In addition, in our study, a significant proportion of participants reported orofacial pain and headaches associated with TMDs, which is consistent with the study by Restrepo et al., in which 25.5% of the study population presented pain, with muscle pain being the most common symptom [30]. In the same line, in the study conducted by Rentsch, one of the most common symptoms was muscle pain (6.8%) [2]. The higher prevalence of pain in women was also a finding shared by both studies, which underlines the importance of considering gender as a risk factor.

The pain reported by our participants was primarily associated with psychological factors, such as anxiety and stress. Studies such as that by Marpaug et al. also highlight that emotional factors double the risk of developing TMDs [12], reinforcing the need for a multidisciplinary approach to treatment.

Our findings also indicate a high frequency of disc displacement and joint pain, results comparable with those of a study comparing adolescent populations in China and Germany. In that study, the overall prevalence of TMDs was 13.9%, with no significant differences between the two populations, although pain was higher in Chinese adolescents (OR 1.6–6.5) [39]. The similarity in reported symptoms reinforces the need to implement standardized diagnostic strategies that allow for better comparison across cultural settings.

However, in cases where patients were unaware of the pain, an association was observed between this pain and parafunctional habits, such as bruxism; this association was also significant in our study. TMDs and bruxism have been linked as they both share a multifactorial etiology [18,36]. Although we did not have a dedicated category for bruxism, we took into consideration many of the classic symptoms associated with it such as muscle pain and complaints of a sore jaw or face and psychological factors such as depression and anxiety that are linked to a higher likelihood of bruxism. In the scientific literature, Torul et al. found a prevalence of bruxism of 84.3% in children with TMDs; Taneja et al. found statistically significant differences in the association between bruxism and TMDs, with an

OR of 5.87 [34,38]. Subjects with bruxism showed more clinical signs of TMDs than those without, highlighting the need for early interventions to correct these habits and prevent long-term complications.

A recent systematic review and meta-analysis further confirmed that individuals with bruxism have significantly increased odds of developing TMDs. Specifically, awake bruxism was associated with a 2.51-fold increase in TMD risk and sleep bruxism with a 2.06-fold increase [18]. These findings reinforce the role of bruxism as a major comorbid factor in the development of TMDs.

Building on this, bruxism is widely considered one of the most important contributing factors to functional disorders of the temporomandibular joint, and it is strongly associated with underlying psychological and emotional disturbances.

In this regard, the wide confidence intervals in our results may be due to the functional alteration of mastication that these patients present and to other altered functions such as oral breathing. In this study, pain detected during clinical examination was significantly associated with the presence of parafunctional habits such as bruxism.

During clinical examination, 81.5% of patients with symptoms presented a corrected deviation opening pattern, while 11.1% depicted a history of joint block. The high prevalence of mandibular deviation found is consistent with the results of other studies, such as those of Sena et al., who reported that disc displacement is one of the most common clinical manifestations in children and adolescents [1]. In previous studies, disc displacement with reduction has been observed to be the most frequent type of joint dysfunction in children and adolescents. The study by Rentsch et al. found a prevalence of 10.2% of disk displacement with reduction, DDwR, which is consistent with our findings [2]. Furthermore, the high frequency of mandibular deviation during opening suggests the need for more detailed clinical evaluations to detect early functional alterations and prevent long-term complications.

The results show that patients with difficulty initiating or maintaining sleep are 3.6 times more likely to develop TMDs. This finding is consistent with the study by Jie Lei et al., which found a 27% comorbidity between sleep disorders and TMDs [33]. Furthermore, studies such as that of Yazıcıoğlu et al. highlight that factors such as mouth breathing and sleeping with the mouth open are independent predictors of TMDs, while sleeping with the mouth closed acts as a protective factor [40].

Furthermore, the relationship between sleep quality and TMDs is also observed in the high prevalence of nocturnal bruxism in participants with TMDs. Previous studies have suggested that nocturnal bruxism acts as a significant risk factor, increasing the risk of joint and muscle damage [41].

Sleep disorders and psychological stress are correlated with TMDs [33]. In our study, participants with high scores on the CECAD questionnaire, indicative of emotional disorders, presented clinical manifestations of TMDs up to 5.6 times more than those without these disorders. This result is in line with the study by Marpaug et al., which showed that stress and sadness double the risk of developing TMDs [12]. Similarly, Restrepo et al. found that the relationship between TMDs and anxiety and depression was statistically significant ($p = 0.04$ for anxiety and $p = 0.03$ for depression); notably, 43.3% of adolescents reported anxiety problems [30]. Somatization was higher in males, although there were no statistically significant differences between genders when compared with depression. Moreover, according to the results reported by Jie Lei et al., one in three subjects with some symptoms of TMDs experienced sleep disorders, depression, and stress [33]. The Mendiburu-Zavala study (where the population is from) found that 51.9% of patients with TMDs presented some degree of depression [37]. They also highlighted that severe depression was more prevalent in early adolescence, a result that supports our observation

of the strong association between emotional factors and TMDs. In the study by Jie Lei et al. in Asian adolescents, 65.2% experienced anxiety [33]. Furthermore, the study by Torul et al. highlighted that anxiety increases the risk of TMDs, with an OR of 1.09 (95% CI 1.02–1.16) [38]. The high comorbidity between anxiety and TMDs underscores the importance of including emotional management as an integral part of treatment.

In prevalence studies of TMDs, it is worth noting that they have been accompanied by a high prevalence of parafunctional habits. The study by Rentsch et al. in Swiss children aged 7 to 14 years showed a high prevalence of onychophagia (37.7%), teeth clenching (32.2%), and bruxism/grinding (25.5%) [2].

The study by Jin et al. on Chinese adolescents with TMDs who received physical therapy shows complementary findings. Around 60% of the 286 patients treated reported short-term symptom improvement after personalized physical therapy, with significant improvements in pain intensity, maximum mouth opening, and decreased joint sounds. In the long term (30 months on average), 94% of patients had symptom improvement, although 52.8% experienced persistent mild symptoms, such as joint noises (40.9%) and occasional pain (26.9%). Parafunctional habits and an insufficient number of therapy sessions were significantly associated with persisting symptoms (OR = 4.118 and OR = 0.899, respectively). This study reinforces the need to correct harmful habits and ensure an adequate number of treatment sessions to improve long-term prognosis [42].

Among the limitations of this study are the sample size and the lack of a detailed division of participants by age group and socioeconomic status, which could have allowed for a more detailed analysis of the influence of these variables on the development of TMDs. There is also a self-selection bias due to the fact that a community primary care center was selected, which may have influenced more participants with TMDs to decide to participate in the study. All the participants were referred from either private or public dental clinics to participate in the study as long as they conformed to the age range requirement. However, there is always some possibility of participation bias as most of the participants who agreed on participating in the study could have been motivated to participate if they suffered from TMJ pain prior to signing up to the study. This bias could hinder the ability to extrapolate the results to the general population.

In addition, in order to minimize the effect of possible confounding factors, a balanced number of boys and girls was sought. In addition, the sample represents a geographical area characterized by a relatively homogeneous socioeconomic level, helping reduce the variability attributable to this factor.

This study has several strengths, such as the inclusion of a wide range of associated factors, including bruxism, stress, and anxiety. Furthermore, the use of standardized diagnostic tools allowed for an accurate assessment of the clinical manifestations of TMDs, which contributes to the validity of the results.

It is essential to conduct longitudinal studies that allow for the establishment of causal relationships between emotional factors, sleep disorders, and TMDs in pediatric populations. Likewise, it is recommended that researchers develop standardized methodologies that include uniform diagnostic criteria and the integration of more specific tools to assess risk factors associated with TMDs. Future research should also focus on therapeutic interventions aimed at improving sleep quality and reducing emotional stress, with the goal of preventing and managing TMDs in children and adolescents.

Furthermore, it is necessary to further study parafunctional habits, such as bruxism, and their relationship with TMDs, as well as evaluate the impact of educational and preventive programs that promote oral and emotional health at these early ages. These lines of research will contribute to the development of more effective strategies for the

prevention and treatment of TMDs, thereby improving the quality of life of affected children and adolescents.

5. Conclusions

The present study revealed that temporomandibular disorders (TMDs) are common among children and adolescents, with 54% of participants presenting at least one clinical sign or symptom. Emotional disturbances and sleep problems were also prevalent, affecting 41% and 56% of participants, respectively.

The strongest associations with TMD symptoms were observed in children experiencing physiological stress responses and those with difficulties initiating and maintaining sleep. Children reporting muscle pain showed significantly higher levels of sleep-related problems compared to asymptomatic individuals. In contrast, other conditions such as breathing disorders and excessive sweating were not associated with TMDs. Overall, the analysis revealed that children with emotional disorders were over five times more likely to exhibit TMD symptoms, while those with sleep disturbances had a more than threefold increased likelihood.

These findings underscore the need for a holistic diagnostic approach to TMDs that incorporates both emotional wellbeing and sleep quality. It is recommended that pediatric dentists integrate validated psychological and sleep assessment tools into routine clinical practice, particularly when managing patients with pain or functional jaw limitations. Interdisciplinary collaboration among dentists, psychologists, and sleep specialists may significantly enhance early detection and improve treatment outcomes in pediatric TMD cases.

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Article

Comparative Evaluation of Temporomandibular Disorders and Dental Wear in Video Game Players

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Abstract: Background/Objectives: The increasing prevalence of video gaming has raised concerns about its potential impact on musculoskeletal health, particularly temporomandibular disorders (TMDs). This study aims to compare TMD symptoms, mandibular function, and dental wear between gamers and non-gamers among university students. **Methods**: An observational study included 108 students aged 20 to 23 years, divided into gamers (n = 48) and non-gamers (n = 60). Participants completed questionnaires assessing TMD symptoms, gaming habits, and screen time. Clinical examinations measured mandibular movements, palpation-induced pain, and dental wear using the Smith and Knight Tooth Wear Index. Statistical analyses included independent *t*-tests, chi-square tests, Pearson's correlations, and logistic regression. Seven comprehensive tables present the findings with *p*-values. **Results**: Gamers reported significantly higher screen time (Mean = 6.5 h/day) compared to non-gamers (Mean = 4.0 h/day; $p < 0.001$). Maximum unassisted mouth opening was greater in gamers (Mean = 48.31 mm) than in non-gamers (Mean = 46.33 mm; $p = 0.04$). Gamers exhibited a higher prevalence of pain on palpation of the masseter muscle (45.8% vs. 30.0%; $p = 0.05$). Dental wear scores were significantly higher in gamers for teeth 2.3 (upper left canine) and 3.3 (lower left canine) ($p < 0.05$). Positive correlations were found between hours spent gaming and maximum mouth opening (r = 0.25; $p = 0.01$) and dental wear (r = 0.30; $p = 0.002$). Logistic regression showed that gaming status significantly predicted the presence of TMD symptoms (Odds Ratio = 2.5; $p = 0.03$). **Conclusions**: Gamers exhibit greater mandibular opening, increased dental wear, and a higher prevalence of masticatory muscle pain compared to non-gamers. Prolonged gaming may contribute to altered mandibular function and increased risk of TMD symptoms. Further research is needed to explore underlying mechanisms and develop preventive strategies.

Keywords: temporomandibular disorder; dentistry; video gaming; dental wear; mandibular function; screen time; mandibular movements; masticatory muscles; observational study

1. Introduction

The global video gaming industry has seen remarkable expansion, reaching a market value of approximately USD 200 billion [1]. With minimal restrictions on gameplay, more individuals are engaging in video gaming during leisure time, potentially leading to increased sedentary behavior [2,3]. While millions enjoy video games in moderation, gaming can negatively affect vulnerable individuals and their families, prompting the

World Health Organization (WHO) to include 'Hazardous gaming' and 'Gaming disorder' in the International Classification of Diseases 11th Revision (ICD-11) [4,5]. This recognition follows the American Psychiatric Association's identification of 'Internet gaming disorder' in the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5), yet the causes of these disorders remain poorly understood in academic research [6,7].

In addition to prolonged sitting, video gaming requires fine motor skills and repetitive movements of the arms, wrists, hands, and fingers, similar to some office work or even more intense activities [8]. Continuous and uninterrupted performance of these movements can lead to musculoskeletal disorders (MSDs), particularly of the upper limbs, which are also associated with physical inactivity, prolonged sitting, and unilateral postures [9].

Temporomandibular disorders (TMDs) are a group of musculoskeletal conditions that impair the function of the temporomandibular joint (TMJ) and the masticatory muscles, leading to pain and dysfunction in jaw movements. These disorders can manifest as difficulty in chewing and speaking and may be accompanied by discomfort in the jaw, face, or neck, with the Diagnostic Criteria for Temporomandibular Disorders (DC/TMDs) being the current internationally accepted diagnostic system [10]. Approximately 34% of the population experiences TMDs, with a higher prevalence among adults aged 18–60 [11,12]. A qualitative analysis revealed that most studies indicate a significant link between TMDs and psychological disorders, with depression and somatization both worsening and contributing to TMD symptoms. Additional contributing factors include physical trauma, malocclusion, poor posture, and chronic stress, which can further exacerbate the complexity and severity of TMD symptoms [13,14].

TMDs, commonly associated with other musculoskeletal conditions, affect the temporomandibular joint, masticatory muscles, and cranio-cervical structures, often correlated to concomitant conditions like headaches, otologic disturbances, cervical spine dysfunction, and postural misalignment [15]. The overuse of smartphones has been associated with a range of physical and psychological health issues, including musculoskeletal pain [16], headaches, fatigue, dizziness, tension, memory loss, and hearing loss [17,18].

Poor posture during gaming, such as slouching or leaning forward, is hypothesized to lead to an unnatural alignment of the cervical spine and jaw [19]. This misalignment increases the strain on the muscles and ligaments surrounding the TMJ and can lead to cartilage disease, which can potentially alter the natural movement of the jaw and increase the risk of TMJ disorders [20,21]. For gamers, this repetitive stress and compromised posture can contribute to changes within the TMJ over time, manifesting as pain, reduced mobility, and other TMJ-related symptoms. The ergonomic setup of the gaming environment and awareness of maintaining good posture can be crucial in minimizing these adverse effects on the TMJ.

Given the prolonged periods of static posture and the intense focus required in gaming, it is hypothesized that gamers will exhibit a higher prevalence and severity of TMD symptoms and greater dental wear compared to non-gamers, suggesting a significant impact of gaming habits on oral and mandibular health. Therefore, the aim of this study is to compare the incidence of temporomandibular disorders between gamers and non-gamers and to evaluate dental wear facets in students who have a hobby related to video games versus those who do not play games but still spend multiple hours daily in front of various devices.

2. Materials and Methods

2.1. Study Design and Participants

This observational cross-sectional study was conducted in accordance with the Declaration of Helsinki and received approval from the Ethics Committee of the University

of Medicine and Pharmacy "Carol Davila" in Bucharest, with the IRB approval number 28286. A total of 108 participants, aged between 20 and 23 years, were recruited from third- and fourth-year students at the university. The study population comprised 66.7% (n = 72) females and 33.3% (n = 36) males.

Participants were divided into two groups based on their gaming habits: gamers (n = 48) and non-gamers (n = 60). Gamers were defined as students who self-identified as regularly playing video games, defined as at least two hours per day, while non-gamers were those who had not played any games for the past six months. Written informed consent was obtained from all participants after explaining the study objectives and procedures.

2.2. Questionnaire and Clinical Examination

An open call for participation was used to recruit participants. Data collection involved both a self-administered questionnaire and a clinical examination. The questionnaire used in this study was meticulously validated to ensure both reliability and internal consistency. To achieve this, the assessment of temporomandibular disorder (TMD) symptoms was based on the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) protocol [22], a widely recognized and validated instrument in clinical research. For evaluating gaming engagement and potential addiction among gamers, an additional section was adapted from the Gaming Addiction Scale for Adolescents (GASA) [23], which has demonstrated strong reliability and validity in previous studies. To further confirm internal consistency, Cronbach's alpha coefficients were calculated for each subscale, resulting in values exceeding the acceptable threshold of 0.70, thereby indicating good internal reliability. Additionally, the questionnaire underwent a pilot testing phase with a small group of participants to identify and rectify any ambiguities or inconsistencies in the items.

The clinical examination included palpation of masticatory muscles and TMJ areas to assess pain or discomfort. Palpation was performed bilaterally on specific muscle groups, including the temporal muscles, masseter muscles, and the TMJ, using standardized pressure as per DC/TMDs guidelines [22]. The presence of pain during palpation was recorded.

2.3. Measurement of Mandibular Movements and Dental Wear

All clinical measurements were conducted by the dental professionals who participated in the current study and were trained in the DC/TMDs protocol to ensure standardized and reliable assessments. Mandibular movements were measured using a millimeter ruler for maximum unassisted and assisted mouth opening, right and left lateral movements, and protrusion. Maximum unassisted mouth opening was measured as the inter-incisal distance at maximum comfortable opening without assistance, while assisted opening involved gentle assistance to achieve the maximum possible opening. Lateral and protrusive mandibular movements were quantified using a millimeter ruler to accurately measure the maximum extent of jaw movement in each direction. During the examination, participants were instructed to perform right and left lateral movements as well as forward protrusion to their maximum comfortable range without assistance. The distances achieved in millimeters were recorded for each movement type, ensuring a standardized and precise assessment of mandibular mobility across all participants.

The nomenclature of teeth used in this study follows the FDI World Dental Federation notation system, a widely recognized and standardized method for identifying and categorizing individual teeth. Dental wear was assessed using the Smith and Knight Tooth Wear Index [24]. Eight specific teeth were evaluated: the first molars (1.6, 2.6, 3.6, 4.6) and canines (1.3, 2.3, 3.3, 4.3). Each tooth was scored from 0 to 4 based on the severity of wear,

with higher scores indicating greater tooth surface loss. The assessment focused on the presence of enamel loss, dentin exposure, and any functional impairment due to wear.

2.4. Statistical Analysis

A convenience sampling method was chosen. The preliminary calculations suggested a minimal sample size of 80 participants to achieve an 80% power with a significance level of 0.05, assuming a medium effect size. However, to enhance the robustness of the study and accommodate potential dropouts, the actual recruitment exceeded this estimate. The final analysis included 108 participants who were divided into two groups: gamers (n = 48) and non-gamers (n = 60). Data were analyzed using SPSS Statistics software version 25. Descriptive statistics were calculated for all variables. Independent *t*-tests were conducted to compare mean values of mandibular movements and dental wear scores between gamers and non-gamers. The normality of data distribution was assessed using the Shapiro–Wilk test. Pearson correlation coefficients were calculated to examine the relationships between hours spent gaming and measurements of mandibular movements and dental wear scores. To interpret the magnitude of effects, we adopted the ranges established by Cohen's guidelines [25]. Specifically, for Cohen's d, effect sizes were classified as small (0.20), medium (0.50), and large (0.80). Similarly, Pearson's r values of 0.10, 0.30, and 0.50 were designated as small, medium, and large effect sizes, respectively. Additionally, for Odds Ratios (OR), the thresholds were set at small (1.44), medium (2.48), and large (4.27). Statistical significance was set at $p < 0.05$ for all analyses. Results were presented with corresponding p-values and 95% confidence intervals where applicable.

3. Results

The demographic characteristics revealed that the average age of gamers was 21.5 years (SD = 0.8), closely matching the non-gamers average age of 21.4 years (SD = 0.9), with no significant difference ($p = 0.6$). A significant gender distribution was observed, where 62.5% of gamers were male compared to only 10% of non-gamers ($p = 0.001$), indicating a predominance of males among gamers. Gamers reported significantly higher daily screen time, averaging 6.5 h (SD = 1.5) compared to non-gamers at 4.0 h (SD = 1.2) ($p < 0.001$). Additionally, gamers engaged in less physical activity, averaging 2.0 h per week (SD = 1.5) versus non-gamers 3.5 h (SD = 2.0) ($p = 0.002$), as presented in Table 1.

Table 1. Demographic characteristics and gaming habits of gamers and non-gamers.

Characteristic	Gamers (n = 48)	Non-Gamers (n = 60)	*p*-Value	Effect Size
Age (years, Mean ± SD)	21.5 ± 0.8	21.4 ± 0.9	0.6	0.10 (Cohen's d)
Gender (%)			0.001	0.35 (Cramer's V)
Male	62.5% (30)	10% (6)		
Female	37.5% (18)	90% (54)		
Daily Screen Time (hours, Mean ± SD)	6.5 ± 1.5	4.0 ± 1.2	<0.001	1.20 (Cohen's d)
Daily Gaming Time (hours, Mean ± SD)	4.0 ± 1.0	N/A	N/A	N/A
Physical Activity (hours/week)	2.0 ± 1.5	3.5 ± 2.0	0.002	−0.68 (Cohen's d)

SD—Standard Deviation; N/A—Not Applicable.

The study identified significant differences in mandibular mobility between gamers and non-gamers, with gamers demonstrating a greater range of jaw motion. Specifically, gamers had a significantly greater maximum unassisted opening of the mandible, averaging 48.31 mm compared to 46.33 mm for non-gamers, with a *p*-value of 0.04. This was also reflected in the maximum assisted opening, where gamers averaged 53.92 mm compared to non-gamers at 51.27 mm, with a *p*-value of 0.05. These findings suggest that gamers might experience increased flexibility or hypermobility in jaw movements, possibly as a

result of their habitual engagement in activities that may require or induce frequent jaw movement or clenching, such as intense gaming sessions.

Despite these differences in mandibular openings, the levels of pain during these movements were higher among gamers, though not reaching statistical significance; 25% of gamers reported pain during unassisted opening and 35% during assisted opening, compared to 15% and 20% among non-gamers, respectively. This discrepancy in pain prevalence, while not statistically significant ($p = 0.18$ and $p = 0.08$), points to a potential increased sensitivity or propensity for pain in gamers, possibly due to the stress placed on the jaw during gaming. Other mandibular movements, such as right and left lateral movements and protrusion, showed no significant differences between the two groups, indicating that the observed variations in mandibular function might be specific to the type of jaw activity elicited by gaming (Table 2).

Table 2. Comparison of mandibular movements and pain during movements between gamers and non-gamers.

Measurement	Gamers Mean ± SD	Non-Gamers Mean ± SD	*p*-Value	Effect Size
Maximum Unassisted Opening (mm)	48.31 ± 5.91	46.33 ± 6.48	0.04	0.43 (Cohen's d)
Pain During Unassisted Opening (%)	25% (12)	15% (9)	0.18	0.14 (phi)
Maximum Assisted Opening (mm)	53.92 ± 8.29	51.27 ± 6.87	0.05	0.38 (Cohen's d)
Pain During Assisted Opening (%)	35% (17)	20% (12)	0.08	0.11 (phi)
Right Lateral Movement (mm)	9.19 ± 3.63	9.28 ± 6.56	0.93	0.03 (Cohen's d)
Pain During Right Lateral Movement (%)	20% (10)	15% (9)	0.48	0.10 (phi)
Left Lateral Movement (mm)	9.39 ± 3.56	8.52 ± 3.49	0.2	0.26 (Cohen's d)
Pain During Left Lateral Movement (%)	22% (11)	18% (11)	0.62	0.09 (phi)
Protrusion (mm)	7.82 ± 3.16	7.49 ± 8.64	0.8	0.05 (Cohen's d)
Pain During Protrusion (%)	18% (9)	12% (7)	0.36	0.12 (phi)

SD—Standard Deviation.

The study revealed a notable difference in palpation-induced pain in the masseter muscle, with a significantly higher prevalence among gamers (45.8%) compared to non-gamers (30.0%), reaching statistical significance with a *p*-value of 0.05. This finding suggests that prolonged gaming sessions, which often involve sustained concentration and potentially stressful postures, may contribute to increased tension and discomfort in the masseter muscle, a key player in jaw movement and clenching. The increased prevalence of pain in this muscle among gamers could point to the habitual engagement of jaw muscles in response to gaming stress or concentration, which, over time, may predispose gamers to higher levels of musculoskeletal discomfort.

Additionally, although not statistically significant, there was a consistent trend showing higher rates of pain in other areas involved in mastication and jaw articulation among gamers compared to non-gamers. Pain in the temporalis muscle was reported by 35.4% of gamers versus 25.0% of non-gamers; TMJ lateral pole pain by 29.2% versus 20.0%; pain in the TMJ periarticular area by 22.9% versus 15.0%; and in the lateral pterygoid region by 20.8% versus 10.0%. These trends, despite lacking statistical significance, suggest a possible correlation between gaming and increased strain or overuse of the masticatory system. The observed differences might be indicative of the broader biomechanical and physiological impacts of gaming on the musculoskeletal system of the jaw, warranting further investigation into preventive and therapeutic strategies to address these issues in regular gamers, as seen in Table 3.

Table 3. Comparison of palpation-induced pain in masticatory muscles between gamers and non-gamers.

Muscle/Area	Gamers Pain Present (%)	Non-Gamers Pain Present (%)	*p*-Value	Effect Size
Masseter Muscle	45.8% (22)	30.0% (18)	0.05	0.19 (phi)
Temporalis Muscle	35.4% (17)	25.0% (15)	0.2	0.15 (phi)
TMJ Lateral Pole	29.2% (14)	20.0% (12)	0.25	0.14 (phi)
TMJ Periarticular Area	22.9% (11)	15.0% (9)	0.28	0.13 (phi)
Lateral Pterygoid Region	20.8% (10)	10.0% (6)	0.11	0.20 (phi)

Dental wear index scores were comparable between gamers and non-gamers for most teeth. Significant differences were observed in tooth 2.3, where gamers had a mean score of 0.68 (SD = 0.73) compared to non-gamers 0.55 (SD = 0.63) ($p = 0.03$), and in tooth 3.3, with gamers scoring 0.58 (SD = 0.68) versus non-gamers 0.42 (SD = 0.53) ($p = 0.04$). Other teeth, including 1.3, 1.6, 2.6, 3.6, 4.3, and 4.6, showed no significant differences in wear index scores between the groups (Table 4).

Table 4. Comparison of dental wear index scores between gamers and non-gamers across multiple teeth.

Tooth	Gamers Mean ± SD	Non-Gamers Mean ± SD	Mean Difference	*p*-Value	Effect Size (Cohen's d)
1.3	0.58 ± 0.71	0.57 ± 0.65	0.01	0.88	0.02
1.6	0.32 ± 0.47	0.19 ± 0.40	0.13	0.14	0.45
2.3	0.68 ± 0.73	0.55 ± 0.63	0.13	0.03	0.37
2.6	0.28 ± 0.62	0.26 ± 0.55	0.02	0.85	0.06
3.3	0.58 ± 0.68	0.42 ± 0.53	0.16	0.04	0.35
3.6	0.37 ± 0.57	0.23 ± 0.43	0.14	0.16	0.34
4.3	0.56 ± 0.77	0.54 ± 0.60	0.02	0.86	0.04
4.6	0.27 ± 0.54	0.32 ± 0.51	−0.05	0.64	−0.17

Independent *t*-tests indicated that gamers had a significantly higher maximum unassisted opening by 1.98 mm (95% CI: 0.11 to 3.85, t = 2.07, $p = 0.04$) and maximum assisted opening by 2.65 mm (95% CI: −0.02 to 5.32, t = 1.98, $p = 0.05$) compared to non-gamers. Additionally, gamers exhibited higher wear scores for tooth 2.3 (mean difference = 0.13, 95% CI: 0.01 to 0.25, t = 2.17, $p = 0.03$) and tooth 3.3 (mean difference = 0.16, 95% CI: 0.01 to 0.31, t = 2.07, $p = 0.04$). Furthermore, gamers reported significantly less physical activity, with a mean difference of −1.5 h per week (95% CI: −2.45 to −0.55, t = −3.10, $p = 0.002$), as seen in Table 5.

Table 5. Independent *t*-tests comparing mandibular measurements and dental wear between gamers and non-gamers.

Measurement	Mean Difference	95% CI	t-Value	*p*-Value	Effect Size (Cohen's d)
Maximum Unassisted Opening (mm)	1.98	0.11 to 3.85	2.07	0.04	0.43
Maximum Assisted Opening (mm)	2.65	−0.02 to 5.32	1.98	0.05	0.38
Tooth 2.3 Wear Score	0.13	0.01 to 0.25	2.17	0.03	0.37
Tooth 3.3 Wear Score	0.16	0.01 to 0.31	2.07	0.04	0.35
Physical Activity (hours/week)	−1.5	−2.45 to −0.55	−3.10	0.002	−0.68

The Pearson correlation analysis from the study underscores the multifaceted impact of gaming on both physical health and behavior. There was a statistically significant positive correlation between the hours spent gaming and the maximum unassisted opening of the mandible (r = 0.25, $p = 0.01$), suggesting that extended periods of gaming could lead to increased jaw mobility, potentially as a result of repetitive jaw movements or stress-related

behaviors such as clenching. This finding is further supported by the positive correlation between gaming hours and tooth wear, particularly for tooth 2.3, where the correlation coefficient was 0.3 with a *p*-value of 0.002, indicating that longer gaming sessions may be associated with more pronounced dental wear due to habitual grinding or clenching.

Additionally, a positive correlation was observed between gaming duration and masseter pain (r = 0.22, $p = 0.02$), implying that the more time individuals spend gaming, the more likely they are to experience muscle pain, possibly from the sustained tension in the jaw muscles during intense gaming. Conversely, there was a significant negative correlation between hours spent gaming and physical activity (r = −0.35, $p < 0.001$), highlighting a concerning trend where increased gaming time is associated with reduced physical activity levels. This trend not only reflects lifestyle choices that may contribute to poorer overall health but also suggests a potential area for intervention to mitigate health risks associated with prolonged gaming (Table 6).

Table 6. Pearson correlation coefficients between hours spent gaming and measurements.

Variable	Correlation Coefficient (r)	*p*-Value
Hours Gaming vs. Max Unassisted Opening	0.25	0.01
Hours Gaming vs. Tooth 2.3 Wear Score	0.3	0.002
Hours Gaming vs. Masseter Pain	0.22	0.02
Hours Gaming vs. Physical Activity	−0.35	<0.001

Logistic regression analysis identified gaming status as a significant predictor of TMD symptoms, with gamers having 2.5 times the odds of experiencing TMD symptoms compared to non-gamers (OR = 2.5, 95% CI: 1.1 to 5.6, $p = 0.03$). Daily screen time was also a significant predictor, where each additional hour increased the odds of TMD symptoms by 20% (OR = 1.2, 95% CI: 1.0 to 1.4, $p = 0.05$). Physical activity served as a protective factor, with each additional hour of physical activity per week reducing the odds of TMD symptoms by 20% (OR = 0.8, 95% CI: 0.7 to 0.95, $p = 0.01$). Gender was not a significant predictor (OR = 1.3, 95% CI: 0.6 to 2.8, $p = 0.5$), as presented in Table 7.

Table 7. Logistic regression analysis predicting the presence of TMD symptoms.

Variable	Odds Ratio (OR)	95% CI	*p*-Value
Gaming Status (Gamer)	2.5	1.1 to 5.6	0.03
Daily Screen Time (hours)	1.2	1.0 to 1.4	0.05
Physical Activity (hours/week)	0.8	0.7 to 0.95	0.01
Gender (Male)	1.3	0.6 to 2.8	0.5

4. Discussion

4.1. Interpretation of Findings

The present study investigates the impact of gaming on temporomandibular disorders, mandibular function, and dental wear among university students. The findings demonstrate a significant increase in awake bruxism, with masseter muscle pain among gamers, suggesting that prolonged gaming may lead to muscle strain or tension in this area. Although other muscle regions showed higher pain prevalence in gamers, the lack of statistical significance implies that masseter pain is the most notable muscular issue related to gaming activities. This finding highlights the importance of addressing specific muscle groups when evaluating the physical impacts of gaming.

Additionally, the increased dental wear in teeth 2.3 (upper left canine) and 3.3 (lower left canine) among gamers suggests that gaming-related behaviors, such as awake bruxism caused by psycho-emotional overload, may contribute to accelerated tooth wear in these

specific areas. The lack of significant differences in other teeth indicates that the impact of gaming on dental wear may be localized rather than widespread, emphasizing the need for targeted dental assessments in gamers. Moreover, the positive correlations indicate that increased gaming time is associated with greater mandibular opening, higher dental wear in tooth 2.3, and increased masseter muscle pain. The negative correlation with physical activity suggests that more gaming hours are linked to reduced engagement in physical exercise. These relationships highlight the multifaceted impact of gaming on both musculoskeletal health and lifestyle behaviors.

The higher wear scores for specific teeth further support the notion that gaming activities may lead to localized dental wear. The reduction in physical activity among gamers aligns with the demographic data, suggesting that decreased exercise may be a contributing factor to the observed musculoskeletal and dental issues. Moreover, these findings underscore the significant role of gaming status and screen time in the likelihood of developing TMD symptoms, suggesting that gaming behaviors directly contribute to these disorders and may require care with advanced splint technologies [26]. The protective effect of physical activity highlights the importance of maintaining an active lifestyle to mitigate the risk of TMDs. The non-significant impact of gender indicates that, within this study, gender was not a determinant factor for TMD symptoms when controlling for other variables.

In examining the multifactorial influences on bruxism and TMDs in children, the studies by Restrepo et al. [27] and da Silva et al. [28] present compelling evidence linking lifestyle factors to this condition. Restrepo et al. investigated the relationship between screen time, sugar consumption, and sleep bruxism (SB) in a cohort of 440 children aged 4 to 8 years. They found a high prevalence of possible SB (35%), which was significantly correlated with mean screen time of 2.1 h per day (Rho = 0.8; $p = 0.002$) and daily sugar consumption (Rho = 0.7; $p = 0.03$), with increases in these activities associated with a higher likelihood of SB (Odds Ratio, OR > 2). In a similar vein, the study by da Silva et al. [28] focused on awake bruxism (AB) and its association with the use of electronic devices and physical activities among 739 children aged 8 to 10 years. They reported a lower prevalence of possible AB (14.9%) but confirmed significant associations with daily use of electronic devices (OR = 1.82) and engaging in sports (OR = 1.60). Both studies underscore the impact of modern lifestyle choices, such as increased use of electronic devices and dietary habits, on bruxism in children, suggesting a need for public health interventions targeting these behaviors to mitigate their potentially adverse effects on pediatric sleep health and dental conditions.

In exploring the impact of modern lifestyle and stress on awake bruxism, two studies provide insights into different demographics and potential triggers. S K Rao et al. [29] conducted a cross-sectional study among information technology (IT) professionals in Bangalore, revealing a significant prevalence of self-reported awake bruxism at 59%. Their findings highlighted that stress was a strong predictor of awake bruxism with an Odds Ratio of 5.9 and that IT professionals with less work experience (1–5 years) reported a higher incidence of bruxism compared to those with over 11 years of experience, who had a substantially lower likelihood (OR = 0.04). In a similar manner, the study by Cássia Cardozo Amaral et al. [30] focused on probable sleep bruxism in children aged 7–8 years and its associations with sleep patterns and screen time. This study, however, found no significant correlation between screen time and sleep bruxism ($p = 0.744$) but noted that difficulties in maintaining sleep and a lower family socioeconomic status significantly contributed to higher prevalence rates of sleep bruxism (Prevalence Ratio [PR] = 1.95). Both studies emphasize the significance of stress and sleep disturbances as influential factors for bruxism, albeit in markedly different age groups and cultural contexts, suggesting that

interventions aimed at stress reduction and sleep improvement could be beneficial across the lifespan.

Moreover, the study conducted by Romina Perri et al. [31] aimed to explore the relationship between extended computer use and TMDs, an important exploration given the increasing prevalence of technology use in daily life. Their investigation recruited participants who were chronic computer users and who experienced pain, collecting data via an online survey. Of the 92 participants who completed the survey, 44% reported symptoms indicative of TMDs, and a significant majority reported experiencing associated pain in the neck (82%) and shoulder (75%). These findings align with previous research linking stress and prolonged device use to musculoskeletal disorders, including TMDs. The repetitive fine motor activities and sustained postures associated with gaming may contribute to muscle strain and joint stress.

The findings from this study underscore the importance of healthcare providers screening for temporomandibular disorders in populations with high screen time, particularly gamers. The correlation between extended gaming and increased mandibular discomfort, alongside the protective role of physical activity against TMD symptoms, suggests that medical advice should not only advocate for regular breaks from screen use but also emphasize the benefits of physical exercise. This could lead to the development of specific ergonomic and physical interventions tailored to reduce the strain on the jaw and improve overall health outcomes for individuals engaged in prolonged computer and gaming activities.

4.2. Study Limitations

This study has limitations that should be considered. The cross-sectional design limits causal inferences. The sample consisted of university students, which may limit generalizability to other populations. The gender imbalance between groups may confound results, although gender was included in the logistic regression model. Self-reported data on gaming habits and physical activity may be subject to bias. Future studies should include larger, more diverse samples and consider longitudinal designs to assess causality. To further enhance the reliability of our findings, subsequent studies will consider stratifying data by gender or employing more sophisticated statistical techniques to control for gender imbalances, thus providing a clearer understanding of the true impacts of gaming on mandibular health. Moreover, future studies can incorporate detailed information on participants' diets, beverage consumption, and any prior TMD diagnoses.

5. Conclusions

The study demonstrates that gamers exhibit greater mandibular opening capacity, increased dental wear on specific teeth, and a higher prevalence of masticatory muscle pain compared to non-gamers. These findings suggest that prolonged gaming may influence mandibular function and contribute to TMD symptoms and dental wear due to awake bruxism, potentially through stress-induced parafunctional habits and reduced physical activity. Dental professionals should be aware of the potential impact of gaming on oral health and consider screening for TMD symptoms in patients who are frequent gamers. Preventive strategies, including patient education on ergonomic practices, stress management, physical activity promotion, and the use of occlusal appliances, may be beneficial. Further research is needed to explore underlying mechanisms and develop targeted interventions.

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Article

Electromyographic Diagnostic Ranges Defining Temporomandibular Disorders and Healthy Individuals' Results in Functional Clenching Index

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Abstract: Background: Temporomandibular disorders (TMDs) represent a significant public health issue, among which masticatory muscle pain is the most common. Current publications increasingly indicate surface electromyography (sEMG) as an effective diagnostic tool for muscle dysfunctions that may be employed in TMDs recognition. The objective of this study was to establish reference ranges for TMDs patients with masticatory muscle pain and healthy individuals in the electromyographic Functional Clenching Index (FCI) for the temporalis muscles (TAs) and masseter muscles (MMs). This research aimed to provide an additional diagnostic tool for TMDs patients. **Methods**: A total of 48 individuals (n = 30 women and n = 18 men) with the muscular painful form of TMDs were recruited alongside a numerically and gender-matched control group—healthy, pain-free controls. The Functional Clenching Indexwas calculated for both groups. **Results**: Data analysis revealed statistically significant differences with a very large effect size. Healthy individuals had higher FCI scores compared to those with TMDs. The healthy group exhibited higher threshold values compared to the TMDs group. **Conclusions**: For healthy individuals, the FCI ranges for TAs were between 58 and 145, while for MMs, between 72 and 210. Lower values may indicate muscle activation disorders and occur in patients with the painful, muscular form of TMDs. This is the first study to define reference ranges for electromyographic indices; therefore, caution is recommended, and the replication of this study on a larger and more culturally diverse sample is advised.

Keywords: electromyography; sEMG; masticatory muscles; functional indices; temporal muscle; masseter muscle; TMD; diagnostic; ranges

1. Introduction

Temporomandibular disorders (TMDs) constitute a significant public health issue, affecting 34% of the global population. The term TMDs describes pain and dysfunction in the chewing muscles, temporomandibular joint, and surrounding tissues [1]. The etiological factors associated with TMDs can be divided into four groups: behavioral factors, social factors, emotional factors, and cognitive factors [2].

The first group includes, among others, bruxism (sleep and awake) [3,4]. Social factors influence the perception and the effect of learned responses to pain [2]. Emotional factors are related to psychological states, such as anxiety and depression [5,6]. Cognitive factors encompass negative thoughts and attitudes [2].

Currently, it is accepted that temporomandibular joint dysfunction typically involves an accumulation of factors leading to dysfunction. However, there are cases where a single factor can cause the disorder [7].

Genetic factors are also associated with TMDs [8,9]. Hormonal factors, on the other hand, are linked to the worsening of symptoms and increased pain response [10,11].

The number of factors influencing the temporomandibular joint, as well as those contributing to the development and exacerbation of TMDs, may explain why, under similar circumstances, one person's TMJ may exhibit more severe clinical symptoms, while another's does not [12].

Due to its multifactorial etiology and sometimes controversial etiologies [12], various diagnostic methods are employed in TMDs studies [1,2], including standardized approaches like the Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) [13] and the Diagnostic Criteria for TMD (DC/TMD) [14]. Rapid screening tools such as the pain screening questionnaire have also been developed [15]. The most common TMD symptom is myalgia within masticatory muscles, with a frequency of 30% [16]. Hence, additional objective diagnostic methods are needed to examine changes in muscle activity in patients with TMDs.

It is worth noting that TMDs are also associated with economic challenges. The treatment of TMDs involves significant expenses for patients as well as for national budgets [17]. The treatment of TMDs creates an annual economic burden of approximately USD 4 billion worldwide [18].

Surface electromyography (sEMG) was first introduced in dentistry in 1949, and the number of such studies has steadily increased [19]. Surface electromyography is a technique based on capturing, recording, and analyzing myoelectric signals generated by physiological changes in the membrane state of muscle fibers [20].

In electromyographic studies, data based on the amplitude and frequency of the signal are used to analyze the sEMG signal [21,22]. The raw amplitude data are normalized using the root mean square (RMS) algorithm for electromyography data analysis. RMS calculates the average power of the myoelectric signal, thereby eliminating the impact of short-term fluctuations [23]. This provides a more accurate picture of muscular activity, allowing for a better evaluation of muscle function during chewing, biting, and other activities related to the stomatognathic system. For this reason, it is frequently used in analyses of the bioelectric activity of masticatory muscles [22,24–26].

Various electromyographic indices based on RMS sEMG amplitude calculations are used within masticatory muscles for comparing results between patients and healthy individuals, including the Activity Index (AcI), Asymmetry Index (AsI) [27], and Percentage Overlapping Coefficient (POC) [28]. In 2021, the Functional Indices were developed, including the Functional Clenching Index (FCI) and Functional Opening Index (FOI) [26]. The FCI relies on resting and functional muscle activity, which may increase its effectiveness in analyses involving gender and other anthropometric variables [26].

Based on the above information, a study was conducted to determine the reference ranges of the FCI for TMDs patients and healthy individuals in the temporalis (TAs) and masseter muscles (MMs). Specifying these data may introduce and provide an additional diagnostic tool for TMDs patients.

2. Materials and Methods

This study was conducted with the approval of the local bioethics committee (KE-0254/25/01/2024). This research was divided into phases.

The first phase of this study involved informing participants about the research procedure, highlighting the specific aspects related to sEMG. Participants were informed

that this study is safe and painless, and that they could withdraw at any point. Subsequently, in this phase, they were asked to complete documentation related to their consent to participate in this study.

The second phase of this study involved analyzing the presence of TMDs, as well as inclusion and exclusion criteria for this study. Detailed information regarding these criteria is provided below. Participants who reported pain symptoms were asked to complete the VAS scale.

The third phase of this study consisted of an electromyographic examination.

The fourth phase involved statistical analysis, with participants divided into two groups: healthy and those with TMDs.

Initially, 48 participants (n = 30 women and n = 18 men) with a muscular form of temporomandibular disorders (TMDs) were recruited based on the RDC/TMD diagnostic criteria [29]. The average level of pain measured using the VAS scale was determined to be 6 points, with a standard deviation of ± 2 VAS [30]. A control group was selected to match the experimental group in terms of size and sex distribution. Participants in the control group were confirmed to be free of TMDs, according to RDC/TMD standards. Both groups were comparable in age, with the experimental group averaging 30 ± 8 years and the control group, 30 ± 10 years. Statistical analysis showed no significant age differences between groups ($Z = -1.18$, $p = 0.24$).

The main inclusion criteria for this study were as follows: age between 20 and 40 years; inclusion of both women and men who provided consent, with four support zones in the dental arch; and no history of surgery or injuries within the last six months.

Both groups were subjected to the following criteria: exclusion of individuals with malocclusions (Angle's Class II or III); exclusion of those undergoing orthodontic treatment; exclusion of individuals with injuries or surgeries involving the head or neck within the past six months; exclusion of individuals with metal implants, regardless of type or location; exclusion of participants whose hair prevented electromyographic measurements; and exclusion of pregnant individuals.

2.1. Study Design Description

The objective of this study was to establish reference ranges for the FCI, derived from electromyographic measurements of the temporalis muscles and masseter muscles. The aim was to enhance diagnostic tools for patients with temporomandibular disorders characterized by masticatory muscle pain.

To ensure a structured approach, this study followed the following steps:

1. Participants were recruited and informed about the study procedure, including consent collection.
2. Participants were analyzed based on inclusion and exclusion criteria as well as for the presence of TMDs.
3. sEMG measurements of the TAs and MMs were performed.
4. Advanced statistical analyses were conducted to interpret the data and establish reference ranges.

This study included two groups:

- Healthy Group: Participants without TMDs or masticatory pain.
- TMD Group: Participants with TMDs characterized by muscle pain.

After screening for inclusion and exclusion criteria, sEMG examinations were conducted. Functional Clenching Index values were calculated for both the temporalis and masseter muscles. These indices are based on the ratio of muscle activity during clenching to resting muscle activity [26].

The obtained FCI values for both muscle groups were compared between the two groups. Advanced statistical analyses were used to determine ranges that could effectively differentiate healthy individuals from those with TMDs, contributing to improved diagnostic accuracy.

2.2. Surface Electromyography Procedure

Before the measurements, the skin was cleaned with 90% alcohol. The tests were conducted between 8:00 and 12:00 AM [19]. Electrodes were placed according to the SENIAM protocol (surface EMG for non-invasive assessment of muscles) [31]. The electrodes used were Ag/AgCl with a diameter of 30 mm and a conductive surface of 16 mm. The electrodes were placed symmetrically on both sides by the same individual, ensuring that the edges of the electrodes were in contact and that there was no hair beneath the conductive surface. The distance between the centers of adjacent electrodes was 30 mm. In accordance with the referenced protocol, the electrodes were positioned on the superficial part of the masseter muscle and the anterior part of the temporalis muscle. The presentation of electrode placement is shown in Figure 1. The placement of the electrodes was preceded by a palpatory examination conducted by a physiotherapist and an sEMG specialist (G.Z.). It was decided to adopt an approach in which an experienced physiotherapist additionally performed the palpation of the examined muscles to reduce the risk of so-called 'cross talk'.

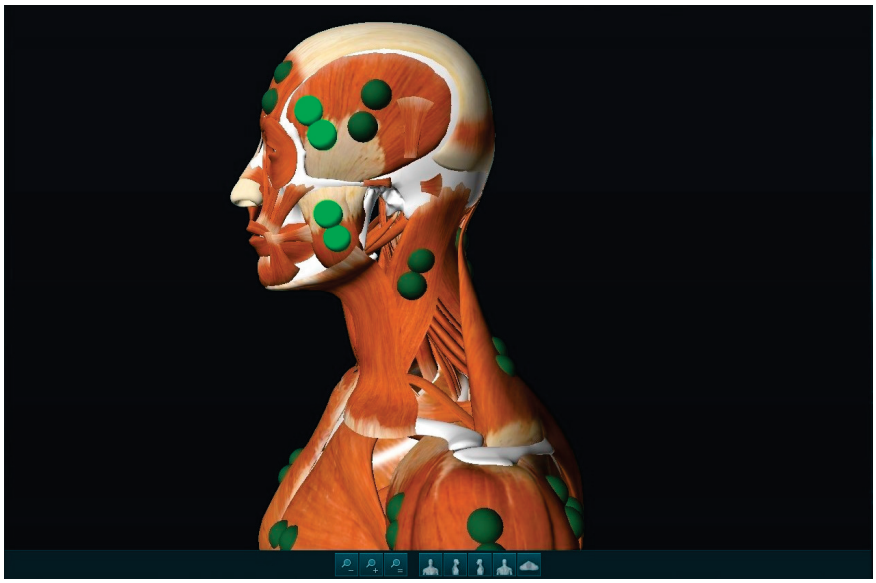

Figure 1. Electrode arrangement during surface electromyography. The green circles indicate the placement of the electrodes, and the graphic is sourced from dedicated electromyographic signal analysis software, Noraxon MR3 3.18.08 software (Noraxon USA, Inc., Scottsdale, AZ, USA).

Cross-talk, in the context of sEMG studies, refers to interference in the electromyographic signal resulting from the recording of electrical activity from adjacent muscles instead of (or in addition to) the target muscle.

Typically, cross-talk constitutes 10–15% of the sEMG signal [20]. It occurs because surface electrodes capture electrical signals not only from the target muscle but also from other nearby muscles, especially if these muscles are active simultaneously.

While the risk of cross-talk was negligible in the context of the temporalis muscle, for the masseter muscle, it required the precise identification of the superficial muscle belly to minimize this risk.

Participants sat upright with their legs supported, torso aligned straight, and the head and neck in a straight position supported by a headrest [19]. The procedure involved

recording resting activity for 10 s and functional activity, including clenching teeth (as hard as possible, 3 repetitions of 3 s, with 2 s intervals). Electromyographic data were recorded using the Noraxon Ultium DTS 8-K MR 3 myo Muscle Master Edition system (Noraxon USA, Inc., Scottsdale, AZ, USA). Settings included the following: sampling rate: 2000 Hz (motion: 200 Hz); high-pass filter cutoff: 10 Hz; low-pass filter cutoff: 500 Hz; input impedance: >100 MΩ; common mode rejection ratio: >100 dB; measurement accuracy: ±1% of the full scale [19]. Signal analysis was conducted using MR3 3.18.08 software, which involved raw signal cleaning and smoothing.

Next, the Root Mean Square, a standard algorithm for analyzing masticatory muscles in electromyographic studies [22,24,25], was calculated. The *RMS* is calculated using a program (Noraxon MR3 3.18.08 software (Noraxon USA, Inc., Scottsdale, AZ, USA) that is based on the following formula [23,32,33]:

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N} x_i^2}$$

In the formula, x_i represents the value of the signal at the i-th sample, while N is the number of samples in the analyzed period.

Electromyographic results were processed to the FCI using the following formula [26]:

$$Functional\ Clenching\ Index\ = \frac{\text{clench}}{\text{rest}}$$

The following mathematical formulas were adopted for the analysis:

$$\text{Functional Clenching Index for TA right-sided } (FCI_{TA\text{-}R}) = CL_{TA\text{-}R}/REST_{TA\text{-}R}$$

$$\text{Functional Clenching Index for TA left-sided } (FCI_{TA\text{-}L}) = CL_{TA\text{-}L}/REST_{TA\text{-}L}$$

$$\text{Functional Clenching Index for MM right-sided } (FCI_{MM\text{-}R}) = CL_{MM\text{-}R}/REST_{MM\text{-}R}$$

$$\text{Functional Clenching Index for MM left-sided } (FCI_{MM\text{-}L}) = CL_{MM\text{-}L}/REST_{MM\text{-}L}$$

2.3. Statistical Analysis

The minimum group size was determined based on previous studies [24]. Calculations were performed using G*Power software 3.1.9.7 (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) [34], with the following assumptions: α = 0.05, power = 0.90, and effect size = 0.50 [35,36] for the *t*-test [24]. The required minimum sample size was 44 participants.

FCI values were computed for the right and left temporalis (TA) muscles (n = 48 each) and the right and left masseter (MM) muscles (n = 48 each). To avoid bias from side-specific results, data for TAs (n = 96) and MMs (n = 96) were combined for analysis. Data processing and analysis involved three stages: raw data management using Excel 2019 (Microsoft, Redmond, WA, USA), distribution analysis and significance testing with Statistica™ 13.3 (TIBCO Software Inc., Palo Alto, CA, USA), advanced analyses, including bootstrap methods, using R statistical software (version 4.1.1, R Core Team, Vienna, Austria) [37,38].

The data distribution was assessed using the Shapiro–Wilk test. Since distributions deviated from normal, the nonparametric Mann–Whitney U-test was used. The effect size was calculated using the formula $r = \frac{2(\overline{R_1} - \overline{R_2})}{n_{1+}n_2}$ [36,39].

Subsequently, interval analysis was conducted using the bootstrap method. Bootstrapping is a statistical technique that allows for estimating confidence intervals or standard

errors without making assumptions about the data distribution [40]. This method was selected due to the nonparametric nature of the data. The bootstrap analysis was performed as follows: each bootstrap sample, denoted as $X^{(b)}$, was generated from the original data [40] through resampling with replacement, following the mathematical notation

$$X^{(b)} \sim X,\ i = 1,2,3,\ldots,\ n$$

For each bootstrap sample $X^{(b)}$, the mean $(X_{boot}^{(b)})$ was computed as

$$X_{boot}^{(b)} = \frac{1}{n}\sum_{i=1}^{n} X_i^{(b)}$$

The distribution of the bootstrap means $(X_{boot}^{(b)})$ was used to determine the confidence intervals. Due to the nonparametric nature of the data, a 95% confidence interval could not be applied [41]. Instead, the 2.5th and 97.5th percentiles were used to define the intervals according to the following notation [42]:

$$Lower\ bound = 2.5(\overline{X}_{boot})$$

$$Upper\ bound = 97.5(\overline{X}_{boot})$$

$\overline{X}_{boot}$ represents values below the 2.5th percentile or above the 97.5th percentile. This allowed for the determination of values for the healthy group (values for TAs and MMs) and for the group with the painful muscular form of TMDs (values for TAs and MMs). Subsequently, the lower cutoff point was determined using the following formula:

$$\text{Lower cut} - \text{off point} = \frac{Upper\ bound_{TMDs} - Lower\ bound_{Healthy\ group}}{2}$$

The upper cutoff point was established based on the calculated upper bound, supplemented by a visual analysis of the data to identify the point of minimal overlap between truly positive and truly negative cases. This approach was adopted because masticatory muscle hyperactivity is also a symptom associated with dysfunction. For example, hyperactivity can occur in bruxism [4,43] and during stressful situations [44,45].

Sensitivity and specificity analyses for the obtained thresholds for the TAs and MMs were conducted using the following formulas [46]:

$$\text{Sensitivity} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}}$$

$$\text{Specificity} = \frac{\text{True Negatives}}{\text{True Negatives} + \text{False Positives}}$$

3. Results

The data analysis revealed statistically significant differences with a large effect size. Healthy individuals had higher FCI values compared to those with TMDs. Additionally, TA FCI values were lower than MM FCI values, regardless of the group. The healthy group had an FCI TA score of 76.46, while the TMDs group scored 52.95. In comparing the MM FCI, the healthy group scored 83.63, whereas the TMDs group scored 61.60 (Table 1).

Table 1. Comparison of FCI results between groups.

	Mean TA FCI	SD	Mean MM FCI	SD	Z	p	ES
Healthy Group	76.46	58.55	83.63	76.87	4.14	0.00	96.5
TMDs Group	52.95	55.87	55.11	61.60	3.74	0.00	96.5

TMDs—temporomandibular disorders; FCI—functional clenching index; TA—temporalis anterior; MM—superficial part of the masseter muscle; ES—effect size.

Following the methodological framework, thresholds were established for both groups. For the healthy group, the TA FCI range was determined to be between 60.48 and 82.62, while for the TMDs group, the TA FCI range was between 35.14 and 55.69. The MM FCI range for the healthy group was between 69.14 and 99.09, whereas for the TMDs group, it was between 48.09 and 74.47 (Table 2).

Table 2. Determination of intervals corresponding to a 95% confidence interval.

	Lower Bound TA FCI	Upper Bound TA FCI	Lower Bound MM FCI	Upper Bound MM FCI
Healthy Group	60.48	82.62	69.14	99.09
TMDs Group	35.14	55.69	48.09	74.47

TMDs—temporomandibular disorders; FCI—functional clenching index; TA—temporalis anterior; MM—superficial part of the masseter muscle.

Healthy participants exhibited higher threshold values compared to individuals with TMDs. Sensitivity and specificity analyses showed that both thresholds had identical specificity values, higher than their corresponding sensitivity values (Table 3).

Table 3. Presentation of adjusted FCI intervals.

	Lower Bound FCI	Upper Bound FCI	Sensitivity	Specificity
TA	58	145	61%	69%
MM	72	210	58%	69%

FCI—functional clenching index; TA—temporalis anterior; MM—superficial part of the masseter muscle.

4. Discussion

This study represents the first attempt to determine ranges for electromyographic patterns within masticatory muscle activity. Additionally, TA FCI values were lower than MM FCI values, regardless of the group. The healthy group had a TA FCI score of 76.46, while the TMDs group scored 52.95. When comparing the MM FCIs, the healthy group scored 83.63, whereas the TMDs group scored 61.60. The observed statistical differences demonstrate the effectiveness of the FCIs in distinguishing the studied population [26]. Based on these differences, FCI ranges were determined: the lower bound was based on statistical analyses, while the upper bound was established according to the described methodology. The upper cutoff point was determined based on the calculated upper bound, supplemented by a visual analysis of the data to identify the point of minimal overlap between truly positive and truly negative cases, highlighting that bioelectrical hyperactivity is also not beneficial [43–45].

Based on the presented research, the FCI ranges for healthy, pain-free individuals for the TA were between 58 and 145, while for the MM, between 72 and 210. Lower values may indicate muscle activation disorders and occur in patients with the painful, muscular form

of TMDs. The established thresholds demonstrated higher specificity levels, suggesting that these ranges could identify healthy individuals with 69% accuracy. Using these thresholds in clinical conditions makes it possible to monitor and predict the reaction of the muscular system in response to orofacial pain.

The Pain Adaptation Model demonstrates that changes in muscle activity limit movement and protect tissues from further injury [47]. Thus, in painful TMDs (e.g., myalgia, myofascial pain), the masticatory muscle has an incorrect activation pattern due to the pain condition, which disrupts both resting and clenching muscle activity. This condition may increase electromyographic values during the resting mandibular position and reduce sEMG potentials during teeth clenching [48]. A change in these parameters can be detected during an sEMG examination, and the results can be analyzed using the FCI. Using the FCI ranges for TMDs and healthy individuals, classifying study subjects or patients into a predisposition group based on the sEMG examination, may have significant clinical value. Hence, a prospective cohort study using electromyographic assessments may confirm the assumptions of specific ranges for the FCI. Moreover, the diagnostic thresholds proposed in this study will allow for exploring ranges for other patterns, such as the ACI, ASI, and POC [27,28].

As noted in the introduction, TMDs are also associated with economic challenges. The treatment of TMDs involves significant expenses for patients as well as for national budgets [17]. The treatment of TMDs creates an annual economic burden of approximately USD 4 billion worldwide [18].

To mitigate these substantial costs for both patients and governments, the development of additional diagnostic tools is crucial. These tools would help identify at-risk groups and facilitate effective prevention [49]. The defined ranges could serve as a screening tool, allowing for the identification of patients at risk before pain arises and dysfunction occurs. This would enable early referral for observation and further monitoring of TMJ function.

On the other hand, TMDs are characterized by a complex etiology [2], and pain-related factors may be influenced by variables such as hormonal fluctuations in women [10,11], adding to the diagnostic challenges. Additionally, defining an upper threshold for bioelectrical hyperactivity is complex as it may also relate to changes in the stomatognathic system or anatomical differences. Therefore, assessing and classifying a patient with TMDs must be approached individually, considering the interviews, thorough clinical diagnostics, imaging tests, assessment of comorbid disorders, and electromyographic examination.

At the end of this discussion, it is also important to consider the potential of combining diagnostic methods for TMJ. This article focuses on electromyographic testing and determining thresholds for electromyographic patterns. Surface electromyography is a quick, non-invasive, and cost-effective diagnostic method for masticatory muscles [19,20]. Another commonly used diagnostic method is ultrasound imaging [50–52]. Both methods can effectively complement each other, providing a complete clinical picture of the patient. The combination of these two methods can help determine whether, in addition to changes in bioelectric activity reflected by alterations in electromyographic patterns in patients with TMDs [1], structural changes in the TMJ, as visualized through ultrasound, will also be observed.

The primary limitation of this study is the lack of ROC curve (Receiver Operating Characteristic) [53] analysis and calculation of AUC (Area Under Curve) [54,55]. While the ROC and AUC are useful for diagnostic tests or classifiers with a single cutoff point, they are unsuitable for tests defining intervals rather than discrete thresholds. When tests define results as a range rather than a single point, assigning a clear decision threshold becomes challenging, rendering ROC curve construction impractical. The effectiveness of such tests

depends on multiple parameters, such as the beginning and end of the range, which the AUC cannot adequately address.

5. Conclusions

The proposed FCI ranges, calculated from RMS sEMG amplitude values for healthy individuals, are as follows: TAs: 58 to 145; MMs: 72 to 210. Lower values may indicate muscle activation disorders and occur in patients with the painful, muscular form of TMDs. This study is the first to propose diagnostic thresholds for electromyographic indices, and we recommend interpreting these findings with caution while encouraging replication in larger, more diverse samples to account for cultural and demographic variations.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Review

Sleep Bruxism and Hypobaric Hypoxia Exposure: Exploring the Physiological Association

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Abstract

Sleep bruxism (SB) is a masticatory muscle activity during sleep which can be categorized as primary, when it remains unclear whether the phenomenon is directly linked to a specific disorder, or if it only coexists, and secondary, when it is proven to be associated with a particular disorder, treatment or lifestyle and bruxism that is part of the signs of a disorder. In this way, SB is associated with various factors, including obstructive sleep apnea and gastroesophageal reflux (GER), where evidence suggests SB has a protective role in airway patency, potentially triggered by microarousals and autonomic instability, especially under hypoxia conditions. Since hypobaric hypoxia exposition—generated by high-altitude exposure—produces a decrease in the partial pressure of oxygen, it triggers alterations in cardiac rhythm and gastric function, which could be associated with physiological alterations mentioned in SB. Therefore, the aim of this review is to determine the effect of hypobaric hypoxia exposure on the physiological and molecular alterations during sleep bruxism. Method: The SANRA-guided narrative review synthesized recent human and animal studies on hypoxia's physiological and molecular effects in sleep bruxism. In conclusion, SB is associated with GER and autonomic dysregulation, which are present in hypobaric hypoxia conditions, where respiratory disturbances, microarousals, and increased muscle activity are associated with SB. High-altitude exposure triggers oxidative stress, genetics, and sleep alteration, which exacerbate its severity. Moreover, neurophysiological and molecular mechanisms, including TRPV1 and HIF-1α activation, are implicated. Finally, polysomnography remains the gold standard for diagnosis; however, studies at high altitude are needed to confirm this association.

Keywords: high altitude; bruxism; gastroesophageal reflux; hypoxia

1. Introduction

Sleep bruxism (SB) is a masticatory muscle activity that occurs during sleep and is characterized as rhythmic (phasic) or nonrhythmic (tonic), but it is not classified directly as a movement disorder or sleep disorder [1]. Bruxism refers to a group of different jaw-muscle activities during sleep or wakefulness that can result in various motor behaviors, expressed either with or without tooth contact [2]. Current evidence [3] indicates that the overall prevalence of bruxism (both during sleep and wakefulness) is approximately 22%, of which SB constitutes a minor portion (21%) as determined by electromyography or self-reports (with or without clinical examination); however, the prevalence varies when polysomnography is used as a diagnostic method, when the occurrence of sleep bruxism

increases to 43%. The reported variations are likely due to differences across studies, which may involve population demographics, diagnostic criteria, or methodological approaches.

Various classification systems have been suggested to describe bruxism, considering the interplay of different contributing factors. For instance, in some cases, bruxism activity may be physiological, whereas in other cases, bruxism may be related to, or a manifestation of, an underlying condition or disorder [2]. In this way, bruxism can be categorized as primary when it remains unclear whether the phenomenon is directly linked to a specific disorder or if it only coexists or secondary when it is demonstrated to be associated with a particular disorder, treatment or lifestyle and when the bruxism is a sign of the disorder [1]. Consequently, in accordance with the clinical effects on orofacial structures, bruxism is considered a risk factor, a protective factor, or an innocuous factor [1] and is also related to the other disorders mentioned above. Since the effects of bruxism can vary from exacerbation of periodontal diseases and destruction of occlusal restorations to contributing as risk factors or aggravating orofacial musculoskeletal symptoms or respiratory pathology, in this context, one study proposed the definition of "patobruxism" for conditions related to orofacial pain, obstructive sleep apnea (OSA), and/or pathological impact on either oral or general health conditions. On the other hand, the term "normo-bruxism" is associated only with normal homeostasis and no signs or symptoms [4]. However, more studies are necessary to determine the principal classification of bruxism.

Currently, studies report that the etiology of SB may include a series of individual factors, such as personality traits, the capacity for adaptability to anxiety and stress, environmental and genetic factors, gene polymorphisms in serotonin and dopamine pathways, biological rhythms, anatomical characteristics, instability in sleep, upper airway patency, and sleep disorders [5–8]. In recent years, there has been significant interest in exploring the relationship between SB and OSA, a normobaric intermittent hypoxia, because of its possible strong association with biological concomitant alterations [9]. However, there is another kind of hypoxia that is generated by environmental factors, hypobaric hypoxia, which is a condition caused by exposure to high altitudes (2500 m above sea level) and is a product of a decrease in the partial pressure of oxygen (PaO_2). Diminishing the bioavailability of this vital gas to humans can lead to cardiovascular [10], metabolic [11] and cognitive alterations [12].

Consequently, as mentioned previously, SB is associated with several physiological alterations, i.e., sleep disorders, cardiovascular alterations, changes in cardiac rhythm, genetic factors, anxiety, and stress, which may be exacerbated by hypoxic conditions [13]. With respect to chronic hypobaric hypoxia, this condition has been shown to be associated with various health issues, including sleep disturbances, central nervous system disease, anxiety, and emotional distress [14]; these alterations can be exacerbated by SB, which acts more as a risk factor than as an innocuous or a protective factor, as discussed in the next sections. Additionally, a human study (288 adult volunteers) by Calderón-Jofré et al. [15] of a particular type of hypobaric hypoxia, termed chronic intermittent hypobaric hypoxia (CIHH), which involves alternating days of exposure to high-altitude and high-sea-level conditions, revealed that CIHH can affect sleep quality and melatonin levels, which are crucial for regulating sleep cycles. Moreover, other factors are present in hypobaric hypoxia—such as activation of the sympathetic nervous system, which was corroborated by a human study at 5620 m for 4 weeks [16], and an increased heart rate [10], where upper airway obstruction or hypoxia has been associated with gastroesophageal alterations [16] and where these factors may contribute to or stimulate the SB process. Therefore, the aim of this review is to determine the effects of hypobaric hypoxia exposure on physiological and molecular alterations during sleep bruxism.

2. Materials and Methods

This narrative review was conducted following the SANRA guidelines [17] to evaluate the effects of hypobaric and normobaric hypoxia on the physiological and molecular alterations associated with SB. A systematic search was performed in internationally recognized databases (Web of Science, PubMed, Scopus and Google Scholar) and peer-reviewed scientific books using keywords such as sleep bruxism, hypobaric hypoxia, high-altitude exposure, normobaric hypoxia, obstructive sleep apnea, autonomic dysregulation, and molecular mechanisms. The inclusion criteria included studies published within the past five years, animal models with hyperreactivity to hypobaric hypoxia, human and animal studies under hypobaric or normobaric hypoxia conditions, and publications in indexed journals or recognized scientific sources. The exclusion criteria included studies older than ten years, nonindexed journals, and studies lacking original data. Relevant data on study design, population characteristics, exposure conditions, and reported physiological or molecular outcomes were extracted and synthesized narratively, considering heterogeneity in study designs and outcomes. This review integrates evidence on autonomic dysregulation, gastroesophageal reflux, sleep microarousals, and molecular pathways such as TRPV1 and HIF-1α activation, providing a comprehensive overview of SB under hypoxic conditions.

3. Sleep Bruxism Mechanism Associated with Gastroesophageal Reflux

Notably, bruxism may also play a physiological role. For instance, jaw movements in SB are related to the ability to secrete stimulated saliva that improves lubrication of the oral cavity and pharynx, which is potentially beneficial during sleep in humans (28.2 ± 8.6 years) [18]. Gastroesophageal reflux (GER) occurs when stomach contents return to the esophagus because of dysfunction of the lower esophageal sphincter (LES). GER is commonly classified into two categories: nonerosive reflux disease (NERD), characterized by reflux-related symptoms in the absence of visible mucosal injury, and erosive reflux disease, defined by the presence of endoscopically confirmed esophageal erosions. Although reflux esophagitis occurs more frequently in men overall, NERD is disproportionately observed in women; additionally, age, habits and pharmacological treatment are important factors to consider, as from the age of 50 and above, tobacco consumption, alcohol intake and pharmacological treatment (aspirin and other nonsteroidal anti-inflammatory agents) increase the risk of developing GER. Epidemiological data indicate that the prevalence of GERD in Western countries ranges from 10–20%, with severe manifestations affecting approximately 6%, whereas in Asian countries, the prevalence is estimated to be approximately 5% [19].

Under physiological conditions, the LES relaxes transiently to allow the passage of food and then contracts to prevent reflux. During sleep, the tone of the LES increases, reducing the likelihood of reflux episodes in patients with SB [20]. Individuals with gastroesophageal reflux may experience inappropriate or sustained relaxations of the LES, decreased esophageal motility, and increased intra-abdominal pressure. During sleep, protective mechanisms such as salivation and swallowing also decrease, which prolongs the exposure and contact time of the esophageal mucosa with acidic contents. As a result, nocturnal reflux tends to be more harmful and more difficult to compensate for patients with GER [21].

Recent studies have suggested that nocturnal GER may act as a trigger for sleep bruxism episodes through a protective reflex mechanism. This physiological sequence has been described as the "triple event model", which includes three consecutive phases: First, during an episode of acid reflux, acid ascends through the esophagus, irritating the esophageal mucosa, which is termed the "initial event"; then a cortical microarousal occurs,

in which the irritation elicits a brief cortical activation (detected by electroencephalography), accompanied by changes in autonomic activity, such as increased heart rate; and finally, the orofacial motor response, which is an episode of rhythmic masticatory muscle activity (RMMA), occurs, promoting salivation and swallowing and contributing to the neutralization of the acidic content in the esophagus. This sequence has been observed in studies using polysomnography combined with esophageal pH monitoring, which revealed that episodes of acid reflux precede several bruxism events [22].

Consequently, this phenomenon involves activation of cortical and motor centers that elicit mandibular movements (RMMA), often accompanied by increased swallowing and salivation—responses that may serve to neutralize or clear acidic refluxate. However, the evidence positing a causal link between GERD and SB remains heterogeneous and largely observational, so the proposition that managing GER is a therapeutic strategy for SB should be regarded as provisional. Recent systematic reviews and clinical case series demonstrate associations and plausible pathophysiological mechanisms, yet they also highlight methodological limitations, confounding (e.g., from obstructive sleep apnea), and lack of meta-analytic synthesis or formal grading of evidence necessary to support robust conclusions [20,23–26].

At the molecular and neurophysiological level, acid exposure in the esophagus appears capable of activating nociceptive receptors (e.g., TRPV1-expressing fibers) and inducing vagal afferent signaling to the nucleus tractus solitarius (NTS); integration of these signals may precipitate microarousals and recruitment of masticatory motor circuits culminating in RMMA. Experimental work has shown upregulation of sensory and neuroinflammatory markers in esophageal mucosa and functional involvement of TRPV1 channels in visceral sensory transmission, providing a biologically plausible substrate for the reflexive and pre-RMMA responses. Nonetheless, most findings are still indirect (animal models, e.g., rat (*Mus musculus*), tissue studies, clinical correlations) and require further validation through longitudinal, interventional, or multimodal human research [27–30].

The so-called "triple event model"—mucosal irritation → vagal activation → motor response—provides a conceptual framework through which esophageal acid exposure might trigger mandibular movements via glutamatergic and cholinergic neurotransmission, ultimately engaging the trigeminal motor nucleus (MotN) in the brainstem, which is critical for initiating RMMA. Recent polysomnographic studies confirm that RMMA episodes are frequently associated with microarousals and with preceding cortical EEG changes, supporting a reflex–cortical–motor chain; however, the mechanistic evidence linking each step—from acid exposure to specific synaptic activation in the MotN—is still incomplete and fragmented, indicating a need for research integrating neuroanatomical tracing, esophageal sensitivity measurements, and simultaneous VEMG/PSG recordings [31–34].

Moreover, previous studies have shown the overexpression, at the brainstem level, of a proto-oncogene termed cellular-Fos (c-Fos) after acid reflux, which triggers the activation of visceral–sensory circuits and then SB [35]. In addition, these last two effects involve glutamatergic and GABAergic signaling that interacts with hypothalamic centers to regulate arousal and oral motor activity [35,36]. With respect to acid reflux, there are neuropeptides such as substance P and calcitonin gene-related peptide (CGRP) that can reinforce nociceptive signaling and modulate orofacial motor output through their action in reticular formation and TGV under these acidic conditions [37], which consequently contributes to RMMA and SB.

Notably, mild hypoxia—such as that experienced at high altitudes—can increase sympathetic activation and plasma noradrenaline (NA) levels [38], thereby potentiating oral motor reflexes. A key hypoxia-regulated transcription factor, hypoxia-inducible factor-1α

(HIF-1α), is stabilized under hypobaric and normobaric hypoxia conditions and modulates multiple molecular pathways associated with inflammation, including those involving interleukin-6 (IL-6) and nuclear factor-kappa B (NF-κB) and various kinase pathways, such as those involving matrix metalloproteinase-1 (MMP-1), matrix metalloproteinase-3 (MMP-3), lysyl oxidase (LOX), A disintegrin and metalloproteinase with thrombospondin motifs-1 (ADAMTS-1), and angiotensin-converting enzyme (ACE); therefore, HIF-1α is present in several physiological and pathological processes under hypoxic conditions [39]. Furthermore, HIF-1α has been implicated in neuronal plasticity [40] and in alterations in visceral sensitivity, such as gastroesophageal inflammation (NF-κB) and oxidative stress caused by exacerbated levels of reactive oxygen species (ROS) under hypoxic conditions, where both effects have been linked to GER and subsequently SB [19,21,41], which was corroborated in residents living at high altitudes, such as Tibetans, through histopathological, immunohistochemical and ultrastructural analyses of gastric biopsies [39]. Therefore, on the basis of the evidence discussed above, HIF-1α may play a critical role in the development of sleep bruxism (SB) under high-altitude conditions. By modulating inflammatory pathways, including the IL-6 and NF-κB pathway, and influencing oxidative stress (ROS), HIF-1α contributes to alterations in oral motor activity and autonomic regulation, thereby potentially exacerbating SB in individuals in hypobaric hypoxic environments. This highlights the importance of further investigating HIF-1α as a key molecular mediator linked to high-altitude hypoxia, inflammation, and SB pathophysiology; this will be discussed in the next section.

4. Hypobaric Hypoxia and Gastroesophageal Reflux

Gastroesophageal alterations associated with GER may be linked to hypoxia. A study by Michaud et al. [42] using an animal model (newborn lambs; $n = 17$) under normobaric hypoxia conditions (10% O_2 for 3 h) demonstrated that the presence of upper airway obstruction (UAO) for 6 h moderately increased the frequency of GER episodes. Additionally, clinical evidence supports a strong association between oxygen desaturation and GER in patients with primary respiratory symptoms, via simultaneous 24-h multichannel intraluminal impedance (IIM)–pH monitoring and continuous oxygen saturation (SpO_2) monitoring using pulse oximetry [43].

However, distinguishing between normobaric and hypobaric hypoxia is crucial, as they induce significantly different physiological and molecular responses. Normobaric hypoxia involves a reduced oxygen concentration at sea-level pressure, typically achieved by decreasing the fraction of inspired oxygen (FiO_2). In contrast, hypobaric hypoxia occurs at reduced atmospheric pressure, simulating high-altitude conditions. These differences lead to distinct ventilatory, cardiovascular, and biochemical adaptations. For instance, compared with normobaric hypoxia, hypobaric hypoxia often results in greater hypoxemia, hypocapnia, and alkalosis because of increased respiratory frequency and lower tidal volume under low-pressure conditions. Additionally, hypobaric hypoxia has been associated with more pronounced oxidative stress and differential gene expression related to hypoxia-inducible factors (HIFs) and mitochondrial function in Sprague-Dawley rats ($n = 6$) under exposure for 6 h at a simulated altitude of 25,000 feet (approximately 7620 m) with barometric pressure reduced to 282 mmHg and exposure for 6 h to an oxygen concentration of 8% (FiO_2) under normobaric conditions [44] and in a human study (27.6 ± 6.2 years) under normobaric hypoxia with a partial pressure of inspired oxygen (PiO_2) of 100.9 ± 1.3 mmHg and hypobaric hypoxia conditions with a PiO_2 of 106.0 ± 0.5 mmHg [45]. Understanding these distinctions is essential for accurately interpreting experimental outcomes and for designing interventions targeting specific hypoxic conditions.

Human studies conducted at high altitudes have linked hypobaric hypoxia to an exacerbation of gastrointestinal symptoms, including nausea, potential mucosal damage [46], and marked abdominal discomfort [47], all of which have been strongly associated with GER episodes. Abdominal discomfort appears to be influenced by factors such as age, sex, alcohol consumption, and smoking status [47]. Moreover, it is important to highlight that under hypobaric conditions, pharmacological strategies are used to mitigate or prevent certain pathological conditions in individuals at high altitude [48], such as acute mountain sickness (AMS) and high-altitude pulmonary hypertension (HAPH). The treatment for these diseases involves the use of drugs that reduce lower esophageal sphincter pressure, including calcium channel blocker agents [49], and, in the case of AMS, the use of aspirin and other nonsteroidal anti-inflammatory drugs, which increase the risk of developing GERD [19].

In addition, studies in patients with alterations in esophageal reflux have demonstrated a significant role for the stabilization of hypoxia-inducible factor subunits (HIF-1α and HIF-2α). In particular, HIF-2α can trigger the overexpression of proinflammatory mediators through reactive oxygen species (ROS) in this context. Furthermore, HIF-2α expression has been characterized as a prognostic biomarker of GER and the progression of Barrett's esophagus to esophageal adenocarcinoma [50]. Prospective studies in 15 patients have shown that the stabilization of HIF-1α [16] and HIF-2α in patients with GER [51] under hypobaric hypoxia is associated with oxidative stress and inflammatory molecules [52], which may support the association between hypobaric hypoxia and GER through oxidative stress and proinflammatory proteins.

Finally, while UAO is clearly involved in the modulation of GER episodes, the direct role of hypoxia—particularly hypobaric hypoxia—in GER pathogenesis remains insufficiently understood. To the best of our knowledge, few studies have directly associated GER with hypobaric hypoxia. Therefore, further research is warranted to elucidate these complex interactions and to improve clinical management, especially in populations exposed to high-altitude conditions. Some recommendations can be useful for preventing or decreasing the secondary effects of SB; for example, the findings of Lile et al. [53] in 60 healthy adult volunteers suggest that natural mouth rinses containing propolis and green tea are effective at reducing dental plaque, with efficacy comparable to that of chlorhexidine. In the context of sleep bruxism, where increased masticatory activity and microtrauma can exacerbate oral and periodontal conditions, the use of such natural antimicrobial agents may help mitigate plaque accumulation and reduce the risk of secondary oral complications. This could be particularly relevant under hypoxic conditions, such as high-altitude exposure, where oxidative stress and autonomic dysregulation associated with bruxism may further compromise oral health.

5. Relationships Among Obstructive Sleep Breathing Disorders, Sleep Arousal and Sleep Bruxism

Various studies have associated obstructive sleep breathing disorders with sleep bruxism, but the exact relationship remains unclear [54–57]. Obstructive sleep breathing disorders (OSBD) are repetitive episodes of complete (apnea) or partial (hypopnea) UAO that occur during sleep. These events often result in reduced blood oxygen saturation and are usually terminated by sleep microarousal [58]. Approximately 50% of adult patients with certain types of OSBD have concomitant SB [59], but others report that the majority of apnea/hypopnea events are unrelated to SB events (84.5% of episodes) [60]. Nevertheless, the tonic activity of the masticatory muscles is evidenced in episodes of SB that occur immediately after or during episodes of apnea/hypopnea, facilitating the re-establishment of the airway and causing the termination of respiratory events [54,61]. Additionally, SB is

linked to subtle forward movements of the lower jaw and tongue muscles, which expand the pharyngeal space and aid in the flow of air to the lungs [61].

Similarly, it has been postulated that the pathophysiology of OSA is intertwined with the pathogenesis of SB through the occurrence of microarousals during respiratory events [54,61]. For example, Yap et al. [60] reported that when apnea/hypopnea-SB events are related, SB events occur after apnea/hypopnea events and are predominant, suggesting a specific form of secondary SB triggered by sleep microarousals. This could be an important factor for individuals exposed to hypobaric hypoxia conditions. The collapsibility of the airway, whether partial or total, may be associated with desaturations in oxygen levels and subsequent arousals, which play a crucial role in initiating sleep [55]. The American Academy of Sleep Medicine defines arousals as an abrupt shift in electroencephalogram (EEG) frequency observed during polysomnography, including alpha, theta, and/or frequencies greater than 16 Hz, which lasts at least 3 s, with at least 10 s of stable sleep preceding the change. Rapid eye movement (REM) sleep is characterized by a concurrent increase in submental electromyography (EMG) lasting at least 1 s [62]. On the other hand, studies have shown that the sudden onset of RMMA during sleep occurs within a brief time when the brain is transitioning from sleep to an electroencephalographic aroused state [55,63]. Microarousals appear to be crucial in the sequence of events leading to the activation of the central pattern generator and jaw-closing muscles [63].

Moreover, Miki et al. [64] used standard nocturnal polysomnography in 14 healthy subjects (31.5 ± 5.7 years) to assess sleep quality and the presence of arousals and electromyography of the masseter muscle to identify episodes of rhythmic masticatory muscle activity (RMMA). They reported that all RMMA episodes coincided with sleep arousals and that movements such as lower limb movements, swallowing, and scratching were more frequent during episodes with RMMA. On the other hand, there is a significant association between sleep bruxism activity (RMMA/SB) and other body movements, particularly during arousals, suggesting a link between SB, arousal mechanisms, and physical movements. SB and OSA are associated with cardiovascular risks, potentially through mechanisms involving oxidative stress, inflammation, and autonomic nervous system activity [65–67]. In this way, through nocturnal polysomnography and venous blood samples, Fulek et al. [68] reported that a greater severity of SB is associated with increased oxidative stress markers, including elevated levels of advanced protein products (AOPPs) and thiobarbituric-acid-reacting substances (TBARSs), as well as a decreased total antioxidant capacity (TAC), with significant implications. These findings suggest that oxidative imbalance may contribute to the pathophysiology of SB. While some markers, such as 8-isoprostane, adiponectin, and leptin, did not show significant overall correlations, the oxidative stress profile—particularly increased oxidative damage and reduced antioxidant capacity—appears to play a role in the severity of SB. These results collectively suggest that oxidative stress markers could serve as indicators of SB severity and may be involved in its underlying mechanisms. However, these molecular signaling pathways and conditions have been well described for individuals exposed to hypobaric hypoxia. A study by Irarrázaval et al. [69] in mountaineers under conditions of acute hypobaric hypoxia, which simulated high-altitude conditions for 8 h, reported a significant increase in TBARS levels in the plasma of humans after 24 h of acute hypobaric hypoxia exposure. These findings are corroborated by preclinical studies under both intermittent (male Wistar rats exposed to 4600 m; 428 Torr) and chronic hypobaric hypoxia conditions (male Wistar rats exposed to 4600 m; 428 Torr) [70–72]. Furthermore, recent studies have shown a decrease in total TAC and an increase in oxidative biomarkers such as TBARSs and superoxide [73]. Therefore, on the basis of the above, we suggest that exposure to hypobaric hypoxia may contribute to

both increased oxidative pathways and reduced antioxidant capacity, which are associated with SB.

Evidence linking sleep bruxism (SB) severity with increased oxidative stress markers, such as elevated levels of advanced oxidation protein products (AOPPs) and thiobarbituric-acid-reacting substances (TBARSs), along with reduced total antioxidant capacity (TAC), is clinically relevant [68–73]. Patients with SB who are exposed to hypobaric hypoxia—either due to high-altitude environments or intermittent hypoxic conditions—may be at heightened risk for oxidative stress-mediated complications, as hypoxia itself has been shown to exacerbate oxidative pathways and impair antioxidant defenses [69–73]. From a clinical perspective, these findings highlight the potential utility of monitoring oxidative stress biomarkers (e.g., TBARSs, TAC, and 8-isoprostane levels) in SB patients, particularly in those with hypoxia exposure, as indicators of both disease severity and systemic oxidative burden. Early detection of oxidative imbalance could inform the development of preventive or therapeutic strategies, such as antioxidant supplementation, lifestyle modifications, or interventions targeting hypoxia-related triggers, ultimately reducing the risk of long-term complications associated with SB and oxidative stress. Moreover, integrating polysomnography findings combined with biochemical profiling may allow clinicians to better stratify patients on the basis of oxidative stress status, facilitating more personalized management approaches for SB in hypoxic settings.

6. Microarousal-Induced Sleep Bruxism and Hypobaric Hypoxia Exposure

Although microarousals are defined as having sudden changes in brain wave frequency observed on polysomnography [74], current studies in male Sprague–Dawley rats under acute exposure to natural hypobaric hypoxia at 3270 m above sea level for 24 h (acute hypobaric hypoxia) have focused primarily on related aspects such as autonomic nervous system instability, cardiorespiratory function, and brain activation patterns [74]. Recent evidence in 12 young healthy women (mean age: 24.0 $\pm$ 4.2 years) exposed to hypobaric hypoxia (3500 m) for 4 days revealed reduced cardiac baroreflex sensitivity (cBRS), diminished vagal tone, and increased sympathetic activation—physiological conditions that favor the occurrence of microarousals during sleep [75]. Nevertheless, the direct relationship between microarousals and hypobaric hypoxia remains unexplored [76,77]. Future research should therefore employ polygraphic or polysomnographic studies at high altitude or in hypobaric chamber simulations, integrating EEG, cardiac baroreflex sensitivity, heart rate variability, respiratory parameters, and oxygen saturation to quantify the incidence, frequency, and severity of microarousals under hypoxic stress. Such studies would help clarify the neurophysiological pathways linking hypobaric hypoxia, autonomic dysregulation, and sleep fragmentation [75–77].

On the other hand, it has been proposed that the administration of melatonin improves sleep quality and the occurrence of such involuntary movements, which could be used as a preventive measure. In hypoxic contexts relevant to sleep bruxism, melatonin exhibits antioxidant and HIF-1α modulating properties and improves sleep continuity in individuals with COMISA/OSA, potentially reducing the number of microarousals that precede RMMA. Observational data in humans also suggest altered nocturnal melatonin in SB. While these findings in human studies support melatonin as a preventive adjunct targeting sleep stability, direct evidence that melatonin reduces SB/RMMA remains limited; hence, treatment of underlying sleep-disordered breathing should be prioritized, with melatonin considered an adjunct pending SB-specific trials [78,79].

On the other hand, recent studies of mountaineers (high-altitude exposure on Mount Blue Sky (4350 m), CO, USA) and humans, both adapted high-altitude dwellers (such

as Andeans and Tibetans) and outsiders in the process of acclimatization at over 6000 m of altitude, highlight that respiratory support systems, including continuous positive airway pressure (CPAP), supplemental oxygen, and acetazolamide, effectively alleviate sleep-disordered breathing and improve sleep quality under high-altitude and hypobaric hypoxia conditions [80,81]. These interventions reduce the apnea–hypopnea index (AHI), increase oxygen saturation, and decrease the frequency of arousal, thereby enhancing sleep continuity and autonomic stability. Although no direct evidence currently links these interventions to reduced sleep bruxism (SB) or rhythmic masticatory muscle activity (RMMA), the pathophysiological overlap is compelling: SB episodes frequently follow microarousals, which are intensified by hypoxia-induced autonomic dysregulation. Thus, by mitigating hypoxia-related arousal and sleep fragmentation, respiratory support strategies may indirectly reduce SB occurrence. Future studies integrating polysomnography with masseter electromyography and autonomic markers should evaluate whether CPAP, oxygen supplementation, or acetazolamide confer protective effects against SB in hypoxic environments.

Finally, future research integrating sleep recordings (such as polysomnography) with these measurements under hypobaric hypoxia or high-altitude conditions (over 2500 m) is needed to confirm this association (Figure 1).

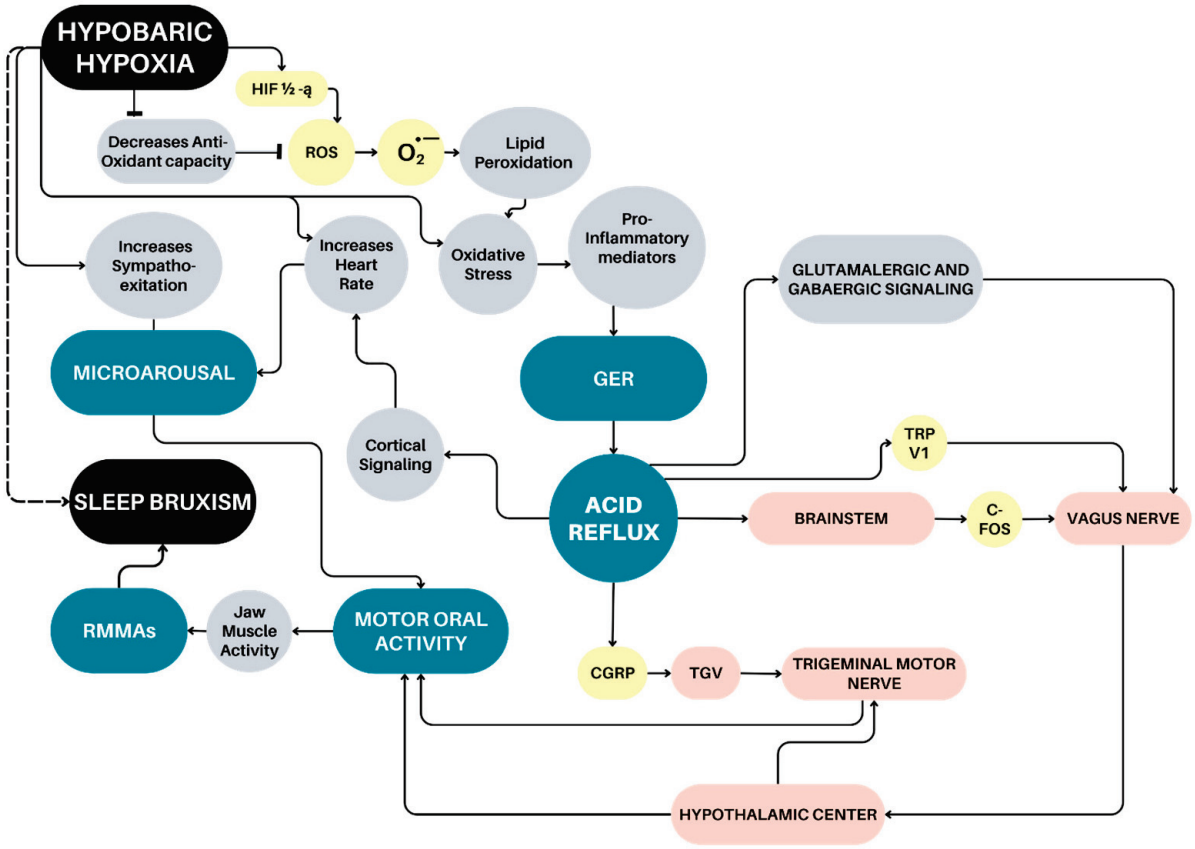

Figure 1. Hypothetical scheme of association with hypobaric hypoxia conditions and Sleep Bruxism (SB). HIF-1α (Hypoxia-Inducible Factor 1-alfa), ROS (Reactive Oxygen Species), O_2 (molecular oxygen), GER (GastroEsophageal Reflux), TRPV1 (Transient Receptor Potential Vanilloid 1), c-FOS (cellular proto-oncogene Fos), CGRP (Calcitonin Gene-Related Peptide), TGV (Trigeminal Ganglion V) and RMMA (Rhythmic Masticatory Muscle Activity).

7. Conclusions

In conclusion, sleep bruxism (SB) is a multifactorial condition that can range from benign physiological behavior to a pathophysiological phenomenon influenced by gastroesophageal reflux (GER), autonomic instability, and hypobaric hypoxia exposure. Respiratory events such as airway obstructions and hypoxia act as key triggers for microarousals, which are subsequently associated with increased masticatory muscle activity. Additional factors—including psychological stress, genetic predisposition, sleep instability, and environmental influences such as high-altitude hypobaric hypoxia—further modulate the severity and frequency of SB episodes and related sleep disturbances. High-altitude environments, characterized by reduced atmospheric pressure and intermittent or chronic hypoxia, may exacerbate SB through sympathetic overactivation, sleep fragmentation, and an increased incidence of microarousal.

Oxidative stress appears to play a significant role in the pathophysiology of SB, with reactive oxygen species contributing to increased orofacial motor activity. Neurotransmitter systems, including brainstem reflex circuits and central pattern generators, mediate involuntary jaw muscle activity, whereas hypoxia and autonomic nervous system activation further modulate these processes. The potential protective role of SB in facilitating airway reopening, along with its interplay with central pattern generators and autonomic responses, underscores the multifaceted nature of this sleep phenomenon.

Molecular interactions between GER and neural pathways highlight the complex biochemical environment contributing to SB episodes. GER, which may be aggravated under hypoxic conditions, can trigger a brainstem-mediated protective sequence known as the "triple event model", consisting of acid reflux, cortical arousal, and rhythmic masticatory muscle activity. Hypoxia-inducible factors (HIFs), nociceptive receptors, and neuropeptides contribute to neuroplastic changes and increased orofacial motor responses. While further studies are warranted, the current evidence supports a plausible link between hypobaric hypoxia and increased SB activity, emphasizing the need for integrated diagnostic approaches and targeted preventive strategies, particularly for individuals exposed to high-altitude environments.

Clinical Implications

Understanding the multifactorial contributors to SB can guide individualized patient management. Assessing oxidative stress and autonomic responses may help identify patients at greater risk of severe SB and related systemic complications. Differentiating exposure to normobaric versus hypobaric hypoxia is essential in high-altitude settings. Integrated management strategies should address GER control, sleep stabilization, and a reduction in sympathetic overactivation. Polysomnography remains the gold standard for SB evaluation, but studies directly assessing SB at high altitude are limited, highlighting the need for further research to translate mechanistic insights into clinical practice.

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Abbreviations

The following abbreviations are used in this manuscript:

SB	Sleep bruxism
OSA	Obstructive Sleep Apnea
CIHH	Chronic Intermittent Hypobaric Hypoxia
PaO_2	Partial Pressure of Oxygen
TG	Tooth Grinding
GER	Gastroesophageal Reflux
LES	Lower Esophageal Sphincter
RMMA	Rhythmic Masticatory Muscle Activity
TRPV1	Transient Receptor Potential Vanilloid 1
NTS	Nucleus Tractus Solitarius
MotN	The trigeminal motor Nucleus
TGV	Trigeminal Nerve
c-FOS	Cellular-Fos
CGPR	Calcitonin Gene-Related Peptide
HIF-1α	Hypoxia-inducible factors
NA	Noradrenaline
UAO	Upper Airway Obstruction
ROS	Reactive Oxygen Species
OSBD	Obstructive Sleep Breathing Disorders
OSA	Obstructive Sleep Apnea Syndrome
EEG	Electroencephalogram
REM	Rapid Eye Movement
EMG	Electromyography
CAP	Cyclic Alternating Pattern
AOPP	Advanced Protein Products
TBARS	Thiobarbituric Acid-Reacting Substances
TAC	Total Antioxidant Capacity
cBRS	Reduced Cardiac Baroreflex Sensitivity

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Review

Multimodal Approaches in the Management of Temporomandibular Disorders: A Narrative Review

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Abstract: Background/Objectives: Temporomandibular disorders (TMDs) are the most common cause of non-dental pain in the orofacial region. Due to the complex and multifactorial nature of TMD, a multidisciplinary approach is often required. The objective of this narrative review is to evaluate the effectiveness of multimodal therapies in the management of TMD. **Methods:** A literature search was performed using a combination of keywords: "TMD", "TMJ", "disorders", "manual therapy", "physical therapy", "dry needling", "botulinum toxin", "Botox", "splint", and "psychotherapy". The search was conducted in the PubMed, Google Scholar, and Scopus databases, focusing on studies involving human subjects. **Results:** The included studies reported that the use of multimodal approaches—such as physiotherapy, botulinum toxin injections, occlusal splints, and/or psychotherapy—led to symptom improvement or complete resolution in patients with TMD. **Conclusions:** Temporomandibular disorders are complex conditions with a multifactorial etiology involving both somatic and psychological components. Given the wide range of symptoms and the functional connections of the temporomandibular joint with the nervous, muscular, and skeletal systems—including the cervical spine—effective treatment of TMD requires a multidisciplinary strategy.

Keywords: TMD; TMJ; disorders; manual therapy; physical therapy; dry needling; botulinum toxin; Botox; splint; psychotherapy

1. Introduction

The temporomandibular joint (TMJ) is a bilateral synovial joint located on either side of the craniomandibular complex [1,2]. It consists of the mandibular fossa, the articular eminence, and the condylar process of the mandible, separated by an articular disc. The TMJ plays an essential role in functions such as swallowing, chewing, speech, and involuntary movements including yawning, teeth grinding, and clenching [1,3,4].

Temporomandibular disorders (TMDs) are becoming increasingly prevalent [5,6]. The term refers to pain and dysfunction of the TMJ and related structures, most commonly involving the masticatory muscles [7,8]. Clinical symptoms may include headaches, restricted joint mobility, hypertrophy and pain in the masticatory muscles, joint inflammation, and audible sounds such as clicking or crepitus during mandibular movements [9].

The etiology of TMD remains unclear and is considered multifactorial, involving biomechanical, neuromuscular, biological, and biopsychosocial components [5,10–12]. Occlusal overload and parafunctions such as bruxism are key biomechanical contributors. Elevated levels of estrogen have also been proposed as biological factors influencing TMJ function, particularly in women. Estrogen levels have been shown to be associated with pain modulation in the temporomandibular joint and the entire orofacial region [13,14]. Among biopsychosocial factors, stress, anxiety, and depression are frequently reported [15, 16].

Conditions associated with TMD include bruxism, capsulitis, and intra-articular disc abnormalities [1,17]. Dental occlusion and bruxism are commonly diagnosed as comorbidities. The co-occurrence of TMD and bruxism is thought to be influenced by overlapping genetic, hormonal, ethnic, and geographical factors [12,18]. Zieliński et al. suggest that the co-occurrence of bruxism and TMD in the global population is approximately 17% [12]. Additionally, the authors observed that a 1% increase in the proportion of women in the study group was associated with a 4.4% increase in the likelihood of TMD and bruxism co-occurrence [12], highlighting the influence of sex as a contributing factor in TMD [13,14,19,20].

TMD is the most common cause of non-dental pain in the orofacial region [21]. The global prevalence of TMD is estimated at around 34%, although this figure varies by region and population group [10]. For instance, the occurrence of TMD was notably greater in South America, reaching 47%, in contrast to 33% in Asia and 29% in Europe [10]. Chronic pain is the most frequent reason why patients seek professional help [22,23].

Numerous studies suggest a link between TMD and cervical spine dysfunction [24–28]. This association is believed to result from the neuroanatomical convergence of nociceptive inputs from the trigeminal and cervical nerves. The topographical organization of the spinal trigeminal nucleus allows bidirectional information transfer between these systems. Consequently, stimulation of structures innervated by the trigeminal nerve can lead to cervical pain, and vice versa [24–28]. It shows the complexity of the factors that may influence the TMJ.

There is no universally effective treatment for TMD [2,29,30]. Due to its multifactorial nature, an interdisciplinary approach is essential. Effective management requires the collaboration of dentists, physiotherapists, and mental health professionals, given the well-established relationship between TMD and psychological stress [6,7,16,31,32]. Each case should be approached individually, with a comprehensive diagnostic process to identify the primary contributing factors [33].

Currently, conservative treatment is recommended as the first-line approach for managing TMD [34]. This includes physiotherapy involving manual techniques targeting the joint and surrounding soft tissues, muscle relaxation or strengthening exercises, and physical therapy modalities [35]. Occlusal splints are commonly used to stabilize the mandible and reduce muscle tension [36,37]. For moderate to severe pain, pharmacological interventions such as non-steroidal anti-inflammatory drugs (NSAIDs), analgesics, and muscle relaxants have shown clinical effectiveness [38–40].

In cases where conservative therapies fail to achieve satisfactory outcomes, more invasive interventions may be considered. Intra-articular corticosteroid injections are used to reduce inflammation, and in cases of persistent muscular hyperactivity, botulinum toxin type A (BoNT-A) has been applied. BoNT-A is approved by the FDA for the treatment of various pain conditions, including certain forms of dystonia [41,42].

The purpose of this narrative review is to evaluate the effectiveness of a multimodal, multidisciplinary approach in the treatment of temporomandibular disorders.

2. Materials and Methods

A literature search for relevant papers indexed in the literature from 2020 to 2025 was conducted using the PubMed, Scopus, and Google Scholar databases. This time frame was chosen because it covers the period directly following the outbreak of the COVID-19 pandemic. The pandemic had a significant impact on both the mental and physical health of the population, increasing levels of stress and anxiety, and altering many people's lifestyles—all of which are closely linked to the development and exacerbation of TMD symptoms [43–45]. The intensification of these factors may also have contributed to the advancement of research and therapeutic approaches aimed at improving the effectiveness of treatment methods [46–48].

Three researchers reviewed the databases from 1 March to 1 May 2025. The search was conducted by two independent researchers, and all discrepancies were resolved by a third investigator. In our paper, we included clinical trials, pilot studies, and prospective studies concerning the impact of TMD disorders, physical therapy, manual therapy, botulin toxin BTX-A, and splints. The methodology for study selection was adapted from [10,18].

Keywords included "TMD", "TMJ", "disorders", "manual therapy", "physical therapy", "dry needling", "botulinum toxin", "Botox", "splint", and "psychotherapy". The keywords were searched with MeSH terms. Only studies published in English were considered to maintain clarity and accuracy in data interpretation The authors reviewed selected articles according to topic relevance. The reference lists of selected manuscripts were also revised. Relevant titles identified during this process led to further examination of the corresponding articles. If these articles provided additional pertinent information, they were subsequently included in the review. The inclusion criteria are listed in Table 1.

Table 1. Inclusion and exclusion criteria.

Data Source	**PubMed, Scopus, Google Scholar**
Publication date	January 2020–2025
Language	Open-access English version with full text
Type of paper	Clinical trials, pilot study, prospective study, pre–post intervention study, one-group, quasi-experimental, case-series study
Inclusion criteria	Articles relating to main focuses with similar materials and methods
Exclusion criteria	1. Non-English-language articles, books, other types of articles 2. No open-access version with full text
Journal category	All

3. Treatment of Temporomandibular Joint Disorders

3.1. TMD Disorders and Physiotherapy Treatment

3.1.1. Manual Therapy and Joint Mobilization

There is no single gold standard in the treatment of TMD [2,29,30], and the literature increasingly supports the use of multimodal therapeutic approaches [10,48,49]. Among conservative interventions, physiotherapy plays a central role, particularly through manual therapy, exercise, and adjunct physical modalities.

One frequently applied technique in the management of TMJ dysfunction is joint mobilization, particularly the Maitland mobilization method. This technique has been reported to restore normal function in both joints and surrounding muscles [50,51]. In a

study by Nambi and Abdelbasset, the effectiveness of a 4-week Maitland mobilization program was compared to a home-based training regimen in patients with TMJ dysfunction following bilateral cervicofacial burns [50]. The group receiving Maitland mobilizations demonstrated significantly greater improvements in mouth opening, pain intensity, functional limitations, kinesiophobia, sleep quality, and overall quality of life. These findings highlight the benefit of targeted manual therapy, particularly in cases where scar-related contractures contribute to TMJ dysfunction [6,52].

Complementary findings were reported by Barone et al., who assessed the immediate effects of a single session of rhythmic TMJ mobilization. Results showed statistically significant improvements in pain intensity, pressure pain threshold, and mandibular opening, suggesting that even short-term interventions can provide measurable relief [53].

3.1.2. Therapeutic Exercise and Yoga-Based Interventions

Therapeutic exercises represent another cornerstone in the physiotherapeutic management of TMD. Gębska et al. emphasized their simplicity and safety, especially in patients with myogenic TMD [54].

Furthermore, yoga-based exercise programs have emerged as an alternative therapeutic approach. Long-term yoga practice has been shown to modulate pain centers in the brain and improve pain tolerance [55]. In a study by Atilgan et al., yoga sessions incorporating breathing techniques, relaxation, and physical postures (asanas) significantly reduced TMJ and neck pain, improved range of motion, and alleviated depressive symptoms in women with myofascial TMD [56].

Vassis et al. demonstrated that jaw-targeted exercises in children with juvenile idiopathic arthritis—a rheumatic disease that often affects the facial region—led to a reduction in pain frequency and intensity, as well as improvements in jaw function, including maximum mouth opening, laterotrusion, and protrusion [57].

3.1.3. Cervical Spine Integration and Trigeminocervical Complex

The interconnection between the cervical spine and TMJ is another important consideration. Anatomically, biomechanically, and neurophysiologically, the cranio-mandibular and upper cervical regions function as an integrated system, linked via the trigeminocervical complex, which facilitates nociceptive signal transmission [26,58–60]

Studies have shown impaired neck muscle function and structural deficits in patients with TMD [61,62]. Rezaie et al. found that integrating manual therapy targeting both the upper cervical spine and TMJ into standard care resulted in superior outcomes compared to routine treatment alone [63].

Similarly, Crăciun et al. reported that a 3-month physiotherapy protocol targeting the cervical and temporomandibular regions significantly reduced pain and improved Jaw Functional Limitation Scale and Neck Disability Index scores [64]. Further supporting this, Oliveira-Souza neck et al. demonstrated that motor control training for neck muscles was significantly more effective than the placebo in improving jaw pain and function [65].

3.1.4. Dry Needling and Combined Interventions

Another promising modality is dry needling, which targets myofascial trigger points to disrupt pathological impulses and improve local circulation [66,67]

Dib-Zakkour et al. found that deep needling of the masseter muscles resulted in reduced pain, decreased muscle activity, improved mandibular positioning and motion symmetry, and increased maximum mouth opening compared to a placebo group [66]. Moreover, Dunning et al. demonstrated that combining dry needling with cervical spinal manipulation produced significantly greater improvements in pain relief and pain-free

mouth opening than standard treatments such as NSAIDs, occlusal splints, and TMJ mobilization [68].

3.1.5. Myofascial Techniques and Muscle Relaxation

Manual techniques such as post-isometric relaxation (PIR) and myofascial release are also effective in TMD with a predominantly muscular component.

Research by Urbański et al. showed that both approaches significantly reduced muscle tension and bioelectrical activity in the masseter and anterior temporalis muscles, as well as lowering pain intensity [69].

Tariq and co-authors published a paper, the main aim of which was to compare the effects of massage therapy alone and massage therapy combined with post-isometric relaxation exercises in patients with TMD in terms of pain and maximum mouth opening. Group A received conventional treatment including massage and therapeutic exercises consecutively for 2 weeks. Group B (n = 23) received conventional treatment combined with a post-isometric relaxation technique. Both groups showed significant improvements in pain and MMO scores after treatment. However, the group that received a massage with isometric relaxation exercises showed significantly better results compared to the group of participants who received a massage alone. This suggests that the combination of PIR and a massage was more effective in treating TMD than a massage alone [70].

A study by Kuć and co-authors on 50 patients diagnosed with myofascial pain with radiation showed that soft tissue mobilization leads to a significant reduction in masticatory muscle activity, suggesting the effectiveness of this therapy in muscle relaxation in TMD patients [71]. On the other hand, Javed and co-authors when studying the effects of the post-isometric relaxation technique and Bowen therapy on pain, range of motion, and functional activity in patients with temporomandibular joint disorders found that post-isometric relaxation was more effective in terms of pain, range of motion of opening the mouth, lateral deviation, and functional activity of patients with temporomandibular joint disorders [72].

Another randomized clinical trial involving 72 patients found that the trigger point release technique (PRT) significantly reduced pain and improved function compared to a placebo. The effects persisted for at least three months after the therapy was completed [73].

3.1.6. Physical Modalities

Recently, interest has also grown in the application of physical modalities such as extremely low-frequency magnetic field (ELF-MF) therapy, either alone or in combination with LED light therapy.

Kubala et al. reported that all intervention groups experienced a significant reduction in pain perception on the VAS, indicating the potential value of these adjunct techniques in managing masticatory muscle hypertonia [74]. Physical therapy is also becoming a valuable tool in aiding recovery from invasive treatments for temporomandibular joint disorders.

Frisca and co-authors demonstrated in their study that pulsed electromagnetic fields (PEMFs) can accelerate the reduction in swelling and pain in patients undergoing orthognathic surgery in the maxillofacial surgery department. The results of their study suggest that it is worth using PEMF to accelerate postoperative recovery [75].

3.1.7. Patient Education and Multimodal Strategies

Lastly, patient education is a fundamental component of physiotherapeutic interventions. Evidence suggests that combining manual and physical therapy with education yields better short-term outcomes than home exercise or education alone [76].

The Aguiar et al. study shows that adding a new individualized educational intervention on pain science improved disability in individuals receiving manual therapy and exercise-based care for TMD [77]. Counseling, including education about etiological factors, avoidance of parafunctional and sleep habits, and dietary advice, significantly reduced pain intensity and improved oral health-related quality of life in patients with TMD. Compared with the control group, patients who received counseling showed a greater and consistent improvement in both pain and quality of life throughout the follow-up period [78].

In the study by Liu et al., the authors conclude that patient education and targeted treatment contribute to the improvement of oral behaviors (OBs). Factors influencing this improvement included patient age, level of education, and the initial severity of their OBs [79]. Education included an explanation of the anatomy and functioning of the temporomandibular joint, teaching the resting position for the joint, and posture correction. Patients also received a list of individual recommendations (Table 2).

Table 2. Temporomandibular disorders and physiotherapy.

Authors	TMD and Physiotherapy	Type of Study
Crăciun et al. [64] 2022	Effectiveness of physiotherapy in the treatment of temporomandibular joint dysfunction and the relationship with the cervical spine	Non-randomized controlled
Nambi and Abdelbasset [50] 2020	Efficacy of Maitland joint mobilization technique on pain intensity, mouth opening, functional limitation, kinesiophobia, sleep quality, and quality of life in temporomandibular joint dysfunction following bilateral cervicofacial burns	randomized controlled study
Barone et al. [53] 2021	Immediate effects of rhythmic joint mobilization of the temporomandibular joint on pain, mouth opening, and electromyographic activity in patients with temporomandibular disorders	one-group, quasi-experimental
Gębska et al. [54] 2023	Evaluation of the efficacy of manual soft tissue therapy and therapeutic exercises in patients with pain and limited mobility TMJ	randomized controlled trial
Atilgan et al. [56] 2023	Effect of yoga-based exercise program in female patients with myofascial pain of temporomandibular disorders	randomized controlled trial
Rezaie et al. [63] 2022	Efficacy of neck and temporomandibular joint manual therapy in comparison with a multimodal approach in the patients with TMJ dysfunction	randomized controlled trial
de Oliveira-Souza et al. [65] 2024	Effectiveness of an 8-week neck exercise training on pain, jaw function, and oral health-related quality of life in women with chronic temporomandibular disorders	randomized controlled trial
Dib-Zakkour et al. [66] 2022	Evaluation of the effectiveness of dry needling in the treatment of myogenous temporomandibular joint disorders	randomized controlled trial
Dunning et al. [68] 2024	Dry needling and upper cervical spinal manipulation in patients with temporomandibular disorder: A multi-center, randomized clinical trial	randomized controlled trial
Urbański et al. [69] 2021	Application of manual techniques in masticatory muscles' relaxation as adjunctive therapy in the treatment of temporomandibular joint disorders	randomized controlled trial

Table 2. *Cont.*

Authors	TMD and Physiotherapy	Type of Study
Tariq et al. [70] 2024	Efficacy of massage versus massage with post-isometric relaxation in temporomandibular disorders: A randomized controlled trial	randomized controlled trial
Javed et al. [72] 2024	Comparative effects of post-isometric relaxation technique and Bowen's therapy on pain, range of motion, and function in patients with temporomandibular joint disorder	randomized controlled trial
Serrano Hernanz et al. [73] 2023	Pressure release technique versus placebo applied to cervical and masticatory muscles in patients with chronic painful myofascial temporomandibular disorder: A randomized clinical trial	randomized controlled trial
Kubala et al. [74] 2022	Multidisciplinary and nonpharmacological management of pain in temporomandibular disorders (TMDs)	randomized controlled trial
Friscia et al. [75] 2024	Pulsed electromagnetic fields (PEMFs) as a valid tool in orthognathic surgery to reduce postoperative pain and swelling: A prospective study	prospective study
Shah et al. [76] 2024	Effectiveness of manual therapy physical therapy in conjunction with patient education for temporomandibular disorders	randomized controlled trial
Aguiar et al. [77] 2023	Education-enhanced conventional care versus conventional care alone for temporomandibular disorders	randomized controlled trial
de Barros Pascoal et al. [78] 2020	Effectiveness of counseling on chronic pain management in patients with temporomandibular disorders	randomized controlled trial
Liu et al. [79] 2025	Effects of patient education on the oral behavior of patients with temporomandibular degenerative joint disease	case-series study

3.2. Occlusal Splints of TMD: Mechanisms and Clinical Applications

Occlusal splints have gained wide acceptance as a conservative, non-invasive option for managing TMD. Their therapeutic potential lies in the mechanical redistribution of occlusal forces across the dental arch, which helps to mitigate excessive tooth wear, relieve muscle tension, and foster symmetrical masticatory muscle activity. This mechanical equilibrium plays a crucial protective role for the TMJ, minimizing dysfunctional loading that can predispose to disc displacement and degenerative changes. Moreover, by establishing a stable occlusal relationship, splints contribute to neuromuscular balance, which is essential for long-term symptom relief [37].

Recent studies have begun to unravel the neuromuscular implications of splint therapy. For example, in their research, Gupta et al. examined the electromyographic (EMG [80]) activity of both masticatory and cervical muscles, including the masseter, temporalis, sternocleidomastoid, and digastric muscles. TMD patients were observed to exhibit diminished EMG activity at rest and during function, a possible indicator of muscular inefficiency or dysfunction. Following a three-month regimen of wearing a flat upper stabilization splint, patients demonstrated a noticeable increase in both resting and functional EMG activity. In addition, improved symmetry in muscle activation suggested a reestablishment of coordinated muscle function. These results underscore the neuromuscular benefits of occlusal splints beyond simple joint stabilization [81].

Given the multifactorial nature of TMD, combination therapies have gained prominence. A study by Bachani et al. compared the outcomes of patients treated with occlusal splints alone to those receiving additional therapeutic exercises. While both groups experi-

enced symptomatic relief by the third week, the group undergoing combination therapy showed earlier improvements in pain reduction. The splints facilitated condylar repositioning and occlusal contact balance, while the exercises likely addressed muscular tightness and improved joint function. These findings suggest that a synergistic approach—mechanical and functional—can accelerate recovery and improve overall outcomes, especially in patients with moderate to severe TMD symptoms [82].

Another layer of complexity in TMD management involves patient engagement with therapy protocols. Wänman et al. investigated this by assigning patients to either splint therapy, unsupervised home exercises, or supervised physiotherapeutic training. Interestingly, the home exercise group exhibited the highest dropout rate, implying that motivation and compliance are critical factors in therapeutic success. While joint sound reduction was comparable across all groups, supervised exercise seemed to offer additional benefits in terms of general well-being and patient satisfaction. This reinforces the idea that supportive, structured therapy environments may foster greater long-term adherence and psychosocial resilience in TMD patients [83] (Table 3).

Table 3. Temporomandibular disorders and occlusal splints.

Authors	TMD and Occlusal Splints	Type of Study
Gupta et al. [81] 2024	Effect of a centric stabilization splint on masticatory muscles in patients with temporomandibular disorders	pilot study
Bachani et al. [82] 2025	Synergism of occlusal splints along with therapeutic exercise on individuals with temporomandibular joint disorders	pilot study
Wänman and Marklund [83] 2020	Treatment outcome of supervised exercise, home exercise, and bite splint therapy, respectively, in patients with symptomatic disc displacement with reduction	randomized controlled trial

3.3. Botulinum Toxin Treatment of TMD

While occlusal splints provide a mechanical and neuromuscular approach to the management of temporomandibular disorders, botulinum toxin type A (BTX-A) has emerged as a promising biochemical intervention targeting muscular hyperactivity and pain. TMD often presents with chronic myofascial discomfort, joint noises, and functional limitations of the masticatory apparatus [84]. BTX-A, a neurotoxin known for its ability to block presynaptic acetylcholine release at the neuromuscular junction and to inactivate calcium channels at nerve endings, leads to temporary muscle paralysis [85]. This mechanism offers a targeted approach to alleviating tension and pain in overactive masticatory muscles.

Clinical evidence consistently supports the efficacy of BTX-A in reducing myofascial pain. In a randomized controlled trial, De la Torre Canales et al. conducted a longitudinal study on female patients suffering from persistent myofascial TMD, administering BTX-A in varying doses to the masseter and temporalis muscles [86]. Over a 72-month follow-up, patients reported sustained reductions in pain intensity as measured by the Visual Analog Scale (VAS), and objective increases in pain pressure threshold (PPT) values. Interestingly, although a short-term reduction in muscle thickness was observed via ultrasonography, this effect was reversible, with no significant long-term change at six years [87]. These findings underscore both the durability of the analgesic effects and the reversibility of muscular atrophy, addressing concerns about long-term muscle degradation. Nonetheless, some studies have questioned the consistency of these outcomes across patient populations,

with varying reports of efficacy depending on the BTX-A dosage, injection technique, and baseline severity of symptoms.

Beyond pain reduction, BTX-A therapy has demonstrated benefits in relieving secondary symptoms such as headache. Several studies suggest that TMD-related myofascial trigger points (MTrPs) may act as sources of referred pain, contributing to tension-type or myogenic headaches [88]. In this context, BTX-A appears to exert therapeutic effects through both peripheral desensitization and central modulation of nociceptive pathways. So Ra Kim and José A. Blanco-Rueda et al., in their pilot study, found notable reductions in headache frequency and intensity following BTX-A injections in tender masticatory regions [84,89]. In fact, Blanco-Rueda's group found headache relief in over 70% of patients at a six-week follow-up, supporting a close neurophysiological link between orofacial myofascial pain and headache syndromes [84].

However, these findings should be interpreted with caution, as placebo-controlled trials remain limited, and the duration of headache relief is often transient.

An emerging advancement in BTX-A administration is the use of ultrasound (US) guidance to increase precision and reduce complications. Real-time US imaging enables accurate localization of the target muscle, particularly the masseter, and helps avoid surrounding anatomical structures. Visualization of all three heads of the masseter muscle allows for an even distribution of the toxin, improving therapeutic outcomes while minimizing risks such as asymmetry or unintentional diffusion. Furthermore, ultrasound guidance supports the adjustment of the needle depth based on the soft tissue thickness and enables a quantitative assessment of the treatment response by measuring changes in muscle thickness pre- and post-injection. This technique is particularly valuable for optimizing efficacy and ensuring a reproducible placement in both clinical and research settings [90].

When examining TMJ-related symptoms, such as joint clicking, the literature reveals mixed outcomes. Rezazadeh et al. reported no statistically significant improvement in TMJ sounds following extraoral BTX-A injections into the lateral pterygoid muscle [86]. Conversely, Blanco-Rueda et al. observed a subjective improvement in joint noise in 75% of cases after a combined intra-articular and intramuscular BTX-A protocol [84]. This discrepancy may reflect differences in injection sites, dosages, or evaluation metrics, indicating the need for further standardized investigations. Moreover, while some patients report auditory symptom relief, objective verification through imaging or acoustic assessment is often lacking.

In terms of functional improvements, botulinum toxin has also shown promise in enhancing mandibular mobility. In a randomized controlled trial, Rezazadeh et al. observed increased lateral jaw movement following BTX-A injection into the lateral pterygoid [86], while other studies, including those by De la Torre Canales and Hosgor, confirmed increased maximum mouth opening (MMO) post-treatment [91,92]. Notably, improvements were seen across low-, medium-, and high-dosage groups, suggesting that the functional gains may not be strictly dose-dependent. After 180 days, all treated groups demonstrated a statistically significant enhancement in range of motion compared to the placebo [92] (Table 4).

Despite these promising findings, BTX-A should be considered an adjunct rather than a first-line treatment, especially given the limited long-term safety data and lack of regulatory approval for TMD in many countries.

Similarly, occlusal splints, though widely used, also show heterogeneous outcomes; some randomized trials suggest significant benefits in reducing pain and joint noises, while others find no clear advantage over the placebo or behavioral interventions.

Taken together, these findings reinforce the clinical utility of BTX-A in addressing both pain and functional impairment in TMD patients. Its reversible mechanism, combined with a favorable safety profile and its effects on secondary symptoms such as headache and jaw mobility, makes it a valuable addition to the multidisciplinary management of temporomandibular disorders.

Nevertheless, ongoing research is needed to clarify its indications, optimize dosing protocols, and better understand its effects on joint-related symptoms in comparison to more established modalities like occlusal splints.

Table 4. Temporomandibular disorders and botulinum toxin (BTX-A).

Authors	TMD and BTX-A	Type of Study
Blanco-Rueda et al. [84] 2023	Preliminary findings of the efficacy of botulinum toxin in temporomandibular disorders	pilot study
De La Torre Canales et al. [87] 2022	Long-term effects of a single application of botulinum toxin type A in temporomandibular myofascial pain patients: A controlled clinical trial	randomized controlled trial
Rezazadeh et al. [86] May 2023	Effects of botulinum toxin A injection on the lateral pterygoid muscle in patients with a painful temporomandibular joint click	randomized controlled trial
Kim et al. [89] 2023	Effect of botulinum toxin on masticatory muscle pain in patients with temporomandibular disorders	pilot study
Hosgor et al. [91] 2023	Assessing change in functional outcomes and quality of life in myogenic temporomandibular disorders undergoing botulinum toxin injection: A before and after comparison	randomized controlled trial
De La Torre Canales et al. [92] 2022	Efficacy of botulinum toxin type A I in the improvement of mandibular motion and muscle sensibility in myofascial pain TMD	randomized controlled trial

3.4. Psychological Aspects of TMD Management

The psychological aspects of the treatment of TMD play an important role due to the strong association of these ailments with stress, anxiety, and depressive factors [7,12,16,31,32]. Studies show that psychotherapeutic interventions can be a useful tool in reducing the severity of TMD symptoms.

In a study by Simões and co-authors, both the psychological counseling group and the psychological counseling combined with jaw exercise group showed efficacy in treating TMD, improving patients' symptoms compared to baseline assessment. The study reported a statistically significant difference in the resolution of TMJ clicks at the end of the follow-up period, with the combined treatment group demonstrating superior outcomes [93].

Digital therapies (DTx) can exert therapeutic effects by controlling behavioral factors through the delivery of appropriate interventions. Park and co-authors conducted an open randomized controlled trial to evaluate the effectiveness of DTx in treating TMD. The RCT demonstrated the potential of DTx in TMD, showing improvements in pain and

mouth opening compared to conventional treatment. The intervention group showed a significant reduction in pain scores as measured by the Numerical Rating Scale (NRS) and a statistically significant increase in maximum mouth opening compared to the control group. However, there were no significant changes in other outcomes, as assessed by the Jaw Functional Limitations Scale, the Oral Behavior Checklist, and the Patient Health Questionnaire-4 between the intervention and control [94].

An app has been developed that records TMD pain and parafunctional activities for cognitive behavioral therapy (CBT). However, evidence supporting the reduction in patients' clinical symptoms through repetitive software-based CBT remains limited. Hwangbo and co-authors conducted a study to investigate the effectiveness of a CBT-supported application in improving clinical symptoms of temporomandibular joint disorders. The intervention group received conservative treatment in combination with app-based therapy, while the control group received conservative treatment only. Compared to the control group, the experimental group showed a significant improvement in the number of tender points and the degree of mouth opening. They also showed an improvement in pain levels, joint sounds, and locking, although these changes were not statistically significant [95] (Table 5).

Table 5. Temporomandibular disorders and psychotherapy.

Author	Temporomandibular Disorders and Psychotherapy	Type of Study
Simões et al. [93] 2023	Counselling treatment versus counselling associated with jaw exercises in patients with disc displacement with reduction—a single-blinded, randomized, controlled clinical trial	randomized controlled clinical trial
Park et al. [94] 2024	Randomized controlled trial of digital therapeutics for temporomandibular disorder: A pilot study	randomized controlled trial
Hwangbo et al. [95] 2023	Evaluation of clinical symptoms improvement by cognitive behavioral therapy using a smartphone application in patients with temporomandibular disorder	randomized controlled trial
de Oliveira Melchior et al. [96] 2020	Mindfulness-based intervention reduces sensitivity parameters in women with chronic painful TMD	pre–post intervention study
Takeuchi-Sato et al. [97] 2020	Efficacy of an email-based recording and reminding system for limiting daytime non-functional tooth contact in patients with temporomandibular disorders: A randomized controlled trial	randomized controlled trial

A pre–post intervention study by de Oliveira Melchior et al. used a mindfulness program to examine sensitivity parameters in women with chronic TMD. It appears that the mindfulness program was effective in reducing parameters suggestive of central pain sensitization in women with chronic, painful TMD. The intervention affected both the stimulus (allodynia, hyperalgesia) and perceptual (PPT) domains of pain sensation. The

increase in mindfulness correlated with clinical improvement—suggesting that mental techniques affect the physical experience of pain [96].

Takeuchi-Sato et al. conducted a randomized controlled trial to evaluate the effectiveness of an email-based recording and reminding system for limiting daytime nFTC in patients with TMDs. Thirty patients were randomly assigned to three groups according to the intervention for limiting non-functional tooth contact (nFTC), which are considered etiological factors for temporomandibular disorders. Each group consisted of 10 participants. The first group received cognitive behavioural therapy with an email-based recording and reminding system for 20 days, while the second one received CBT with a sticky note reminder for 20 days, and the third one received simple verbal instructions to avoid non-functional tooth contact. The incidence of nFTC significantly decreased after the intervention in groups one and two. Of the three groups, the decrease in the frequency of nFTC was maximum in group one. In addition, the extent of pain-free, unassisted mouth opening showed a significant increase in all three groups, with the maximum improvement in group one [97].

Studies show that combining psychological therapies with conservative treatment yields better results in reducing pain, improving the mandibular range of motion, and reducing parafunctional behavior (Table 5).

4. Discussion

The purpose of this narrative review is to evaluate the effectiveness of a multimodal, multidisciplinary approach in the treatment of temporomandibular disorders (Figure 1).

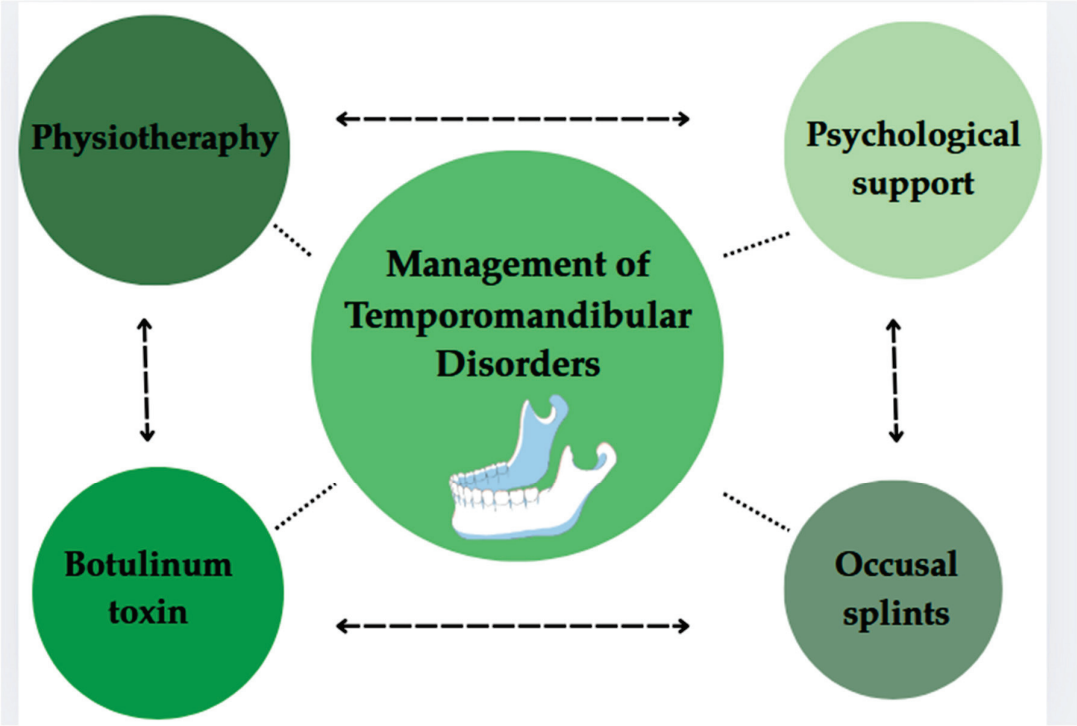

Figure 1. Multidimensional treatment of TMD.

The management of temporomandibular disorders encompasses a wide range of options, from non-pharmacological conservative therapies to invasive surgical interventions. Although numerous studies have examined treatment strategies for TMD [94,95], the heterogeneity of approaches makes it difficult to establish a universal treatment protocol. Most researchers agree that an effective approach should be multidisciplinary, multiphase, and individualized. A comprehensive therapeutic model that acknowledges the condition's

complexity appears to be the most effective [2,74]. To date, no single therapy has been unequivocally shown to be superior to others.

Physiotherapy is widely recognized as a safe and effective modality in TMD management [80,98,99]. Our findings support its efficacy in alleviating key symptoms such as pain and muscular hyperactivity. Mechanistically, techniques such as mobilization and soft tissue therapy activate proprioceptors and mechanoreceptors, which compete with nociceptive input according to the gate control theory of pain modulation [99]. Functional exercises enhance neuromuscular coordination, restore physiological muscle recruitment patterns, and improve mandibular motor control [100]. Additionally, myofascial techniques facilitate lymphatic and venous drainage in the TMJ region, reducing inflammation and improving tissue trophism [71]. By downregulating sympathetic nervous system activity, physiotherapy creates a physiological state conducive to recovery [101].

However, detailed investigations into the potential adverse effects and long-term durability of physiotherapy outcomes are lacking. The majority of existing studies emphasize short-term efficacy without reporting side effects. Furthermore, the current evidence base is limited by methodological weaknesses, short follow-up durations, and the lack of standardized intervention protocols. Future high-quality clinical trials with extended follow-up periods and clearly defined treatment methodologies are necessary to draw more reliable conclusions [71,102].

Botulinum toxin type A acts by inhibiting acetylcholine release at the neuromuscular junction, resulting in temporary muscle weakening or paralysis. It also modulates pain by suppressing the release of neurotransmitters such as substance P, glutamate, and calcitonin gene-related peptide (CGRP), thereby reducing both peripheral and central sensitization. This mechanism is particularly beneficial in managing chronic muscular pain associated with TMD [103]. The ability of BTX-A to reduce TMJ pain and related headaches, while enhancing jaw mobility, makes it a valuable adjunctive therapy [104]. Injections into the masseter muscle have demonstrated high efficacy and a favorable safety profile, although complications can occur. Peng et al. reported that 30% of subjects experienced transient reductions in masticatory strength, with other side effects including bruising, headaches, smile asymmetry, paradoxical bulging, and hollowing of the cheeks [105]. A systematic review and meta-analysis of both human and animal studies indicated that Botox may cause a reduction in mandibular cortical bone thickness by approximately 6% in humans. Animal models further revealed significant reductions in both cortical and trabecular bone mass. However, the majority of studies did not evaluate the impact of repeated injections or high dosages, highlighting the need for further research into long-term outcomes [106].

This study also demonstrated that occlusal splints increase both resting and functional EMG activity in masticatory muscles, reduce pain, and help restore functional balance within the TMJ and surrounding soft tissues [36,37,80]. Nevertheless, this intervention is not without limitations. A 2010 study documented three cases in which the prolonged use of stabilizing splints resulted in irreversible occlusal changes, including tooth displacement and bite alterations [105]. Albagieh et al. concluded that there is no strong evidence supporting the superiority of occlusal splints over physiotherapy in TMD treatment [37].

Considering the biopsychosocial nature of TMD, a holistic and interdisciplinary approach involving a physiotherapist, dentist, and psychologist often yields the most favorable outcomes, particularly for patients with chronic pain [1]. However, the efficacy of such comprehensive care can vary between individuals, therapeutic effects typically manifest over an extended period, and the overall treatment burden can be high in terms of time and cost. Incorporating psychotherapy into the therapeutic plan may offer substantial benefits but requires careful patient selection and individualized planning [107].

Due to the lack of diagnostic and therapeutic standardization, short follow-up periods, and small sample sizes in many studies, cross-comparison of treatment efficacy remains challenging. Future research should prioritize well-designed randomized clinical trials with larger cohorts, longer observation periods, and greater methodological rigor. Moreover, a deeper understanding of the mechanisms of action underlying various treatment modalities is necessary. We hope that our work contributes to addressing these limitations and encourages a more unified and evidence-based approach to TMD management.

Considering the multifactorial etiology of TMD, a structured yet flexible multimodal framework may optimize treatment outcomes. Based on current evidence, early-stage TMD can be effectively managed with physiotherapy and behavioral strategies, while more chronic or refractory cases may require adjuncts such as BTX-A or occlusal splints. A stepwise, individualized protocol based on the symptom type (muscular, articular, psychosocial), chronicity, and previous treatment response may serve as a clinical decision-making guide.

From a research and clinical perspective, future directions should include the development of standardized multimodal care protocols with consistent outcome measures, such as pain intensity, joint function, and patient-reported quality of life. At the same time, personalization should remain central: factors such as psychological comorbidities, age, or occupational load must inform treatment planning. A stratified approach to care, combined with long-term follow-up and larger randomized studies, may yield clearer insights into optimal treatment combinations and sequencing.

Finally, key clinical recommendations include using physiotherapy as a first-line conservative measure, considering BTX-A only in selected cases due to unresolved safety concerns, avoiding prolonged splint use without regular dental supervision and integrating psychological care where indicated to address chronic pain behavior and emotional distress.

Limitations

This review is subject to several limitations. First, the included studies exhibit significant methodological heterogeneity in terms of study design, sample size, intervention protocols, and outcome measures, which complicates a direct comparison of results. Second, the lack of standardized diagnostic criteria and treatment protocols for TMD across studies introduces variability that may affect the generalizability of findings. Third, many of the analyzed papers focused on short-term outcomes, with limited follow-up data to assess the durability of treatment effects. Finally, this review did not conduct a formal risk of bias assessment, which limits the ability to critically appraise the overall quality of evidence. A limitation of this study is the exclusion of articles that were not available in open access.

Future systematic reviews should aim to include more homogeneous studies, apply standardized evaluation tools, and assess long-term clinical outcomes to strengthen the reliability of conclusions.

5. Conclusions

Temporomandibular disorders are a complex condition influenced by a range of somatic and psychological factors. Due to the wide range of symptoms and the interaction of the temporomandibular joint with the nervous, muscular, and skeletal systems—including the cervical spine—effective management of TMD requires a comprehensive, multidisciplinary approach.

The literature strongly supports conservative treatment as the first-line therapy. This includes manual therapy, kinesitherapy, physical modalities, and the use of occlusal splints. Research shows that properly selected physiotherapy—targeting both the temporomandibu-

lar joint and cervical spine—using techniques such as post-isometric relaxation or dry needling, can significantly reduce pain, improve joint function, and enhance patients' quality of life.

In cases of chronic muscle pain and movement limitations, botulinum toxin type A (BTX-A) may serve as an effective adjunctive treatment. Its analgesic effects and potential to improve mandibular mobility have been confirmed in multiple clinical studies.

In conclusion, TMD treatment should be individually tailored. A multimodal strategy—incorporating physical, psychological, and pharmacological components—offers the most favorable outcomes. Further research is necessary to optimize therapeutic protocols and evaluate the long-term effectiveness of various interventions.

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Review

The Importance of Genetic Background and Neurotransmission in the Pathogenesis of the Co-Occurrence of Sleep Bruxism and Sleep-Disordered Breathing—Review of a New Perspective

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Abstract: Sleep bruxism (SB) and sleep-disordered breathing (SDB) are two prevalent conditions that significantly impact overall health. Studies suggest that up to 49.7% of individuals with SDB also exhibit symptoms of SB. This review aims to provide a comprehensive analysis of the role of genetic background and neurotransmission in the pathogenesis of the co-occurrence of SB and SDB. It seeks to synthesize current knowledge, highlight gaps in the existing literature, and propose a new perspective that integrates genetic and neurobiological factors. This review shows that both SB and SDB may be influenced by a combination of genetic, neurochemical, and environmental factors that contribute to their shared pathophysiology. The key neurotransmitters—dopamine, serotonin, and GABA—may play a significant role in their co-occurrence by regulating motor activity, sleep architecture, and respiratory control. Understanding genetic and neurochemical mechanisms may allow for more precise diagnostic tools and more personalized treatment approaches regarding SB and SDB. Clinically, there is a need for interdisciplinary collaboration between sleep specialists, dentists, neurologists, and geneticists. There is also a need to conduct large-scale genetic studies, coupled with neuroimaging and neurophysiological research, uncovering additional insights into the shared mechanisms of SB and SDB.

Keywords: sleep bruxism; sleep-disordered breathing; obstructive sleep apnea; neurotransmission; genetics; dopamine; serotonin; GABA

1. Introduction

Sleep bruxism (SB) and sleep-disordered breathing (SDB) are two prevalent conditions that significantly impact sleep quality and overall health. In accordance with the consensus from 2018, SB is defined as a masticatory muscle activity during sleep that is characterized as rhythmic (phasic) or non-rhythmic (tonic) and is not a movement disorder or a sleep disorder in otherwise healthy individuals [1]. It is commonly associated with symptoms such as masticatory muscle pain, headaches, and tooth wear [1–4]. However, it should be noted that in otherwise healthy individuals, bruxism should not be considered as a disorder, but rather as a behavior that can be a risk (and/or protective) factor for certain clinical consequences [1]. Conversely, SDB encompasses a range of conditions, including obstructive sleep apnea (OSA), characterized by repeated episodes of partial or complete upper airway obstruction during sleep, leading to intermittent hypoxia, sleep fragmentation, and cardiovascular stress [5].

The global prevalence of SB is 21%, and the occurrence based on polysomnography is estimated at 43% [6]. Approximately 1 billion of the world's population of 7.3 billion people, between the ages of 30 and 69 years, are estimated to have the most common type of sleep-disordered breathing, OSA [7]. The co-occurrence of SB and SDB is increasingly

recognized in clinical settings, with studies suggesting that up to 49.7% of individuals with SDB also exhibit symptoms of SB [8]. The co-occurrence of SB and SDB complicates the clinical management of affected individuals, often requiring multidisciplinary approaches involving dentists, sleep specialists, and neurologists. Furthermore, this overlap poses challenges in diagnosis and treatment, as symptoms can be mistakenly attributed to one condition without recognizing the contribution of the other [8,9].

Historically, research has treated SB and SDB as distinct entities with separate pathophysiological mechanisms. SB was primarily associated with psychological stress, dental occlusion, and peripheral sensory factors, while SDB was linked to anatomical abnormalities, obesity, and neuromuscular control of the airway [10,11]. Early studies explored the role of micro-arousals from SDB events in triggering SB episodes, but the causative relationship remained ambiguous [12]. The more recent literature has shifted towards exploring common pathophysiological pathways, such as autonomic nervous system dysregulation and shared environmental risk factors, yet a comprehensive understanding of the interaction between these conditions remains limited [13,14].

The emerging interest in the genetic and neurotransmission aspects of these conditions stems from the recognition that both SB and SDB may share common neurobiological underpinnings. Genetic studies have identified potential links between genes regulating neurotransmission, especially the serotonin pathway, and the predisposition to both conditions. Wieckiewicz et al. reported that 5-hydroxytryptamine receptor 2A (HTR2A) rs2770304 polymorphism might contribute to the association between SB and SDB [15]. Additionally, neurotransmission imbalances affecting sleep regulation, arousal responses, and muscle tone may contribute both to SB and SDB [15–21]. By focusing on genetic background and neurotransmission pathways, this review aims to uncover novel insights into the shared pathogenesis, which could pave the way for more targeted and effective therapeutic strategies.

This review aims to provide a comprehensive analysis of the role of genetic background and neurotransmission in the pathogenesis of the co-occurrence of SB and SDB. It seeks to synthesize current knowledge, highlight gaps in the existing literature, and propose a new perspective that integrates genetic and neurobiological factors. The scope of this review includes a detailed examination of genetic studies, neurotransmission pathways, and their interaction, with a focus on how these factors may influence the development and manifestation of both conditions. By offering an updated perspective, this review hopes to contribute to a deeper understanding of the complex interplay between genetic predisposition, neurotransmission, and the co-occurrence of SB and SDB, ultimately informing future research and clinical practice.

2. Pathophysiology

2.1. Pathophysiology of Sleep Bruxism

Although the exact cause of SB remains unclear, several key factors have been identified in its pathogenesis.

2.1.1. Central Nervous System Dysfunction

SB is believed to be primarily driven by central nervous system processes, with a focus on the brainstem and its regulation of motor activity during sleep [21–23]. Studies have shown that SB episodes are often preceded by an arousal from sleep, which activates motor neurons in the brainstem, leading to rhythmic masticatory muscle activity (RMMA). These arousals are usually associated with transient autonomic activity, such as increased heart rate and blood pressure, suggesting a link between autonomic nervous system dysregulation and SB [1,10,21–27].

2.1.2. Autonomic Nervous System Dysregulation

It is believed that dysregulation of the autonomic nervous system, specifically the sympathetic branch, plays a significant role in SB [26,28,29]. Bruxism episodes are often

preceded by shifts in autonomic activity, which may be triggered by cortical arousals. This heightened autonomic activity may increase the likelihood of SB episodes by stimulating the motor neurons involved in jaw muscle activity [26,28–33].

2.1.3. Genetic and Neurotransmitter Influences

Genetic predisposition also plays a role in the development of SB. Research has identified potential genetic markers, including polymorphisms in genes that regulate neurotransmitter systems, such as dopamine and serotonin [15,34–36]. Severe SB was reported to be associated with lower serotonin levels, but also with no differences in the level of enzymes involved in serotonin synthesis [16,17]. Dopamine dysfunction has been also implicated in the pathophysiology of sleep bruxism due to its role in motor control and arousal regulation [15,22,29,36].

2.1.4. Psychological and Behavioral Factors

While SB is primarily considered a motor condition, psychological factors such as stress, anxiety, and emotional disturbances have been potentially linked to increased bruxism activity [1,29,34,37–41]. These factors may exacerbate arousal responses during sleep, further contributing to the onset of SB episodes [40,41].

2.1.5. Other Risk Factors

As SB seems to be largely influenced by genetic and neurological factors, exogenous factors such as caffeine, nicotine, and alcohol have been also linked to increased bruxism episodes [1,29,42]. These external influences can heighten arousal responses during sleep, further triggering masticatory muscle activity [43,44]. Sleep disorders like OSA and environmental factors, such as noise, can also disrupt sleep and exacerbate bruxism [1,42,44]. In accordance with the 2024 meta-analysis geographical region and ethnological factors may also be considered as new factors in the pathophysiology of SB [6].

2.2. Mechanisms Underlying Sleep-Disordered Breathing

SDB encompasses a spectrum of conditions characterized by abnormal breathing patterns during sleep. OSA is the most common form, in which repetitive episodes of partial or complete obstruction of the upper airway occur, leading to reductions in airflow (hypopnea) or complete cessation of airflow (apnea) [5]. Below we present the primary pathophysiological mechanisms underlying OSA.

2.2.1. Upper Airway Obstruction

OSA is caused by intermittent collapse of the upper airway during sleep, particularly in the oropharyngeal region. This collapse is often due to anatomical factors, such as a narrow airway, enlarged tonsils, or excessive tissue in the throat. In some cases, abnormal airway tone or muscle activity in the pharyngeal dilator muscles also contribute to airway obstruction [45,46].

2.2.2. Arousal-Induced Breathing Resumption

During an OSA event, blood oxygen levels drop, leading to hypoxia and hypercapnia, which is increased levels of carbon dioxide [45,46]. This may trigger an arousal response in the brain, which reactivates the muscles that open the airway, allowing for breathing resumption. These frequent arousals disrupt the continuity of sleep, resulting in poor sleep quality and fragmentation, which are hallmark features of OSA [45–47].

2.2.3. Autonomic and Cardiovascular Implications

Repeated episodes of apnea and hypopnea lead to intermittent hypoxia, which stimulates the sympathetic nervous system, resulting in surges in blood pressure and heart rate during sleep. This autonomic activation may be associated with long-term cardiovas-

cular consequences, including hypertension, arrhythmias, and an increased risk of heart disease [45,48,49].

2.2.4. Risk Factors for Obstructive Sleep Apnea

The risk factors for OSA include obesity, male gender, advanced age, and anatomical abnormalities. Excess body weight is particularly important, as fat deposits around the upper airway can contribute to airway narrowing and collapse [50]. Additionally, conditions such as nasal obstruction, alcohol use, and sedative medications can worsen OSA by relaxing the muscles that keep the airway open [45,51]. It is reported that the prevalence of OSA varies depending on geographical region [7].

2.3. Potentially Common Pathways and Physiological Overlap of Sleep Bruxism and Sleep-Disordered Breathing

The co-occurrence of SB and SDB, particularly OSA, is increasingly recognized in clinical research. Several common physiological pathways may explain this overlap.

2.3.1. Autonomic Nervous System Dysregulation

Both SB and OSA involve dysregulation of the autonomic nervous system, particularly in response to arousals during sleep [1,10,21–33,45–49]. In OSA, episodes of airway obstruction trigger sympathetic activation, leading to a spike in autonomic activity [45,48,49]. Similarly, SB episodes are associated with transient surges in autonomic function, suggesting that heightened sympathetic activity may be a shared mechanism between these two conditions. The micro-arousals caused by apneic events in OSA may serve as triggers for SB episodes, further linking them [52–54].

2.3.2. Arousal Mechanisms

The arousal response plays a crucial role in both conditions. In OSA, arousals from sleep are necessary to resume breathing after airway obstruction, serving as protective factor. Furthermore, SB episodes were hypothesized to be a protective factor for OSA as mandibular movements can influence restoring airflow through the respiratory tract [1,25,29]. These arousals are often accompanied by an increase in RMMA, potentially triggering bruxism episodes. Studies have shown that a significant proportion of SB events occur shortly after apneic episodes, supporting the hypothesis that OSA-induced arousals may precipitate SB [26,52–55].

2.3.3. Shared Risk Factors

Both SB and OSA share several common risk factors, including obesity, alcohol consumption, and smoking. These factors can exacerbate both conditions by increasing the likelihood of airway obstruction and intensifying autonomic activity during sleep [56,57]. Additionally, stress and anxiety, which are known to increase the frequency of SB, may also contribute to SDB, highlighting the complex interplay between psychological and physiological factors [58,59]. There is also the possibility of the occurrence of shared geographical and/or ethnological factors [6,7].

2.3.4. Genetic and Neurotransmission Susceptibility

Emerging research suggests that there may be genetic factors that predispose individuals to both SB and OSA [15]. Genes involved in the regulation of neurotransmitters such as dopamine and serotonin, which influence arousal and motor control, may contribute to the co-occurrence of these conditions; as an example, serotonin was reported to be potentially involved both in SB and SDB [16–18]. While the genetic basis of this overlap is still being explored, early findings indicate that shared genetic predispositions may play a role in the pathophysiology of both entities [15–18,60].

Figure 1 presents common pathways and physiological overlap of SB and SDB.

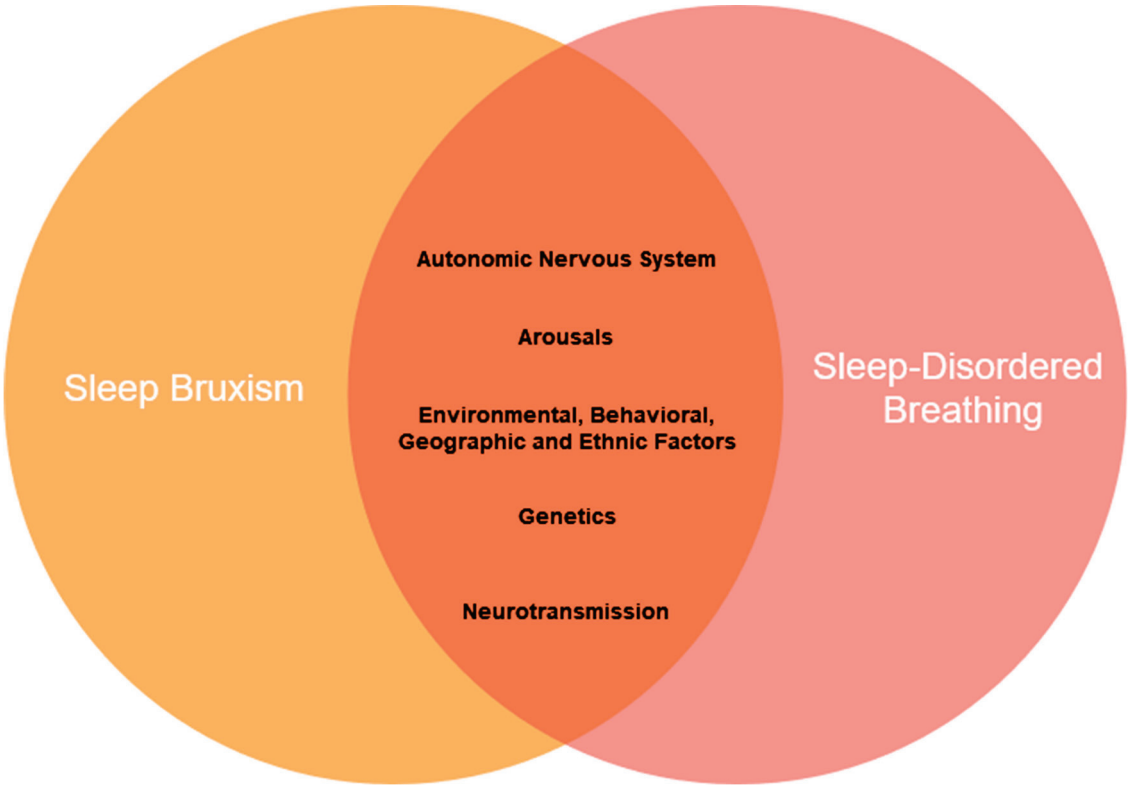

Figure 1. Potentially common pathways and physiological overlap of sleep bruxism (SB) and sleep-disordered breathing (SDB).

3. Genetic Factors

3.1. Genetic Factors Implicated in Sleep Bruxism

In the last 15 years, increasing evidence suggests that genetic predisposition may play a significant role in the development of SB. Several studies have explored the hereditary nature of bruxism, indicating a familial tendency for the condition [1,19,61,62]. Twin studies have been particularly useful in establishing the genetic basis of bruxism, showing that monozygotic twins have a higher concordance rate for bruxism compared to dizygotic twins [61,62]. This suggests that genetic factors may contribute to the likelihood of developing the condition.

One of the primary areas of genetic research on SB focuses on the role of neurotransmitter regulation, particularly genes that influence the dopaminergic and serotonergic pathways. Variants in the DRD1, DRD2, and DRD3 genes, which encode the dopamine D1, D2, and D3 receptors, have been implicated in bruxism. This is consistent with the understanding that dopamine plays a critical role in motor control and arousal regulation, both of which are believed to be involved in the pathogenesis of SB [17,36,63,64]. Additionally, genes involved in serotonin regulation, such as HTR2A, have been linked to SB, further supporting the hypothesis that neurochemical imbalances in the brain may contribute to it [15,35,36,65,66]. What is more, associations of bruxism and metalloproteinase 9 (MMP9) and cathecol-o-methyltransferase (COMT) genes in adults and alpha-actinin-3 (ACTN3) gene in children were also reported [67,68].

3.2. Genetic Determinants of Sleep-Disordered Breathing

SDB—particularly OSA—may be also influenced by genetic factors. Studies have shown that OSA tends to cluster in families, suggesting a heritable component [69]. Studies have identified several genetic loci associated with OSA, particularly those involved in craniofacial structure, obesity, and neuromuscular control of the airway [69–71].

For example, polymorphisms in genes such as PTEN and FOXC2, which are involved in craniofacial development, have been linked to a higher risk of airway obstruction, a key feature of OSA [72,73]. Additionally, genes related to adiposity, such as FTO and LEP (leptin), have been associated with increased body mass index and a higher likelihood of developing OSA. Since obesity is a major risk factor for OSA, these genetic findings highlight the importance of metabolic pathways in the pathophysiology of SDB [74].

Further, genes that regulate neuromuscular control of the airway, such as PHOX2B, which is involved in the autonomic nervous system and control breathing, may also be implicated in OSA. These genetic factors contribute to a weakened ability to maintain airway patency during sleep, leading to repeated episodes of SDB [75,76].

3.3. Shared Genetic Risk Factors and Their Influence on Co-Occurrence of Sleep Bruxism and Sleep-Disordered Breathing

The co-occurrence of SB and SBD could be partly explained by overlapping genetic influences on neurochemical systems, craniofacial structure, and autonomic nervous system regulation. Unfortunately, there are not many studies on the genetic basis of the co-occurrence of SB and SDB [15,77].

One potential shared mechanism involves the dopaminergic system. Variants in the DRD2 gene, as mentioned earlier, have been associated with bruxism and also with sleep disorders, including restless legs syndrome and periodic limb movement disorder, both of which potentially share some neurophysiological similarities with OSA. The involvement of dopamine in motor control and arousal regulation suggests that disturbances in dopamine could contribute to both conditions, particularly through mechanisms that involve arousal-induced muscle activity [29,30,36,64,78].

A second potential mechanism involves the serotonergic system. Wieckiewicz et al. reported that HTR2A rs2770304 polymorphism might contribute to the association between SB and OSA [15].

In summary, genetic factors seem to play a significant role in both SB and SDB, with only potentially shared genetic pathways contributing to their co-occurrence. While the exact mechanisms remain under investigation, familial clustering, heritability studies, and the identification of specific genetic markers provide valuable insights into the complex etiology of these conditions. Further research is needed to explore the genetic overlap between SB and SDB and understand how genetic and environmental factors interact to influence the development and progression of these conditions.

Figure 2 presents potentially shared genetic risk factors between SB and SDB.

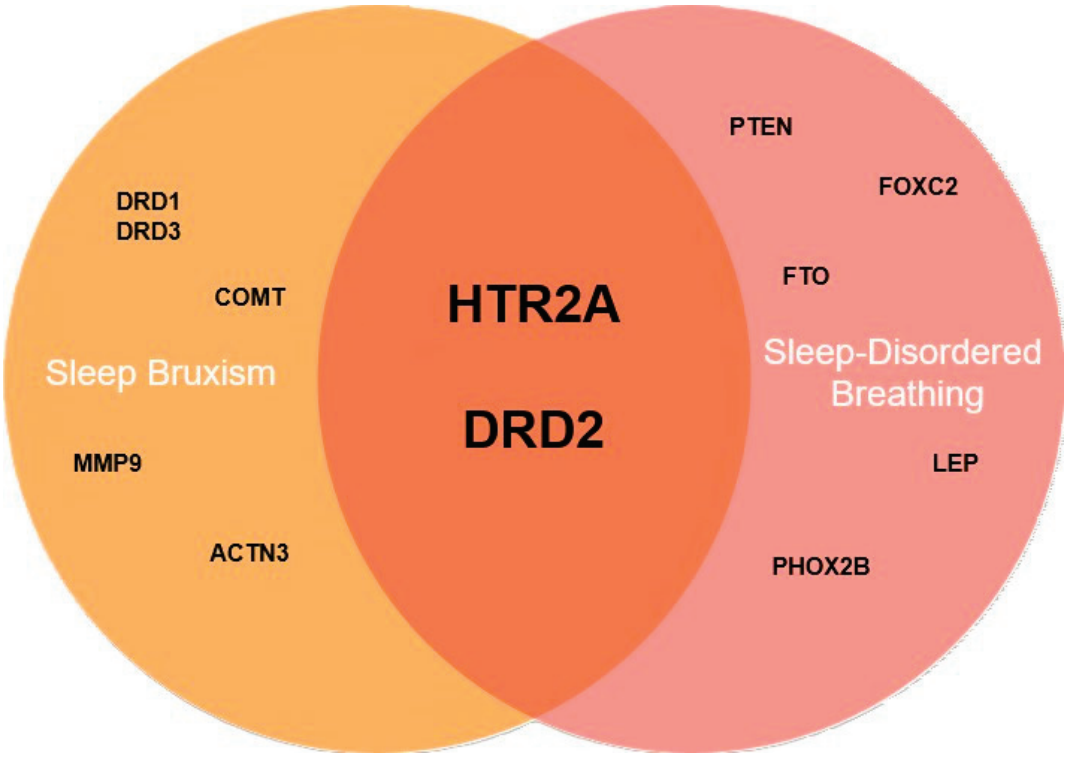

Figure 2. Potentially shared genetic risk factors between sleep bruxism (SB) and sleep-disordered breathing (SDB). Legend: ACTN3—gene encoding alpha-actinin-3, COMT—gene encoding catechol-O-methyltransferase, DRD1—gene encoding dopamine receptor D1, DRD2—gene encoding dopamine receptor D2, DRD3—gene encoding dopamine receptor D3, FOXC2—gene encoding fork-head box protein C2, FTO—gene encoding fat mass and obesity-associated protein, HTR2A—gene encoding 5-hydroxytryptamine receptor 2A, LEP—gene encoding leptin, PHOX2B—gene encoding paired-like homeobox 2B.

4. Neurotransmission and Neuromodulation

4.1. Overview of Neurotransmitters Involved in Sleep Regulation, Muscle Activity, and Respiratory Control

Neurotransmitters play a crucial role in regulating the different stages of sleep, motor activity, and respiratory control, all of which are involved in both SB and SDB. Sleep is governed by a delicate balance between excitatory and inhibitory neurotransmitters that modulate arousal, muscle tone, and respiratory patterns. Key neurotransmitters involved in these processes include dopamine, serotonin, and gamma-aminobutyric acid (GABA) [79–82].

Serotonin is a neurotransmitter in the central nervous system derived from tryptophan [83]. Most serotonin is synthesized in the gastrointestinal tract, while only a small percentage, approximately 5%, is produced in the central nervous system, especially in the raphe nuclei located in the brainstem [84,85]. Approximately 90% of the total human body's serotonin is stored in the enterochromaffin cells in the gastrointestinal tract, 8% is stored in blood platelets, and 1–2% is stored in the central nervous system [83–85]. The serotonin system functions through a complex receptor family, including seven subtypes, which mediate both excitatory and inhibitory signals. Serotonin is reported to be mainly involved in cognition, attention, emotion, pain, sleep, and arousal [83–85].

Dopamine is a chemical compound from the group of biogenic catecholamines. It belongs to the same group of substances as adrenaline and norepinephrine. It is synthesized from tyrosine. The biosynthesis of catecholamines occurs in adrenergic neurons and in the chromaffin cells of the adrenal medulla. Dopaminergic neurons are primarily localized in the substantia nigra pars compacta and the ventral tegmental area, projecting to the

striatum, frontal cortex, and limbic structures [86]. Dopamine affects many key processes in the human body, acting as both a neurotransmitter and a hormone. In the nervous system, it is responsible for regulating. Dopamine is integral to the regulation of motor control, reward processing, emotions, and executive functions. As a hormone, dopamine influences the cardiovascular system [86,87].

GABA is the primary inhibitory neurotransmitter in the central nervous system, synthesized from glutamate. GABAergic neurons are distributed ubiquitously throughout the brain, with dense networks in the cortex, hippocampus, and cerebellum [88,89]. GABA exerts its effects via GABA_A and GABA_B receptors, which mediate fast synaptic inhibition and slow modulatory inhibition, respectively [89]. The GABA system is critical for maintaining neural circuit stability. It influences mood, sleep, and muscle tone [88,89].

Dopamine and serotonin are particularly important in modulating arousal, motor function, and mood, while GABA acts as the primary inhibitory neurotransmitter in the central nervous system, promoting sleep and suppressing motor activity. The interactions between these neurotransmitters are critical in ensuring smooth transitions between sleep stages, maintaining airway patency during sleep, and regulating muscle tone [79,82,90].

4.2. Potential Role of Neurotransmitters in Sleep Bruxism and Sleep-Disordered Breathing

Considering the available literature on the impact of neurotransmission and neuromodulation on SB and SBD, the following chapter will mostly consist of considerations on the activity patterns of individual substances on the co-occurrence of SB and SBD.

4.2.1. Dopamine

Dopamine is a key modulator of motor control, arousal, and reward pathways [90]. It could potentially play role in both SB and SBD [91,92]. There is a lack of original research indicating the direct influence of dopamine on SB. However, considering the role of dopamine in sleep, its dysfunction may potentially contribute to the abnormal activation of motor pathways during sleep that may be associated with SB [93].

The dopaminergic system may be also implicated in the pathophysiology of SDB, especially in relation to the control of upper airway muscles. Dopamine influences respiratory motor output and has been shown to affect the activity of muscles that maintain airway patency [94]. In individuals with OSA, disruptions in dopamine signaling may potentially impair the ability to maintain adequate airway tone during sleep, contributing to airway collapse [92–96].

4.2.2. Serotonin

Serotonin is involved in regulating both sleep architecture and respiratory function. It plays a critical role in maintaining muscle tone in the upper airway and modulating arousal thresholds during sleep [60,97,98]. In the context of bruxism, reduced serotonin levels were reported to be associated with increased motor activity during sleep [16,17].

In SDB, serotonin's role is particularly important in maintaining airway stability. Serotonergic neurons in the brainstem help control the muscles responsible for keeping the upper airway open. In OSA, disruptions in serotonergic signaling may reduce airway muscle tone, making the airway more susceptible to collapse during sleep. Additionally, serotonin helps regulate arousal from sleep, and abnormal serotonin levels may contribute to the increased arousals seen in both SB and OSA [26,31,60,97,98]. What is more, the tendency to SDB seems to co-occur with lower blood serotonin and higher tryptophan hydroxylase 1 (involved in serotonin synthesis) levels [18].

4.2.3. Gamma-Aminobutyric Acid

GABA is the primary inhibitory neurotransmitter in the central nervous system and is essential for promoting restful sleep and inhibiting motor activity [99]. Potentially, in SB, reduced GABAergic inhibition may lead to excessive motor activity, particularly in the muscles of orofacial area [91,100,101].

In SDB, GABA plays a role in regulating the excitability of neurons involved in respiratory control. GABAergic neurons help maintain a balance between excitation and inhibition within respiratory circuits, ensuring that breathing remains stable during sleep. Disruptions in GABAergic signaling may lead to instability in respiratory patterns, contributing to the apneas and hypopneas seen in OSA [102,103].

In conclusion, neurotransmission and neuromodulation may play crucial roles in the pathophysiology of SB and SDB. Imbalances in key neurotransmitters, such as dopamine, serotonin, and GABA, may affect motor control, arousal thresholds, and respiratory stability, providing potential mechanisms for the co-occurrence of these conditions [16–18,59,91–103]. Understanding these neurochemical pathways may potentially offer new insights into the treatment of individuals suffering from both SB and SBD, potentially leading to more targeted and effective therapeutic interventions.

Figure 3 presents neurotransmitters potentially involved in SB and SDB co-occurrence.

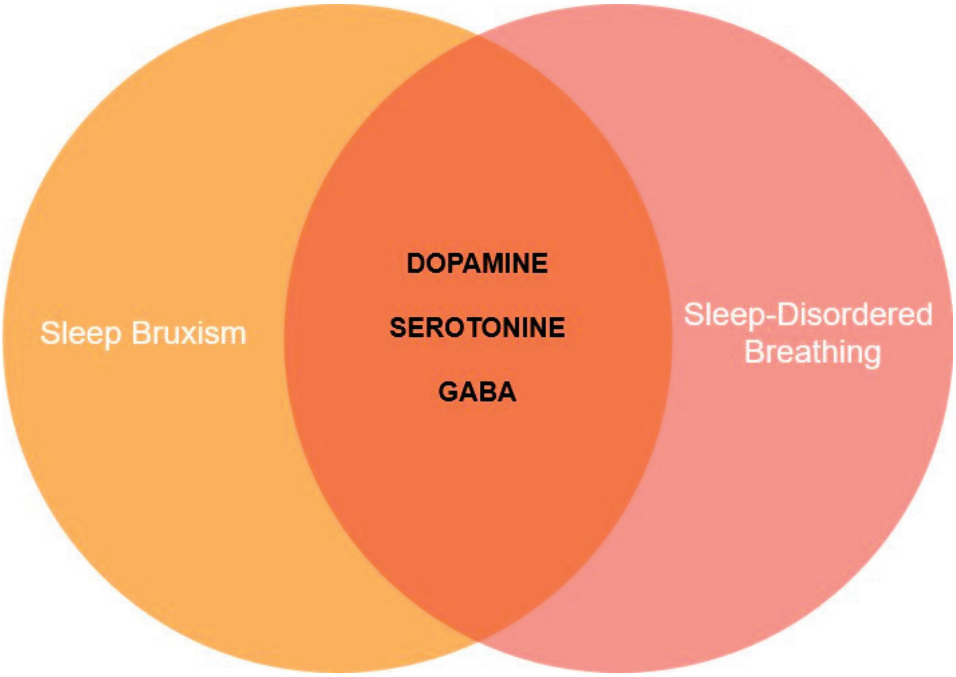

Figure 3. Neurotransmitters potentially involved in sleep bruxism (SB) and sleep-disordered breathing (SDB) co-occurrence. Legend: GABA—gamma-aminobutyric acid.

5. Clinical Implications and Future Directions

5.1. Clinical Implications

The potential integrated pathogenetic model proposes that the co-occurrence of SB and SDB may be the result of complex interactions between genetic predisposition, neurotransmitter imbalances, and autonomic nervous system dysregulation. These factors converge to create an environment in which arousal-driven activation of motor pathways and impaired muscle tone contribute to the development of both SB and SDB [1,10,22–59]. Understanding the genetic and neurochemical mechanisms underlying this co-occurrence can provide valuable insights into the pathophysiology of these conditions and lead to more targeted therapeutic approaches. As research continues to uncover the genetic and neurotransmitter pathways involved, this integrated model will help guide future studies and improve clinical outcomes for individuals with co-occurring SB and SDB.

The growing body of research linking genetic predisposition and neurotransmission dysfunction to the co-occurrence of SB and SDB offers significant implications for clinical management [15–18,35,36,59–74,104–106]. Recognizing these underlying biological factors

can fundamentally change how these conditions are diagnosed and treated, moving beyond symptom management toward a more targeted, individualized approach [107].

By understanding the role of genetic and neurotransmitter imbalances, clinicians can improve the accuracy of diagnosing co-occurring SB and SDB. For example, patients with a known family history of either condition or specific genetic markers associated with dopamine, serotonin, or GABA dysfunction could be flagged for more detailed assessments. This could include using comprehensive sleep studies (polysomnography) or genetic screenings to identify patients at higher risk for both SB and OSA. Identifying these risk factors early could lead to proactive treatment strategies that prevent the progression of symptoms.

Since neurotransmitter imbalances may play a key role in both SB and SDB, pharmacological interventions targeting specific neurotransmitter systems could offer new therapeutic options. Medications that influence dopaminergic, serotonergic, or GABAergic activity may help normalize the neurotransmission imbalances responsible for triggering SB and influencing airway tone in OSA.

Understanding the shared mechanisms between SB and SDB emphasizes the need for a multidisciplinary treatment approach. Patients presenting with SB could benefit from referrals to sleep specialists, while individuals diagnosed with OSA may be screened for SB as part of an integrated care pathway. Collaboration between dentists, sleep specialists, and neurologists can lead to more comprehensive care, with coordinated treatments targeting the root causes of both conditions.

5.2. Future Directions

One of the most exciting clinical implications of the research on genetic and neurotransmitter factors is the potential for personalized, precision-based treatment approaches. Rather than using a one-size-fits-all model, clinicians could tailor treatments based on a patient's specific genetic profile and neurochemical imbalances.

As genetic research continues to advance, clinicians may be able to use genetic profiling to identify patients at risk for co-occurring SB and SDB. For example, patients with certain polymorphisms in genes such as DRD2 and HTR2A could be considered at higher risk for both conditions. These individuals might benefit from earlier interventions, such as lifestyle changes, stress management, or pharmacological treatments, to prevent the onset or progression of SB and OSA [15,29,30,36,64,77,78].

Personalized treatments could also involve the use of neurotransmitter-targeted therapies. For example, patients with dopamine-related genetic predispositions might respond well to dopaminergic drugs, while those with serotonin-related issues could benefit from serotonin precursors [16–18,92–98]. Similarly, patients with GABA-related dysfunction could be treated with GABAergic agents to stabilize motor activity and improve respiratory control during sleep [99–103]

The field of genetic research into SB and SDB is still in its early stages, with much more to be discovered. Future studies could focus on identifying additional genetic markers that contribute to the co-occurrence of these conditions. Large-scale genome-wide association studies could help pinpoint new genetic variants associated with neurotransmitter regulation, muscle activity, and sleep architecture [15,77]. Further research could also explore the epigenetic mechanisms that influence gene expression in response to environmental factors like stress, diet, and lifestyle, leading to a more nuanced understanding of how these conditions develop [108,109].

There is also significant potential for future research into pharmacological interventions targeting the neurotransmitter systems involved in SB and SDB. Clinical trials could investigate the efficacy of drugs that modulate dopamine, serotonin, or GABA activity in reducing the frequency and severity of SB episodes and improving respiratory function in OSA [15–18,92–103]. In particular, combination therapies that address both neurotransmitter imbalances and other risk factors, such as obesity or upper airway dysfunction, may offer the most promising results.

Developing integrative diagnostic models that combine genetic, neurochemical, and clinical data could revolutionize the way SB and SDB are diagnosed and treated. Such models would consider a patient's genetic predisposition, neurotransmitter imbalances, autonomic regulation, and behavioral risk factors to provide a comprehensive assessment. These models could be used to develop personalized care plans, incorporating both pharmacological and non-pharmacological treatments to optimize patient outcomes. Additionally, these diagnostic models could improve early detection, allowing for preventive measures to be implemented before symptoms worsen.

Advances in sleep technology, such as wearable devices and at-home sleep monitors, could play a role in future research and treatment approaches. These devices can provide real-time data on sleep patterns, muscle activity, and respiratory function, allowing for more detailed assessments of how SB and SDB interact during sleep. Incorporating these technologies into clinical practice could enable more precise monitoring of treatment efficacy and better adaptation of therapy over time [1,110,111].

To better understand the long-term impact of genetic and neurotransmitter factors on the co-occurrence of SB and SDB, longitudinal studies are needed. These studies should track patients over time to assess how genetic predispositions and neurotransmitter imbalances influence the progression of these conditions. Additionally, multicenter trials involving diverse populations could provide insights into how these factors vary across different demographic groups, helping to ensure that personalized treatments are effective for a broad range of patients.

Figure 4 presents the potential integrated pathogenetic model of SB and SDB co-occurrence.

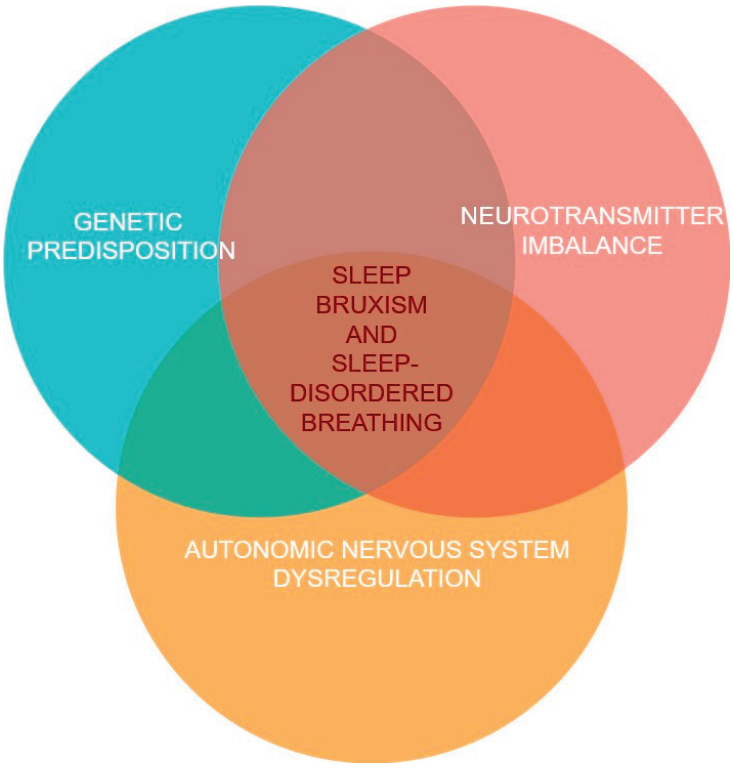

Figure 4. The potential integrated pathogenetic model of sleep bruxism (SB) and sleep-disordered breathing (SDB) co-occurrence.

6. Discussion

This review has explored the complex relationship between SB and SDB, particularly OSA, focusing on the role of genetic predisposition and neurotransmission pathways in their co-occurrence. Both conditions may be influenced by a combination of genetic, neu-

rochemical, and environmental factors that contribute to their shared pathophysiology. The research highlights key neurotransmitters—dopamine, serotonin, and GABA—that may play significant roles in regulating motor activity, sleep architecture, and respiratory control, all of which are critical in understanding the overlapping mechanisms of SB and OSA. Genetic studies have provided insights into polymorphisms related to neurotransmitter function, autonomic regulation, and craniofacial development, offering a clearer understanding of how these conditions may develop together.

These findings underscore the importance of considering SB and SDB not as isolated disorders, but as interconnected conditions that share common biological pathways. The co-occurrence of these disorders presents a unique set of challenges for diagnosis and treatment, which can be better addressed by incorporating genetic and neurochemical factors into clinical practice.

The exploration of genetic and neurotransmission perspectives is critical for advancing our understanding of the pathogenesis of SB and SDB. Genetic predispositions, such as polymorphisms in dopamine, serotonin, and GABA-related genes, may play a key role in influencing neurotransmission pathways that regulate sleep, motor control, and respiratory function. These imbalances can lead to heightened motor activity in the jaw muscles during sleep (bruxism) and impaired upper airway muscle tone (OSA), creating a feedback loop that exacerbates both conditions.

Understanding these genetic and neurochemical mechanisms allows for more precise diagnostic tools and more personalized treatment approaches. For example, individuals with specific genetic markers may benefit from targeted therapies that modulate neurotransmitter function, such as dopamine agonists or GABA-enhancing agents. Furthermore, recognizing the role of autonomic dysregulation in both conditions may help refine treatment strategies, focusing on stabilizing arousal thresholds and reducing sympathetic activation during sleep.

This perspective also highlights the need for interdisciplinary collaboration between sleep specialists, dentists, neurologists, and geneticists. By integrating these fields, clinicians can offer more comprehensive care to patients, addressing not only the symptoms of bruxism and OSA but also the underlying neurobiological factors that drive their co-occurrence.

Future research should continue to explore the genetic factors and neurotransmitter pathways involved, with an emphasis on identifying biomarkers that can guide treatment decisions. Large-scale genetic studies, coupled with neuroimaging and neurophysiological research, will be key to uncovering additional insights into the shared mechanisms of SB and OSA. As this field progresses, the integration of genetic screening into routine clinical practice could lead to earlier diagnoses and more targeted interventions, ultimately improving patient outcomes and quality of life.

In conclusion, the genetic and neurotransmitter perspectives on the co-occurrence of SB and SDB provide a fresh and promising framework for understanding these complex conditions. This integrated approach has the potential to revolutionize how we diagnose, treat, and manage these conditions, opening the door to more personalized and effective therapies that address the underlying causes of both SB and OSA. Through continued research and collaboration, we can develop more comprehensive strategies to improve patient care and enhance overall health outcomes.

7. Conclusions

- Both SB and SDB may be influenced by a combination of genetic, neurochemical, and environmental factors that contribute to their shared pathophysiology.
- The key neurotransmitters—dopamine, serotonin, and GABA—may play a significant role in SB and SDB co-occurrence by regulating motor activity, sleep architecture, and respiratory control.
- Understanding genetic and neurochemical mechanisms allows for more precise diagnostic tools and more personalized treatment approaches regarding SB and SDB.

- Clinically, there is a need for interdisciplinary collaboration between sleep specialists, dentists, neurologists, and geneticists.
- There is a need to conduct large-scale genetic studies, coupled with neuroimaging and neurophysiological research, uncovering additional insights into the shared mechanisms of SB and SDB.

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Systematic Review

Biopsychosocial Predictors of Pain Persistence and Pain Chronification in Temporomandibular Disorders: A Systematic Review

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Abstract

Background/Objectives: Temporomandibular disorders (TMD) are common causes of orofacial pain, but their clinical course varies, with some patients developing persistent symptoms. Evidence supports a biopsychosocial model of pain chronification, yet prognostic factors for pain persistence in TMD remain insufficiently synthesized. This systematic review aimed to identify biological, psychological, and social predictors associated with pain persistence and chronicity in painful TMD. **Methods:** This review was conducted in accordance with PRISMA 2020 guidelines and registered in PROSPERO (CRD420261286566). MEDLINE, Embase, and Web of Science were searched for studies published between January 2010 and December 2025. Eligible studies included adult patients with painful TMD and assessed baseline biopsychosocial predictors of pain persistence or chronicity at follow-up $\geq$ 3 months. Risk of bias was assessed using QUIPS and PROBAST. Due to heterogeneity across studies, findings were synthesized narratively. **Results:** Six prospective cohort studies were included, with follow-up durations ranging from 6 to 24 months. Psychological factors, particularly pain catastrophizing and depression, were associated with increased risk of pain persistence. Higher baseline pain intensity and widespread pain also showed prognostic value. Sleep-related and behavioral factors demonstrated inconsistent associations, and social predictors were rarely examined. The certainty of evidence ranged from moderate for catastrophizing and pain intensity to very low for sleep-related and occlusal factors. **Conclusions:** Pain persistence in TMD is influenced by multiple biopsychosocial factors. Psychological variables, especially catastrophizing and depression, appear to be the most consistent predictors, although this finding should be interpreted with caution, given the small number of included studies. These findings highlight the importance of comprehensive biopsychosocial assessment in patients with painful TMD and the need for further longitudinal research.

Keywords: TMD; chronic pain; pain predictors; orofacial pain; depression

1. Introduction

Temporomandibular disorders (TMD) are commonly described as a diversified group of conditions affecting the temporomandibular joints, the masticatory muscles, and surrounding tissues [1,2]. The etiology of TMD, including masticatory muscle pain as well as pain in the joints, both known as a painful TMD, is multifactorial [3,4]. According to the biopsychosocial model, there can be distinguished three major groups of factors leading to the development of TMD, namely: biological, psychological, and social factors [5].

Masticatory muscle pain is among the most frequent causes of non-odontogenic orofacial pain and is commonly encountered in daily dental and orofacial pain practice [6]. It is often regarded as a reversible and self-limiting condition, particularly at early stages. Nevertheless, longitudinal observations indicate that this assumption is not always justified. There have been reported cases in which pain persists beyond the expected period of tissue healing and gradually becomes chronic, leading to functional impairment and deterioration of quality of life [2,7,8]. Once pain persistence is established, treatment outcomes tend to be less predictable, and the overall burden for patients increases, both clinically and socially [9].

Over the last two decades, prospective cohort studies have substantially contributed to the understanding of factors associated with the onset and persistence of painful TMD [8]. In particular, findings from the Orofacial Pain: Prospective Evaluation and Risk Assessment (OPPERA) project have demonstrated that local musculoskeletal findings alone do not sufficiently explain why pain persists in some patients but not in others [2,8,9]. It has been suggested that pain chronicity develops rather as a consequence of interactions between altered pain processing, psychological vulnerability, and broader contextual or behavioral influences [2,8].

From a biological perspective, increased pain sensitivity has been repeatedly identified as a relevant factor preceding the development of painful TMD. Reduced pressure pain thresholds, widespread hyperalgesia, and other indicators of facilitated nociceptive processing have been associated with both first-onset TMD and persistence of pain over time [7,8]. These findings are commonly interpreted within the framework of central sensitization (CS) and suggest that, at least in a subgroup of patients, masticatory muscle pain reflects a more generalized disturbance of pain modulation rather than a strictly local muscle disorder. In addition, genetic and inflammatory mechanisms have been proposed to influence individual susceptibility, as associations between polymorphisms in pain- and inflammation-related genes and pain severity or persistence have been reported [10–12].

Psychological factors appear to contribute to the clinical course of painful TMD in a meaningful way. Prospective data indicate that pain catastrophizing, anxiety, depression, negative affect, and stress-related variables are associated with an increased risk of developing painful TMD as well as with less favorable pain trajectories over time [7,13]. These factors may influence how pain is perceived and interpreted, but also how patients respond behaviorally to pain. Results from twin and family studies further suggest that cognitive–emotional pain-related phenotypes contribute to pain chronicity beyond shared genetic background, underlining the independent role of psychological processes [14].

Social and behavioral factors have also been implicated in the chronification of painful TMD, although the available evidence is less consistent. Sleep disturbances, general health status, parafunctional behaviors, and occupational stress have been reported to be associated with painful TMD and with chronic overlapping pain conditions [15–17]. It has been proposed that impaired sleep may act as a nonspecific amplifier of pain sensitivity and stress responsiveness, thereby interacting with biological and psychological mechanisms involved in pain maintenance [16].

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Despite growing recognition of the biopsychosocial nature of pain chronicity, the existing literature remains heterogeneous and difficult to integrate. Many studies focus on single domains or on pain onset rather than pain persistence. Moreover, cross-sectional designs are still frequently employed, limiting prognostic interpretation. Even within longitudinal studies, biological, psychological, and social predictors are often examined separately, without adequate consideration of their potential interactions.

Therefore, the aim of the present systematic review was to identify biopsychosocial predictors of pain chronicity in patients with painful TMD. By synthesizing evidence from prospective and longitudinal studies, this review seeks to clarify which baseline factors are associated with pain persistence and to contribute to a more clinically oriented, individualized understanding of chronic pain risk in this patient population.

2. Materials and Methods

2.1. Protocol and Registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA 2020) [18]. The completed PRISMA 2020 checklist is provided in the Supplementary Materials. The protocol was registered in the PROSPERO database under the registration number CRD420261286566.

2.2. Eligibility Criteria

Eligibility criteria were defined according to the PICOS framework and are summarized in Table 1 [19].

Table 1. Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Population	Adults (≥18), painful TMD	<18, non-painful TMD only, painful TMD not defined
Prognostic factors/Exposure	Baseline biopsychosocial/behavioral factors	No predictor/prognostic factor analysis
Comparator	Persistent/chronic pain vs. improved/remitted pain (within-study)	No within-study comparison for pain persistence/chronicity
Outcomes	Pain persistence/chronicity; follow-up > 3 months	Follow-up < 3 months, outcomes unrelated to pain persistence,
Study design	Cohort (prospective/retrospective), case–control	Cross-sectional, case series, case reports

The following inclusion criteria were applied:

(P) Population.

Studies involving adult participants (>18 years old) diagnosed with painful TMD were eligible, including myogenous, arthrogenic, or mixed TMD type. Studies focusing exclusively on non-painful TMD conditions (e.g., disc displacement with reduction) were excluded. A painful TMD diagnosis was preferably established using standardized diagnostic criteria, such as the Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD), the Diagnostic Criteria for Temporomandibular Disorders (DC/TMD), or the International Classification of Orofacial Pain (ICOP). To ensure broad identification of relevant evidence, studies applying other clearly described clinical diagnostic approaches were also considered eligible, provided that painful TMD was explicitly defined.

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(I/E) Prognostic factors/Exposure.

Studies investigating biological, psychological, social, or behavioral prognostic factors assessed at baseline and examined in relation to subsequent pain outcomes were eligible. Prognostic factors included, but were not limited to, psychological variables (e.g., depression, anxiety, pain catastrophizing), pain-related characteristics (e.g., baseline pain intensity, pain-related disability), sleep-related factors, behavioral factors (e.g., parafunctional activities), and demographic characteristics. Studies reporting pain persistence/chronicity outcomes without assessing prognostic factors were excluded.

(O) Outcomes.

The primary outcome was pain persistence or pain chronicity in painful TMD, requiring follow-up of at least 3 months. This threshold is consistent with the IASP/ICD-11 definition of chronic pain, which requires pain to persist for more than three months [20]. Related outcomes (e.g., transition to chronic pain, lack of remission, or persistence of clinically significant pain measured with validated instruments such as the Graded Chronic Pain Scale) were considered eligible if they reflected sustained pain over time. For the purpose of this review, the following definitions were applied: pain persistence refers to the continued presence of painful TMD symptoms at follow-up without clinically significant improvement; pain chronicity denotes the presence or progression of clinically significant pain, and transition from acute to chronic pain describes the process by which acute-onset TMD pain evolves into a chronic state, defined as pain duration exceeding three months in accordance with IASP/ICD-11 classification [20–22].

(S) Study design.

Eligible designs included prospective or retrospective cohort studies, case–control series, and secondary analyses of longitudinal cohorts. Purely cross-sectional studies without follow-up, case series, and case reports were excluded.

2.3. Search Strategy

A comprehensive literature search was conducted in the electronic databases MEDLINE, Embase, and Web of Science. These databases were selected to identify a broad range of relevant clinical and dental research on painful TMD. The search covered publications from January 2010 to December 2025 and was limited to peer-reviewed English-language articles. The grey literature was not searched because the review was intentionally limited to peer-reviewed studies with established methodological rigor and transparent reporting, to minimize the risk of bias arising from insufficient quality control and to enhance the comparability and reliability of the clinical conclusions. The databases were last searched on 5 January 2026. The selected time frame (2010–2025) was chosen to capture a period of substantial advances in pain research, particularly in chronic pain, as well as increasing standardization of TMD diagnostic frameworks and outcome measures. This improved methodological comparability across studies and ensured that the included evidence aligns with current concepts and assessment approaches.

Search terms combined controlled vocabulary (MeSH/Emtree) and free-text keywords; no study design filters were applied. The full database-specific search strategies are provided in Table 2.

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Table 2. Search strategies for each database.

Database	Search String
Medline	("Temporomandibular Disorders"[Mesh] OR "temporomandibular disorder*"[tiab] OR TMD[tiab] OR "temporomandibular joint" OR "temporomandibular joint disorder" OR "myogenous TMD"[tiab] OR "myogenic TMD"[tiab] OR "masticatory muscle pain"[tiab] OR "masticatory myalgia"[tiab] OR "muscle related TMD"[tiab] OR "myofascial pain"[tiab] OR "jaw muscle pain"[tiab]) AND (chronic*[tiab] OR persistent[tiab] OR "persistent pain"[tiab] OR "pain persistence"[tiab] OR "pain duration"[tiab] OR "follow-up"[tiab] OR longitudinal[tiab] OR prospective[tiab] OR cohort[tiab]) AND (predictor*[tiab] OR "risk factor*"[tiab] OR prognos*[tiab] OR determinant*[tiab] OR associated[tiab] OR baseline[tiab])
Embase	('temporomandibular disorder'/exp OR 'temporomandibular disorder*':ti,ab OR TMD:ti,ab OR 'temporomandibular joint':ti,ab OR 'temporomandibular joint disorder*':ti,ab OR 'myogenous TMD':ti,ab OR 'myogenic TMD':ti,ab OR 'masticatory muscle pain':ti,ab OR 'masticatory myalgia':ti,ab OR' myofascial pain':ti,ab OR 'jaw muscle pain':ti,ab) AND (chronic*:ti,ab OR persistent:ti,ab OR 'persistent pain':ti,ab OR 'pain persistence':ti,ab OR 'pain duration':ti,ab OR 'follow-up':ti,ab OR longitudinal:ti,ab OR prospective:ti,ab OR cohort:ti,ab) AND (predictor*:ti,ab OR 'risk factor*':ti,ab OR prognos*:ti,ab OR determinant*:ti,ab OR associated:ti,ab OR baseline:ti,ab)
Web of Science	TS = (("temporomandibular disorder*" OR TMD OR" temporomandibular joint" OR "myogenous TMD" OR "myogenic TMD" OR "masticatory muscle pain" OR "masticatory myalgia" OR "myofascial pain" OR "jaw muscle pain") AND (chronic* OR persistent OR "persistent pain" OR "pain persistence" OR "pain duration" OR "follow-up" OR longitudinal OR prospective OR cohort) AND (predictor* OR "risk factor*" OR prognos* OR determinant* OR associated OR baseline))

2.4. Selection Process

All records identified through the database searches were imported into Rayyan QCRI (Qatar Computing Research Institute, Doha, Qatar, and Rayyan Systems, Cambridge, MA, USA) for duplicate removal and study screening [23]. Two reviewers (P.S. and M.D.) independently screened titles and abstracts to assess eligibility. Potentially relevant studies were retrieved in full text and evaluated by the same reviewers.

Throughout the screening process, reviewers were blinded to each other's decisions. Any disagreement at either the title/abstract or full-text screening stage was resolved by consensus through discussion.

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2.5. Data Collection

Data extraction was performed independently by two reviewers (P.S. and M.D.) using a predefined data extraction form. Reviewers were blinded to each other's extracted data. Any discrepancies were resolved through consensus after discussion.

For each included study, the following data were extracted: study characteristics (authors, year of publication, study design), sample characteristics (sample size at baseline and follow-up, age, sex), diagnostic criteria for painful TMD (e.g., RDC/TMD, DC/TMD, ICOP or other clearly described criteria), TMD type (myogenous, arthrogenic, mixed), and pain characteristics (definition of chronic or persistent pain, baseline pain duration).

In addition, information on outcomes (outcome definition and outcome measures, e.g., pain intensity or Graded Chronic Pain Scale), baseline prognostic factors analyzed, and the statistical model used was extracted.

2.6. Risk of Bias Assessment

Risk of bias was assessed using the Quality In Prognosis Studies (QUIPS) tool [24]. Each included prognostic factor study was evaluated across six domains: study participation, study attrition, prognostic factor measurement, outcome measurement, study confounding, statistical analysis, and reporting.

For studies that involved the development or validation of multivariable prediction models, risk of bias was assessed using the Prediction model Risk Of Bias ASsessment Tool (PROBAST), in accordance with current methodological recommendations for prediction model studies [25].

Risk of bias assessments were performed independently by two reviewers (P.S and M.D), who were blinded to each other's judgments. Any disagreements were resolved by consensus through discussion.

For QUIPS-based assessments, an overall risk-of-bias judgment was derived from domain-level ratings. Studies were rated as having a high overall risk of bias when at least one critical domain (e.g., study confounding or outcome measures) was judged to be high risk. When high risk of bias was identified only in non-critical domains, the overall risk of bias was considered moderate to high.

PROBAST assessments were reported according to the four domains of the tool (participants, predictors, outcome, and analysis), and the overall risk of bias judgment followed PROBAST guidance [25].

2.7. Data Synthesis

Due to substantial clinical and methodological heterogeneity across studies regarding study populations, definitions of pain persistence or chronicity, prognostic factors assessed, follow-up durations, and statistical approaches, a quantitative meta-analysis was not performed.

Findings were synthesized using a narrative synthesis, supported by structured tables summarizing study characteristics, outcomes, and prognostic factors.

3. Results

3.1. Study Selection

The database search yielded 4171 records. After removal of duplicates, titles and abstracts were screened, followed by full-text assessment of potentially eligible articles. Six studies met the predefined inclusion criteria and were included in the systematic review [22,26–30]. The study selection process is presented in the PRISMA 2020 flow diagram (Figure 1).

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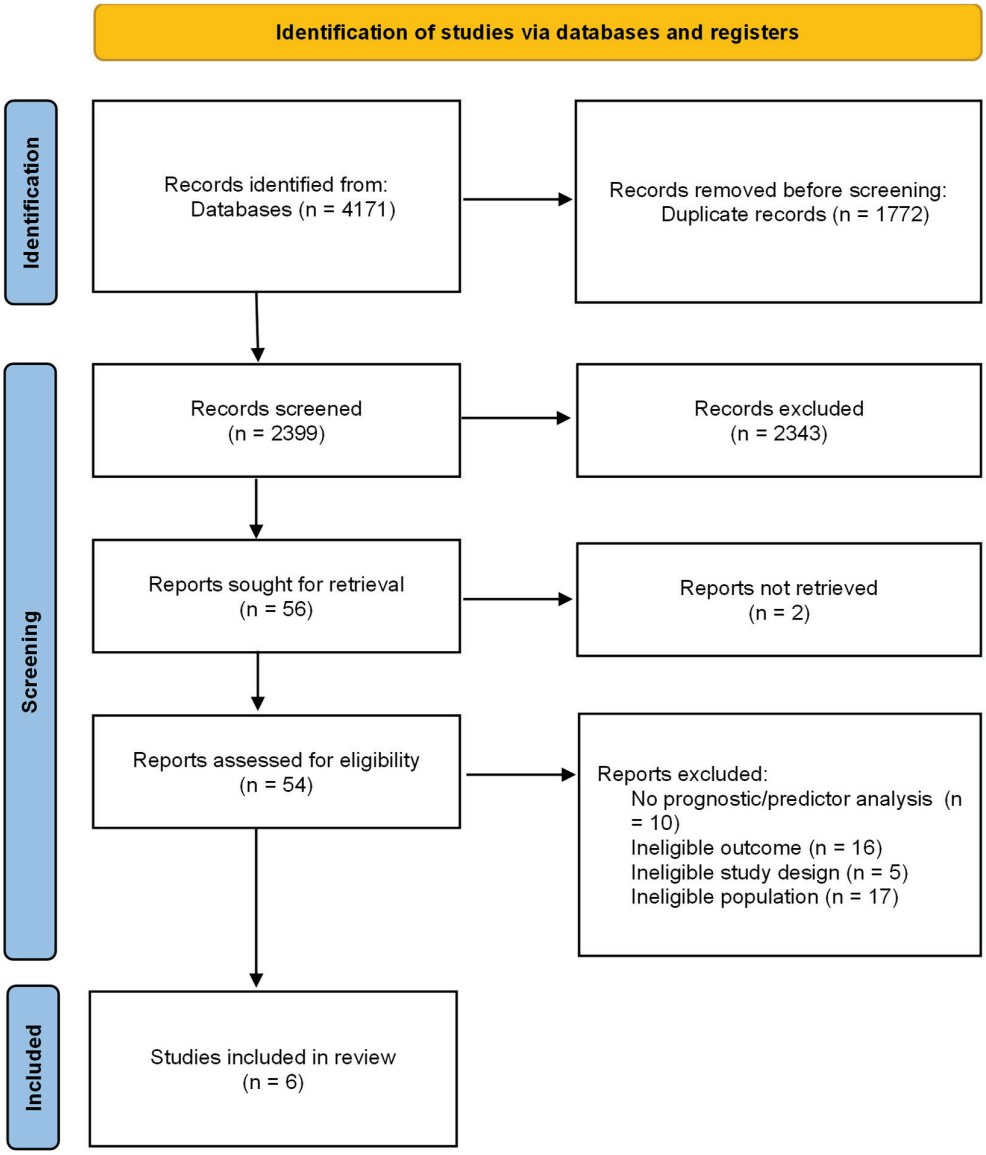

Figure 1. The PRISMA 2020 flow diagram.

3.2. Study Characteristics

The characteristics of the included studies are summarized in Tables 3 and 4. All included studies had a prospective observational design and assessed pain persistence or pain chronicity in patients with painful TMD. Across studies, baseline sample size varied from 63 to 480 participants. Follow-up time ranged between 6 and 24 months. All included studies used the Research Diagnostic Criteria for Temporomandibular Disorders. Outcomes focused on pain persistence or progression to clinically significant pain, and were measured using validated tools such as the Graded Chronic Pain Scale (GCPS), Characteristic Pain Intensity (CPI), or on the basis of sustained painful symptoms. Advanced statistical models were employed (e.g., regression-based analyses) for predictor analyses.

Table 3. Studies characteristics.

l.p	Author	Year	Study Design	Sample Size (Baseline)	Sample Size (Follow-Up)	Age (Mean ± SD/Range)	Diagnostic Criteria	TMD Diagnosis Subtype	Pain Duration at Baseline	Outcome Type (Pain Persistence, Pain Chronicity)	Chronic Pain/Pain Persistence Definition	Outcome Measure (e.g., Pain Intensity, GCPS)
1	Elsaraj et al.	2023 [22]	prospective cohort study	456	378	41.74 ± 16.29	RDC/TMD and DC/TMD	painful TMD (muscle and/or joint)	acute cohort < 3 months; chronic > 3 months	Pain chronification (transition from acute to chronic) and persistence of chronic painful TMD	Pain duration > 3 months; Dysfunction GCPS II-IV	Pain persistence at 3-month follow-up (pain duration > 3 months), GCPS (1 vs. II-IV), Characteristic pain intensity
2	Ohrbach et al.	2020 [28]	prospective cohort study	260	147	N.D	RDC/TMD	Painful TMD	No TMD at baseline	Pain persistence	Persistence defined as examiner-verified TMD at 6–8 months after onset	Examiner-verified presence of symptoms of TMD
3	Forssell et al.	2016 [26]	prospective cohort study	399	263	40.5 ± 12.7	RDC/TMD	Painful TMD	TMD pain in last month	Pain persistence	pain persistence at 1 year follow-up (according to GCPS)	GCPS at 1 year
4	Velly et al.	2011 [30]	prospective cohort study	570	480	35.85 ± 12.48	RDC/TMD	Painful TMD	>3 months	Pain persistence/chronicity	pain frequency of at least once per week, and duration of at least 3 months	GCPS-CPI
5	Marklund et al.	2010 [27]	case–control with 2-year prospective cohort	371	280	N.D	RDC/TMD	Painful TMD	N.D	Pain persistence	2 years of pain persistence	Persistence of painful symptoms at 0, 12 and 24 months
6	Su et al.	2020 [29]	prospective cohort study	63	63	40.5 ± 13.9	RDC/TMD	Myofascial pain	pain for at least 1 month	pain persistence	Pain persistence in the 6 and 12-month follow-up	GCPS-CPI

Table 4. Predictors of pain persistence and chronicity in temporomandibular disorders.

l.p	Author	Predictors Analyzed (e.g., Somatization, Number of Painful Sites)	Statistical Model (Logistic Regression, Linear Regression)	Significant Predictors
1	Elsaraj et al. [22]	• EDS, • Insomnia, • PHQ-4, • Characteristic Pain Intensity, • Baseline acute/chronic status, • GCPS	• Logistic regression	• No associations between insomnia and persistence or transition to chronic pain, • Borderline association between transition or persistence risk and EDS,
2	Ohrbach et al. [28]	• Psychosocial measures (perceived stress/negative life events, anxiety, mood/affect, depression, somatic symptom reporting, pain catastrophizing), • Sleep quality and health-related quality of life, • Oral parafunctional behaviors and jaw functional limitation, • Quantitative sensory testing, pressure pain thresholds and thermal/mechanical pain response	• Logistic and linear change	• None reported

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Table 4. *Cont.*

l.p	Author	Predictors Analyzed (e.g., Somatization, Number of Painful Sites)	Statistical Model (Logistic Regression, Linear Regression)	Significant Predictors
3	Forssell et al. [26]	• Comprehensive multidimensional pain questionnaire assessing TMD pain related and general health factors, and psychosocial prognostic factors using validated self-report scales.	• Logistic regression	• Number of healthcare visits (last 6 months), • Pain intensity/dysfunction of other pain conditions, • Number of other pain conditions: (borderline), • Number of disability days (baseline), • Perceived ability to control pain (borderline)
4	Velly et al. [30]	• Catastrophizing, • Depression, • Widespread pain, • Worst pain intensity, • GCPS at baseline,	• Linear regression, binary logistic regression, ordinal logistic regression	• Baseline catastrophizing, • Pain intensity at baseline, • Widespread pain,
5	Marklund et al. [27]	• Self-reported bruxism, • Dental occlusal factors, • Parafunctions,	• Logistic regression	• Self-reported bruxism, • Crossbite, • Mandibular instability in the Intercuspal Position, • Lateral slide 1 mm between the retruded contact position and the Intercuspal Position
6	Su et al. [29]	• Pain characteristics (baseline Characteristic Pain Intensity, pain duration/chronicity, pain elsewhere), • Prior TMD pain treatment, • Psychosocial factors (SCL-90 depression and somatization), • Bruxism, • Mandibular function impairment	• Logistic regression	• Pain elsewhere • Depression, • Bruxism, • Mandibular Function

(EDS—Excessive Daytime Sleepiness, PHQ-4—Patient Health Questionnaire 4, GCPS—Graded Chronic Pain Scale, TMD—Temporomandibular Disorders, SCL-90—Symptoms Checklist 90).

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Across the included studies, the identified predictors could be broadly grouped into three domains consistent with the biopsychosocial framework. Biological predictors included pain-related characteristics (e.g., baseline pain intensity, widespread pain). Psychological predictors encompassed cognitive and affective variables (e.g., depression, pain catastrophizing, anxiety). Social and behavioral predictors related to illness behavior and daily functioning (e.g., healthcare-seeking behavior, functional disability, sleep-related factors). A full overview of predictors analyzed across studies is presented in Table 4.

3.3. Risk of Bias

A summary of the risk of bias assessment is presented in Table 5.

Table 5. Risk of bias analyzed with QUIPS tool.

Author	Study Participation	Study Attrition	Prognostic Factor Measurement	Outcome Measurement	Study Confounding	Statistical Analysis and Reporting	Overall Bias
Elsaraj et al. [22]	Moderate	Moderate	Low	Low	High	Moderate	High
Ohrbach et al. [28]	Low	High	Low	Low	Moderate	Moderate	Moderate
Forssell et al. [26]	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Velly et al. [30]	Low	Moderate	Low	Low	Moderate	Low	Moderate
Markulund et al. [27]	High	Moderate	Low	Low	High	High	High

In the included prognostic factor studies, the risk of bias across most domains was judged to be low to moderate. The domains of prognostic factor measurement and outcome measurement were consistently rated as low risk of bias, due to the use of standardized diagnostic criteria (RDC/TMD) and other validated measurement tools. Higher risk of bias was more frequent in the domains of study attrition and study confounding, primarily due to loss to follow-up and confounding in multivariable analyses.

In PROBAST analysis, the one study assessed demonstrated concerns mainly in the domain of outcome and analysis, including a lack of external validation and potential risk of overfitting.

The overall methodological quality of the included studies was considered sufficient to support qualitative synthesis of prognostic findings.

3.4. Certainty of Evidence

The certainty of evidence for associations between biopsychological predictors and pain persistence or chronicity was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) approach. Although GRADE was originally developed for intervention research, its application to prognostic studies is supported by published methodological guidance and has been increasingly adopted in systematic reviews of prognostic factors [31,32]. Overall, the certainty of the evidence was judged to be moderate to very low, depending on the predictor. Higher certainty ratings were observed for selected psychological and pain-related factors, whereas evidence for sleep-related and occlusal factors was rated as low or very low. Downgrading was most commonly caused by risk of bias, inconsistency across studies, and imprecision. Only predictors supported by sufficiently comparable data were included in the GRADE assessment. A summary of the findings is presented in Table 6.

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Table 6. GRADE assessment.

Prognostic Factor	No. of Studies (First Author)	Total N	Outcome Definition	Effect Estimate (Adjusted)	Certainty of Evidence (GRADE)
Catastrophizing	2 (Velly; Forssell)	~740	GCPS II–IV/progression or persistence	OR 1.72–2.16	●●●○ Moderate
Baseline pain intensity	2 (Velly; Forssell)	~740	GCPS II–IV/disability	Dose–response relationship	●●●○ Moderate
Depression	2 (Velly; Forssell)	~700	GCPS II–IV/persistence	OR ~1.2–1.5	●●○○ Low
Widespread pain/pain elsewhere	2 (Velly; Forssell)	~700	GCPS II–IV/persistence	OR ~1.3–1.8	●●○○ Low
Excessive daytime sleepiness (EDS)	1 (Elsaraj)	378	Pain > 3 months/GCPS II–IV	RR 1.13 (1.00–1.26)	●○○○ Very low
Bruxism/occlusal factors	1 (Marklund)	280	2-year persistence	Inconsistent effects	●○○○ Very low

●●●● High, ●●●○ Moderate, ●●○○ Low, ●○○○ Very low.

3.5. Definitions of Pain Persistence and Pain Chronicity

Across the included studies, outcomes related to pain persistence and chronicity were defined using similar but not identical definitions. Pain persistence was often defined as the continued presence of painful TMD symptoms at follow-up or as the lack of improvement over time [26–28]. Pain chronicity refers to the presence or progression of clinically significant pain [26,30]. Pain significance was often validated using tools such as the Graded Chronic Pain Scale (GCPS), or part of it, namely Characteristic Pain Intensity (CPI) [28–30]. In some studies, persistence or chronicity was based on sustained pain during repeated follow-up assessments [27,29]. Follow-up varied from 6 to 24 months.

The definitions of pain chronicity and pain persistence overlapped substantially, as both referred to the continued presence of painful TMD symptoms over time and were analyzed using similar tools.

4. Discussion

4.1. Summary of Main Findings

This systematic review synthesized evidence from prospective observational studies on predictors of pain persistence and chronicity in TMD. Across the six included studies, prognostic factors were heterogeneous and contained biological, psychological, social, and behavioral aspects. Overall, psychological factors, i.e., depression and catastrophizing, were associated with pain persistence or pain chronicity. Biological factors, including baseline pain intensity, number of pain conditions, and baseline number of disability days, also demonstrated prognostic value.

Social and behavioral factors were assessed less frequently and were mainly captured through indicators of illness behavior and functional impairment rather than through direct social variables. In this domain, functional disability influencing the ability to work and health care seeking were the most relevant factors associated with pain persistence or progression.

The certainty of evidence ranged from moderate to very low, reflecting methodological heterogeneity, limited sample sizes, and variability in outcome definitions across studies. In particular, the variability in outcome definitions across studies may have introduced inconsistencies in the reported findings. Some studies defined pain persistence as the continued presence of symptoms at follow-up, while others used validated tools such as GCPS to analyze the clinically significant pain. These differences limit direct comparison of results across studies and should be considered when interpreting the overall pattern of identified predictors.

To make interpretation easier, predictors identified in the included studies were grouped according to the biopsychosocial framework into three domains: biological, psy-

chological, and social or behavioral factors. This structure allowed a clearer comparison of predictors across studies and helped identify which domains showed the most consistent prognostic associations with persistent TMD pain.

In summary, these findings support the biopsychosocial model of pain persistence and pain chronicity in patients with TMD while highlighting the need for prospective studies that more precisely analyze social and behavioral mechanisms in prognosis models.

4.2. Biological Predictors of Pain Persistence and Chronicity

Across the included studies, biological predictors of pain persistence and pain chronicity in painful TMD were mostly related to baseline pain characteristics, pain intensity, and pain distribution on other sites of the body. Physiological measures of pain were not employed. In the study by Velly et al., higher baseline pain intensity was associated with the onset and progression of clinically significant pain at 18-month follow-up [30]. It was still valid after adjustment for psychological factors and measures of widespread pain. Similarly, Marklund et al. reported that higher baseline pain was associated with persistence of TMD pain in the two-year period [27]. Therefore, it emphasizes the importance of the initial pain factor in the chronification process.

The distribution of pain outside of the orofacial region was also an important biological factor in pain persistence. Both Velly et al. and Su et al. identified the presence of widespread pain or pain elsewhere in the body as a predictor of pain persistence or progression [29,30]. A similar pattern has been observed in previous cross-sectional studies in chronic TMD patients, in which higher pain intensity and greater pain-related disability were associated with higher overall symptom burden [33–35]. These findings may demonstrate that chronic pain in TMD patients is related to alterations in pain processing and not only a localized musculoskeletal disorder. Such conclusions are in line with the concept of enhanced central pain amplification or reduced pain inhibition, although tools for CS were not employed in the included studies [33,36,37].

In a broader context outside of TMD, studies in other pain conditions suggest that baseline pain intensity and pain in other body sites are among the most consistent clinical predictors of pain persistence and long-term disability, regardless of the primary diagnosis [35,38]. Patients with chronic musculoskeletal and widespread pain with higher initial pain severity and greater area of body affected by pain, present poorer prognosis [38]. In this context, identified biological predictors in painful TMD patients align with the literature regarding chronic pain in general, where pain intensity and multisite pain act as markers of altered pain processing, rather than specific condition mechanisms [35,36]. This similarity may indicate that painful TMD shares common predictors with other chronic pain conditions.

Interestingly, functional parameters of the temporomandibular region showed some interesting results. A study by Su et al. reported that lower mandibular function impairment at baseline was associated with a higher likelihood of pain persistence at follow-up [29]. This finding may indicate that some patients experience persistent pain despite relatively preserved jaw function, suggesting that pain persistence in these cases is driven more by central mechanisms than by local functional impairment.

What is worth noting is that objective neurophysiological measures, such as quantitative sensory testing, were rarely incorporated, and their prognostic value for pain persistence was not clearly established, which limits the strength of the evidence regarding biological predictors in painful TMD. Biological factors were primarily assessed using self-reported pain tools such as GCPS [22,26,29,30]. Although measures such as pressure pain thresholds and other quantitative sensory testing parameters were assessed in one included study, they were not consistently identified as prognostic predictors, limiting

the ability to analyze the relationship between biological predictors and pain-processing mechanisms, such as CS.

Therefore, although the biological predictors identified in TMD are consistent with those observed in other chronic pain conditions, further research is needed to better understand the underlying pathophysiological process, not only the patient's self-reported pain experience.

4.3. Psychological Predictors of Pain Persistence and Pain Chronicity

In the included studies, psychological factors were examined more frequently and more precisely than biological aspects. Analyzed parameters encompassed psychological measures such as depression, anxiety, catastrophizing, somatization, quality of life, and perceived stress [26,28–30]. Psychological variables were typically assessed using validated, standardized self-report questionnaires.

Results of the studies demonstrated that pain catastrophizing (defined as a maladaptive cognitive-affective response to pain characterized by rumination, magnification and helplessness) plays an important role in unfavorable pain trajectories [30,39]. In the study by Velly et al., higher baseline levels of catastrophizing were associated with both the onset and progression of clinically significant pain at follow-up, even after adjustment for demographic variables and baseline pain intensity [30]. A similar relationship was also found for catastrophizing and pain-related disability at follow-up [30]. These findings may suggest that catastrophizing acts as an amplifier that affects pain perception and coping and can contribute to pain maintenance in TMD patients. Consistent with these findings, Forssell et al. reported that higher perceived ability to control pain can have a protective effect and was associated with more favorable outcomes [26]. It supports the thesis that the ability to cope with pain can predict long-term pain-related outcomes [26].

Interestingly, depression was also an important predictor of pain progression and disability, but after adjustment for pain catastrophizing and baseline pain-intensity it did not remain significant, while catastrophizing remained a predictor for pain outcomes [30].

Other psychological aspects showed less consistent results with pain persistence. Anxiety and psychological distress were examined in three studies, but their predictive value was not significant after adjustment for pain-related variables and comorbid conditions [26,27,29]. Findings from the OPPERA cohort confirm the dynamic relationship between psychological factors and pain persistence. Specifically, a study by Ohrbach et al. demonstrated that psychological distress may vary, and it tends to increase around TMD onset and is elevated in patients with persistent pain, but is declining in those whose symptoms are decreasing [28]. These findings support a dynamic model of the bidirectional relationship between psychological distress and TMD pain.

Chronic pain was previously associated with psychological disorders, particularly with depression and anxiety symptoms, which were also recognized as predictors of chronic pain conditions [40]. In a study by Aaron et al., approximately 40% of adults with chronic pain had significant depression and anxiety symptoms [41]. Interestingly, greater severity of psychological disorders was observed in participants with nociplastic pain conditions, such as fibromyalgia, compared with patients presenting nociceptive pain mechanisms (i.e different types of arthritis) [41]. It supports the view that centrally mediated pain is closely related to psychological impairment.

These observations are important in the context of painful TMD, where chronic myogenous pain was linked to altered pain processing mechanisms. Studies in patients with chronic masticatory muscle pain demonstrated a strong association between depression and anxiety symptoms and markers of CS, suggesting that psychological factors may be related to central nervous system alterations and not only the tissue damage [33].

Chronic pain and psychological disorders, such as depression, involve overlapping brain regions such as the hippocampus, thalamus, and amygdala, which are responsible for emotional regulation but also for pain processing [42,43].

The findings regarding psychological factors indicate that baseline psychological aspects, especially catastrophizing and depression, may be a relevant clinical predictor of pain persistence in painful TMD. It highlights the importance of assessing psychological factors during patient evaluation and supports the biopsychosocial model of understanding pain chronification.

4.4. Social and Behavioral Predictors of Pain Persistence and Pain Chronicity

In the biopsychosocial framework, the social domain refers to how patients function in their social context, including daily roles, work, interpersonal functioning, and healthcare use. Classical social determinants such as socioeconomic status, education, or social support were not directly assessed in the prospective studies included in the review. Therefore, "social predictors" in this analysis mainly refer to proxies of social functioning and illness behavior rather than direct measures of social context.

Four domains were identified: previous healthcare visits, healthcare utilization, functional disability impacting work or social life, and socio-behavioral stressors. Overall, social predictors were rarely investigated heterogeneously, and only two domains showed consistent prognostic relevance.

Regarding previous healthcare visits, only one study demonstrated that earlier healthcare contact may predict later pain persistence. Forssell et al. evaluated the number of pain-related healthcare visits in the six months preceding baseline. Each additional visit significantly increased the risk of clinically significant pain after one year, and this variable remained significant in multivariable analysis [26]. This finding was interpreted as reflecting frequent healthcare-seeking behavior, possibly indicating more complex symptom presentation or greater distress.

In contrast, Su et al. recorded previous treatment for TMD pain as a binary variable, which did not predict persistence at 6 or 12 months [29]. In OPPERA, participants with prior diagnosis or treatment were excluded, and in Marklund, Velly, and Elsaraj, healthcare history was not analyzed as a prognostic factor [22,27,28,30]. These discrepancies may partly reflect methodological differences, particularly the use of continuous versus dichotomous indicators.

Regarding general healthcare utilization, none of the included prospective studies formally evaluated it as an independent predictor of chronic pain. Although utilization was mentioned in several studies, no cohort included detailed quantitative measures, such as the number of consultations or treatment intensity, in prognostic models [26,28,29]. Consequently, current evidence does not allow conclusions regarding whether healthcare utilization per se predicts persistence of painful TMD.

Functional disability interfering with work and social activities emerged as the most consistent social predictor. Velly et al. used the disability component of the Graded Chronic Pain Scale, which includes interference with daily occupational and social activities [30]. Baseline pain-related disability significantly predicted both the onset and the progression of clinically significant chronic pain over 18 months. Higher initial interference increased the risk of developing more severe pain grades.

In other studies, functional limitation was assessed mainly in clinical terms. Ohrbach analyzed jaw functional limitation and chewing difficulties, and Su et al. used the Mandibular Function Impairment Questionnaire; however, these measures reflected stomatognathic function rather than work or social participation [28,29]. Consequently, only Velly et al. directly evaluated the prognostic role of work- and social-related disability [30]. Finally,

socio-behavioral stressors were not systematically assessed as independent prognostic predictors of pain chronicity. Most cohorts focused primarily on psychological constructs such as depression, anxiety, or catastrophizing. Although some authors discussed potential social mechanisms, such variables were not included in statistical models. Therefore, current evidence does not support an independent prognostic role of broader social stressors in painful TMD.

In summary, prospective studies indicate that the social component of the biopsychosocial model has been only partially investigated in painful TMD. Among the selected domains, only two constructs showed prognostic relevance: frequent early healthcare-seeking behavior and functional disability interfering with work and social activities. Importantly, these variables serve as proxies for illness behavior and social functioning rather than classical social determinants. In contrast, general health care utilization and socio-behavioral stressors were either not assessed or not consistently associated with the outcome.

These findings indicate that social predictors of chronicity are mainly related to early maladaptive illness behavior and to the social consequences of pain rather than to external stress exposures. At the same time, the scarcity of positive results highlights an important gap in current research. Most studies concentrate on biological and psychological mechanisms, while the social dimension of chronic pain remains underrepresented. Future longitudinal studies should systematically include measures of occupational functioning, social participation, healthcare-seeking patterns, and social support in order to better understand how social context contributes to the persistence of painful TMD.

4.5. Clinical Implications

The findings of this systematic review have important implications for clinical practice regarding the assessment and treatment of patients with painful TMD. The identified psychological factors, such as pain catastrophizing and depression, highlight the importance of including psychological aspects in the daily routine in the management of painful TMD. Standardized screening tools, such as validated questionnaires, may help identify patients at higher risk of unfavorable pain trajectories.

Higher baseline pain intensity and widespread pain also demonstrated prognostic value, pointing out that assessment should consider regions outside of the orofacial area. It can also suggest possible alterations in pain processing.

Behavioral factors, such as parafunctional activities or sleep disturbances, may also contribute to pain persistence, although current evidence is limited and less consistent.

Early identification of prognostic factors may help to plan more appropriate and effective treatment. It should include patient education, behavioral changes, and interdisciplinary management.

4.6. Limitations of the Review and Future Research Directions

This review has several limitations. First, the number of included studies was relatively small, which limits the strength and generalizability of the conclusions. Second, high heterogeneity was observed in outcome definitions, follow-up duration, and the predictors assessed, making it impossible to perform a meta-analysis. In particular, follow-up periods ranged from 6 to 24 months, which may have influenced the findings; shorter follow-up periods may not capture late onset chronification, whereas longer follow-up introduces greater risk of attrition and changes in clinical management over time. Third, the certainty of evidence ranged from moderate to very low for most predictors. In addition, most studies relied primarily on self-reported measures, while objective physiological or neurophysiological indicators were rarely assessed and showed inconsistent prognostic value. Fourth, grey literature was not searched, which may introduce publication bias and limit

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the scope of the identified evidence. Fifth, the single study evaluated using PROBAST showed concerns regarding external validation and risk of overfitting, which further limits the generalizability of its findings.

Future studies should use standardized outcome definitions, objective pain measures, and comprehensive biopsychosocial assessments to improve the prognostic accuracy.

5. Conclusions

This systematic review showed that pain persistence in painful TMD is influenced by multiple biopsychosocial factors. Psychological variables, especially pain catastrophizing and depression, represent predictors of unfavorable pain outcomes, although this conclusion is limited by the small number of included studies and heterogeneity across outcome definitions. Biological factors, such as higher baseline pain intensity and widespread pain, also contribute to increased risk of persistent pain.

These findings support the biopsychosocial model of pain chronification and highlight the importance of comprehensive assessment beyond local musculoskeletal factors.

Further longitudinal studies using standardized outcome definitions and comprehensive biopsychosocial assessment are needed to improve prognostic models and support targeted preventive strategies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm15072498/s1, PRISMA 2020 Checklist.

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Abbreviations

The following abbreviations are used in this manuscript:

TMD	Temporomandibular Disorders
TMJ	Temporomandibular Joint
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
RDC/TMD	Research Diagnostic Criteria for Temporomandibular Disorders
ICOP	International Classification of Orofacial Pain
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PICOS	Population, Intervention/Exposure, Comparator, Outcome, Study Design
PROSPERO	International Prospective Register of Systematic Reviews
QUIPS	Quality In Prognosis Studies
PROBAST	Prediction model Risk Of Bias ASsessment Tool
GRADE	Grading of Recommendations Assessment, Development, and Evaluation
GCPS	Graded Chronic Pain Scale
CPI	Characteristic Pain Intensity
EDS	Excessive Daytime Sleepiness

ISI	Insomnia Severity Index
PHQ-4	Patient Health Questionnaire-4
SCL-90	Symptom Checklist-90
CS	Central Sensitization
OR	Odds Ratio
RR	Risk Ratio
CI	Confidence Interval

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Systematic Review

Arthroscopic Discopexy Techniques for Articular Disc Displacement: A Systematic Review and Meta-Analysis

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Abstract

Background/Objectives: Anterior disc displacement (ADD) is a common temporomandibular joint (TMJ) disorder and may progress to internal derangements. Although arthroscopic discopexy (minimally invasive disc repositioning with fixation) has been adopted, suggested techniques and pooled outcomes have not been comprehensively synthesized. The aim of the present study was to summarize the effectiveness of arthroscopic discopexy in treating patients with disc-related TMJ disorders. **Methods**: This systematic review and meta-analysis followed Cochrane guidance and PRISMA 2020 protocol. Four databases were searched through 1 September 2025. A total of 26 studies were included in this review. Nine studies met the eligibility criteria for meta-analysis and were pooled. The remaining 17 studies were narratively described, focusing on surgical characteristics. Continuous outcomes (MIO, pain score (VAS 0–10)) were pooled as mean differences (MD) with 95% confidence intervals (CIs), and joint sounds were synthesized as dichotomous outcomes. Analyses and heterogeneity were performed in RevMan 5.4. Certainty was graded with GRADE. (PROSPERO: CRD420251145229). **Results**: 1086 TMJs were analyzed. Arthroscopic discopexy significantly improved MIO, pain, and joint sounds at all time points. The MD of MIO was 10.58 mm (95% CI: 4.46 to 16.70; $p \leq 0.001$), 9.83 mm (95% CI: 4.09 to 15.57; $p \leq 0.001$), and 13.06 mm (95% CI: 4.40 to 21.72; $p \leq 0.001$), respectively. The MD of the pain score was −4.36 (95% CI: −6.89 to −1.82; $p \leq 0.001$), −3.91 (95% CI: −6.23 to −1.59; $p \leq 0.001$), and −4.56 (95% CI: −7.81 to −1.31; $p < 0.01$), respectively. At 12 months, joint sounds were less frequent than preoperatively (OR = 0.07; 95% CI: 0.01 to 0.37; $p < 0.01$). Overall, the certainty of evidence according to the GRADE approach was rated as low. Therefore, the results should be interpreted with caution, as high heterogeneity was observed across the three follow-up time points and the included studies were observational. **Conclusions**: These findings underscore the significance of arthroscopic discopexy in enhancing TMJ function and alleviating symptoms. Current evidence, characterized by a low risk of bias and low certainty, supports the advantage of arthroscopic discopexy. Due to the observational evidence base and heterogeneity, high-quality randomized trials conducted under standardized treatment protocols and with longer follow-up are needed.

Keywords: temporomandibular joint; arthroscopic discopexy; disc repositioning; anterior disc displacement; suture anchor fixation

1. Introduction

The temporomandibular joint (TMJ) plays a fundamental role in maintaining essential functions for human survival, including occlusion and the masticatory system. Similar

to the knee joint, which bears body weight, the TMJ is responsible for absorbing and distributing loads generated during occlusal contact and mastication. Mastication imposes mechanical stress on the TMJ, which the joint must withstand. It exhibits highly specialized and complex anatomical characteristics. However, excessive and repetitive loading, as seen in parafunctional habits such as bruxism, can exceed the adaptive capacity of the joint, leading to TMJ arthritis, internal derangements (IDs), and ultimately temporomandibular joint disorders (TMDs). TMDs represent one of the most common TMJ pathologies, with an estimated global prevalence of approximately 34% [1]. The TMJ is most commonly attributed to anterior disc displacement (ADD), which has been reported to result in reduced maximal mouth opening and impairment of masticatory efficiency [2,3]. In patients with dentofacial deformities, TMD is reported to occur more frequently in individuals with Class II malocclusion or facial asymmetry [4]. Of particular concern is progressive condylar resorption (PCR), which has been documented following orthognathic surgery in patients with Class II malocclusion [5–7]. The etiology of PCR remains unclear. However, excessive mechanical stress and the influence of sex hormones have been suggested as contributing factors [8–10]. Our previous studies have demonstrated, through animal models, the association of these factors with PCR [11–13]. Importantly, we further identified that patients with PCR often present with ID before orthognathic surgery [14], with anterior disc displacement without reduction (ADDwoR) being particularly prevalent [15–20]. These findings highlight the clinical relevance of pre-existing ID in patients with mandibular retrognathism, suggesting that failure to address such pathology may predispose patients to postoperative PCR. Therefore, careful assessment and management of ID—especially ADDwoR—should be considered an integral component of preoperative evaluation and treatment planning in orthognathic surgery. Therapeutic approaches for ADDwoR include physical therapy, occlusal splint therapy, arthrocentesis, and disc repositioning procedures [19,21,22].

Clinical intervention is typically necessary when patients experience TMD, characterized by joint pain or limited mouth opening. Treatment often progresses stepwise. First, physical therapy begins, followed by splint therapy. Arthrocentesis is used if needed. The role of disc repositioning remains controversial due to a lack of high-quality and long-term evidence. Narrative reviews have mentioned disc repositioning, but few systematic reviews have evaluated its outcomes for ADDwoR. Moreover, for severe ADD, the strong scientific evidence is limited to open surgery. Nonetheless, numerous reports show favourable postoperative outcomes with arthroscopic discopexy. We therefore hypothesized that arthroscopic discopexy would improve MIO, reduce pain, and diminish joint sounds at 6, 12, and 24 months compared with preoperative values.

2. Materials and Methods

The study protocol of this systematic review and meta-analysis was conducted in accordance with the Cochrane Handbook and reported following the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) 2020 statement [23,24]. This review was registered in the International Prospective Register of Systematic reviews (PROSPERO) before data extraction began (registration number: CRD420251145229). Ethical approval was not required for this review, as it involved no direct access to identifiable patient information or direct approach with participants.

2.1. Aim and Objectives

The goal of this review was to summarize the effectiveness of arthroscopic discopexy for patients with anterior disc displacement (ADD), both with and without reduction. We assessed postoperative pain, MIO, and joint sounds improved at 6, 12, and 24 months and compared them with preoperative values. We ensured that all results were reported

in standardized units/scales. The review protocol was prospectively registered in the PROSPERO database (ID: CRD420251145229).

2.2. Research Question

How does arthroscopic discopexy improve TMJ function and alleviate symptoms at 6, 12, and 24 months after treatment?

2.3. Eligibility Criteria and Search Strategy

Two researchers (N.S. and J.P.) looked for studies about this topic published before 1 September 2025 from four electronic databases (PubMed, Embase, Scopus, Web of Science). All search strategies were provided in Supplementary Table S1. They followed review guidelines to determine search terms and select the types of studies to include or exclude. Details about the search terms and the criteria for inclusion and exclusion are shown in Tables 1 and 2.

Table 1. PICOS-based search strategy and terms used across databases (PubMed, Embase, Scopus, and Web of Science.

PICO Question		Search Terms
P	Patients diagnosed with temporomandibular joint disorders, specifically articular disc displacement (with or without reduction, with or without limited mouth opening)	("Temporomandibular Joint Disorders"[Mesh] OR "Temporomandibular Disorders"[tiab] OR TMD [tiab]) AND ("Temporomandibular Joint Disc Displacement"[Mesh] OR "disc displacement"[tiab] OR "disk displacement"[tiab] OR "anterior disc displacement"[tiab] OR "internal derangement"[tiab])
I	Arthroscopic disc repositioning and anchor fixation techniques (Suturing, pin, or screw)	("Open Surgical Procedures"[Mesh] OR "open surgery"[tiab] OR "open reduction"[tiab] OR "open joint surgery"[tiab] OR "Arthroscopy"[Mesh] OR arthroscopy[tiab])
C	Pre-surgical baseline values (VAS, MIO, Joint sounds) compared with post-surgical outcomes (before–after comparison)	
O	Pain score by VAS (score 1–10) Maximal interincisal opening (MIO) (mm) Joint sounds (clicking, popping, or crepitation) (Present/Absent)	("Complications"[Mesh] OR "postoperative complications"[Mesh] OR complication[tiab] OR complications[tiab] OR "adverse event"[tiab] OR "adverse events"[tiab] OR "adverse effects"[tiab] OR "surgical outcome"[tiab] OR outcome[tiab] OR outcomes[tiab] OR sequelae[tiab] OR morbidity[tiab] OR "treatment failure"[tiab])
S	Clinical studies (prospective or retrospective cohort study, case series and randomized controlled trials)	

TMD, Temporomandibular Disorder and VAS, visual analogue scale.

Table 2. Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Language	English	Non-English
Study design	Full-text peer-reviewed clinical studies (RCTs, cohort studies, case series)	Reviews, meta-analyses, abstracts, posters, protocols, books
Population	Patients diagnosed with TMJ disc displacement (with or without reduction)	Animal, cadaveric
Type of operation	Arthroscopic disc repositioning with anchor fixation (suture/pin/screw), or Disc discopexy technique	Other surgical procedures
Surgical site	Temporomandibular joint	Other areas
Outcomes	Reported at least one clinical outcome (Pain score by VAS, MIO, joint sounds)	Studies without relevant clinical outcomes
Timeframe	Studies published up through 1 September 2025	Studies published after the cut-off date

RCTs, Randomized Controlled Trials; TMJ, Temporomandibular joint; VAS, visual analogue scale; MIO, maximal interincisal opening.

2.4. Data Extraction and Management

After collecting the data, duplicate records were removed using EndNote 21 and Rayyan [25] (version 1.4.3). Screening was conducted in two stages: titles and abstracts were screened first, followed by a full-text review. Two researchers (N.S. and J.P.) worked independently. Disagreements were resolved by discussion, with final decisions by the third author (Y.K.). The full texts of potentially eligible articles were reviewed against inclusion and exclusion criteria (Table 2). All exclusion reasons were recorded. If a study described a relevant surgical procedure, it was also reviewed. Articles that met the criteria were included in the meta-analysis. Articles that described surgical techniques were excluded from meta-analysis but retained for qualitative discussion. Two researchers (N.S. and J.P.) extracted general characteristics of articles. Another researcher (Y.K.) verified the extracted data. Extracted data included: first author, publication year, study design, numbers of participants and TMJs, participant characteristics, suture material, disc repositioning and fixation technique, anchorage location or material, co-interventions, pain score (measured by visual analogue scale (VAS) 0–10; 0 representing no pain and 10 representing the worst pain; mean ± SD), maximal interincisal opening (MIO, mean ± SD), and improvement in joint sounds (number of patients with or without clicking, popping, or crepitation). Data that were unclear or missing were noted and excluded from evaluation.

2.5. Assessment of Research Quality

Two researchers (N.S. and J.P.) assessed the quality of the studies, using checklists from the National Heart, Lung, and Blood Institute (NHLBI) Quality Assessment Tool (Quality Assessment Tool for Before-After (Pre-Post) Studies with No Control Group and Quality Assessment Tool for Case Series Studies) [26]. Another researcher (Y.K.) randomly checked some of the ratings. If they disagreed, they discussed it until they reached an agreement. Y.K. made the final decision.

2.6. Data Synthesis and Statistical Analysis

The meta-analysis was conducted using three time points (6-month, 12-month, and 24-month follow-up) and three variables (pain score, MIO, and joint sounds), comparing baseline (pre-surgery) with post-surgery outcomes. Effect sizes were calculated as mean differences (MD) with standard deviations (SD) for pain and MIO scores, and as dichotomous outcomes for joint sounds. A 95% confidence interval (CI) was set at $\alpha = 0.05$. Pairwise comparisons between pre- and post-surgery were evaluated using MD. Heterogeneity was assessed by the chi-square test (χ^2) and the I^2 statistic, with levels interpreted as low (<25%), moderate (25–50%), and high (≥50%). Forest plots for each outcome at each time-point model were generated to illustrate the pooled results. Statistical analyses were performed in StataNow19 (StataCorp LLC, College Station, TX, USA; 2025). Significance was defined as a *p*-value of less than 0.05, highly significant as a value of less than 0.01, and the highest significance as a value equal to or less than 0.001. The quality of the evidence was evaluated using the GRADE (Grading of Recommendations Assessment, Development, and Evaluation) framework and categorized as high, moderate, low, or very low [27].

3. Results

3.1. Study Selection

Following the PRISMA 2020 guidelines, the screening process is summarized in the PRISMA flow diagram (Figure 1). From four electronic databases, 433 articles were initially identified. After 215 duplicated articles were removed, 218 records remained for title and abstract screening. Twenty articles that met the inclusion criteria (Table 2) were assessed in the full screening process. Among them, only eight studies with accessible full texts and

one from hand-searched articles that clearly reported postoperative pain, MIO, or joint sounds at 6, 12, or 24 months after surgery were included in the meta-analysis models. Ten excluded articles and seven additional full-text articles identified through hand-searching, all of which described arthroscopic disc repositioning and anchor fixation techniques, were included in the qualitative discussion of surgical techniques.

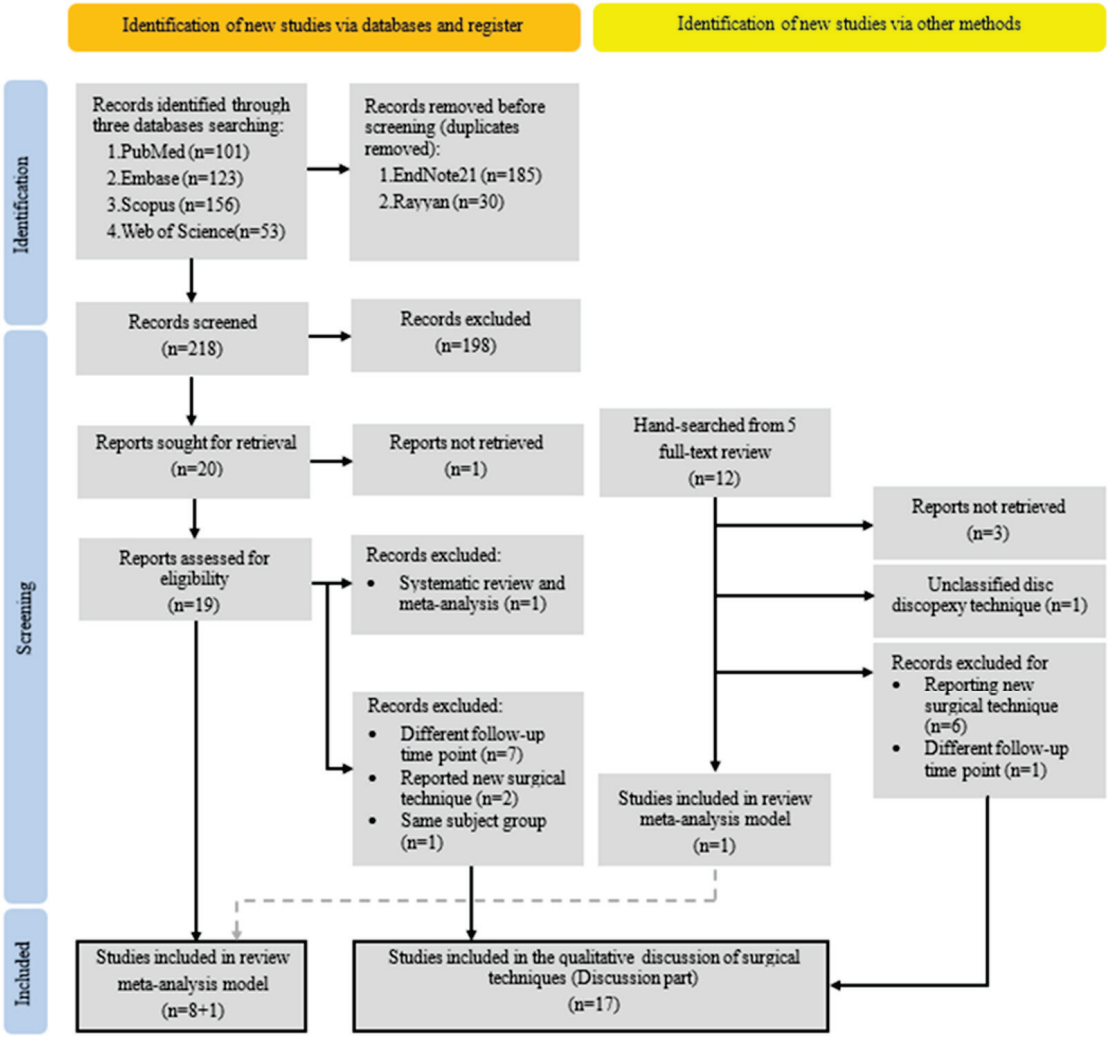

Figure 1. PRISMA 2020 process flow diagram illustrates the literature selection process.

3.2. Characteristics and Quality of the Included Studies

A total of 1086 temporomandibular joints (TMJs) with ADD, based on clinical characteristics and magnetic resonance imaging (MRI), were included and analyzed at postoperative three-time points. The functional parameters pain score (VAS, 0–10; mean ± SD), maximal interincisal opening (MIO; measured as the maximum distance between the incisal edges of the upper and lower incisors during painless mouth opening, in millimetres), and the presence of joint sounds were evaluated and recorded (present or absent). Descriptive information and clinical outcome of the studies included in each meta-analysis model are presented in Tables 3 and 4. Overall, postoperative trends of surgical outcomes showed that arthroscopic discopexy techniques were associated with improved MIO, reduced pain, and concomitant reductions in joint sounds. An exception was the study by McCain et al. (2015) [16], which reported higher postoperative pain compared with preoperative levels.

Six different TMJ disc fixation techniques, derived from twenty-five research articles, are summarized in Table 5 and Figure 2.

Table 3. Main characteristics of the included studies.

First Author, Year	Study Design	Patients/ TMJ (n)	Gender (M, F)	Age Range (y), Mean (SD)	Diagnosis	Arthroscopic Discopexy Technique	Resorbable Suture Material	Location or Material of Anchorage	Additional Surgical Procedure and Postoperative Management
Goizueta- Adame et al., 2014 [28]	CS	27/34	M1, F26	17–45, 31.2 ±NM	ADDwR (n = 3) ADDwoR (n = 27) ADDwoR with bone surface change (n = 4)	An arthroscopic disc repositioning using resorbable pin	Not used	Resorbable pin at the lateral surface of the convexity of the condyle (Two pins 33 joints, single pin 1 joints (because small perforation was found)) (SmartNail®; PLA)	1. Capsulotomy-myotomy 2. Disc reduction 3. Infiltration with sodium hyaluronate Post-operative management: 1. Medication (lornoxicam, ±muscle relaxant) 2. Functional rehabilitation 3. Soft diet 4. Mouth opening and lateral excursion were not forced for 3 months 5. Occlusal splint
Liu et al., 2019 [29]	RS	532/ 749	M147, F385	13–63, 21.23 ±3.53	Rotational ADD Anterolateral (n = 408) Anteromedial (n = 341)	Modified Yang's discopexy: double horizontal mattress–like suturing	No (Polyester)	Tragus cartilage (Suture knot)	1. The anterior attachment release 2. Disc reduction Post-operative management: 1. Medication (Antibiotics and NSAID) 2. Soft diet for 3 days 3. Mouth opening exercise start after operation 1 week 4. A functional appliance (in transient postoperative malocclusion)
Abdelrehem et al., 2021 [30]	PS	104/ 130	M22, F82	16–57, 27.47 ±9.65	ADDwR (n = 23) ADDwoR (n = 107)	Yang's discopexy: double horizontal mattress–like suturing (Yang et al., 2012 [31])	No	The anterior wall of the external auditory canal (Suture knot)	1. The anterior attachment release 2. Disc reduction Post-operative management: NM
Zhang et al., 2023 [17]	RS	24/27	M2, F22	NM, 24.38 ±8.04	Relapsed ADD	The redo arthroscopic disc repositioning and suturing (Single suture discopexy technique at bilaminar zone and posterior band of the disc)	NM	External auditory canal cartilage (Suture knot)	1. The anterior attachment release 2. Disc reduction Post-operative management: 1. Medication (Antibiotics and NSAID for three days) 2. Mouth opening exercise was started after operation 1 week (vertical and lateral step by step for 3–6 months) 3. Stabilizing soft splint for 6 months 4. Orthodontic treatment (if needed)
Lee et al., 2025 [15]	CS	31/31	M2, F29	16–45, 26.35 ±7.26	ADDwoR (Wilkes Classification III-IV)	Posterior double-pass suture technique	No (2/0-Ti-Cron™ polyester)	Subcutaneous tissue (Suture knot)	1. The anterior attachment release 2. Disc reduction Post-operative management: 1. Anterior disc repositioning splint 2. Mouth opening training (for 2–3 months after operation 2 days)

Table 3. *Cont.*

First Author, Year	Study Design	Patients/ TMJ (n)	Gender (M, F)	Age Range (y), Mean (SD)	Diagnosis	Arthroscopic Discopexy Technique	Resorbable Suture Material	Location or Material of Anchorage	Additional Surgical Procedure and Postoperative Management
Goizueta- Adame et al., 2012 [32]	CS	16/21	M1, F15	17–49, 32 ±8.00	ADDwR (n = 1) ADDwoR (n = 12) ADDwoR + OA (n = 3)	Posterior double-pass suture technique	Yes (2/0-PDS)	Subcutaneous tissue (Suture knot)	1. Removed adhesion 2. Capsulotomy with anterior myotomy 3. Disc reduction Post-operative management: 1. Medication (Piroxicam, Omeprazole, and Metamizol) 2. Functional rehabilitation 3. Soft diet for at least two months
McCain et al., 2015 [16]	PS	32/42 (s:20 /29)	M4, F28 (s: M2, F18)	Success group: NM, 27.36 ±12.5	Wilkes Classification II-V	Single suture discopexy technique	Yes (0-PDS)	Lateral capsule and Subcutaneous tissue (Suture knot)	1. The anterior attachment release and lavage 2. Complete pterygoid myotomy 3. Retrodiscal contracture or scarification 4. Disc reduction Post-operative management: NM
Martín- Granizo et al., 2016 [33]	CS	26/34	NM	22–65, 41.5 ±NM	ADDwoR (Wilkes Classification III)	An arthroscopic disc repositioning using resorbable pin	Not used	Resorbable pin (SmartNail®; PLA) (Two pins 13 joints, single pin 21 joints)	1. The anterior attachment release and lavage 2. Partial pterygoid myotomy 3. Disc reduction Post-operative management: 1. Medication (NSAID) 2. Soft diet for at least one month 3. Active physiotherapy during first month (3 sections per day) 4. Splint therapy
Martínez- Gimeno et al., 2021 [34]	RS	19/21	M1, F18	22–58, 36.84 ±11.16	ADDwR (n = 16) ADDwoR (n = 5)	Single suture discopexy with single-port arthroscope	No (3/0-nylon)	Tragus cartilage (in Antero-posterior direction)	1. Removed intraarticular adhesion (if necessary) 2. No Capsulotomy or anterior myotomy 3. Disc reduction Post-operative management: 1. Medication (Metamizole and Diclofenac) 2. Soft diet and limited mouth opening for one week after operation, then normal diet and mouth opening exercise

NM, not mentioned; s, success group; ADD, Anterior disc displacement; CS, Case series; RS, retrospective cohort, single-arm; PS, Prospective cohort, single-arm; ADDwR, Anterior disc displacement with reduction; ADDwoR, Anterior disc displacement without reduction; OA, Degenerative arthrosis; PDS, Polydioxanone suture; PLA, Polyglycolic polylactic acid; g, gram; NSAID, non-steroidal anti-inflammatory drugs.

Table 4. Baseline characteristics and treatment outcome of the included studies.

First Author, Year	MIO (mm) (Mean ± SD)			VAS (0–10) (Mean ± SD)			Joint Sounds (n) Present (P)-Absent (A) Case (%)		
	Pre-surgery	Post-surgery	n	Pre-surgery	Post-surgery	n	Pre-surgery	Post-surgery	n
Follow-up post-surgery 6-month model (Short-term)									
Goizueta-Adame et al., 2014 [28] ▲▲▲▲	34.3 ± 5.2 n = 34(NM)	38.4 ± 5.5 n = 29(NM)	-	7.08 ± 1.65 n = 32(NM)	0.66 ± 0.92 n = 29(NM)	-	P: 12 (35.3%) A: 22 (64.7%)	P: NM A: NM	34 (patients)
Martín-Granizo et al., 2016 [33] ***	32.04 ± 7.54	38.14 ± 4.61	26 (patients)	6.58 ± 2.45	1.58 ± 1.75	26 (patients)	NM	NM	NM
Liu et al., 2019 [29]	26.65 ± 7.87	32.68 ± 6.37	532 (patients)	2.06 ± 2.13	0.96 ± 1.56	532 (patients)	NM	NM	NM
Abdelrehem et al., 2021 [30] ▲▲▲▲	17.08 ± 2.90	35.61 ± 2.22	104 (patients)	7.05 ± 1.12	0.18 ± 0.38	130 (joints)	P: 73 (70.2%) A: 31 (29.8%)	P: 1 (1.00%) A: 103 (99.00%)	104 (patients)
Zhang et al., 2023 [17] **	25.07 ± 9.73	37.37 ± 6.67	24 (patients)	4.11 ± 0.85	0.93 ± 0.87	24 (patients)	NM	NM	NM
Lee et al., 2025 [15]	23.13 ± 3.54	39.35 ± 2.50	31 (patients)	4.77 ± 0.96	1.16 ± 0.79	31 (patients)	NM	NM	NM
Follow-up post-surgery 12-month model (Mid-term)									
Goizueta-Adame et al., 2012 [32]	31.13 ± 4.63	39.88 ± 2.61	16 (patients)	7.08 ± 1.65 n = 32(NM)	1.00 ± 0.96	16 (patients)	NM	NM	NM
Goizueta-Adame et al., 2014 [28] ▲▲▲▲	34.3 ± 5.2 n = 34(NM)	43.2 ± 6.1 n = 29(NM)	-	7.08 ± 1.65 n = 32(NM)	0.84 ± 1.54 n = 29(NM)	-	P: 12 (35.3%) A: 22 (64.7%)	P: NM A: NM	34 (patients)
McCain et al., 2015 [16] *, ▲▲▲	30 ± 8	37.9 ± 3.8	20 (patients)	4.19 ± 1.44	7.15 ± 1.87	20 (patients)	P: 11 (61%) A: 9 (49%)	P: 6 (46%) A: 14 (54%)	20 (patients)
Martín-Granizo et al., 2016 [33] ***, ▲	32.04 ± 7.54	39.57 ± 4.54	26 (patients)	6.58 ± 2.45	1.79 ± 1.88	26 (patients)	P: 17 (65%) A: 8 (35%)	P: 7 (29%) A: 18 (71%)	25 (patients)
Liu et al.,2019 [29]	26.65 ± 7.87	34.02 ± 6.12	532 (patients)	2.06 ± 2.13	0.79 ± 1.24	532 (patients)	NM	NM	NM
Abdelrehem et al., 2021 [30] ▲▲▲▲	17.08 ± 2.90	37.20 ± 1.63	104 (patients)	7.05 ± 1.12	0.17 ± 0.76	130 (joints)	P: 73 (70.2%) A: 31 (29.8%)	P: 4 (3.80%) A: 100 (96.20%)	104 (patients)
Martínez-Gimeno et al., 2021 [34] **, ▲▲	36.21 ± 8.09	39.58 ± 4.35	19 (patients)	5.53 ± 1.93	1.00 ± 1.67	19 (patients)	P: 14 (73%) A: 5 (27%)	P: 0 (0%) A: 19 (100%)	19 (patients)
Zhang et al., 2023 [17] **	25.07 ± 9.73	39.43 ± 7.23	24 (patients)	4.11 ± 0.85	0.70 ± 0.67	24 (patients)	NM	NM	NM

Table 4. *Cont.*

First Author, Year	MIO (mm) (Mean ± SD)			VAS (0–10) (Mean ± SD)			Joint Sounds (n) Present (P)-Absent (A) Case (%)		
Follow-up post-surgery 24-month model (Long-term)									
Goizueta-Adame et al., 2014 [28] ▲▲▲▲	34.3 ± 5.2 n = 34(NM)	43.9 ± 4.8 n = 12(NM)	-	7.08 ± 1.65 n = 32(NM)	0.48 ± 0.76 n = 12(NM)	-	P: 12 (35.3%) A: 22 (64.7%)	P: NM A: NM	34 (patients)
Liu et al., 2019 [29]	26.65 ± 7.87	34.73 ± 6.28	532 (patients)	2.06 ± 2.13	0.73 ± 1.43	532 (patients)	NM	NM	NM
Abdelrehem et al., 2021 [30] ▲▲▲▲	17.08 ± 2.90	38.18 ± 1.21	104 (patients)	7.05 ± 1.12	0.20 ± 0.78	130 (joints)	P: 73 (70.2%) A: 31 (29.8%)	P: 0 (0%) A: 104 (100%)	104 (patients)
Zhang et al., 2023 [17] **	25.07 ± 9.73	38.44 ± 7.08	24 (patients)	4.11 ± 0.85	0.63 ± 0.79	24 (patients)	NM	NM	NM

n, numbers of participants or TMJs; MIO, Maximal interincisal opening; mm, millimetre; VAS, Visual analogue scale (0–10); P, Present; A, Absent; NM, not mentioned. * Report only successful cases (20 Patients, 29 Joints). ** Unclear unit of n, so researchers assume that unit of n is patients. *** One patient was lost to follow-up and excluded from the study (pre-surgery: n = 26, post-surgery: n = 25). ▲ joint sounds (clicking and popping). ▲▲ Joint sounds (clicking or joint sounds present). ▲▲▲ joint sounds (clicking and crepitation). ▲▲▲▲ joint sounds (clicking).

Table 5. Summary of arthroscopic disc repositioning and suturing techniques from a systematic review.

First Author, Year	Arthroscopic Discopexy Technique	Anchorage	Included Model or Excluded Result
Israel, H. A., 1989 [35]	Single suture discopexy technique (at posterior lateral corner of the disc-condyle)	Lateral capsule and Subcutaneous tissue (non-resorbable suture). Disc position maintained by retrodiscal scarring after stitch removal (1–2 weeks)	Reported new surgical technique
Tarro et al., 1989 [36]		Lateral capsule and Subcutaneous tissue (Resorbable surgical knot) (holding the disc in a posterior lateral position)	Different follow-up time points (post-operation, 3–12 months)
McCain et al., 1992 [37]			Reported new surgical technique
Zhang et al., 2011 [38]			Different follow-up time points (post-operation $\bar{x}$ = 10.3 months)
McCain et al., 2015 [16]			Included in 12-month model
McNamara et al., 1996 [39]		Cartilaginous part of the external auditory canal (endaural plication) using a non-resorbable suture; the surgical stitch was removed 2 weeks after the operation	Different follow-up time points (post-operation 3 months and 3 years)

Table 5. *Cont.*

First Author, Year	Arthroscopic Discopexy Technique	Anchorage	Included Model or Excluded Result
Martínez-Gimeno et al., 2021 [34]	Single suture discopexy at the posterolateral disc-condyle corner using a single-port arthroscope (irrigation, visualization, and laser in one working cannula)	Tragal cartilage (anteroposterior direction); non-resorbable surgical knot; stitch removed 2 weeks postoperatively	Included in 12-month model
Rosenbrg and Goss, 2020 [40]	Single suture discopexy technique (at bilaminar zone or retrodiscal zone)	External auditory canal cartilage (non-resorbable suture) (endaural approach); stitch removed 2 weeks postoperatively	Reported new surgical technique
Zhang et al., 2023 [17]	The redo arthroscopic disc repositioning and suturing (Single suture discopexy technique at bilaminar zone and posterior band of the disc)	External auditory canal cartilage (Suture knot)	Included in 6-month, 12-month, and 24-month model
Ward et al., 2025 [18]	Double-suture arthroscopic discopexy (modified from the single-suture discopexy technique)	Posterolateral aspect of the articular disc anchored to the TMJ fibrous capsule, and the posteromedial aspect anchored to the tragal cartilage (resorbable surgical knot)	Different follow-up time points (post-operation $\bar{x}$ = 9 months)
Goizueta-Adame et al., 2012 [32]	Posterior double-pass suture technique, with the needle penetrating the disc from lateral to medial in the posterior zone	Subcutaneous tissue (Resorbable surgical knot)	Included in 12-month model
Lee et al., 2025 [15]		Subcutaneous tissue (non-resorbable surgical knot)	Included in 6-month model
Del Santo et al., 2023 [41]		Tragus cartilage (resorbable surgical knot)	Reported new surgical technique
Zhang et al., 2010 [42]	An arthroscopic double horizontal mattress–like suturing technique performed through 3 punctures (triangulation technique) for pure ADD (Yang's technique)	The anterior wall of the external auditory canal (non-resorbable surgical knot)	Different follow-up time points (post-operation 1–7 days)
Wang et al., 2011 [43]			Different follow-up time points (post-operation, 49 days)
Yang et al., 2012 [31]			Reported new surgical technique
Abdelrehem et al., 2021 [30]			Included in 6-month, 12-month, and 24-month model
Jerez et al., 2022 [44]	Modified Yang technique (Yang et al., 2012 [31]): five punctures; the suture passes from the posterior border of the bilaminar zone and the posterior band of the disc to the medial retrodiscal tissue in the upper joint space	The anterior wall of the external auditory canal (resorbable or non-resorbable surgical knot)	Reported new surgical technique

Table 5. *Cont.*

First Author, Year	Arthroscopic Discopexy Technique	Anchorage	Included Model or Excluded Result
de Barros and Ono, 2025 [45]	Modified Yang technique (Yang et al., 2012 [31]): arthroscopic access to both upper and lower compartments	The retrotragal cartilage	Reported new surgical technique
Liu et al., 2019 [29]	Modified Yang's discopexy: double horizontal mattress–like suturing (6 punctures) for pure ADD/rotational DD; complex technique	Tragus cartilage (Suture knot)	Included in 6-month, 12-month, and 24-month model
Dong et al., 2025 [46]	Modified Yang's technique: double horizontal mattress–like suturing (5 punctures) for pure ADD modified from Yang et al. (2012) [31] and Liu et al. (2019) [29]	External auditory canal cartilage (non-resorbable surgical knot)	Different follow-up time points (post-operation, 1 and 3 months)
Goizueta-Adame et al., 2014 [28]	An arthroscopic disc repositioning using resorbable pin	Resorbable pin at the lateral surface of the convexity of the condyle (SmartNail®; PLA)	Included in 6-month, 12-month, and 24-month model
Martín-Granizo et al., 2016 [33]		Resorbable pin at postero-lateral corner of the disc (SmartNail®; PLA)	Included in 6-month and 12-month model
Martín-Granizo et al., 2022 [47]			Reported new surgical technique
Millón-Cruz et al., 2020 [48]			Same subject group with Martín-Granizo et al., 2016 [33]
González-García et al., 2008 [49]	Unclear surgical technique		Unclassified disc discopexy technique
Ângelo et al., 2023 [50]	Unclear surgical technique		Different follow-up time point (post-operation $\bar{x}$ = 523.7 days)
McCain et al., 1992 [37]	-	-	Reports not retrieved
McCain and Menis, 1996 [51]	-	-	Reports not retrieved
McCain and Hossameldin, 2011 [52]	-	-	Reports not retrieved
Tang et al., 2024 [19]	-	-	Systematic review and meta-analysis of Open Discopexy with suture Anchors

TMJ, Temporomandibular joint; ADD, Anterior disc displacement; DD, disc displacement.

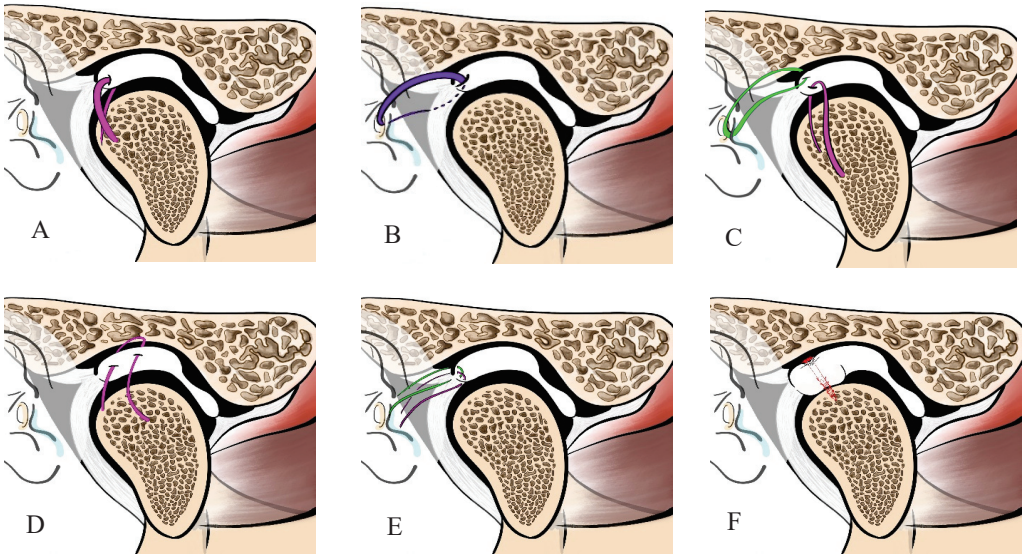

Figure 2. Summary of arthroscopic discopexy techniques, focusing on suture methods and anchorage sites. (**A**) Single suture discopexy technique (at the posterior lateral corner of the disc-condyle). (**B**) Single suture discopexy technique (at bilaminar zone or retrodiscal zone). (**C**) Double-suture arthroscopic discopexy. (**D**) Posterior double-pass suture technique (the needle penetrating the disc from lateral to medial in the posterior zone). (**E**) Double horizontal mattress-like suturing technique (Yang's technique). (**F**) An arthroscopic disc repositioning using a resorbable pin.

3.3. Research Quality Assessment

Tables 6 and 7 illustrate the quality of each study, assessed with the NHLBI tool and categorized by study design. Most were rated as good quality, except for the research by McCain et al. in 2015, which was rated as poor quality mainly because only the surgical outcomes of the successful group were reported; other reasons contributing to this rating are listed in Table 6 [16].

Table 6. Quality assessment of included study by NHBI Qualifier Score in cohort study design.

First Author, Year	NHLBI Quality Assessment Tool for Before-After (Pre-Post) Study with No Control Group												Quality (Overall Judgement)
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	
Liu et al., 2019 [29]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	NA	Good (10)
Abdelrehem et al., 2021 [30]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	NA	Good (10)
Zhang et al., 2023 [17]	Yes	Yes	Yes	Yes	NR	Yes	Yes	No	Yes	Yes	Yes	NA	Good (9)
McCain et al., 2015 [16]	Yes	Yes	No	No	NR	Yes	Yes	No	NR	No	No	NA	Poor (4)
Martínez-Gimeno et al., 2021 [34]	Yes	Yes	Yes	Yes	NR	Yes	Yes	No	Yes	Yes	Yes	NA	Good (9)

Yes, the study meets the criterion; No, the study does not meet the criterion; NA (Not Applicable), The item is not relevant to the particular study design; NR, not reported. Q1: Was the study question or objective clearly stated? Q2: Were eligibility/selection criteria for the study population prespecified and clearly described? Q3: Were the participants in the study representative of those who would be eligible for the test/service/intervention in the general or clinical population of interest? Q4: Were all eligible participants who met the prespecified entry criteria enrolled? Q5: Was the sample size sufficiently large to provide confidence in the findings? Q6: Was the test/service/intervention clearly described and delivered consistently across the study population? Q7: Were the outcome measures prespecified, clearly defined, valid, reliable, and assessed consistently across all study participants? Q8: Were the people assessing the outcomes blinded to the participants' exposures/interventions? Q9: Was the loss to follow-up after baseline 20% or less? Were those lost to follow-up accounted for in the analysis? Q10: Did the statistical methods examine changes in outcome measures from before to after the intervention? Were statistical tests performed that provided *p*-values for the pre-to-post changes? Q11: Were outcome measures of interest taken multiple times before the intervention and multiple times after the intervention (i.e., did they use an interrupted time-series design)? Q12: If the intervention was conducted at a group level (e.g., a whole hospital, a community, etc.) did the statistical analysis take into account the use of individual-level data to determine effects at the group level?

Table 7. Quality assessment of the included study by the NHBI Qualifier Score in the case series study design.

First Author, Year	NHLBI Quality Assessment Tool for Case Series Studies									Quality (Overall Judgement)
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	
Goizueta-Adame et al., 2012 [32]	Yes	Yes	NR	Yes	Yes	Yes	Yes	Yes	Yes	Good (8)
Goizueta-Adame et al., 2014 [28]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Good (8)
Lee et al., 2025 [15]	Yes	Yes	NR	Yes	Yes	Yes	Yes	Yes	Yes	Good (8)
Martín-Granizo et al., 2016 [33]	Yes	Yes	NR	Yes	Yes	Yes	Yes	Yes	Yes	Good (8)

Yes, the study meets the criterion; No, the study does not meet the criterion; NA (Not Applicable), The item is not relevant to the particular study design; NR, not reported. Assessment: Good: Met 7–9 criteria, Fair: Met 4–6 criteria, Poor: Met 0–3. Q1: Was the study question or objective clearly stated? Q2: Was the study population clearly and fully described, including a case definition? Q3: Were the cases consecutive? Q4: Were the subjects comparable? Q5: Was the intervention clearly described? Q6: Were the outcome measures clearly defined, valid, reliable, and implemented consistently across all study participants? Q7: Was the length of follow-up adequate? Q8: Were the statistical methods well-described? Q9: Were the results well-described?

3.4. Synthesis of Results

A total of 1086 TMJs from 811 patients and nine studies were divided into three main meta-analysis models, depending on the outcome variable (MIO, pain score, joint sounds), and subgrouped into three postoperative observational time points (6 months, 12 months, and 24 months). Three variables (MIO, pain score, and joint sounds) were evaluated before and after surgery (Table 4).

Arthroscopic disc repositioning and anchor fixation techniques demonstrated a significant improvement in postoperative MIO at all time points. The most significant effect was observed in the short-term (6-month) follow-up period (MD = 10.58 mm; 95% CI: 4.46 to 16.70; $p \leq 0.001$; $I^2 = 99\%$), the intermediate-term (12-month) follow-up period (MD = 9.83 mm; 95% CI: 4.09 to 15.57; $p \leq 0.001$; $I^2 = 99\%$), and in the long-term (24-month) follow-up period (MD = 13.06 mm; 95% CI: 4.40 to 21.72; $p \leq 0.001$; $I^2 = 99\%$). Heterogeneity was high across the three time points (Figure 3).

This technique also presented a highly significant reduction in postoperative pain scores across all follow-up time points. In the short-term (6-month) follow-up period (MD = −4.36; 95% CI: −6.89 to −1.82; $p \leq 0.001$; $I^2 = 99\%$), in the intermediate-term (12-month) follow-up period (MD = −3.91; 95% CI: −6.23 to −1.59; $p \leq 0.001$; $I^2 = 99\%$) and high significant reduction in the long-term (24-month) follow-up period (MD = −4.56; 95% CI: −7.81 to −1.31; $p < 0.01$; $I^2 = 99\%$). Moreover, a high level of heterogeneity was observed among the three time points (Figure 4). Although follow-up data on joint sounds were limited in the 12-month follow-up period, this technique also reported a highly significant decrease in the incidence rate of postoperative joint sounds (OR = 0.07; 95% CI: 0.01 to 0.37; $p < 0.01$; $I^2 = 82\%$) with a high level of heterogeneity (Figure 5).

3.5. Assessment of the Quality of Evidence

The quality of evidence for the studies included in the meta-analysis was collectively categorized as low using the GRADE approach (Table 8). This rating was primarily due to heterogeneity across most comparisons and the inclusion of observational studies.

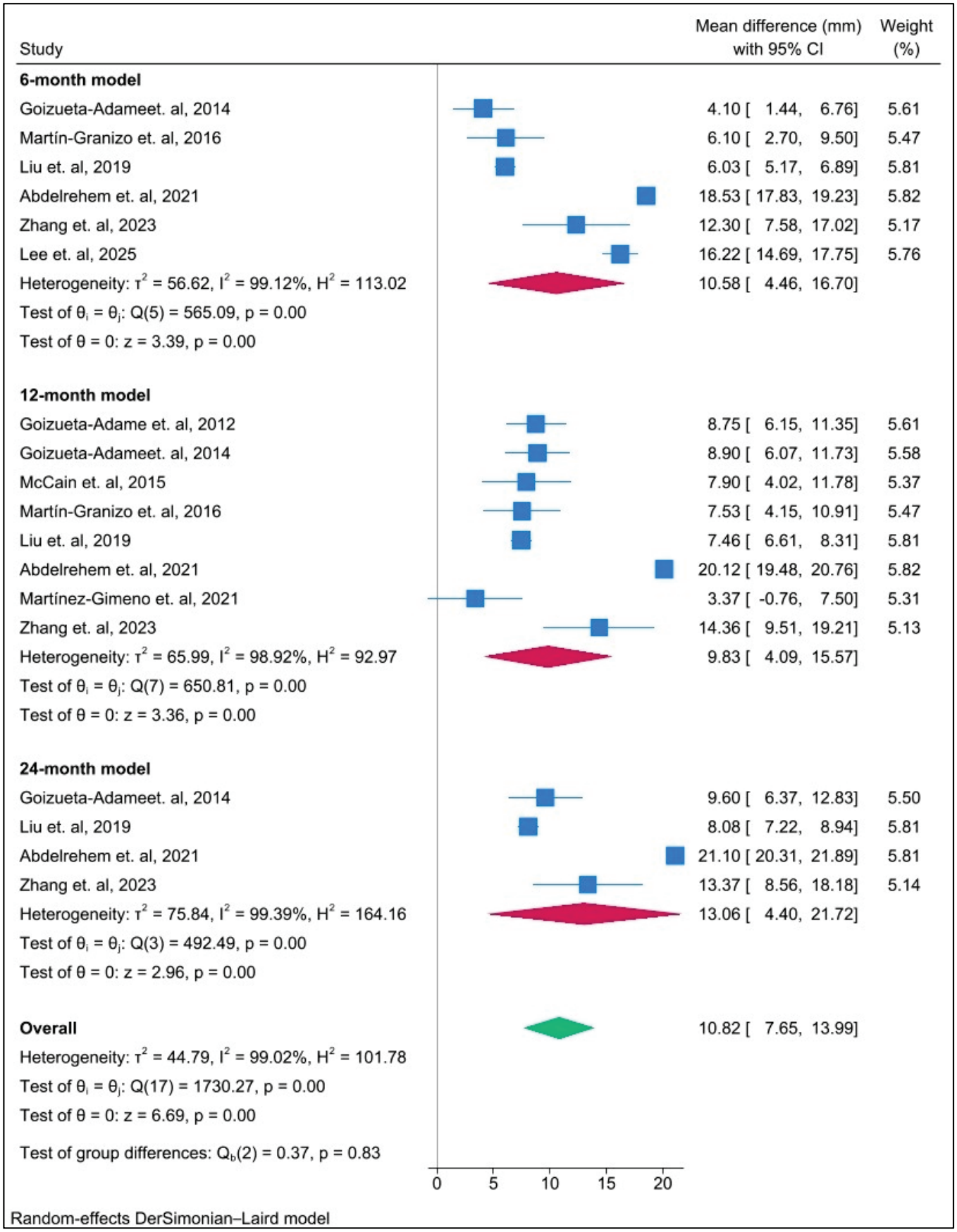

Figure 3. Forest plot illustrating postoperative maximal interincisal opening (MIO; mm) compared with pre-surgery (baseline) across different follow-up time points.

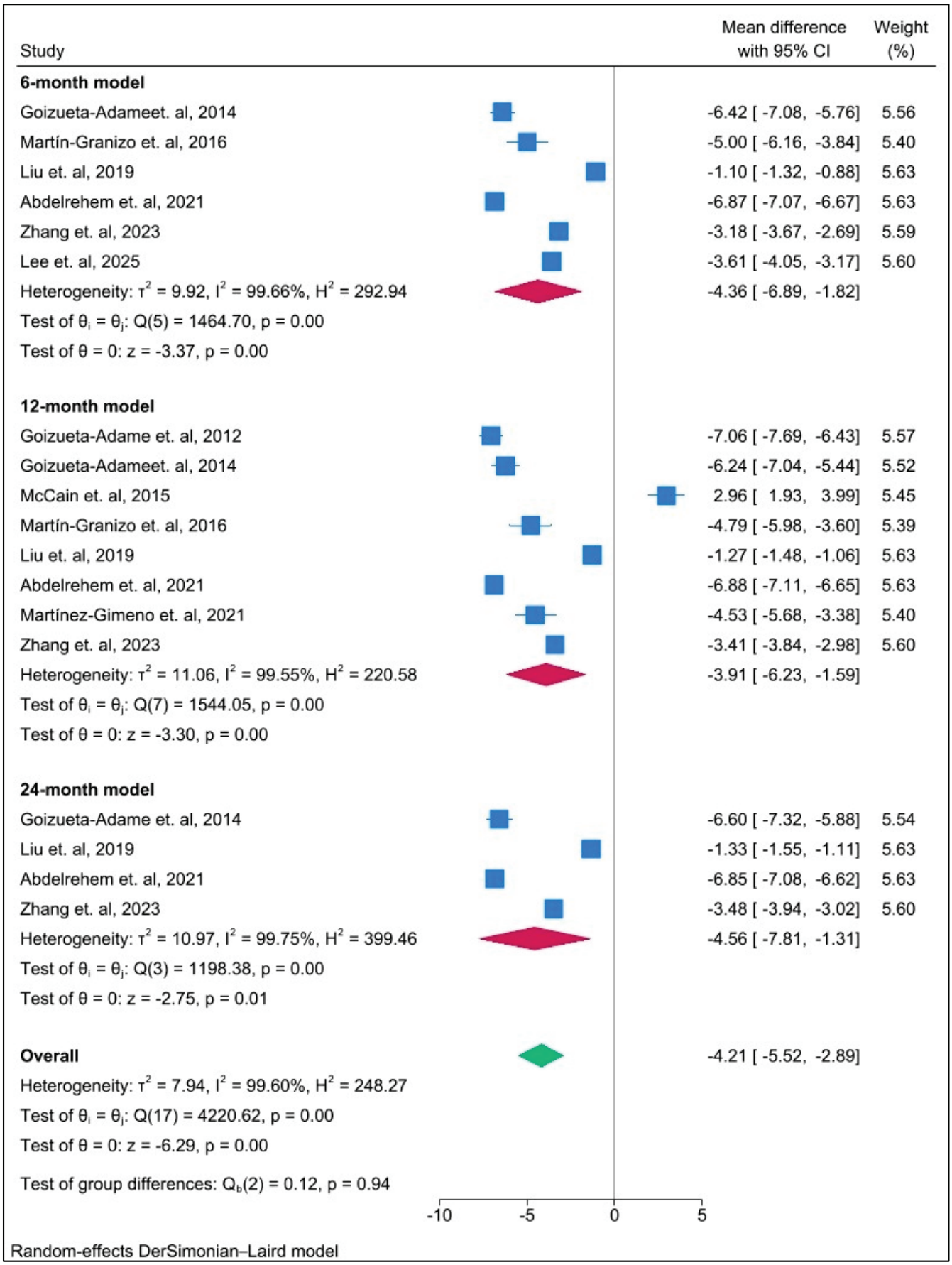

Figure 4. Forest plot illustrating postoperative pain scores (measured by VAS; 0–10 scale) compared with pre-surgery (baseline) across different follow-up time points.

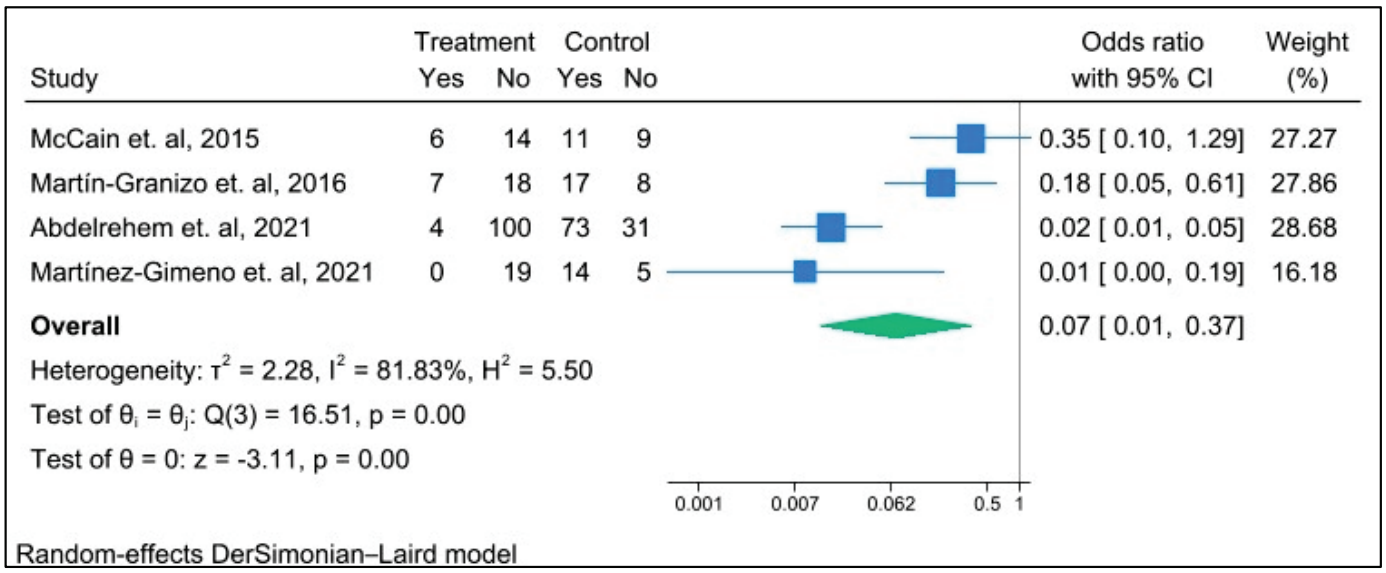

Figure 5. Forest plot illustrating postoperative joint sounds (clicking, popping, or crepitation) compared with pre-surgery (baseline) at the 12-month follow-up.

Table 8. Grade assessment result.

Certainty Domain	Justification	Downgrade/Upgrade	Estimation
Start	Observational studies (cohort and case series)	-	Low (⊕⊕◯◯)
Downgrade estimation			
Risk of Bias	Uncontrolled confounding, lack of blinding	Downgraded 1 level	very low (⊕◯◯◯)
Inconsistency	Although heterogeneity was high, the direction of effect was consistent across studies	No downgrade	very low (⊕◯◯◯)
Indirectness	Population, intervention, comparator, and outcomes directly addressed the review question	No downgrade	very low (⊕◯◯◯)
Imprecision	95% CI do not cross the line of no effect; however, intervals were wide in several analyses	No downgrade	very low (⊕◯◯◯)
Publication bias	Not assessed	No downgrade	very low (⊕◯◯◯)
Overall (after downgrades): Very low (⊕◯◯◯)			
Upgrade estimation			
Large Effect	Large effect size	Upgraded 1 level	low (⊕⊕◯◯)
Dose–response	Not observed	No upgrade	low (⊕⊕◯◯)
Residual confounding toward the null	Not observed	No upgrade	low (⊕⊕◯◯)
Final certainty rating: Low (⊕⊕◯◯)			

4. Discussion

Generally, clinical characteristics of TMD are limited mouth opening, TMJ pain, and joint sounds. Abnormal disc position, especially ADDwoR, has been associated with ID and osteoarthritis. Among stepwise treatment approaches, surgical techniques stand out for functional recovery, pain relief, and long-term joint stability. Nevertheless, open surgery remains controversial due to its invasiveness. Nowadays, there is a growing consensus on the management of ADDwoR. Additionally, most therapeutic approaches have relied on non-surgical treatment, including patient education, physiotherapy, and occlusal splint therapy. More recently, disc repositioning and fixation procedures, especially those performed under arthroscopic guidance, have been increasingly reported as potential treatment options for disc displacement. Therefore, the present systematic review and meta-analysis aimed to evaluate the clinical efficacy of arthroscopically assisted disc repositioning and fixation for the management of anterior disc displacement of the TMJ.

The present systematic review and meta-analysis provide evidence that arthroscopic disc repositioning combined with anchor fixation yields favourable clinical outcomes in patients with TMJ disc displacement. Across short-, intermediate-, and long-term follow-up periods, this surgical approach was consistently associated with significant improvements in MIO, reductions in pain scores, and decreased incidence of joint sounds. These findings support the role of minimally invasive arthroscopic techniques in the management of symptomatic TMJ disc displacement, particularly when non-surgical treatment has failed.

The improvement in MIO was both statistically and clinically significant at all follow-up intervals, with the largest mean difference observed at 24 months. Figure 3 illustrates the postoperative improvement in MIO at 6, 12, and 24 months after surgery, with pooled mean differences exceeding 9 mm across all models. These findings indicate sustained recovery of TMJ function following arthroscopic discopexy [15–17,28–30,32–34].

Figure 4 demonstrates postoperative improvement in pain by VAS at 6, 12, and 24 months after surgery [15–17,28–30,32–34]. A pooled mean difference demonstrated significant decreases with mean reductions of over 3 points in all models. Although a pool mean difference at 12 months after operation illustrated a minimal increase correlated with a slight decrease in MIO, at 24 months, all results show the highest satisfaction across all observation periods. It can be concluded that arthroscopic discopexy techniques improve both function and clinical outcomes in patients with TMJ disc displacement. In contrast, McCain et al. (2015) noted worsened postoperative pain in the successful case patients' group [16]. This exception highlights that benefits vary across patients and indications warrant careful consideration.

Because joint sound follow-up was limited at 12 months postoperatively, the pooled odds ratio indicated that this operation had a significant impact on the incidence rate of joint sounds (Figure 5) [16,30,33,34]. It can be assumed that the articular disc remains appropriately positioned, and mechanical interference was treated at 12 months. In the future, extended postoperative MRI to assess the position of the TMJ disc would help verify both the clinical effect and the underlying anatomy.

Overall, improvements in MIO, pain, and joint sounds indicate that arthroscopic discopexy can effectively improve TMJ dysfunction. By restoring disc–condyle relationships, these techniques can normalize joint loading and prevent progressive degenerative changes. Nevertheless, due to high heterogeneity following patient selection, surgical expertise, fixation techniques, and postoperative rehabilitation protocols, the interpretation of these results should be performed with caution, as high heterogeneity reduces confidence in the pooled MD estimate. Moreover, the methodological quality was limited in the observational study design, resulting in a low-grade rating. In the future, high-quality randomized trials with standardized protocols should be performed.

Arthroscopic discopexy is a minimally invasive surgical procedure reported to provide early improvement. Although it is classified as Level 3 out of 4 in terms of arthroscopic surgical complexity, the rate of postoperative complications has been reported to be low (ranging from 1.7% to 4.4%) [53–55]. The most common complications are otological complications, extravasation of irrigation fluid, and intra-articular bleeding [55,56]. However, these complications can be prevented and managed by having the procedure performed by an experienced surgeon, properly positioning the patient, monitoring irrigation flow and pressure, and avoiding instrument-related iatrogenic injuries [55,56]. Overall, arthroscopic discopexy has benefits over non-surgical treatment by decreasing the long-term recurrence rate and directly treating any pathology, and over open surgery by being a minimally invasive procedure in selected cases [57]. In comparison with the VAS and MIO outcomes reported in the systematic review and meta-analysis of invasive surgical procedures, arthroscopic discopexy demonstrated a more favourable pooled mean difference, despite the

limitation of heterogeneous follow-up durations across studies [58]. By limiting disease progression, it can restore normal joint mechanics, reduce abnormal loading, and potentially prevent degeneration. Nevertheless, this review has several limitations. First, the evidence base was limited by the small number of studies, variation in long-term postoperative variables and MRI, and ADD subtype classification [42,59]. Future well-designed RCTs are needed to confirm these findings. Second, designs varied considerably across studies. Third, publication bias is possible, as negative or inconclusive results may not be published.

5. Conclusions

Although the level of evidence remains limited, this systematic review and meta-analysis confirm that arthroscopic discopexy was associated with significant improvements in TMJ function, a decrease in joint sounds and chronic discomfort, which compromise quality of life across different follow-up periods. However, due to high heterogeneity and an insufficient evidence base, these results should be interpreted cautiously, and patients should be carefully selected. In the future, larger patient numbers and well-designed RCTs with various observational outcomes are crucial to establish the true efficacy and safety profile of this technique.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/jcm14228046/s1. Table S1. Full search strategies used in the systematic review and meta-analysis. Supplementary File S1: Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist [60].

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Systematic Review

Autogenous Injections in Temporomandibular Disorders: A Systematic Review

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Abstract

Background/Objectives: Temporomandibular disorders (TMD) are a heterogeneous group of musculoskeletal conditions affecting the temporomandibular joints and masticatory muscles. In recent years, autogenous injections have been investigated as minimally invasive therapeutic options to alleviate pain and improve function. However, the clinical effectiveness of such therapies across different TMD phenotypes remains uncertain. **Methods:** Electronic searches were performed in MEDLINE, Embase, and Web of Science for articles published between January 2015 and May 2025. Studies involving intra-articular or intra-muscular autogenous injections in TMD patients were included. The risk of bias was assessed using the Cochrane Risk of Bias 2 tool and the Joanna Briggs Institute (JBI) Critical Appraisal Tools. **Results**: Thirteen studies met the inclusion criteria. Six were randomized controlled trials (RCTs) and seven were non-randomized clinical studies. Ten studies evaluated intra-articular conditions such as disc displacement or Temporomandibular Joint (TMJ) osteoarthritis, while three focused on myofascial pain. Platelet-Rich Plasma (PRP) was the most frequently investigated agent. Most studies reported statistically significant reductions in pain and improvements in mandibular mobility following autogenous injections, with PRP generally outperforming comparators such as hyaluronic acid, corticosteroids, or saline. No serious adverse events were reported. **Conclusions**: All PRP and Platelet-Rich Fibrin (PRF) injection protocols reviewed were effective in reducing pain and improving mobility in patients with TMD. However, differences in protocols and follow-up times prevented a meta-analysis from being conducted. More standardized RCTs are needed to determine clear clinical guidelines.

Keywords: temporomandibular disorders; autogenous injections; orofacial pain; platelet-rich plasma; platelet-rich fibrin; injections; intra-muscular; injections; intra-articular; masticatory muscles

1. Introduction

Temporomandibular disorders (TMD) are a complex group of conditions that affect the temporomandibular joint (TMJ) and surrounding muscles, leading to pain and dysfunction [1]. These disorders can significantly reduce quality of life by causing acute or chronic pain, most often in the orofacial region, difficulty with jaw movement, and even

psychological distress [2–4]. Recent meta-analytical (2024) findings reveal TMD prevalence at 34% within the population [5]. TMD prevalence is projected to rise to 44% by 2050, indicating a growing public health concern [5]. The economic burden of TMD stems from direct healthcare costs, including diagnostics and treatments such as occlusal splints, physiotherapy, and surgery, as well as indirect costs resulting from productivity loss due to pain and functional limitations [5]. These costs vary significantly across regions, influenced by factors such as access to healthcare and insurance coverage, with patients often incurring substantial out-of-pocket expenses where coverage is limited. Addressing the socioeconomic impact of TMD requires strategic public health initiatives and investments in innovative treatments to improve management and reduce long-term costs [4,5]. Among various treatment options, autogenous injection therapies have gained popularity because they are minimally invasive and may provide rapid symptom relief [3,6].

The first approved temporomandibular injections appeared in 1989 [7,8]. Over the past ten years, various injection substances have been used in the treatment of TMD to relieve symptoms and promote healing [3]. These injection therapies vary in effectiveness, often depending on individual patient factors and the specific nature of their TMD [6,9,10]. The choice of substance may depend on the severity of symptoms, the underlying cause of the disorder, and the patient's overall health profile [6,10]. Biomimetic injectable substances are typically based on hyaluronic acid, which is used to enhance lubrication, restore the normal viscosity of synovial fluid, and provide cushioning for the TMJ. Corticosteroids provide rapid anti-inflammatory effects, especially in acute cases of TMD [11,12]. While they can offer immediate relief, their use is typically limited due to potential side effects with repeated administration [13]. Autogenous injections are becoming a promising option for these substances, utilizing the healing properties of growth factors derived from the patient's own tissue [11,14]. Autogenous injection generally represents a significant advance in regenerative therapies, leveraging the body's cells or tissues to promote healing and recovery [12]. This technique reduces the risk of rejection and complications related to foreign materials, making it a promising option for various medical conditions [13].

Platelet-rich plasma (PRP) and platelet-rich fibrin (PRF) are both autogenous injections derived from a patient's own blood, rich in various growth factors that play crucial roles in healing and tissue regeneration [15]. The specific growth factors found in PRP and PRF include Platelet-Derived Growth Factor (PDGF), which is essential for cell proliferation and plays a significant role in the healing process by attracting stem cells and promoting angiogenesis [16,17]. Transforming Growth Factor Beta (TGF-β) plays a crucial role in regulating cell growth and differentiation, particularly in the formation of connective tissue and the synthesis of collagen, making it vital for tissue repair [16,18]. Insulin-like Growth Factor (IGF), which supports cell growth and development, aids in repairing damaged tissues by promoting the proliferation of various cell types. Epidermal Growth Factor, involved in cell growth and differentiation, is also important [18]. The key difference between the two substances is the concentration of the mentioned factors. For PRP, TGF-β can range from 23.62 to 64.74 pg/mL, whereas PRF contains between 26.21 and 35.80. Within the PRF, growth factors and cells are distributed unevenly. The concentration of platelets and mononuclear cells is higher near the yellow-red interface, whereas polynucleated cells are primarily located below this interface [19–23]. Both PRP and PRF utilize these growth factors to enhance healing, reduce inflammation, and promote tissue regeneration in conditions such as TMD, thereby providing symptomatic relief and improving function [6,10,12].

Autogenous injection, especially PRP and PRF, in the treatment of TMD, represents a promising frontier in regenerative medicine [13,15]. By harnessing the potent growth factors intrinsic to these therapies, clinicians can potentially enhance tissue healing, reduce inflammation, and restore function in affected areas. These biologically active substances

not only promote tissue regeneration but also may contribute to improved overall quality of life for patients suffering from chronic pain and dysfunction associated with TMD. The use of autogenous injection treatment is primarily affected by inconsistencies in clinical protocols, differences in methodologies, and the absence of large-scale studies that could help establish standardized practices. Many practitioners may lack adequate training in the techniques required for effective autologous cell extraction and injection. Additionally, there is a lack of consensus on platelet concentration and activation, as well as the specific conditions that benefit from such treatments. This gap can lead to variability in patient outcomes and may hinder wider acceptance and integration of autogenous injection therapies in mainstream medicine. As research continues to elucidate their roles and optimize their use, autogenous treatment is likely to remain an integral component of modern therapeutic strategies aimed at managing TMD effectively [15–18].

This systematic review focused on studies investigating the use of autologous injections for treating TMD. The primary hypothesis of this review is that autologous injections are effective in alleviating pain and enhancing mandibular mobility in patients with TMD. The following paper will compare the outcomes from various clinical studies to assess this hypothesis.

2. Materials and Methods

2.1. Protocol and Registration

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA 2020) [24]. The protocol was registered in the PROSPERO database under the registration number CRD420251006942.

2.2. Eligibility Criteria

Studies were selected based on the PICOS framework [25]. The following inclusion criteria were applied: (P) adult patients diagnosed with TMD based on Diagnostic Criteria for Temporomandibular Disorders (DC/TMD) [26], Research Diagnostic Criteria for Temporomandibular Disorders (RDC/TMD) [27] or International Classification for Orofacial Pain (ICOP) [28] diagnostic criteria; (I) autogenous intra-articular or intra-muscular injections, including platelet-rich plasma (PRP), platelet-rich fibrin (PRF), injectable PRF (i-PRF), autologous stem cells, or exosomes; (C) comparators included no treatment, placebo, or other forms of treatment such as hyaluronic acid (HA), corticosteroids, physical therapy, dry needling (DN), or non-steroidal anti-inflammatory drugs (NSAIDS); (O) outcomes included pain intensity—e.g., Visual Analogue Scale (VAS) or Numeric Rating Scale (NRS)—mandibular mobility (e.g., maximum mouth opening), quality of life measures (e.g., Satisfaction with Life Scale), and reported adverse effects (e.g., pain, swelling); (S) study designs eligible for inclusion were randomized controlled trials (RCT), non-randomized controlled trials, prospective or retrospective cohort studies, case control studies and cross-sectional studies.

The following exclusion criteria were applied: animal studies; studies involving patients with systemic diseases that could significantly affect healing or inflammatory responses, such as rheumatoid arthritis, psoriatic arthritis, systemic lupus erythematosus, ankylosing spondylitis, Parkinson's disease, multiple sclerosis, or any form of cancer; case reports, case series, and reviews were excluded. The eligibility criteria are summarized in Table 1.

Table 1. Inclusion and exclusion criteria.

	Inclusion Criteria	Exclusion Criteria
Population	Adult patients diagnosed with TMD based on DC/TMD, RDC/TMD, or ICOP	Animals, patients with systemic diseases affecting healing or inflammatory response
Intervention	Autogenous intra-articular or intra-muscular injections	-
Comparison	Any or none	-
Outcome	Primary: pain intensity VAS, NRS, mandibular mobility (e.g., Maximum Mouth Opening (MMO)) Secondary: quality of life (e.g., SLS reported adverse effects (e.g., pain, swelling)	-
Study design	Randomized controlled trials, non-randomized controlled trials, prospective and retrospective cohort studies, case-control studies, cross-sectional studies	Case reports, case series, reviews; studies published before 2015; non-English articles

Glossary: TMD—Temporomandibular Disorders; DC/TMD—Diagnostic Criteria of Temporomandibular Disorders; RDC/TMD—Research Diagnostic Criteria of Temporomandibular Disorders; ICOP—International Classification for Orofacial Pain; VAS—Visual Analogue Scale; NRS—Numeric Rating Scale; SLS—Satisfaction with Life Scale; MMO—Maximum Mouth Opening.

2.3. Search Strategy

A comprehensive search was conducted across electronic databases, including MEDLINE, Embase, and Web of Science. These databases were selected because they provide the most comprehensive coverage of biomedical, clinical, and interdisciplinary knowledge. Together, they ensured a broad and thorough search of the relevant literature. The search process was conducted between 6 April and 31 May 2025. Searches were limited to peer-reviewed journal articles; grey literature was not included. The search encompassed English-language studies published between 1 January 2015 and 1 May 2025. This time frame was selected to capture the most recent and clinically relevant evidence, as autogenous injection techniques for TMD have been primarily investigated within the past decade [3,5]. It ensured the inclusion of contemporary studies while minimizing outdated practices.

The following search string was used in MEDLINE: ("platelet-rich plasma" OR "PRP" OR "platelet-rich fibrin" OR "PRF" OR "autogenous injection" OR "injection" OR "stem cells" OR "exosomes") AND ("temporomandibular disorders" OR "TMD" OR "temporomandibular joint dysfunction" OR "temporomandibular joint" OR "TMJ pain" OR "TMJ arthralgia" OR "TMJ degenerative disease" OR "masticatory muscles" OR "masticatory muscle pain" OR "masseter muscle" OR "temporal muscle"). Equivalent search strategies were adapted for Embase and Web of Science according to the indexing and syntax of each database.

2.4. Selection Process

All identified references were imported into Rayyan QCRI (Qatar Computing Research Institute, Doha, Qatar, and Rayyan Systems, Cambridge, MA, USA) to optimize the screening process [29]. Initially, duplicate records were automatically identified and removed under the supervision of one of the reviewers. The remaining records underwent the following steps: (1) screening of titles and abstracts by two independent and blinded reviewers, supported by Rayyan's keywords highlighting for potential inclusion or exclusion criteria; (2) full-text assessment of potentially eligible studies; and (3) final inclusion and data extraction. Disagreements were resolved through discussion or by consulting a third reviewer.

2.5. Data Collection

The data were extracted by two independent reviewers (P.S. and S.O.) using a standardized form, collecting the following: (1) Author; (2) year of publication; (3) number of participants; (4) study design; (5) assessment method (DC/TMD, ICOP); (6) TMD diagnosis type; (7) Intervention type; (8) Comparator; (9) Outcomes. Outcomes included pain intensity (e.g., VAS, NRS), mandibular mobility (e.g., Maximum Mouth Opening), quality of life measures, and reported adverse effects. As the included studies varied in clinical focus and design, not all outcomes were available across all articles.

2.6. Risk of Bias Assessment

For a randomized controlled trial, the Cochrane Risk of Bias 2 (RoB 2) tool was applied [30]. RoB 2 evaluates five domains: (1) randomization process, (2) deviations from intended interventions, (3) missing outcome data, (4) measurement of the outcome, and (5) selection of the reported result. Each domain was judged as "low risk," "some concerns," or "high risk," and an overall risk-of-bias judgment was derived. For non-randomized studies, the appropriate Joanna Briggs Institute (JBI) critical appraisal tool was used, depending on the study design (e.g, cohort, case-control, quasi-experimental), with items assessed as "Yes," "No," "Unclear," or "Not applicable." [31]. Risk of bias was assessed independently by two reviewers (P.S. and A.M.). Conflicts were resolved through consultation with the third author (S.O.).

2.7. Data Synthesis

A narrative synthesis was used to summarize the findings from the included studies. This method was chosen because the studies differed substantially in their design (randomized vs. non-randomized), types of autogenous injections (e.g., PRP, PRF, i-PRF), outcome measures (e.g., VAS, MMO), and follow-up durations. These variations made it inappropriate to conduct a meta-analysis. Therefore, the results were grouped narratively based on the type of intervention and comparator used, and discussed in the context of study design, clinical condition, and outcome domains. This approach allowed for a transparent comparison of effects across studies despite heterogeneity.

3. Results

3.1. Study Selection

A total of 3728 potentially relevant studies were initially retrieved through database searches. After removing 980 duplicates, 2748 titles and abstracts were screened. During this stage, Rayyan's automatic keyword highlighting tool was used to assist in identifying non-eligible studies. Based on the screening, 106 articles were selected for full-text reading. Following a thorough assessment, 13 studies fulfilled the inclusion criteria and were included in the systematic review [32–44]. Detailed selection steps are illustrated in Figure 1 [45].

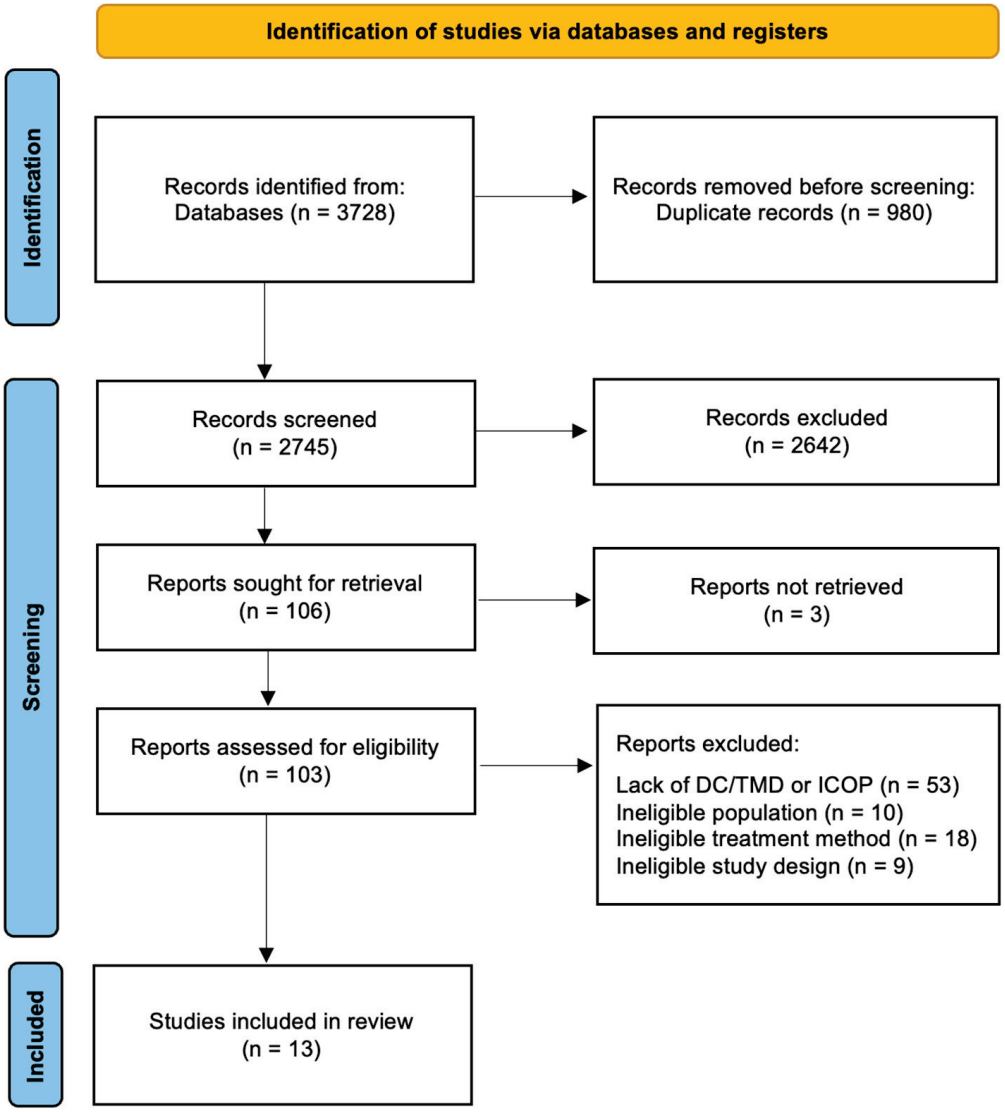

Figure 1. The PRISMA 2020 flow diagram.

3.2. Study Characteristics

A total of 13 studies were included in this systematic review. The studies were published between 2015 and 2024 and involved a combined sample of 926 participants. Sample sizes ranged from 20 to 128 individuals per study.

Among the included studies, six were randomized controlled trials, while the remaining seven were non-randomized clinical studies, including non-randomized controlled trials and retrospective cohort studies. Among the included studies, the most commonly used diagnostic system was the RDC/TMD, applied in nine studies, followed by Di DC/TMD, used in three studies. The ICOP was employed in one study. The included studies addressed both intra-articular and myogenous forms of TMD. Articular conditions encompassed internal derangement, disc displacement with or without reduction, TMJ osteoarthritis, and TMJ pain. Myogenous conditions primarily included myofascial pain and localized masticatory muscle tenderness. Details of the included studies are presented in Tables 2 and 3.

Table 2. Detailed information of the included studies.

l.p	Author	Year	Number of Participants	Study Design (RCT, Cross-Sectional, etc.)	Assessment Method (DC/TMD, ICOP)	TMD Diagnosis
1	Mathpati et al. [36]	2024	128 (64 PRP, 64 placebo)	Randomized Controlled Trial (double-blinded)	DC/TMD	TMJ pain, diagnosed via DC/TMD
2	Nitecka-Buchta et al. [42]	2019	58 (29 PRP, 29 Placebo)	Randomized Controlled Trial (double-blinded)	RDC/TMD	Myofascial pain within the masseter muscles
3	Checinski et al. [33]	2024	78 (39 PRP, 39 HA)	Controlled Clinical Trial	ICOP (2020)	TMJ pain
4	Vingender et al. [35]	2023	68 (24 PRP, 20 iPRF, 24 HA)	Non-randomized Controlled Trial	RDC/TMD	Internal derangement of the TMJ
5	Rajput et al. [32]	2022	24 (12 PRP, 12 Arthrocentesis)	Randomized prospective study	RDC/TMD	Groups II and III
6	Kutuk et al. [44]	2019	60 (20 PRP, 20 HA, 20 CS).	Randomized Controlled Trial	RDC/TMD	Axis I Group IIIb
7	Usman et al. [36]	2023	24 (12 PRP, 12 Corticosteroid)	Non-randomized Controlled Trial	RDC/TMD	Anterior disc displacement
8	Yuce et al. [40]	2020	47 (17 i-PRF, 14 HA, 16 Arthrocentesis)	Retrospective Cohort Study	RDC/TMD	TMJ internal derangement and TMJ pain
9	Isık et al. [38]	2022	36 (18 i-PRF + Arthrocentesis; 18 arthrocentesis)	Randomized Controlled Trial	DC/TMD	Temporomandibular joint osteoarthritis
10	Yilmaz et al. [43]	2021	82 (27 LA; 26 BTX; 29 PRP)	Retrospective Cohort Study	RDC/TMD	Myofascial pain within the masseter muscles
11	Jamal et al. [37]	2023	10 (PRP)	Controlled Clinical Trial	RDC/TMD	TMJ pain
12	Pihut, Gala [41]	2020	100 (50 PRP, 50 HA)	Randomized Controlled Trial (double-blinded)	RDC/TMD	Disc Displacement without Reduction
13	Agarwal et al. [39]	2022	30 (15 PRP; 15 Dry Needling)	Randomized Controlled Trial	DC/TMD	Myofascial pain within the masseter muscles

PRP—Platelet-Rich Plasma, DC/TMD—Diagnostic Criteria for Temporomandibular Disorders, HA—Hyaluronic Acid, i-PRF—injectable Platelet-Rich Fibrin, TMJ—Temporomandibular Joint, RDC/TMD—Research Diagnostic for Temporomandibular Disorders, LA—Local Anaesthetic.

Table 3. Detailed information about the study's methodology and risk of bias assessment.

l.p	Author	Year	Intervention	Comparison	Outcome	Risk of Bias	A Tool for Risk of Bias
1	Mathpati et al. [34]	2024	PRP injection	Intra-articular injections of normal saline	Significant reduction in TMJ pain in the PRP group	Low Risk	Risk of Bias tool 2
2	Nitecka-Buchta et al. [42]	2019	PRP injections	Intra-muscular isotonic saline injections	Pain intensity reduction (VAS) at day 5 and day 14.	Some concerns	Risk of Bias tool 2
3	Checinski et al. [33]	2024	PRP injection	Five intra-articular injections of 2% HA	No significant mandibular mobility improvement with PRP; significant with HA	Low risk	Appropriate JBI tool *
4	Vingender et al. [35]	2023	PRP injection; i-PRF	HA	All groups showed significant VAS pain reduction at 6 and 12 months; only the HA group showed significant improvement in MMO.	Low risk	Appropriate JBI tool *
5	Rajput et al. [32]	2022	PRP injection	Arthrocentesis	Both groups showed significant improvement in painless mouth opening and reduction in pain. Arthrocentesis yielded slightly better results in terms of pain relief and mouth opening, while PRP was more effective in reducing joint noise, deviation, and tenderness.	Some concerns	Risk of Bias tool 2
6	Kutuk et al. [44]	2019	PRP injection	HA and corticosteroids	Intra-articular PRP injections decreased TMJ palpation pain more effectively compared with the HA and CS groups.	Some concerns	Risk of Bias tool 2
7	Usman et al. [36]	2023	PRP injection	Corticosteroid (triamcinolone 1.5 mL)	Pain reduction, enhanced mouth opening, and slight increases in joint tenderness.	Low risk	Appropriate JBI tool *
8	Yuce et al. [40]	2020	Arthrocentesis plus I-PRF	Arthrocentesis only, arthrocentesis plus HA	A significant decrease in pain and an increase in MMO were observed in all groups. Arthrocentesis + HA and arthrocentesis + iPRF presented greater differences in pain and MMO at all follow-up time points, in comparison to the arthrocentesis alone.	Low risk	Appropriate JBI tool *
9	Isık et al. [38]	2022	i-PRF after arthrocentesis	Arthrocentesis	The pain levels for the i-PRF group were observed to decrease postoperatively at the 1st, 2nd, 3rd, and 6th months, with these decreases in pain levels preserved through to the postoperative 12th month.	Low risk	Risk of Bias tool 2
10	Yilmaz et al. [43]	2021	PRP injection	Group I (LA injection), group II (BTX injection)	Significant pain reduction in all groups. BTX and LA yielded better outcomes in decreasing VAS scores at 3 months, and BTX provided better outcomes at 6 months of follow-up.	Some concerns	Risk of Bias tool 2
11	Jamal et al. [37]	2023	PRP Injection	No comparator	Increased mobility of the mandible and decreased TMJ pain	Some concerns	Risk of Bias tool 2
12	Pihut, Gala [41]	2020	PRP injection	HA	VAS reduced after treatment in both groups; the same occurred with the mobility of the mandible.	Low risk	Risk of Bias tool 2
13	Agarwal et al. [39]	2022	PRP injection	Dry Needling	PRP is a more effective treatment modality compared to Dry Needling for the management of MTrPs	Some concerns	Risk of Bias tool 2

* JBI Critical Appraisal Checklist for Quasi-Experimental Studies (non-randomized experimental studies), PRP—Platelet-rich Fibrin, TMJ—Temporomandibular Joint, VAS—Visual Analog Scale, HA—Hyaluronic Acid, MMO—Maximum Mouth Opening, BTX—Botulinum Toxin, LA—Local Anaesthetic, MTrPs—Myofascial Trigger Points.

3.3. Risk of Bias

Among the thirteen included studies, the risk of bias was evaluated using tools appropriate to their design. Nine studies were assessed using the Cochrane RoB 2 tool, and four studies were evaluated using the JBI checklist for quasi-experimental studies. Seven studies were rated as having a low risk of bias [33–36,38,40,41], while six received a moderate risk rating [32,37,39,42–44]. The most common issues leading to some concerns of risk of bias were insufficient detail on randomization procedures or unclear bias in the measurement of the outcome. Overall, the methodological quality was considered acceptable, with the majority of studies showing strong internal validity. More detailed analysis of the risk of bias is presented in Table 4.

Table 4. Risk of Bias for randomized studies.

	Random Sequence Generation	Deviations from Intended Interventions	Missing Outcome Data	Measurement of the Outcome	Selection of the Reported Result	Overall Bias
Mathpati et al. [36]	+	+	+	+	+	+
Nitecka-Buchta et al. [42]	+	+	+	+	?	?
Rajput et al. [32]	?	+	+	?	+	?
Kutuk et al. [44]	?	+	+	?	+	?
Isik et al. [38]	+	+	+	+	+	+
Yilmaz et al. [43]	?	+	+	?	+	?
Jamal et al. [37]	?	+	+	?	+	?
Pihut et al. [41]	+	+	+	+	+	+
Agarwal et al. [39]	+	+	+	?	+	?

+ Low risk of bias; ? Some concerns; - High risk of bias.

3.4. Evaluation of the Quality of the Evidence

The quality of the evidence presented in the studies, with overall GRADE (Grading of Recommendations Assessment, Development and Evaluation) scores for outcomes, is shown in Table 5.

Table 5. Summary findings for the primary outcome and quality of evidence.

Outcome Significance	Author and Year	Quality of Evidence (GRADE)
Autologous injections are effective in alleviating pain and enhancing mandibular mobility in TMD	Mathpati et al., 2024 [36]	++++ high
	Nitecka-Buchta et al., 2019 [42]	+++- moderate due to imprecision
	Checinski et al., 2024 [33]	++++ high
	Vingender et al., 2023 [35]	+++- moderate due to imprecision
	Rajput et al., 2022 [32]	+++- moderate due to risk of bias
	Kutuk et al., 2019 [44]	++++ high
	Usman et al., 2023 [36]	+++- moderate due to imprecision
	Yuce et al., 2020 [40]	++++ high
	Isık et al., 2022 [38]	++++ high
	Yilmaz et al., 2021 [43]	++-- moderate due to imprecision and indirectness
	Jamal et al., 2023 [37]	+++- moderate due to imprecision
	Pihut, Gala 2020 [41]	++++ high
	Agarwal et al., 2022 [39]	+++- moderate due to indirectness

++++ high certainty; +++- moderate certainty; ++-- low certainty.

The studies reviewed in this study were very heterogeneous; therefore, it was not possible to perform a meta-analysis, and instead, a narrative and qualitative summary was prepared. The GRADE approach was used to assess the quality of evidence for outcomes [46]. The quality of evidence was assigned to one of the following categories: very low, low, moderate, or high. Articles classified as high-quality evidence were character-

ized by a randomized protocol, a detailed description of methodology, and the obtained results. Studies with inaccuracies in methodology, based on a very small sample group, or with a risk of bias were described as moderate. Studies with low quality of evidence lacked complete methodological descriptions, lacked basic information about the size of the study group, and had no randomization protocol or presented a high risk of bias. Six of the thirteen articles qualified for this systematic review were rated as high quality [33,34,38,40,41,44]. The remaining seven papers were rated as moderate due to the small study group, lack of a control group, or suspected risk of bias [32,35–37,39,42,43]. None of the studies included were classified as very low quality of evidence.

3.5. TMD Type

3.5.1. Myogenous TMD

Three studies focused on patients with muscle-related TMD. Nitecka-Buchta et al. evaluated intra-muscular PRP injections into the masseter muscle and reported a 58.15% reduction in pain intensity by day 5 and a 47.16% reduction by day 14, compared with only 10.24% and 4.62% reductions in the placebo group ($p < 0.001$) [42]. Yilmaz et al. retrospectively compared PRP, botulinum toxin, and local anesthesia for myofascial trigger points in the masseter [43]. All groups showed symptom improvement at one and three months; however, botulinum toxin achieved significantly greater pain reduction and functional improvements lasting up to six months, whereas PRP showed only modest short-term benefits [43]. Agarwal et al. conducted a randomized trial comparing PRP with dry needling and found PRP to be more effective, with greater pain relief and improvement in mandibular function, although precise values were not reported [39]. Collectively, these results suggest that autogenous injections, particularly PRP, provide short-term analgesic effects in myogenous TMD, but botulinum toxin appears more effective in sustaining long-term outcomes.

3.5.2. Articular TMD

Ten studies investigated intra-articular conditions such as disc displacement and temporomandibular joint osteoarthritis. Mathpati et al. demonstrated significant improvements with PRP injections, where mean VAS pain scores decreased from 6.8 ± 1.2 at baseline to 2.1 ± 1.0 after eight weeks ($p < 0.001$), while MMO increased from 38.2 ± 2.5 mm to 43.5 ± 3.1 mm ($p < 0.001$) [34]. Checiński et al. reported that HA resulted in significantly greater gains in mandibular mobility than PRP, with mean improvements in abduction of +4.05 mm ($p < 0.001$) and protrusion of +0.97 mm ($p = 0.03$) [33]. Pihut and Gala observed significant improvements in both PRP and HA groups in disc displacement without reduction, with comparable reductions in VAS pain scores and increases in interincisal distance [41]. Rajput et al. found that both PRP and arthrocentesis significantly improved pain and MMO at twelve months ($p = 0.0002$ and $p = 0.0022$, respectively), though intergroup differences were not significant; PRP showed superiority in reducing joint noise and tenderness [32]. Jamal et al. observed more than 50% pain reduction in seven of ten patients after a single PRP injection, with mean VAS scores decreasing from 7.3 to 3.9 [37]. Kutuk et al. compared PRP, HA, and corticosteroids in TMJ osteoarthritis and reported the largest analgesic effect in the PRP group, with significant reductions in pain between the first and third months ($p = 0.01$) and between the second and third months ($p = 0.002$) [44]. Usman et al. noted greater pain reduction and improvement in MMO after PRP than with corticosteroid injections, although quantitative differences were modest [36]. Vingender et al. compared HA, PRP, and i-PRF for disc displacement, showing significant VAS pain reduction across all groups at six and twelve months ($p < 0.01$), but only the HA group achieved a statistically significant increase in MMO ($p < 0.01$) [35]. Yuce et al. demonstrated

that arthrocentesis combined with i-PRF achieved the most pronounced benefits, with significantly greater reductions in pain than the A+HA group at twelve months ($p < 0.008$), and superior improvements in MMO at nine and twelve months [40]. Isik et al. confirmed sustained benefits of i-PRF combined with arthrocentesis in TMJ osteoarthritis, with rapid pain reduction in months 1 and 2 ($p < 0.001$) maintained throughout twelve months, while the control group showed pain recurrence after six months [38].

In summary, intra-articular autogenous injections, particularly PRP and i-PRF, consistently reduced pain and improved mandibular mobility in articular TMD. The greatest and most durable benefits were observed when autogenous preparations were combined with arthrocentesis. Although hyaluronic acid demonstrated superior effects on mandibular mobility in some trials, autogenous injections provided more consistent long-term analgesia and functional stability.

3.6. Preparation Type

3.6.1. Injectable Platelet-Rich Fibrin

Vingender et al. examined the effectiveness of platelet-rich fibrin (I-PRF) therapy. The researchers evaluated the efficacy of various substances—hyaluronic acid (HA), PRP, and I-PRF—used in intra-articular injections to treat temporomandibular joint disc displacement. Sixty-eight patients were divided into three groups, and the study measured outcomes such as maximum mouth opening (MMO) and pain levels using the VAS scale. A significant reduction in pain ($p < 0.01$) was observed in all groups after 6 months, with notable differences between 6 and 12 months. HA and PRP demonstrated slightly better results than I-PRF. However, only the HA group showed a statistically significant improvement in MMO ($p < 0.01$). PRP and I-PRF showed improvements in MMO, but these were not statistically significant [35].

Yuce et al. tested three different therapies in their study: arthrocentesis (AO), arthrocentesis plus injection of hyaluronic acid (A+HA), and arthrocentesis plus injection of liquid platelet-rich fibrin (A+I-PRF). The follow-up period was 12 months, during which they assessed results using the VAS scale and MMO. All groups demonstrated a significant decrease in pain levels over time. The A+I-PRF group showed a significantly greater reduction in pain compared to the A+HA group 12 months post-treatment ($p < 0.008$). Both the A+HA and A+I-PRF groups were more effective than the arthrocentesis-only group throughout the observation period. The A+I-PRF group achieved the most tremendous improvement in MMO, with statistically significant differences observed at 9 and 12 months compared to the A+HA group. Therefore, the authors demonstrated the superiority of therapy with an autologous preparation over HA or arthrocentesis alone [40].

Isik et al. also observed similar findings when examining patients with temporomandibular joint osteoarthritis in two groups: the first receiving I-PRF + arthrocentesis, and the control group receiving only arthrocentesis. The follow-up period was 12 months. Clinical assessments included VAS, MMO, and lateral and protrusive jaw movements. Clinical outcomes showed that the I-PRF group experienced rapid and significant pain reduction in months 1 and 2 ($p < 0.001$), which was maintained through 12 months. The control group experienced pain relief up to 6 months, but it recurred by month 12. The difference between the groups was statistically significant throughout the follow-up ($p < 0.001$). In the I-PRF group, MMO and both lateral and protrusive movements significantly improved until month 6 and remained improved through month 12. In the control group, improvements peaked at 6 months but declined by month 12, indicating significant functional loss. The authors concluded that I-PRF preparations combined with arthrocentesis, rather than isolated arthrocentesis alone, especially I-PRF, should be considered a preferred adjunct in the long-term management of TMJ-OA [38].

3.6.2. Platelet-Rich Plasma

Mathpati et al. conducted a prospective, randomized, double-blind, placebo-controlled clinical trial to assess the effectiveness of PRP injections in young adults with mild TMD. The study included 128 participants aged 18–35, randomly assigned to either a PRP treatment group or a placebo group. The PRP group received intra-articular injections of 0.5 mL of PRP per temporomandibular joint, while the placebo group received 0.5 mL of normal saline. The primary outcome measures were TMJ pain (evaluated with the VAS scale), maximum mouth opening (MMO), lateral excursions, and patient-reported outcomes related to daily activities. After eight weeks, the PRP group experienced a statistically significant reduction in pain (VAS score decreased from 6.8 ± 1.2 to 2.1 ± 1.0, $p < 0.001$), along with notable improvements in MMO (from 38.2 ± 2.5 mm to 43.5 ± 3.1 mm, $p < 0.001$) and lateral excursions (from 12.3 ± 1.5 mm to 14.9 ± 2.0 mm, $p < 0.001$). Furthermore, improvements were noted in daily activities, including eating, speaking, and sleeping. The placebo group showed no significant changes. No serious adverse events occurred, confirming the safety and potential of PRP as a minimally invasive therapy for TMJ pain management in young adults [34].

Nitecka-Buchta et al. conducted a randomized, double-blind, placebo-controlled clinical trial to evaluate the analgesic effect of platelet-rich plasma intra-muscular injections in treating myofascial pain within the masseter muscle in patients diagnosed with TMD. A total of 59 patients were randomized into two groups: one receiving PRP injections and the other receiving isotonic saline as a placebo. Each patient underwent three bilateral intramuscular injections (six sites total, 0.5 mL per site) into the masseter muscles. Pain intensity was assessed using the VAS on days 0, 5, and 14. The PRP group demonstrated a 58,15% reduction in pain on day 5 and a 47,16% reduction on day 14, whereas the placebo group showed reductions of only 10,24% and 4,62%, respectively ($p < 0.001$). Minor, transient side effects such as swelling and muscle soreness were reported. The authors concluded that PRP might be effective in providing short-term analgesic relief in myofascial TMD pain [42].

Checinski et al. conducted a prospective clinical study to compare the effectiveness of PRP and hyaluronic acid intra-articular injections in improving mandibular mobility and reducing joint pain in patients with TMD. A total of 78 patients (128 TMJs) were assigned to two equal groups of 39 patients each, receiving either HA or PRP in five sessions at 7–10 day intervals. Clinical outcomes were assessed using maximum mouth opening (MMO) and the VAS for pain recorded at baseline and follow-up. The HA group demonstrated statistically significant improvements in all directions ($p < 0.01$), while the PRP group did not show significant changes from baseline. Between-group analysis revealed that HA resulted in significantly greater improvements in abduction (MD = -4.05 mm, $p = 0.00$) and protrusion (MD = -0.97 mm, $p = 0.03$). The authors concluded that HA provides superior improvement in mandibular mobility compared to PRP, likely due to its lubricating properties. The study was non-randomized and non-blinded, with a non-concurrent control group [33].

Rajput et al. conducted a prospective clinical study to compare the clinical effectiveness of intra-articular PRP injections with arthrocentesis in patients with groups II and III of RDC/TMD. A total of 24 patients were equally divided into two groups. One group received a single PRP injection into the superior joint space, while the other group received arthrocentesis with Ringer's lactate. Clinical assessments were performed over a 12-month period, evaluating pain (VAS), painless and maximum mouth opening, lateral jaw movement, and joint tenderness. In both groups, intragroup comparisons revealed statistically significant improvements in pain and mandibular mobility. In the arthrocentesis group, VAS scores improved significantly ($p = 0.0001$), and in the PRP group, the improvement

was also significant ($p = 0.0002$). Maximum mouth opening was also significantly enhanced, with $p = 0.0010$ for arthrocentesis and $p = 0.0022$ for PRP. However, intergroup comparisons showed no statistically significant differences in either pain reduction or jaw mobility between the two treatment modalities ($p > 0.05$). Arthrocentesis yielded slightly better results in terms of pain relief and mouth opening, while PRP was more effective in reducing joint noise, deviation, and tenderness. No adverse effects were reported [32].

Kutuk et al. examined the clinical effects of intra-articular PRP, hyaluronic acid, and corticosteroid (CS) injections in the treatment of temporomandibular joint osteoarthritis (TMJ-OA). Sixty patients diagnosed with TMJ-OA were randomly assigned to three treatment groups and received 1 mL injections monthly for three months. Pain (VAS), crepitation, loss of function, and muscle strength were assessed on a monthly basis. A Friedman test showed a statistically significant reduction in pain over time across all treatment groups combined ($p < 0.0028$), confirming the overall effectiveness of intra-articular therapy. Among the three treatments, the PRP group experienced the greatest pain reduction, with significant improvements observed between the first and third months ($p = 0.01$) and between the second and third months ($p = 0.002$). Although HA also showed a significant analgesic effect, CS injections demonstrated limited efficacy. No serious adverse effects were reported during the study [44].

Yilmaz et al.'s study aimed to evaluate and compare the effectiveness of local anesthesia (LA), botulinum toxin (BTX), and PRP injections for treating myofascial trigger points (TrPs) in the masseter muscle. Conducted as a retrospective study, it included 82 patients with myofascial TrPs in the masseter muscle, divided into three groups: 27 patients received LA injections, 26 received BTX injections, and 29 received PRP injections. The findings showed that all treatment methods improved symptoms at both 1 and 3 months. However, BTX injections were superior, showing significant improvements in pain, jaw function, and quality of life up to 6 months. LA injections were effective in the short term, while PRP showed less improvement compared to the other methods. The study concluded that BTX injections offer longer-lasting relief for myofascial TrPs in the masseter muscle [43].

Jamal et al. conducted a prospective observational clinical trial involving 10 participants (9 women and 1 man) aged between 27 and 75 years, who suffered from painful dysfunction of the temporomandibular joint (TMJ). The study aimed to assess the effectiveness of a single PRP injection in reducing joint pain and improving mandibular motion. The study revealed that 7 out of 10 patients experienced a significant decrease in pain intensity (more than a 50% reduction), 2 patients showed partial symptom resolution, and 1 patient showed no improvement and subsequently underwent arthrocentesis. The average pain score decreased from 7.3 preoperatively to 3.9 postoperatively. The study concluded that PRP injections have a statistically significant and strong correlation with pain reduction, supporting their role as an effective treatment for TMJ internal derangement [37].

Pihut with Gala study focuses on the effectiveness of two different intra-articular injection treatments, PRP and HA, for patients suffering from disc displacement without reduction. The study was designed as a double-blind clinical trial involving 100 patients diagnosed with TMD (IIb according to the RDC/TMD). Participants were alternately assigned to either the PRP group or the HA group, with 50 patients in each. The sample included a mix of genders, with the PRP group comprising 38 females and 12 males, while the HA group included 40 females and 10 males. All patients reported symptoms persisting for 10 days to 2 months prior to treatment, and each underwent a comprehensive functional examination of the masticatory system, assessing parameters such as maximal interincisal distance and pain intensity using a VAS. Both groups received intra-articular injections of either 0.4 mL of PRP or 0.4 mL of HA into the temporomandibular joint. This procedure was repeated three times at 10-day intervals. The outcomes indicated that both

treatments resulted in significant improvements in pain and function, suggesting that both PRP and HA are effective options for managing TMD related to disc displacement without reduction [41].

Agarwal et al. investigated the comparative effectiveness of PRP injection and dry needling for TrPs in the Masseter Muscle. The randomized controlled trial included 30 participants. Patients in the test group received a PRP injection of 0.5 mL per trigger point (TrP) in the masseter muscle using a 1.5-inch, 27-gauge needle. In contrast, the control group underwent dry needling (DN) at the TrPs in the masseter muscle with the same needle size, but without any solution. Based on the study's findings, it can be concluded that PRP appears to be more effective than DN in treating myofascial trigger points (MTrPs) in patients with myofascial pain syndrome [39].

4. Discussion

Patients with TMD often experience masticatory muscle pain and limited mouth opening, which, in advanced cases, can significantly hinder daily activities [47,48]. TMD may reduce quality of life and place a broader burden on the healthcare system [49]. Current TMD treatments aim to relieve pain and restore normal TMJ function. One rapidly growing treatment option for TMD is intra-articular injection therapy. Its increasing popularity is due to its minimally invasive nature and proven effectiveness in quickly decreasing joint pain and improving mandibular movement [47–50].

From an economic standpoint, the cost of PRP/PRF treatments can vary significantly based on the provider, geographic location, and specific protocols used [4]. Often, these treatments can be expensive and may not be covered by insurance, which could limit accessibility for some patients. Patients must weigh the potential benefits against the financial burden, especially if multiple treatment sessions are required. Accessibility also plays a crucial role [4,5]. Not all clinics offer PRP/PRF treatments, and patients may need to travel to specialized facilities, which could pose additional costs and challenges. Furthermore, the frequency and duration of treatment can affect patient compliance and overall effectiveness [6,9].

Concomitant treatments, including the use of splints and medications, alongside patient characteristics such as age, gender, and disease duration, can have a considerable impact on treatment outcomes for TMD [51]. These factors can influence how patients respond to various interventions, potentially leading to differing efficacy rates among individuals. Splints and medications play a crucial role in influencing treatment outcomes for TMD [52]. Occlusal splints are designed to alleviate jaw tension and stabilize the bite, which can lead to decreased muscle strain and enhanced comfort for patients [52]. Medications play a pivotal role in managing the symptoms of TMD, providing relief from pain and inflammation associated with this condition. For instance, non-steroidal anti-inflammatory drugs, muscle relaxants, and corticosteroids can provide symptomatic relief by reducing inflammation, making them first-line options for many patients' muscles [53]. The effectiveness of these treatments can vary based on individual patient characteristics, including the specific TMD phenotype being treated, the duration of symptoms, and concurrent health conditions.

Commonly recognized phenotypes include myogenic, arthrogenic, and mixed types [9,13]. Myogenic TMD is primarily related to muscle dysfunction and pain, often associated with bruxism or jaw clenching. Arthrogenic TMD, on the other hand, involves joint-related issues, such as internal derangements or osteoarthritis of the temporomandibular joint (TMJ). Mixed types exhibit characteristics of both muscle and joint dysfunction [13].

The most common scale used across all reviewed studies was VAS. Main limitations of the VAS include its reliance on the patient's subjective interpretation of pain, which may vary based on individual differences in pain perception and expression. Additionally, VAS may not adequately capture the multidimensional nature of pain, such as its emotional or psychological components [54].

4.1. Platelet-Rich Plasma

Platelet-rich plasma is an autologous blood-derived product obtained through centrifugation of the patient's peripheral blood. The final product is a plasma concentrate with a high platelet count and an abundance of growth factors such as PDGF, TGF-β, vascular endothelial growth factor (VEGF), epidermal growth factor (EGF), and IGF, which play key roles in tissue regeneration and repair [55,56]. Different PRP preparation methods result in compositional and therapeutic discrepancies. From the clinical perspective, the lack of standardization hampers the comparison of results from clinical trials that may have employed different protocols for PRP production. This fact may explain the heterogeneity of results observed and contribute to the uncertainties related to the clinical effects of PRP [57,58]. Platelet-rich plasma is widely used due to its anti-inflammatory effects and ability to promote tissue regeneration. Leukocyte-rich PRP (LR-PRP) can enhance acute-phase inflammation, aiding tissue repair [59,60]. However, excessive platelet levels may impair tissue repair [61]. These variations in PRP composition significantly impact clinical outcomes.

In the management of TMD, the PRP injection technique involves intra-articular administration of the prepared concentrate directly into the temporomandibular joint space. PRP exhibits anti-inflammatory, analgesic, and regenerative properties, making it a promising alternative or adjunct to conventional conservative treatments for temporomandibular joint osteoarthritis (TMJOA) [62,63]. These mechanisms are not fully understood and may depend on growth factor-mediated pathways [57,58].

The studies reviewed demonstrate several benefits of using PRP in intra-articular injections. There is a significant reduction in pain and improvement in jaw function [33,34,37,44]. Additionally, there is a decrease in myofascial pain and a reduction of myofascial trigger points in the masseter [39,42]. PRP has proven more effective in alleviating joint noise, deviation, and tenderness [32]. In summary, PRP therapy appears to be a promising, effective, and minimally invasive option for managing various TMD-related conditions. However, its effectiveness may vary depending on the specific disorder and treatment approach. Furthermore, PRP injections are described as a very safe procedure, associated with a low risk of complications, making it a desirable treatment option.

4.2. Platelet-Rich Fibrin

Injectable Platelet-Rich Fibrin is a second-generation autologous platelet concentrate, developed to overcome some of the limitations of traditional PRP and solid PRF. Solid platelet-rich fibrin (PRF), in its membrane or clot form, presents several limitations that may restrict its clinical applicability in dentistry. Due to its solid consistency, it cannot be injected into anatomically constrained sites, such as narrow bony defects or intra-articular spaces, where a liquid formulation like injectable PRF (i-PRF) may offer superior adaptability. Furthermore, solid PRF must be applied immediately after centrifugation, as the fibrin matrix rapidly dehydrates, leading to loss of biological activity. Finally, the dense fibrin architecture may impede the uniform diffusion of growth factors, potentially resulting in a less homogeneous and temporally restricted regenerative stimulus when compared with liquid platelet concentrates [64]. Unlike solid PRF, which forms a fibrin clot during centrifugation, i-PRF remains in liquid form for several minutes after preparation, allowing for

injectable use and more versatile clinical applications [65]. The i-PRF preparation protocol is based on the Low-Speed Centrifugation Concept (LSCC), which helps preserve higher concentrations of platelets and leukocytes in the upper plasma layer, while maintaining bioactive molecules in a more physiologically favorable fibrin matrix [66,67]. Due to the absence of anticoagulants, i-PRF begins to polymerize slowly after injection, forming a fibrin scaffold in situ. This scaffold facilitates sustained release of growth factors, such as PDGF, TGF-β, and vascular endothelial growth factor (VEGF), over several days [68]. These bioactive molecules play essential roles in promoting angiogenesis, reducing inflammation, and stimulating tissue regeneration [69]. In the field of temporomandibular joint disorders, i-PRF has demonstrated its potential to reduce joint pain, improve mandibular mobility, and promote cartilage regeneration through its regenerative and anti-inflammatory properties [70,71].

The studies we analyzed proved the effectiveness of injection therapies using autologous preparations in patients with TMD. The authors of the studies describe the following effects after using PRF: increased mouth opening range and reduced pain [35,38,40]. Additionally, in the long-term management of TMD, PRP and I-PRF support the repair of damaged tissues by releasing growth factors, including PDGF, TGF-β, and VEGF [35,38,40]. The preparations are derived from the patient's blood, eliminating the risks of allergic reactions, rejection, or disease transmission [38,40]. As a result, these preparations are associated with a very low complication rate, mainly mild, localized symptoms such as pain or swelling, without any serious effects. The procedure is simple and performed on an outpatient basis [35,38].

In addition to techniques using autologous preparations for intra-articular injections in patients with temporomandibular joint dysfunction, several scientific studies have also explored the technique of isolated arthrocentesis and intra-articular injections of preparations such as hyaluronic acid, collagen, or glucocorticosteroids.

4.3. Arthrocentesis

Arthrocentesis of the TMJ is a minimally invasive procedure that involves lavage of the joint space using a physiological solution, typically achieved by inserting two needles into the upper joint compartment. This technique is beneficial in the management of TMJ functional disorders, especially in cases of limited mandibular mobility, joint pain, and disc displacement without reduction (most beneficial in early stages of displacement without reduction) [72].

Arthrocentesis can also serve as a method of access for intra-articular injections of anti-inflammatory drugs, hyaluronic acid, PRP, or i-PRF [73]. Its mechanisms of action include the reduction in intra-articular pressure, the removal of inflammatory mediators (e.g., prostaglandins, cytokines), the release of adhesions, and the improvement in disc mobility and joint function [74,75].

Clinical studies show high efficacy of arthrocentesis in reducing joint pain and improving mouth opening in patients with TMJ dysfunction, particularly in those unresponsive to conservative therapy [76]. Kim et al. reported that the average MMO increase after arthrocentesis in patients with TMD was 9.10 mm. The average pain relief of patients after arthrocentesis was 3.03 on the VAS scale [77]. Demir et al. in their study evaluated the effect of arthrocentesis in terms of maximum mouth opening and pain in patients with TMD of intra-articular origin. Arthrocentesis was observed to be effective in terms of pain and function in TMJ patients in this study. It was observed that splint therapy, physical therapy, and medical therapy made no additional contribution to arthrocentesis in terms of MMO or pain [78].

4.4. Glucocorticosteroids

Corticosteroids are frequently employed as a minimally invasive option for treating internal disorders of the TMJ. Their strong anti-inflammatory properties have been effective in alleviating joint-related pain. These agents work by suppressing the synthesis and release of pro-inflammatory cytokines, as well as limiting the accumulation of immune cells, such as macrophages and neutrophils, at inflammatory sites. Additionally, they prevent the buildup of inflammatory cells, such as macrophages and neutrophils, by downregulating endothelial adhesion molecules and reducing the synthesis of plasminogen activators. Among the corticosteroids most often used for intra-articular applications are hydrocortisone, methylprednisolone, dexamethasone, betamethasone, prednisolone, and triamcinolone [79]. The choice of corticosteroid will depend on the specific clinical situation and should be based on pharmacokinetics, duration of action, and risk to cartilage [80,81].

In the literature, there are reports on the effectiveness of using corticosteroids in treating pain [80,82–85].

Isacsson et al. also evaluated the effectiveness of a single intra-articular injection of methylprednisolone for pain relief in patients with TMJ arthritis, in comparison with a placebo. The study involved 26 patients in the methylprednisolone group and 26 in the placebo group. The intervention consisted of a single 40 mg intra-articular injection of methylprednisolone. The observation period lasted four weeks. Additionally, both groups received stabilization splint therapy. No significant differences were found between the groups in terms of resting pain or pain during mouth opening. The authors attributed the observed reduction in resting pain to the use of the occlusal splint [86].

Frid et al. assessed the safety and efficacy of intra-articular corticosteroid injections into the TMJ in adolescents with juvenile idiopathic arthritis (JIA), evaluating both clinical outcomes and Magnetic Resonance Imaging (MRI) findings. All patients received concurrent standard systemic treatment, including methotrexate or biological agents. MRI results showed a statistically significant reduction in the mean additive inflammatory score, from 4.4 ± 1.8 to 3.4 ± 2.0 ($p = 0.040$). The maximum incisal opening (MIO) improved slightly, with a mean increase from 44 mm to 45 mm ($p = 0.045$). However, clinical assessment revealed no significant change in pain levels, indicating a lack of correlation between objective imaging improvement and subjective symptom relief. What may be related to the patient's psychoemotional state and the way he subjectively assesses his well-being. The authors concluded that intra-articular corticosteroid injections are radiologically effective. Nonetheless, they acknowledged a discrepancy between improvement in MRI and the patients' subjective perception of symptoms [87]. The researchers did not find any serious adverse effects [87]. Torres et al. conducted a comprehensive analysis of the potential clinical application of steroids in injections for patients with TMD in their systematic review. Across 20 randomized trials (810 participants), betamethasone showed the most consistent pain reduction at one to three months, while arthrocentesis combined with dexamethasone was effective up to six months. No corticosteroid demonstrated clear advantages in improving mandibular function or quality of life compared with arthrocentesis alone. Methylprednisolone, however, was linked to more frequent adverse effects, warranting caution in its use. Clinically, corticosteroid injections may be considered for patients with persistent TMJ pain unresponsive to conservative measures, with betamethasone preferred for short- to medium-term relief. Dexamethasone can be useful in combination with arthrocentesis, whereas routine use for functional outcomes is not supported. The authors of the review, despite conducting a thorough analysis of numerous studies, are unable to provide specific application protocols or indicate clear clinical guidelines for the use of steroids in joint injections for patients with TMD. Treatment decisions should weigh potential benefits

against risks, costs, and patient preferences, while further long-term trials are needed to strengthen the evidence base [79].

It is therefore worth noting that glucocorticosteroids can be an alternative to intra-articular injections of preparations derived from the patient's blood in a specific group of patients, namely those with autoimmune diseases. This group of patients, particularly those with rheumatoid arthritis or psoriatic arthritis, will develop a complex of symptoms associated with temporomandibular joint dysfunction. Consequently, it will also be a group of patients in whom injections of autogenous preparations may be contraindicated in some cases [88–90].

4.5. Hyaluronic Acid

Another substance successfully used in injections into the TMJ is hyaluronic acid.

Baron et al. conducted a prospective, open-label pilot study to evaluate the effects of a single intra-articular injection of cross-linked hyaluronic acid with mannitol (HANOX-M-XL) in 36 patients with temporomandibular joint osteoarthritis (TMJ-OA). Over a 6-month follow-up, significant improvements were observed: pain during chewing decreased from 6.9 to 2.9, and jaw opening increased from 29 mm to 35 mm. No serious side effects occurred. While specific trends suggested that prior intra-articular injection of HA with or greater early pain relief may predict higher satisfaction, no strong statistical predictors were identified. The study supports HANOX-M-XL as a safe, effective, and convenient single-injection option for managing TMJ-OA symptoms, though larger controlled trials are needed to confirm these findings [91].

Hepguler et al. evaluated intra-articular hyaluronic acid (HA, Orthovisc) in a randomized, double-blind, placebo-controlled trial in 38 patients with disc displacement with reduction. Patients received two HA or saline injections one week apart. At both 1 and 6 months, the HA group showed significant improvements in pain, joint sounds, and jaw function compared to the placebo group. Clinical improvement was observed in 89.5% of HA-treated patients at 1 month and 63% at 6 months. Therefore, the short duration of the effect indicates short-term effectiveness and is a certain limitation for the use of HA preparations. No adverse events were reported. The authors of the study report that HA injections are a safe and effective non-surgical option for managing TMJ disorders with disc displacement, offering benefits lasting up to 6 months [92].

Chęciński et al. in their controlled clinical trial compared the effects of a single intra-articular injection of HA and PRP on mandibular mobility in patients with temporomandibular joint disorders. A total of 78 patients were divided equally into two groups (HA vs. PRP). Mandibular movements—mouth opening (abduction), protrusion, and lateral excursions—were measured after treatment. In this study, HA significantly improved mouth opening (+4.05 mm) and protrusion (+0.97 mm) compared to PRP. No significant differences were observed for lateral movements. HA was more effective than PRP in increasing mandibular mobility, particularly in cases of limited mouth opening. These findings may be attributed to the superior lubricating properties of hyaluronic acid. According to the authors, in cases of TMD characterized primarily by reduced mandibular mobility, intra-articular injections of HA appear to be more appropriate than PRP for symptomatic management [33].

Peng et al. investigated the therapeutic effect of a single intra-articular injection combining PRP and HA in patients with temporomandibular joint osteoarthritis. Twelve participants received one injection of a 1:1 PRP–HA mixture and were followed for six months. The treatment resulted in a marked reduction in pain intensity (VAS score decreased from 6.9 to 2.8) and a significant increase in mandibular mobility, with maximum mouth opening improving from 29.4 mm to 36.5 mm ($p < 0.01$). Additionally, MRI data

demonstrated that after 6 months of treatment, PRP/HA regenerated the condylar cartilage and reduced disc displacement. The therapy was well-tolerated with no reported adverse effects. However, due to the small study group, larger studies are needed to confirm safety. These findings suggest that the PRP–HA combination may offer a safe and effective option for symptom relief and functional improvement in TMJ-OA [93].

The systematic review by Agostini et al. provides a systematic organization of information regarding the use of HA in injections for patients with TMD. An umbrella review was conducted to evaluate the role of intra-articular hyaluronic acid (HA) injections in the management of TMD. Eighteen systematic reviews were included, thirteen of which analyzed only randomized controlled trials. Overall, the evidence suggested that HA injections may provide pain reduction and functional improvement, although outcomes were not superior to corticosteroid injections. Platelet-derived products often demonstrated more favorable analgesic effects compared to HA. Importantly, HA injections appeared safe, with no serious adverse events reported other than transient pain at the injection site. However, the methodological quality of the included reviews was generally low, with only a small proportion rated as high quality. Consequently, while HA injections represent a promising option for symptom management in TMD, the certainty of the evidence remains limited, and further high-quality randomized trials with longer follow-up are required to confirm their efficacy [94].

4.6. Collagen

Sakr et al. compared the effectiveness of intra-articular injections of collagen versus HA in treating anterior disc displacement with reduction of the temporomandibular joint. Clinical outcomes were assessed using a modified Helkimo Index focusing on pain (P) and joint noise (S), at intervals of 1 week, 1 month, and 3 months after the second injection. The results showed significant improvement in both pain and joint noise within each group over time; however, there was no statistically significant difference between the collagen and HA groups at any follow-up point. This study is notable for being the first to investigate intra-articular collagen injections as a treatment for TMD. The findings support the efficacy of both HA and collagen, and suggest that collagen may represent a promising therapeutic option. However, collagen remains the least studied substance and requires further investigation for broader applications [95]. A systematic review of collagen injections in the case of TMD is limited, although the presented studies and clinical trials show promising results. However, more rigorous studies with longer observation periods are necessary to determine the long-term effectiveness and optimal protocols for collagen injections, as well as specific indications for the use of this type of injection in TMD.

Despite promising preliminary results obtained with PRP and PRF injections and the associated benefits in patient care, further research in larger RCTs is needed, focusing on reducing the risk of bias, to better define the benefits, applications, and protocols associated with the use of PRP or PRF in the treatment of temporomandibular joint disease. It would also be extremely valuable to combine autogenous preparations with hyaluronic acid, collagen, or to use only the arthrocentesis procedure.

4.7. Limitations of the Evidence

The chosen primary studies vary in diagnoses, sample sizes, injectable medications, treatment protocols, and follow-up periods. Additionally, the fact that grey literature was not searched may have led to the omission of unpublished data, which could introduce publication bias.

Because of the limitations of this systematic review, the findings should be interpreted carefully. Studies often do not include a control group, and when they do, different

approaches are used, with specialists having varying levels of experience performing the treatments. For this reason, a meta-analysis was not suitable.

5. Conclusions

In summary, all PRP and PRF injection protocols included in this review showed positive outcomes, relieving pain and improving mobility in patients with TMD, especially in short–medium-term follow-up. A meta-analysis was not feasible due to significant heterogeneity among the clinical studies included in this systematic review. Insufficient and inconsistent data were reported for predefined subgroups (such as stratification by age, sex, disease severity, or comorbidity status). In many instances, subgroup data were missing, inadequately reported, or based on small sample sizes, making any statistical pooling unreliable and susceptible to false-positive or false-negative findings. Therefore, more RCTs with similar methodology are needed to clarify this subject better and establish clear indications for the use of specific intra-articular injection agents in particular clinical situations. Arthrocentesis prior to injection also seems to have a beneficial effect on treatment outcomes. Consequently, it is important to study this topic uniformly and compare the clinical effects in terms of efficacy, safety, and long-term joint preservation against established injection therapies and analgesic effects in myogenous TMD with those of other intra-articular and intra-muscular injections, such as corticosteroids, collagen, or hyaluronic acid.

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Abbreviations

The following abbreviations are used in this manuscript:

PRP	Platelet-Rich Plasma
PRF	Platelet-Rich Fibrin
i-PRF	Injectable Platelet-Rich Fibrin
TMD	Temporomandibular Disorders
TMJ	Temporomandibular Joint
OA	Osteoarthritis
AO	Arthrocentesis
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PICOS	Population, Intervention, Comparator, Outcome, Study design
PROSPERO	International Prospective Register of Systematic Reviews
JBI	Joanna Briggs Institute
DC/TMD	Diagnostic Criteria for Temporomandibular Disorders
RDC/TMD	Research Diagnostic Criteria for Temporomandibular Disorders
ICOP	International Classification of Orofacial Pain
VAS	Visual Analogue Scale

NRS	Numerical Rating Scale
MMO	Maximum Mouth Opening
HA	Hyaluronic Acid
CS	Corticosteroids
DN	Dry Needling
NSAIDs	Non-Steroidal Anti-Inflammatory Drugs
RCT	Randomized Controlled Trial
PDGF	Platelet-Derived Growth Factor
TGF	Transforming Growth Factor
IGF	Insulin-like Growth Factor
BTX	Botulinum Toxin
LA	Local Anesthetic
QCRI	Qatar Computing Research Institute

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Systematic Review

Neurological Complications Following Temporomandibular Joint Injections in Patients with Temporomandibular Disorders: A Systematic Review of Reported Adverse Events

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Abstract

Background: Temporomandibular joint (TMJ) injections and arthrocentesis are commonly used minimally invasive methods for treating temporomandibular disorders (TMDs). Although considered safe, they can cause neurological complications. The aim of this systematic review was to synthesize all identified evidence for neurological adverse events following intra-articular TMJ interventions. **Methods:** This review was based on a systematic search with BASE, DOAJ, PubMed, SciELO, and Semantic Scholar on 28 May 2025. It included primary studies involving patients diagnosed with TMDs who underwent intra-articular injections into the TMJ or were treated with arthrocentesis, and in whom neurological adverse effects associated with the intra-articular intervention were reported. Studies reporting non-specific symptoms or unrelated systemic conditions were excluded. The risk of bias was assessed using the Joanna Briggs Institute's critical appraisal tools. Results were presented in summary tables. **Results:** The search yielded five eligible studies comprising 319 patients, of whom 320 neurological adverse events were reported. Included studies comprised a randomized controlled trial, two retrospective studies, and two case reports. Four studies had a low risk of bias, and one had a moderate risk of bias according to the Joanna Briggs Institute appraisal tools. The proportion of patients affected ranged from 14% to 65% depending on the study design and intervention type. The most common adverse event was transient facial nerve (cranial nerve VII) paralysis, mainly involving the temporal and zygomatic branches. Less commonly reported complications involved the trigeminal nerve branches (V1, V3). There is also a single case of epidural hematoma with palsy of the oculomotor nerve (III). Most symptoms resolved spontaneously within a few hours to a few days. The use of local anesthesia and large volumes of irrigation (60 mL) during arthrocentesis increases the risk of complications. Attempts to explain the mechanisms of complications include local anesthetic diffusion, compression neuropraxia due to lavage fluid leakage, and corticosteroid neurotoxicity. One of the limitations of the study is the scarcity of data. **Conclusions:** Although most adverse events are mild and reversible, these findings highlight that precise, real-time guided injection and careful

control of lavage volumes can minimize extra-articular spread of anesthetics or fluids, thereby reducing the likelihood of neurological complications. This study received no funding. PROSPERO ID number: CRD420251088170.

Keywords: temporomandibular joint; intra-articular injections; adverse effects; facial nerve diseases; arthrocentesis

1. Introduction

The temporomandibular joint (TMJ) enables mandibular movement relative to the temporal bones and is essential for mastication, speech, and swallowing. Temporomandibular joint disorders (TMDs) are a collective name for various deviations from the physiological norm in the functioning of the TMJ. TMDs manifest themselves with acoustic symptoms, pain, and limited mobility. In more advanced cases, there is degradation of both the structure of the articular disc and the articular surfaces on the mandibular head and temporal bone [1–5].

Treatment approaches range from conservative therapy to invasive interventions such as intra-articular injections, joint cavity rinsing, arthroscopic surgery, or even joint replacement with a prosthesis [2,5–11].

Intra-articular injections are an increasingly popular method of TMD treatment. Due to their invasiveness, they are an alternative to conservative treatment, especially in cases where it has ceased to be effective. Intra-articular injections are used to reduce inflammation and, consequently, relieve pain and improve joint mobility. Hyaluronic acid and blood products administered as autografts are primarily used for this purpose. Different substances reduce the symptoms of TMD in different ways. For example, an important mechanism of action of hyaluronic acid is the lubrication of joint surfaces, autologous products (e.g., platelet-rich plasma, injectable platelet-rich fibrin) have a chondroprotective potential, and inflammation reduction may be achieved by administering drugs [1,2,5,6,12,13].

Although injections into the TMJs are generally considered safe, they can lead to rare but potentially serious complications, including neurological complications. Neurological complications include symptoms such as paralysis, paresis, hypoesthesia, or paresthesia in the area of innervation. The mechanisms of these complications may include damage to the nerve by the needle, toxic effects of the administered substances, or secondary edema leading to compression of the nervous structures. These mechanisms were proposed by the authors of the included studies and represent hypotheses rather than definitive causal determinations. The facial nerve, the auriculotemporal nerve, and the anterior branch of the great auricular nerve run in the area of TMJ injection, and each of them can potentially become the subject of one of the complications discussed. Although these cases are relatively rare in the context of TMJ injections, their potential burden and impact on patients' quality of life deserve further investigation [14–19].

The anatomical proximity between the TMJ, parotid gland, orbit, and cranial cavity poses a potential risk for a variety of complications. Physiological and nonphysiological connections between anatomical spaces facilitate the spread of anesthetics or irrigating fluid. This increases the risk not only of unintended neural dysfunction but also of mechanical and chemical effects of the injected agent on other structures, such as connective tissue. Excessive intracranial or intraorbital pressure is a condition that requires immediate intervention and, while unlikely as a consequence of TMJ injection therapy, is potentially very serious [20–23].

Despite the increasing use of intra-TMJ injections, neurological complications have not been systematically summarized. Existing publications are limited to case reports or series, which do not allow for a broader analysis of mechanisms or preventive measures. This review fills this gap by systematically identifying, for the first time, all available evidence regarding neurological complications of intra-articular temporomandibular joint surgery, analyzing the mechanisms, and proposing preventive measures.

This review is intended to synthesize the available scientific literature on neurological complications resulting from intra-articular injections involved in the TMD treatment. The analysis focuses on identifying the complication types and severity, exploring potential risk factors, and discussing the mechanisms of their occurrence. These results may improve the safety of clinical practice and provide a better understanding of this rare but clinically significant group of complications.

Null hypothesis: The volume of the intra-articularly administered agent has no effect on the occurrence of neurological complications.

2. Materials and Methods

This study was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. It was registered in the International Prospective Register of Systematic Reviews (PROSPERO) under the number: CRD420251088170 [24,25].

The review was conducted to systematically compile and assess available evidence on neurological complications following intra-articular TMJ procedures, aiming to inform clinical decision-making and preventive strategies.

2.1. Eligibility Criteria

Studies involving patients diagnosed with TMDs were included in the review. Papers describing treatment with TMJ lavage or intra-articular injections into the TMJ or the TMJ area (e.g., in the bilamellar zone) were included. Studies involving more invasive concurrent procedures (e.g., arthroscopy, open surgery) were excluded.

For inclusion in this review, no comparator was required in a given study; however, a comparative meta-analysis of the incidence and severity of neurological complications between the following groups was planned as follows: (1) placebo injection (e.g., saline or Ringer's solution), (2) injection of an active substance (e.g., hyaluronic acid, platelet-rich plasma, platelet-rich fibrin injection, steroid, hypertonic dextrose, etc.), (3) joint lavage (arthrocentesis). A comparative analysis was initially planned, but could not be performed because of insufficient homogeneous data across the included studies.

The specific inclusion criterion for this review was the occurrence of at least one neurological symptom as a consequence of injection therapy in the presented group of patients. Neurological complications were defined as any nerve-related adverse events reported in the included studies, ranging from transient sensory disturbances (e.g., paresthesia, numbness) to persistent motor deficits (e.g., facial nerve palsy). Both minor and transient symptoms and more severe manifestations were considered eligible, provided they were explicitly described as neurological in origin by the study authors. The following were taken into account: (1) consequences of anesthesia for injection therapy, (2) mechanical action of the needle or fluid during intra-articular injection, and (3) the effect induced by the introduced substance. Pain as a sole symptom without accompanying sensory or motor deficit (unless the investigators made a diagnosis of neuralgia) and symptoms caused by a known comorbidity (e.g., diabetes, shingles) were excluded.

There were no restrictions on the type of study design, thus allowing studies with varying degrees of evidence, including (1) randomized controlled trials, (2) non-randomized

controlled trials, (3) uncontrolled studies and case series, (4) single case reports. The formal summary of inclusion and exclusion criteria for selection purposes is presented in Table 1.

Table 1. Summary table of study inclusion and exclusion criteria.

Framework Component	Criteria for Inclusion	Criteria for Exclusion
Patient population	Patient with TMDs	Cadaver or animal studies
Index intervention	TMJ intra-articular injection	More invasive concurrent procedure
Comparator (included in selected analyses only)	Placebo, active substance injection, or arthrocentesis	Not applicable
Outcomes	Neurological adverse effects related to intra-articular injections	Non-specific symptoms or unrelated systemic conditions
Study design and settings	Articles on primary studies	No English abstract available

2.2. Information Sources and Search Strategy

The identification of complications related to intra-articular TMJ injections and the development of search terms were described in our previous publication. The present systematic review used the keywords established in that work [23].

Initial searches were conducted using PubMed and Bielefeld Academic Search Engine (BASE). For transparency and the ability of readers to repeat searches, it was decided to use only open-access engines. Finally, the following electronic databases and platforms were searched: (1) Bielefeld Academic Search Engine (BASE), (2) Directory of Open Access Journals (DOAJ), (3) National Library of Medicine (PubMed), (4) Scientific Electronic Library Online (SciELO), and (5) Semantic Scholar. No filters or other modifiers were available as tools of the individual search engines were applied. All final searches were conducted on 28 May 2025.

Based on the above-mentioned eligibility criteria, subsequent queries were developed, and after completing the initial searches, the final search strategy was formulated as follows:

"(temporomandibular OR tmj OR tmd) AND (injection OR injections OR intra-articular OR intraarticular OR intra-cavitary OR intracavitary OR arthrocentesis OR rinse OR rinsing OR lavage) AND (paralysis OR paresis OR hypoesthesia OR paresthesia OR dysesthesia OR neuropathy)".

2.3. Selection and Data Processing

The authors (M.C., K.C.) performed blinded selection against the eligibility criteria based on the titles and abstracts. In case of discrepancies, the given record was promoted to full-text review on an equal footing with the unanimously approved ones. The full-text evaluation was performed on the same basis. No automation tools were used for selection. The same authors conducted a fully manual extraction into tables.

The following data were collected: (1) data identifying a given paper (first author, year of publication, unique identifier), (2) number of patients with neurological complications and total number of patients, (3) diagnosis (e.g., internal derangement, osteoarthrosis, degenerative joint disease, hypermobility), (4) type of intervention (arthrocentesis, injection, or combination), (5) injected substance (e.g., saline, Ringer's solution, hyaluronic acid, platelet-rich plasma, hypertonic dextrose), (6) number of injections, (7) volume per injection, (8) total volume administered, (9) type of complication, (10) information on resolution of the complication (transient with duration or persistent during the follow-up period with an indication of the length of follow-up), and (11) recurrence (in the case of resolution during the follow-up period).

The extracted data were organized into tables. A tabulated meta-synthesis was then conducted, arranged by cranial nerve affected. The synthesis included the number of previously reported cases of each complication and presented the proposed mechanism of action, including the interpretations provided by the authors of the individual source articles.

2.4. Study Risk of Bias Assessment

The risk of bias was assessed using the Joanna Briggs Institute's critical appraisal tools, which are specifically tailored to address various types of research, including randomized controlled trials, cross-sectional studies, and case reports [26]. These standardized checklists facilitate a critical evaluation of research studies by analyzing key methodological aspects.

The assessment was performed independently by two reviewers (M.C., I.C.). The inter-rater agreement was calculated using Cohen's kappa statistic. All discrepant assessments were resolved through discussion until a consensus was reached.

3. Results

3.1. Study Selection

The selection process is presented in Figure 1. Of the 132 records identified (Table A1), 113 were excluded based on the content of their titles and abstracts. The remaining 19 were deduplicated, where five records were rejected as duplicates. The resulting set was evaluated in full-text form, leading to further exclusions (Table A2).

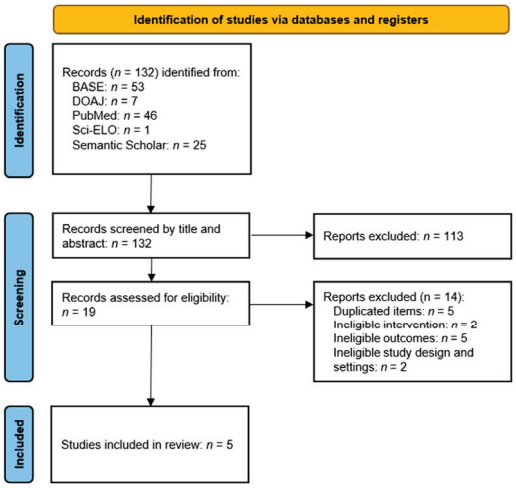

Figure 1. Flow diagram.

3.2. Study Characteristics

This systematic review included five studies published between 2000 and 2025. Two retrospective studies, two case reports, and a randomized controlled trial were incorporated. Their brief characteristics are presented in Table A3 [27–31].

3.3. Risk of Bias in Studies

The assessment of bias risk revealed that four studies had a low risk of bias [27–30]. The studies conducted by Baş et al. and Aliyev et al. fulfilled all the criteria of the Joanna Briggs Institute critical appraisal checklist, indicating high methodological quality [27,29]. Only one study demonstrated a moderate risk of bias due to the lack of identification and management of confounding factors and unclear statistical analysis [31]. The inter-rater agreement was almost perfect ($\kappa = 0.82$), indicating very good consistency between reviewers. A detailed assessment is presented in Tables A4–A6.

3.4. Results of Individual Studies

Table 2 summarizes studies that reported neurological complications after intra-articular temporomandibular joint procedures. Both drug injections and joint irrigation with solutions, often combined with auriculotemporal nerve blockade, were included. Details of the intervention and complications observed are provided for each study [27–31].

Table 2. Summary of studies reporting neurological complications following intra-articular interventions for TMJ disorders.

First Author, Publication Year	Diagnosis per Authors	Substance and Intervention	Intra-Articular Injection Volume	Neuro Complications (n/N)	Type and Course of Complication	Duration (Until Resolution or End of Observation)
Baş, 2025 [27]	Painful intra-articular temporomandibular disorders	Lidocaine local anesthesia and lactated Ringer solution two-needle arthrocentesis	60–100 mL in one session	30/210	Transient facial nerve paralysis (mainly temporal and zygomatic branches)	Resolved within a few hours
Carroll, 2000 [28]	TMJ dysfunction	Lactated Ringer solution arthrocentesis	60–80 mL in one session	1/1	Right-sided extradural haematoma with third nerve palsy and left hemiparesis; required craniotomy and clot evacuation; full neurological recovery	Neurological symptoms resolved within 2 weeks after craniotomy; 3-month follow-up was uneventful
Aliyev, 2019 [29]	Severe bruxism causing painful jaw locking and trismus in the right TMJ	Intra-articular articaine injection and two-needle arthrocentesis with lactated Ringer solution	2.5 mL articaine hydrochloride, 102–202 mL lactated Ringer solution (administration stopped during the second 100 mL portion)	1/1	Transient right-sided facial nerve paralysis; anesthesia of the inferior alveolar and lingual nerves	Resolved within 24 h (symptoms observed for ~2 h post-op; no complications on next-day follow-up)
Isacsson, 2019 [30]	Unilateral TMJ arthralgia without sounds in the affected joint	Auriculotemporal nerve block with 1.8 mL prilocaine-felypressin and intra-articular methylprednisolone 40 mg/mL	1 mL in one session	3/27 cases of eyelid paresthesia and 2/27 cases of numbness (overlap between cases not reported)	Transient paresthesias and numbness	Resolved during 4-week follow-up (exact timing not specified)
Vaira, 2018 [31]	Temporomandibular disorders	Auriculotemporal nerve block with mepivacaine with adrenaline; two-needle arthrocentesis with lactated Ringer solution; intra-articular sodium hyaluronate	100 mL lactated Ringer solution and 1.5–2 mL sodium hyaluronate	282/433 procedures in 315 patients	Transient frontalis and orbicularis oculis paresis (facial nerve)	Fully resolved with the end of the local anaesthesia effect

n—number of patients with neurological complications; N—total number of patients in the study.

Neurological complications can involve both sensory (e.g., ophthalmic or mandibular nerve) and motor (e.g., facial nerve) nerves and are usually transient. The most serious complication reported was an epidural hematoma with oculomotor nerve palsy, which also resulted in full recovery after neurosurgical treatment. In most cases, symptoms resolved spontaneously within hours or days, suggesting a dominant effect of the local anesthetic as the main mechanism of these complications [27–31].

3.5. Results of Syntheses

Owing to substantial heterogeneity in study designs, intervention protocols, and outcome definitions, a formal meta-analysis was not feasible, and results are presented descriptively.

Table 3 summarizes neurological complications identified in the analyzed material, grouped by damaged cranial nerves. For each nerve, the number of recorded cases and the presumed mechanism of the disorders are given [27–31].

Table 3. Neurological complications per cranial nerve in the entire dataset.

Cranial Nerve	Number of Cases	Assumed Mechanism
III (Oculomotor)	1	(1) Extradural hematoma due to vascular injuryor or (2) Solution leakage
V1 (Ophthalmic branch of trigeminal)	3	(1) Local anesthetic effect causing sensory disturbances (2) Administration of corticosteroids
V3 (Mandibular branch of trigeminal)	3	(1) Local anesthetic effect causing sensory disturbances (2) Administration of corticosteroids
VII (Facial)—temporal and zygomatic branches	313	(1) Diffusion of local anesthetic resulting in transient motor blockadeor or (2) Extravasation of irrigation fluid causing compressive neurapraxia

The analysis indicates that most of the described complications came from Baş et al. and Vaira et al. and concerned the facial nerve (VII), where the effects of the local anesthetic led to a transient blockade of motor functions. Complications related to the ophthalmic (V1) and mandibular (V3) branches of the trigeminal nerve were also reported, most likely resulting from the anesthetic effect. An exceptional complication, described only once, was an epidural hematoma, which manifested as contralateral hemiparesis and palsy of the unilateral oculomotor nerve [27–31].

4. Discussion

4.1. General Interpretation

This review found that most neurological complications following intra-articular TMJ procedures are transient facial nerve palsies, with a single report of epidural hematoma. The small number of studies and predominance of non-randomized designs limit the strength of conclusions.

The identified data on adverse neurological events associated with minimally invasive manipulations of the TMJ are scarce. It may be suspected that they are reluctantly reported or their reporting is limited to a brief mention in the full text of the article, which limits indexing and does not allow for identification through literature searches. In the included retrospective and controlled studies, the percentage of adverse events of the nature of excessive anesthesia is significant and amounts to up to 65%. Therefore, it should be suspected that this may be more frequent than currently reported, but robust data are

lacking. However, due to its transience with the wear off of the anesthesia effect and its low inconvenience, it may be omitted in the reports of many investigators [27–31].

All reported complications were related to the TMJ irrigation procedure or intra-articular corticosteroid injection. The most commonly affected nerve is the facial nerve (cranial nerve VII), especially its temporal and zygomatic branches, probably due to the diffusion of local anesthetic and involvement of neural branches that were not intended to be anesthetized. Another possible mechanism is neuropraxia from compression resulting from extravasation of irrigating fluids outside the joint cavity [27,29–31].

While most complications are minor and self-limiting, one serious complication has been reported—an epidural hematoma, which is an exceptional case but provides an idea of the risks associated with the proximity of the cranial cavity. The nature of this complication was not completely explained. Lactated Ringer solution 60–80 mL was used at that time, which could presumably be a volume sufficient to penetrate the cranial cavity (provided that an appropriate connection is created) and mechanically cause separation of the dura mater from the inner surface of the temporal bone. In such a scenario, it is natural that the resulting cavity, primarily filled with lactated Ringer solution, is replaced with blood over time. Another considered mechanism of this complication is laceration of a vessel large enough that the resulting bleeding was sufficient to produce the described hematoma. Nevertheless, the hypotheses of mechanisms remain speculative and not supported by direct anatomical or clinical evidence [28,32].

Apart from the above-mentioned single case of epidural hematoma, in the course of this review, no other neurological complications of TMJ injections or irrigations more serious than transient nerve conduction disturbance were identified in the world literature. The latter particularly concerned the temporal and zygomatic branches of the facial nerve, following their anatomical proximity. Apart from the hematoma, where the method of patient anesthesia was not presented, in all cases of neurological complications, intra-articular intervention was preceded by local anesthesia, often specified as auriculotemporal nerve block [27,29–31].

The use of an anesthetic before TMJ injection is not obvious. Some research teams administer substances intra-articularly without prior anesthesia of the area undergoing the procedure. This approach eliminates the risk of sensory disturbances and temporary motor block resulting from the diffusion of the anesthetic. The situation is different with double-needle (and presumably also double-lumen) arthrocentesis, where the amount of fluid passed through the joint cavity strongly supports the use of anesthesia. Furthermore, Baş et al. assume that not only the anesthesia itself, but also the leakage of the rinsing fluid outside the joint cavity may be the cause of neurological disorders, which they explain by mechanical compression and neuropraxia [6,12,27,31,33,34].

4.2. Future Perspectives

Neurological complications of intra-articular injections are primarily related to (1) the use of local anesthesia, (2) rinsing the joint cavity with at least 60 mL using the double-needle method, or (3) the administration of corticosteroids. Although they are transient, they may suggest irregularities in the technique itself. Excessive local anesthesia, involving subsequent nerve branches, is not the only possible mechanism of neurological complications typical of minimally invasive manipulations associated with TMJ. Leakage of rinsing fluid outside the joint cavity, resulting in neuropraxia and corticosteroid neurotoxicity, is another realistically considered mechanism of action leading to complications. Its occurrence suggests an imperfection of the blind injection technique into the joint cavity and even the presumably common but unaware extra-articular administration. Alternative

etiologies should be considered in the differential diagnosis, including surgical, infectious, and inflammatory processes affecting the head and neck region [27,29–31,35].

In the context of the above considerations, the following strategies can be considered to reduce the risk of extra-articular deposition or its sequelae:

(1) Minimize the risk of complications by administering a smaller volume—choose injection rather than arthrocentesis if possible.
(2) Choose substances safer with regard to deposition in an unintended location, including extra-articular or even intravascular.
(3) Attempt real-time guided deposition or per surgical template, although these are theoretical solutions, as the ultrasonography so far tested in this indication does not give unequivocal results [36–38].

Therefore, clinicians performing TMJ injections or arthrocentesis should consider using the minimal effective volume, employ meticulous technique to reduce extra-articular spread, and document any neurological symptoms. Future studies should use standardized complication definitions, report detailed procedural parameters, and evaluate preventive strategies such as image guidance.

4.3. Strengths

The systematic review was designed to ensure reliability, transparency, and reproducibility. Neurological complications associated with temporomandibular joint injections are rarely discussed in the literature, which makes this review innovative and potentially fills an important knowledge gap. The review has clinical significance, providing practical information for dentists, maxillofacial surgeons, and specialists treating TMJ disorders, helping to improve the safety of the procedures used. Another strength is the broad perspective that the review takes, including different injection techniques, such as intra-articular corticosteroids, hyaluronic acid, or platelet-rich plasma, as well as joint irrigation procedures.

4.4. Limitations

The data on neurological complications of TMJ injections and lavage are scarce. The incidence of neurological complications may be relatively high, but their reporting is unsatisfactory. There is a potential risk of publication bias, as studies reporting rare complications may be less likely to be published in the scientific literature. The heterogeneity of the methodologies used in the included studies, including differences in study designs, injection techniques, types of substances used, and diagnostic criteria for complications, makes it difficult to compare results and draw firm conclusions.

In addition to publication bias, potential sources of bias include language bias (eligibility required an English-language abstract), selection bias due to manual screening, reporting bias in case reports and small series, and the lack of long-term follow-up data. Due to the small number of studies and their heterogeneity, a formal assessment of publication bias (e.g., funnel plot asymmetry or Egger's regression test) was not feasible.

Given the finite list of medical article databases searched with the selected engines, there is a risk that papers published in less well-indexed journals were missed. The search strategy was intentionally limited to open-access databases to ensure replicability of the review. However, this approach may have led to the omission of relevant studies indexed solely in restricted-access databases. Manual screening and extraction, without the use of automation tools, may introduce selection bias and reduce reproducibility. This approach was adopted intentionally, as AI-based automation tools for study selection are still considered more error-prone, whereas human screening remains the gold standard in systematic reviews.

5. Conclusions

(1) Neurological complications following intra-articular injections for TMD are rarely described but potentially common, especially when local anesthesia and/or joint irrigation with 60 mL or more of fluid using the double-needle technique are used.
(2) The most common are transient facial nerve palsies (temporal and zygomatic branches), resulting from the spread of the anesthetic agent or pressure from fluid leakage outside the joint cavity.
(3) These mechanisms may result from an imprecise technique, suggesting the need for careful deposition and developing navigation to optimize clinical safety.
(4) Although most complications are mild and self-limiting, one case of epidural hematoma has been reported.

The conclusions of this review are based on a very limited number of studies, most of which have methodological constraints. Therefore, the certainty of evidence regarding neurological complications following intra-articular TMJ interventions is very low, primarily due to a low number of source studies, their observational designs, and small sample sizes.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

TMDs	Temporomandibular disorders
TMJ	Temporomandibular joint

Appendix A

Table A1. Number of records identified and database coverage on the day of the search.

Search Engine	Total Retrieval Range	Identified Records
Bielefeld Academic Search Engine (BASE)	423,038,726	53
Directory of Open Access Journals (DOAJ)	11,166,729	7
National Library of Medicine (PubMed)	Over 38,000,000	46
Scientific Electronic Library Online (SciELO)	14,388,173	1
Semantic Scholar	226,698,359	25

Table A2. Reports that were rejected at the full-text assessment stage.

First Author, Publication Year	Title	Digital Object Identifier (DOI) or Alternative	Reason for Exclusion
Huang, 2024 [39]	A clinical trial of ropivacaine in arthrocentesis for TMD	10.1186/s12903-024-04606-x	No neurological adverse events reported
Talaat, 2022 [40]	Minimally invasive surgeries for the treatment of temporomandibular disorders: Prognostic indicators and persistence of treatment outcomes over a 5-year follow-up	10.4103/abhs.abhs_14_21	Concomitant invasive co-intervention (arthroscopy)
Vervaeke, 2022 [41]	Correlation of MRI and arthroscopic findings with clinical outcome in temporomandibular joint disorders: a retrospective cohort study	10.1186/s13005-021-00305-y	No neurological adverse events reported
Ferreira, 2021 [42]	Clinical outcomes in TMD patients after arthrocentesis with lysis, lavage, and viscossupplementation	10.1080/07853890.2021.1897446	Conference proceeding; no neurological adverse events reported
Zhang, 2020 [43]	Gradient sequential treatment of temporomandibular joint disorders	10.12016/j.issn.2096-1456.2020.01.002	Review article
Patel, 2017 [44]	Clinical and radiological outcome of arthrocentesis followed by autologous blood injection for treatment of chronic recurrent temporomandibular joint dislocation	10.4317/jced.53812	No neurological adverse events reported
Bayoumi, 2014 [45]	Arthrocentesis followed by intra-articular autologous blood injection for the treatment of recurrent temporomandibular joint dislocation	10.1016/j.ijom.2014.05.004	No neurological adverse events reported
Etoz, 2010 [46]	Accidental use of alcohol during arthrocentesis of the temporomandibular joint	10.1016/j.bjoms.2010.11.010	Unintentional use of an inappropriate substance (alcohol)
Simpson, 1968 [47]	Auriculotemporal syndrome after injection into the temporomandibular joint: report of case	PMID: 4299382	Full text not retrieved

Table A3. Studies included in the review.

First Author, Publication Year	Title	Digital Object Identifier (DOI) or Alternative	Study Design
Baş, 2025 [27]	What Are the Complications of Temporomandibular Joint Arthrocentesis?	10.1016/j.joms.2024.12.012	Retrospective study
Carroll, 2000 [28]	Extradural haematoma following temporomandibular joint arthrocentesis and lavage	10.1080/02688690050004633	Case report

Table A3. *Cont.*

First Author, Publication Year	Title	Digital Object Identifier (DOI) or Alternative	Study Design
Aliyev, 2019 [29]	An unusual complication during arthrocentesis: *N. facialis* paralysis, with *N. lingualis* and *N. alveolaris* inferior anesthesia	10.17245/jdapm.2019.19.2.115	Case report
Isacsson, 2019 [30]	Pain relief following a single-dose intra-articular injection of methylprednisolone in the temporomandibular joint arthralgia—A multicentre randomised controlled trial	10.1111/joor.12718	Randomized controlled trial
Vaira, 2018 [31]	Complications and post-operative sequelae of temporomandibular joint arthrocentesis	10.1080/08869634.2017.1341138	Retrospective study

Table A4. Critical appraisal of the randomized controlled trial of Isacsson, 2019 [30].

JBI Critical Appraisal Criteria	Response
Was true randomization used for the assignment of participants to treatment groups?	Yes
Was allocation to treatment groups concealed?	Yes
Were treatment groups similar at the baseline?	Yes
Were participants blind to treatment assignment?	No
Were those delivering the treatment blind to treatment assignment?	Yes
Were treatment groups treated identically, other than the intervention of interest?	Yes
Were outcome assessors blind to treatment assignment?	Yes
Were outcomes measured in the same way for treatment groups?	Yes
Were outcomes measured in a reliable way?	Yes
Was the follow-up complete, and if not, were the differences between groups in terms of their follow-up adequately described and analyzed?	Yes
Were participants analyzed in the groups to which they were randomized?	Yes
Was an appropriate statistical analysis used?	Yes
Was the trial design appropriate, and were any deviations from the standard RCT design (individual randomization, parallel groups) accounted for in the conduct and analysis of the trial?	Yes

Table A5. Critical appraisal of analytical cross-sectional studies.

First Author, Publication Year	Were the Criteria for Inclusion in the Sample Clearly Defined?	Were the Study Subjects and the Setting Described in Detail?	Was the Exposure Measured in a Valid and Reliable Way?	Were Objective, Standard Criteria Used for Measurement of the Condition?	Were Confounding Factors Identified?	Were Strategies to Deal with Confounding Factors Stated?	Were the Outcomes Measured in a Valid and Reliable Way?	Was Appropriate Statistical Analysis Used?
Baş, 2025 [27]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Vaira, 2018 [31]	Yes	Yes	Yes	Yes	No	No	Yes	Unclear

Table A6. Critical appraisal of case reports.

First Author, Publication Year	Were the Patient's Demographic Characteristics Clearly Described?	Was the Patient's History Clearly Described and Presented as a Timeline?	Was the Current Clinical Condition of the Patient on Presentation Clearly Described?	Were Diagnostic Tests or Assessment Methods and the Results Clearly Described?	Was the Intervention(s) or Treatment Procedure(s) Clearly Described?	Was the Post-Intervention Clinical Condition Clearly Described?	Were Adverse Events (Harms) or Unanticipated Events Identified and Described?	Does the Case Report Provide Takeaway Lessons?
Carroll, 2000 [28]	Yes	Unclear	Yes	Yes	Yes	Yes	Yes	Yes
Aliyev, 2019 [29]	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

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Systematic Review

Quality of Life Outcomes Following Total Temporomandibular Joint Replacement: A Systematic Review of Long-Term Efficacy, Functional Improvements, and Complication Rates Across Prosthesis Types

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Abstract

Introduction: Total temporomandibular joint replacement (TMJR) is a well-established surgical solution for patients with severe TMJ disorders. It aims to relieve chronic pain, restore jaw mobility, and significantly enhance quality of life. This systematic review evaluates QoL outcomes following TMJR, analyzes complication profiles, compares custom versus stock prostheses, explores pediatric applications, and highlights technological innovations shaping the future of TMJ reconstruction. **Methods:** A systematic search of PubMed, Embase, and the Cochrane Library was conducted throughout April 2025 in accordance with PRISMA 2020 guidelines. Sixty-four studies were included, comprising 2387 patients. **Results:** Primary outcomes assessed were QoL improvement, pain reduction, and functional gains such as maximum interincisal opening (MIO). Secondary outcomes included complication rates and technological integration. TMJR consistently led to significant pain reduction (75–87%), average MIO increases of 26–36 mm, and measurable QoL improvements across physical, social, and psychological domains. Custom prostheses were particularly beneficial in anatomically complex or revision cases, while stock devices generally performed well for standard anatomical conditions. Pediatric TMJR demonstrated functional and airway benefits with no clear evidence of growth inhibition over short- to medium-term follow-up. Complications such as heterotopic ossification (~20%, reduced to <5% with fat grafting), infection (3–4.9%), and chronic postoperative pain (~20–30%) were reported but were largely preventable or manageable. Recent advancements, including CAD/CAM planning, 3D-printed prostheses, augmented-reality-assisted surgery, and biofilm-resistant materials, are enhancing personalization, precision, and implant longevity. **Conclusions:** TMJR is a safe and transformative treatment that consistently improves QoL in patients with end-stage TMJ disease. Future directions include long-term registry tracking, growth-accommodating prosthesis design, and biologically integrated smart implants.

Keywords: total temporomandibular joint replacement; temporomandibular joint; patient quality of life

1. Introduction

Disorders of the temporomandibular joint (TMJ) greatly impact patients' daily lives, often leading to persistent facial pain, limited jaw movement, difficulties with speaking or chewing, and emotional strain. Etiologies include osteoarthritis, trauma, ankylosis, rheumatoid arthritis, juvenile idiopathic arthritis (JIA), idiopathic condylar resorption, and congenital deformities. In severe cases, joint degeneration leads to airway compromise, malnutrition, and functional disability [1–4].

Historically, end-stage TMJ pathology was managed with autogenous reconstructions such as costochondral grafts. However, early alloplastic implants like Proplast-Teflon were associated with high failure rates, foreign-body reactions, and mechanical degradation [3,5]. These challenges led to the evolution of modern total temporomandibular joint replacement (TMJR) systems, including both FDA-approved stock prostheses (e.g., Biomet/Lorenz) and custom-fabricated prostheses (e.g., TMJ Concepts, Melbourne 3D-printed system) [2,6].

TMJR has become the preferred surgical treatment for patients with end-stage TMJ disease that does not respond to conservative management. A wide body of evidence supports its effectiveness in reducing pain, increasing jaw mobility, and improving essential functions such as chewing, speech, and quality of life. These functional improvements contribute to better nutrition, emotional well-being, and long-term QoL [7–12].

TMJR, while successful, carries risks. Heterotopic ossification (HO) occurs in 15–20% of cases without fat grafting but drops below 5% with prophylactic use of autologous fat [13,14]. Prosthetic joint infections are uncommon (3–4.9%) but can lead to prosthesis failure and necessitate staged revision [15,16]. Chronic postoperative pain affects 20–30% of patients, often linked to central sensitization or comorbid muscular disorders [17,18].

A critical decision in TMJR planning is choosing between stock and custom prostheses. Custom devices, derived from CT imaging via CAD/CAM, offer superior anatomical fit and are ideal for complex or revision cases [2,6,18]. Stock prostheses are readily available and lower in cost, providing comparable outcomes in patients with standard anatomy [8,19–22]. Meta-analyses have found no significant difference in overall pain relief or QoL outcomes between stock and custom designs when matched to appropriate cases [20,23,24].

Recent technological advances are rapidly improving TMJR precision and outcomes. CAD/CAM planning, virtual surgical simulation, and 3D printing allow for enhanced prosthesis customization [19,25,26]. Augmented reality (AR)–assisted navigation offers real-time visualization during surgery [27,28]. Meanwhile, innovations in biofilm-resistant coatings and smart implants are helping to reduce infection risk and monitor prosthesis health [5,26,29]. Tissue-engineered solutions, such as 3D-bioprinted condylar scaffolds, represent a future frontier in biologic TMJ reconstruction [29,30].

Historically, pediatric TMJR was avoided due to concerns over facial growth inhibition. However, recent studies have shown that in carefully selected skeletally immature patients, TMJR leads to substantial improvements in function, airway patency, and QoL—without short-term evidence of growth arrest [11,22,31,32]. Long-term surveillance remains essential, and the development of expandable or growth-accommodating prostheses is a key area of ongoing research [31,33–35].

Therefore, the objective of this systematic review is to evaluate the long-term quality of life (QoL) outcomes following total temporomandibular joint replacement (TMJR), with a focus on functional improvements, complication profiles, and differences between custom and stock prostheses across adult and pediatric populations.

2. Materials and Methods

2.1. Study Design

Although this review was not registered in PROSPERO, all steps—including objectives, eligibility criteria, search strategy, and synthesis plan—were pre-defined and followed to ensure transparency and reproducibility. This limitation is acknowledged in the manuscript.

2.2. Eligibility Criteria

Eligibility was defined using the PICOS framework:

- Population: Patients of any age undergoing total temporomandibular joint replacement (TMJR) for end-stage TMJ pathology, including osteoarthritis, rheumatoid arthritis, juvenile idiopathic arthritis, trauma, ankylosis, condylar resorption, or neoplasms.
- Intervention: Alloplastic TMJR using stock or custom prostheses. Studies including adjunctive procedures (e.g., fat grafting, orthognathic surgery) were included if TMJR outcomes were clearly delineated.
- Comparator: Studies with or without comparator groups were eligible. Comparisons could include pre- vs. postoperative outcomes, stock vs. custom devices, or TMJR vs. other surgical options.
- Outcomes:
    - Primary outcomes: Pain reduction (e.g., VAS scores), functional recovery (e.g., maximum interincisal opening [MIO]), and quality of life (e.g., SF-36, TMJ-specific PROMs, narrative assessments).
    - Secondary outcomes: Complication rates (e.g., heterotopic ossification, infection, prosthesis failure, persistent pain), long-term prosthesis survival, and the integration of advanced technologies (e.g., CAD/CAM, 3D printing, AR).
- Study Design: Randomized controlled trials (RCTs), prospective and retrospective cohort studies, and case series including $\geq$5 patients were included.

Exclusion Criteria:

- Case reports or series with <5 patients;
- In vitro or biomechanical-only studies;
- Editorials, reviews, commentaries, or abstracts without peer-reviewed data;
- Non-English language studies without available translations.

2.3. Search Strategy

Three databases were systematically searched from inception to 30 April 2025:

- PubMed (MEDLINE);
- Embase;
- Cochrane Library.

Search terms included combinations of MeSH and free-text keywords:

("temporomandibular joint replacement" OR "TMJ prosthesis" OR "TMJR" OR "total joint replacement") AND

("quality of life" OR "pain" OR "function" OR "MIO" OR "complications" OR "prosthesis type" OR "CAD/CAM" OR "3D printing" OR "pediatrics" OR "technology")

Filters were applied to include only human studies published in English.

Additionally, reference lists of included articles and relevant reviews were screened manually to identify further eligible studies.

2.4. Study Selection

Two reviewers independently screened all titles and abstracts. Full-text articles were retrieved for studies meeting inclusion criteria or requiring clarification. Disagreements were resolved by discussion or third-party adjudication. The study selection process is depicted in the PRISMA 2020 flow diagram (Figure 1).

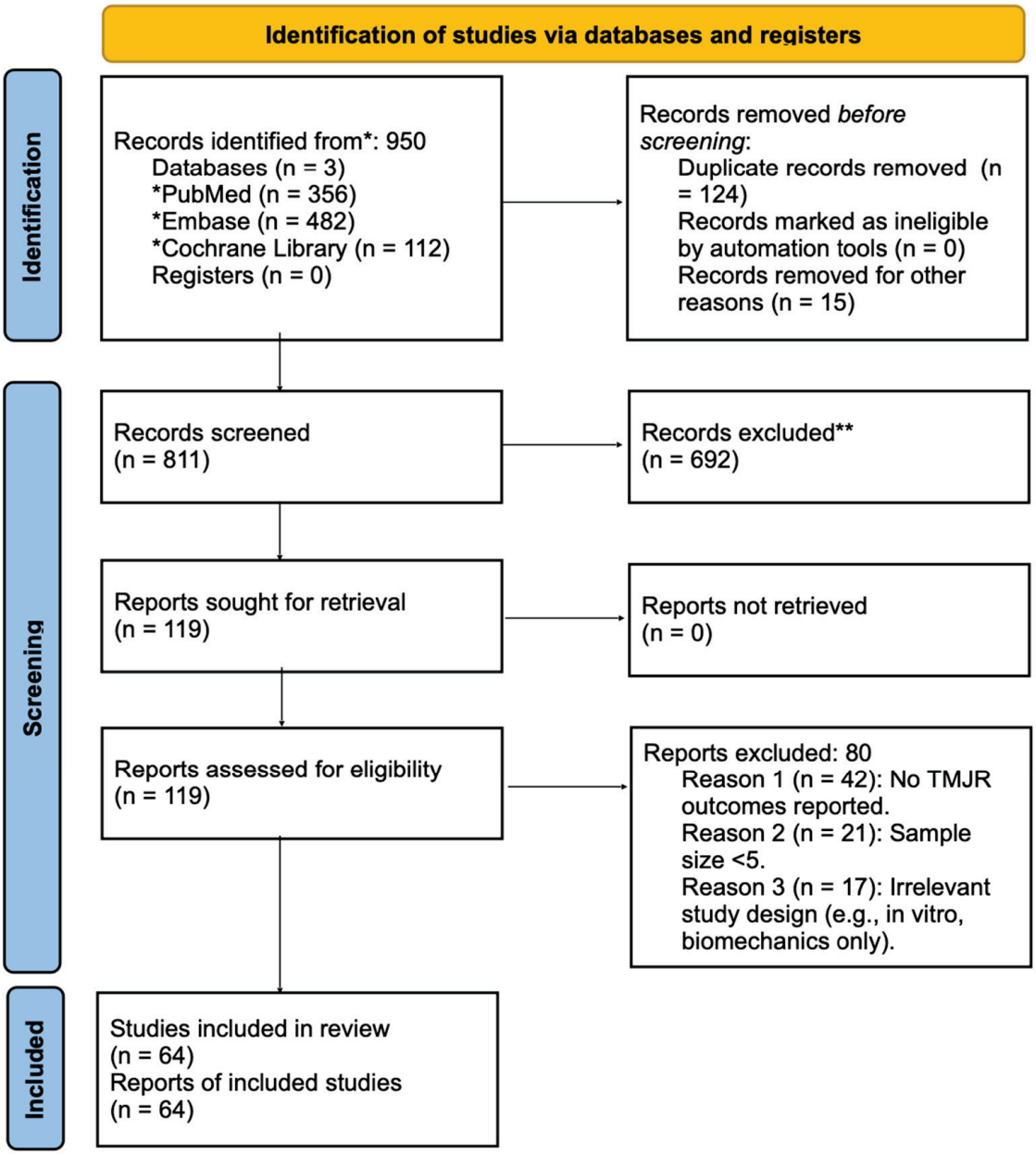

Figure 1. PRISMA 2020 flow diagram. * Studies retrieved for studies meeting inclusion. ** Studies that were excluded after screening.

2.5. Data Extraction

A standardized extraction form was used by two independent reviewers to collect the following:

- Study characteristics (authors, year, country, design);
- Sample size and demographics;
- Indications for TMJR;
- Prosthesis type (stock vs. custom; manufacturer if available);

- Surgical adjuncts (e.g., fat grafting, VSP):
    - Follow-up duration;
    - Outcome measures;
    - Pain scores (pre- and post-op);
    - MIO (pre- and post-op);
    - QoL measures (validated instruments or narrative satisfaction).

Complications (type and rate);
Use of technology (e.g., CAD/CAM, 3D printing, AR, tissue engineering);
Discrepancies in data extraction were resolved through consensus.

2.6. Risk of Bias Assessment

- Randomized controlled trials were assessed using the Cochrane Risk of Bias 2 (RoB 2) tool (11-13 Cavendish Square, London, W1G 0AN, United Kingdom)
- Observational studies were evaluated using the Newcastle–Ottawa Scale (NOS).

Studies were categorized as having low, moderate, or high risk of bias based on selection, comparability, and outcome assessment. Bias ratings were considered in the synthesis.

2.7. Data Synthesis and Analysis

1. Due to heterogeneity in study design, outcome measures, and follow-up durations, meta-analysis was not feasible. A qualitative synthesis was performed.
2. Findings were organized under the following domains:
3. Pain reduction;
4. Functional recovery (MIO, diet);
5. Quality of life outcomes;
6. Complications and management;
7. Prosthesis type comparison (custom vs. stock);
8. Pediatric TMJR outcomes;
9. Technological innovations (CAD/CAM, AR, 3D printing, tissue engineering).

Data was summarized in tables and narrative text where appropriate.

2.8. Ethical Considerations

This review involved no new human or animal data. All information is derived from previously published, peer-reviewed studies. As such, institutional review board (IRB) approval was not required.

3. Results

3.1. Study Selection

- The database search identified a total of 950 records: PubMed (n = 356), Embase (n = 482), and Cochrane Library (n = 112). After removing 124 duplicates and 15 non-relevant records (e.g., non-human studies, editorials), 811 records were screened by title and abstract. Of these, 692 were excluded based on the predefined eligibility criteria.
- Full-text review was conducted on 119 studies, with 80 excluded for the following reasons:

No reported TMJR outcomes (n = 42);
Sample size fewer than 5 patients (n = 21);
In vitro or non-clinical/technical studies (n = 17).

An additional 25 studies were identified through manual reference screening and citation tracking.

A total of 64 studies met all inclusion criteria and were included in the qualitative synthesis.

- No reported TMJR outcomes (n = 42);
- Sample size fewer than 5 patients (n = 21);
- In vitro or non-clinical/technical studies (n = 17);
- A total of 64 studies were included in the final qualitative synthesis: 39 studies from database screening and an additional 25 identified through manual reference screening and citation tracking.

3.2. Study Characteristics

The 64 studies included were published between 2002 and 2024, with sample sizes ranging from 5 to 1262 patients (Table 1). Cohort characteristics are summarized as follows:

- Age range: 13–72 years;
- Gender: Slight female predominance;
- Prosthesis types: 38 custom-fabricated, 19 stock, 8 hybrid or semi-custom;
- Follow-up periods: 6 months to over 20 years;
- Adjunctive procedures reported: fat grafting, orthognathic surgery, virtual surgical planning (VSP), CAD/CAM-guided surgery, and augmented reality-assisted navigation.

3.3. Quality of Life Outcomes

Across nearly all included studies, TMJR resulted in significant improvements in patient-reported quality of life (QoL). These were assessed using:

- The SF-36 Health Survey;
- TMJ-specific patient-reported outcome measures (PROMs);
- Narrative satisfaction reports or structured interviews.
- Reported QoL benefits included:
- Reduced pain and disability;
- Improved chewing, speech, and diet;
- Enhanced social confidence, sleep quality, and emotional well-being.
- Notable studies:
- Gupta et al. reported significant SF-36 improvements across pain, vitality, and social domains [7];
- Alba et al. observed airway, speech, and psychosocial gains in pediatric patients [11];
- Balel and Mercuri documented reduced somatization and anxiety [12].

3.4. Functional Outcomes and Pain Reduction

Maximum Interincisal Opening (MIO):

- Preoperative range: 8–25 mm;
- Postoperative range: 30–42 mm;
- Mean gain: 26–36 mm.

Sustained improvements were observed in ankylosis and complex TMJ cases, including pediatric patients [6,9,15,23,24,36–38].

Pain Reduction:

Most studies reported a 75–87% reduction in VAS scores.

- Consistent across unilateral and bilateral TMJR;
- Comparable between custom and stock prosthesis groups [7–9,15,20,30,39–44].

3.5. Complications and Management (Table 1)

- While TMJR is generally safe, reported complications included the following:

Table 1. Complications in TMJR.

Complication	Approximate Rate	Notes
Heterotopic ossification (HO)	~20% (without fat graft); <5% (with fat graft)	Prevented using autologous fat interposition [13,14]
Prosthetic infection	3–4.9%	Managed with antibiotics, debridement, or staged revision [15,16]
Mechanical failure/ loosening	~4–5%	Often seen in long-term follow-up; usually revised to custom [16,22,24,45]
Chronic pain	20–30%	Frequently due to central sensitization; treated with multimodal pain therapy [17,34]
Facial nerve injury	~10% transient; ~1–2% permanent	Minimized with careful dissection and nerve monitoring [46]

3.6. Stock vs. Custom Prostheses

- Custom prostheses demonstrated slightly better MIO recovery and anatomic fit in complex or revision cases [2,6,18,19,47–53];
- Stock prostheses were comparable in pain reduction, QoL outcomes, and overall satisfaction in routine cases [8,20–22,54–56];
- Meta-analyses and cohort comparisons found no statistically significant difference in functional outcomes when prosthesis selection was appropriate [20,23,24].

3.7. Pediatric TMJR

Pediatric patients undergoing TMJR experienced:

- Significant gains in function, chewing, speech, and psychosocial well-being [11,22,31,32];
- No clear evidence of mandibular growth inhibition during 2–8 years of follow-up;
- Ongoing monitoring is needed as some patients may require revision during growth;
- Development of expandable prostheses remains a critical research priority [33,35].

3.8. Technological Innovations

- Emerging technologies improving TMJR include the following:
- CAD/CAM and 3D printing—enhance implant fit, reduce intraoperative modifications [19,25,26,35,57,58];
- Augmented reality (AR)—assists with intraoperative alignment and surgical precision [19,28,59];
- Biofilm-resistant materials—silver-ion coatings and antibiotic-eluting surfaces to reduce infection risk [5,29,60,61];
- Smart prosthetics—force-sensing implants capable of detecting mechanical wear in real time [26,61,62];
- Tissue engineering—preclinical development of 3D-bioprinted condyles and biologic scaffolds [29,30].

These innovations are steadily transforming TMJR into a more personalized, durable, and biologically integrated treatment modality.

4. Discussion

4.1. Interpretation of Findings

This systematic review demonstrates that total temporomandibular joint replacement (TMJR) is a highly effective, safe, and durable treatment for end-stage TMJ disorders. Across varied populations and indications—including osteoarthritis, inflammatory arthritis, ankylosis, trauma, and idiopathic condylar resorption—TMJR consistently provides substantial

pain relief, functional restoration, and improved quality of life (QoL) [6–10,15,22,29]. Reported pain reductions range from 75 to 87%, while maximum interincisal opening (MIO) improvements average 26–36 mm. These outcomes translate directly into enhanced mastication, speech, airway function, and social participation [7–12].Consistent with our findings, Terletskyi et al. [63] emphasized that while patient-specific implants restore anatomy effectively, the preoperative functional baseline—particularly MIO—remains the most important determinant of long-term success.

4.2. Quality of Life Improvements

QoL enhancement emerged as a central outcome of TMJR, not merely a secondary benefit:

- Patients experienced improved diet, sleep, self-confidence, and return to normal life activities [7,10–12].
- Pediatric patients demonstrated parallel improvements in airway function, speech, and independence [11,22,31,32].
- Functional gains supported emotional and psychological recovery, reinforcing TMJR's role in restoring holistic well-being.

These outcomes support TMJR as a life-improving procedure, particularly in refractory or disabling TMJ disease.

4.3. Prosthesis Type Comparison: Custom vs. Stock

Both prosthesis types delivered excellent results when used appropriately.

- Custom prostheses offered superior anatomic fit and slightly better MIO improvements in complex or revision cases [2,6,18,19].
- Stock prostheses achieved comparable pain relief and QoL outcomes in routine cases, with the advantages of reduced cost and immediate availability [8,20–22].

Meta-analyses found no significant difference in patient satisfaction or complication rates when prosthesis selection was individualized [20,23,24].

4.4. Pediatric TMJR Applications

Historically avoided, pediatric TMJR is now supported by promising medium-term outcomes.

- Children with severe ankylosis or joint destruction experienced restored function, airway expansion, improved chewing, and speech [11,22,31,32].
- No definitive evidence of growth inhibition has been reported in studies with follow-up of 2–8 years.
- However, long-term surveillance is essential. Pediatric TMJR patients may require prosthesis revision as they mature.

Expandable or growth-accommodating prosthetic designs remain a key unmet need [21,31,35].

4.5. Complication Management (Table 2)

When performed by experienced teams using standardized protocols, TMJR complication rates are comparable to or lower than those of orthopedic joint arthroplasty.

Table 2. Complication Management.

Complication	Prevention/Management
Heterotopic ossification (HO)	Autologous fat grafting (reduces incidence to <5%) [13,14]
Infection	Perioperative antibiotics, debridement, staged revision if needed [15,16]
Prosthesis failure	Revision surgery, often converting to custom device [16,32,34]
Chronic pain	Multimodal therapy targeting central sensitization and myofascial dysfunction [17,33]
Facial nerve injury	Surgical planning, nerve monitoring, meticulous dissection [46]

4.6. Technological Innovations

Technological advancements are transforming TMJR from mechanical replacement to digitally guided, biologically integrated treatment:

- CAD/CAM and 3D printing improve implant fit and reduce operative time [19,25,58].
- AR-guided surgery improves precision during placement and reduces surgical error [27,28].
- Biofilm-resistant materials (e.g., silver-ion, antibiotic-eluting coatings) are in development to lower infection risk [5,29,61].
- Smart implants with embedded sensors are being explored to monitor joint loading and detect early mechanical wear [62].

Tissue-engineered constructs offer a biologic alternative, especially for pediatric or reconstructive patients [29,30].

Together, these technologies are leading TMJR toward greater personalization, durability, and data-driven optimization.

4.7. Future Directions

To continue advancing TMJR care and research, we recommend the following:

1. Long-term outcome registries (e.g., UK TMJR database) to track prosthesis performance, complication rates, and QoL at 10–20 years [30].
2. Standardized outcome reporting using validated metrics (e.g., SF-36, TMJ-specific PROMs, VAS, MIO) across all centers.
3. Expandable prosthesis development for pediatric use and staged revision [33,35].
4. Multidisciplinary care models involving surgeons, engineers, pain specialists, and rehabilitation professionals.
5. Smart and regenerative implants to achieve biologic integration, sensor-based monitoring, and long-term adaptability [29,30,61].
6. As TMJR evolves, its success will depend not only on structural reconstruction but also on biologic integration, patient-centered design, and long-term functional outcomes.

5. Conclusions

Total temporomandibular joint replacement (TMJR) is a safe, effective, and transformative treatment for patients with end-stage TMJ pathology. This systematic review confirms that TMJR consistently results in significant improvements in pain relief, mandibular function—including increased maximum interincisal opening—and overall quality of life (QoL). Both custom and stock prostheses offer reliable outcomes, with custom designs showing advantages in complex or revision cases due to their superior anatomical fit. Pediatric patients also benefit from TMJR, particularly those with ankylosis or severe joint damage, and short- to medium-term follow-up studies have shown no definitive evidence of growth inhibition. However, ongoing surveillance remains necessary, and the development of expandable or growth-accommodating prosthetic designs is an impor-

tant research priority. While complications such as heterotopic ossification, infection, and chronic postoperative pain can occur, most are preventable or manageable with appropriate surgical planning and perioperative care. Emerging technologies—including CAD/CAM planning, 3D printing, biofilm-resistant materials, and smart implants—are further enhancing the precision, durability, and personalization of TMJR. Future directions should focus on standardized outcome reporting, long-term registry data, and integration of biologically driven and sensor-enabled prosthetic designs to ensure continued improvement in patient-centered outcomes.

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Hypothesis

Quo Vadis Temporomandibular Disorders? By 2050, the Global Prevalence of TMD May Approach 44%

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Abstract

Background/Objectives: Currently, temporomandibular disorders (TMDs) represent a significant public health concern, affecting approximately 34% of the global population. The primary aim of this study was to determine the prevalence of TMDs in the year 2050. A secondary objective was to estimate the prevalence for the years 2030, 2075, and 2100. Methods: The methodology of a prognostic study was replicated and adapted to develop prevalence projections for TMDs, utilising the most recent meta-analysis of the global prevalence of temporomandibular disorders and analyses conducted within the R environment. Results: Projections indicate a gradual increase in the global prevalence of TMDs over the coming decades. In 2030, the estimated prevalence is 39% (95% confidence interval: 34–44%). This figure is expected to rise to 41% [36–46%] by 2040 and reach 44% [39–49%] by 2050. The upward trend continues, with projections suggesting a prevalence of 47% [42–52%] in 2075 and 49% [44–54%] by 2100. These data highlight a steadily increasing global burden of TMDs. Conclusions: By the year 2050, the global prevalence of TMDs is projected to reach 44%, which, according to estimates, corresponds to approximately 4,252,160,000 individuals. By 2030, 39% of the population is projected to experience TMDs. By 2075, the global TMD prevalence is expected to rise to 47%, and, by 2100, it could increase further to 49% of the global population. Urbanisation affects TMD prevalence in a region-dependent manner; a significant decrease was observed in Asia, while, in the Americas and Europe, the association was negligible. Globally, the lack of a clear impact of urbanisation on TMD occurrence suggests the influence of environmental and cultural factors.

Keywords: TMDs; temporomandibular disorders; meta-analysis; trends; prevalence; 2050; 2075; 2100; prediction; epidemiology

1. Introduction

"Quo vadis, Domine?"—this question is not only a symbolic inquiry into spiritual direction, but also a profound reflection on humanity's future in the face of suffering [1,2].

The Latin phrase "Quo vadis" means "Where are you going?" in English. In the context of medicine and biomedical sciences, the question "quo vadis?" refers to the search for ways to understand, diagnose, and treat diseases. It often arises in medical literature [3–7]. This question has also been posed in the present study in relation to temporomandibular disorders (TMDs).

TMDs refer to a group of dysfunctions involving the temporomandibular joint, the masticatory muscles, and adjacent structures, presenting with pain, limited jaw mobility, and joint sounds [8,9]. Currently, the global prevalence of TMDs is estimated at

approximately 30% [10,11]. However, according to the latest meta-analysis (2024), there is geographical variation in the prevalence of TMDs: South America (47%), Asia (33%), Europe (29%), and North America (26%) [10].

The aetiology of TMDs is complex and involves multiple co-existing factors [12–15]. The development of TMDs may be influenced by biomechanical, neuromuscular, biopsychosocial, and biological elements [14]. Psychosocial factors, including stress, anxiety, and depression, also play a significant role, as they can exacerbate muscle tension and pain symptoms [16,17]. Recent studies have highlighted the comorbidity of bruxism and TMDs [18–20]. Bruxism, through the chronic overload of the masticatory muscles and temporomandibular joints, can lead to increased muscle tension and degenerative changes within the joint, significantly contributing to the development and exacerbation of TMD symptoms [18–21]. The global co-prevalence of bruxism and TMDs is around 17%, with regional variations similar to TMDs alone [10]: 70% in North America; 24% in South America; 14% in Europe; and 9% in Asia [18].

Due to its complex aetiology and high prevalence, TMDs represent a significant economic burden both for healthcare systems and for individual patients [22–24]. The treatment of TMDs involves a multidisciplinary approach, including conservative methods and, in more severe cases, invasive interventions [25–28]. Fundamental therapeutic strategies include occlusal splints, physiotherapy, and relaxation techniques aimed at reducing muscle tension. Pharmacotherapy is often used as an adjunct, including non-steroidal anti-inflammatory drugs, analgesics, and, sometimes, botulinum toxin to reduce masticatory muscle activity [25,27,29]. In chronic cases that are resistant to conservative treatment, surgical procedures may be considered [30,31].

Based on the data presented, it is evident that TMD constitutes a significant issue from epidemiological, diagnostic, and therapeutic perspectives, holding an important position within the interdisciplinary field of modern medicine. Therefore, this study was undertaken to analyse future trends in the prevalence of TMD. At the outset, it is important to emphasise that determining disease trends in medical research always carries a risk of error [32–35]. Nevertheless, even if forecasts are not entirely precise, they remain of great importance as they enable preventive actions and the more effective planning of resources such as hospital bed availability, medical staff, and medicine supplies. Accurate prognostic forecasts enhance the value of diagnosis, allowing for more efficient crisis management [36].

Moreover, identifying health trends allows for the development of prediction-based health policies, including increased preventive efforts such as educational campaigns, vaccination programmes, or the adaptation of medical infrastructure. A lack of such information may, in the long term, pose a greater threat to prevention than the potential inaccuracy of forecasts, which can be corrected over time. In the context of the COVID-19 pandemic, forecasts based on mathematical models played a crucial role in addressing the global health crisis [37–39].

Forecasting the incidence of TMDs may constitute a significant contribution to long-term planning at both the clinical and systemic levels. As predicted, an increase in the prevalence of TMDs could lead to a greater burden on healthcare systems, necessitating appropriate adjustments in training strategies, resource allocation, and the development of policies focused on prevention and early diagnosis [22,40–43].

Adopting a long-term perspective on this issue enables the identification of potential gaps in the availability and quality of care, while also promoting the development of integrated treatment models based on epidemiological analyses [44–46]. In this context, the question “Quo vadis?” in relation to TMDs takes on particular significance, acting as a stimulus for policymakers and clinical practitioners to initiate measures that prepare healthcare systems for future challenges.

To the best of the author's knowledge, no studies have yet been published that forecast the future global prevalence of TMDs in a long-term framework. The projection presented in this work for the years 2030, 2050, 2075, and 2100 is, therefore, novel in nature and represents a meaningful expansion of the current body of knowledge. It may serve as a tool for enhancing the understanding of future epidemiological trends and predicting the potential burden on healthcare systems.

Incorporating long-term forecasts allows for the more precise planning of medical resources and the formulation of effective preventive and therapeutic strategies, which is of crucial importance both from a public health policy perspective and for clinical management within the field of TMD [47].

Therefore, in reference to the question posed in the title—Quo Vadis Temporomandibular Disorders?—a study was undertaken to determine the prevalence of TMDs in the year 2050. A secondary aim was to estimate the prevalence in the years 2030, 2075, and 2100.

2. Materials and Methods

The study design was registered with the Open Science Framework (OSF) under the identification number https://doi.org/10.17605/OSF.IO/U846T.

Based on the model proposed by Holden et al. [34], an attempt was made to estimate the hypothetical prevalence of TMDs in the years 2050 and 2100. The analysis covered six continents: North America, South America, Europe, Africa, Asia, and Australia. Data were grouped into three age categories, consistent with the classification used in the meta-analysis on TMD [10]: under 18 years, 18–60 years, and over 60 years.

Baseline prevalence data for TMDs in each age group were obtained from [10]—Supplementary Material S1. In cases where complete data were unavailable (partly for North America and entirely for Africa and Australia), global prevalence estimates by age group were used: 0–18 years (27%), 18–60 years (41%), and 60+ years (36%) [10]. These values were assumed to refer to the year 2020, in line with the cut-off date for the literature search in the meta-analysis [10], rounded to the nearest whole year (consistent with Holden et al. [34]).

2.1. Modelling and Estimation of Changes

The model developed by Holden et al. [34] was adapted for this analysis, employing linear regression to estimate future changes in TMD prevalence. This approach was deemed appropriate given the parallels between the increasing epidemiological trends observed in both myopia [34] and TMDs [10,11,48], as well as the shared multifactorial aetiology of these conditions (myopia [49–51] and TMDs [52–54]). The model incorporated current prevalence rates, changes in urbanisation ($R^2 = 0.07$) [34], and the Human Development Index (HDI, $R^2 = 0.74$) [55].

To translate the strength of the relationship between exposure variables and outcome, the hazard ratio (HR) was converted into a correlation coefficient (r), following a logistic regression and Cox-model-based approach [56,57]. Based on Bair et al. [58], a mean pseudo-R value of 0.57 was obtained. A 95% confidence interval was calculated for each forecast outcome [59,60].

2.2. Impact of Urbanisation on TMD Prevalence

Due to a lack of clear studies examining the effect of urbanisation on TMD prevalence, a systematic search of the PubMed and Scopus databases was conducted [21,61,62]. The keywords used were "TMD", "temporomandibular disorder", and "rural", with no date restrictions. Of 190 identified articles, 66 abstracts were reviewed, and 18 full texts were analysed. Due to the inability to export data based on urban or rural regions, the following

studies were excluded after full-text assessment: [63–67]. Ultimately, 13 studies [68–80] comparing TMD prevalence in urban and rural populations were included. The summary of the PICO standards (population, intervention, comparison, and outcome) [81,82] is found in Table 1.

Table 1. PICO summary.

P (Population)	I (Intervention/Exposure)	C (Comparison)	O (Outcome)
Individuals from urban and rural populations studied for TMD prevalence.	Urbanisation (percentage of population living in urban areas).	Populations with different levels of urbanisation (rural vs urban regions).	Prevalence of temporomandibular disorders.

Urbanisation rates (%) corresponding to the year of data collection were assigned based on literature values [55]. Studies were categorised by continent: America, Europe, and Asia. For each, linear regression (OLS—ordinary least squares) [83,84] was used to model the relationship between urbanisation (%) and TMD prevalence (%). Influential observations were removed using Cook's distance (>4/n) [85,86]. Coefficients of determination (R^2) were calculated, and regression coefficients were interpreted as the change in TMD prevalence per 1% increase in urbanisation.

These results were compared with the United Nations projections, indicating that 55% of the global population currently lives in cities, a figure expected to rise to 68% by 2050 [87]. As no forecast for the year 2100 was available, a linear extrapolation to 75% was adopted as a moderate and realistic assumption.

Assumed regression coefficients were as follows (Supplementary Material S2):

- For the Americas: −0.023 (i.e., a 0.023 percentage point decrease in TMD prevalence per 1% urbanisation increase);
- For Europe: ~0.000 (negligible effect of urbanisation);
- For Asia: −0.316 (i.e., a 0.316 percentage point decrease per 1% increase in urbanisation);
- Global coefficient: −0.0034. This indicates a negligible and likely clinically insignificant decrease of 0.0034 percentage points in TMD prevalence per 1% increase in urbanisation; yet, this was used in the analysis.

2.3. Annual Growth Model

To model a realistic rate of TMD prevalence increase, an exponential fit function was developed, based on the approach by Holden et al. [34]. The model accounts for a decreasing growth rate as prevalence approaches upper biological limits near 100%. The function was calibrated so that, for a baseline prevalence of 12% [58,88], it yielded an annual growth rate of exactly 3.5% [58] (Supplementary Material S3).

Final formula is as follows:

$$\Delta p_{annual} = 6.99 * e^{-0.057 * p_{2020}}$$

where:

- Δp_{annual} = annual change in TMD prevalence (percentage points);
- p_{2020} = baseline TMD prevalence in the year 2020;
- e = Euler's number (approx. 2.718) [89].

2.4. Age Adjustment Coefficients

To reflect age-related differences in growth rates, correction factors were developed. According to Bair et al. [58], annual prevalence growth was 2.9% (ages 18–24, n = 1421),

3.8% (ages 25–34, n = 736), and 4.7% (ages 35–44, n = 580). A weighted average annual growth rate of 3.52% for ages 18–44 was calculated and adopted as the reference for the broader 18–60 age group, in line with the meta-analysis range [10].

For the 0–18 group, a growth rate of 1.75% (correction factor: 0.50) was assumed, while, for the 60+ group, a rate of 1.3% (factor: 0.37) was applied. These values are based on empirical data and biological–demographic reasoning [10,11,21,34].

2.5. Model Limitations and Saturation Threshold

The adoption of a saturation threshold in forecasts is supported by both empirical evidence and methodological principles, in accordance with the standards of prognostic modelling and trend analysis. From a statistical perspective—particularly in linear regression applied to forecasting temporal values—the absence of anchoring the model within a realistic limit may result in the overestimation of future values and an illogical escalation of the trend [90–93].

Consequently, predictive analyses frequently employ the so-called saturation threshold [92–94], which defines the maximum level of a variable beyond which its growth rate diminishes, and forecasted values either stabilise or begin to decline.

Models of this nature have been known since the nineteenth century; for instance, the Belgian mathematician Pierre François Verhulst (1804–1849) developed the logistic model to describe constrained population growth in the context of finite environmental resources [90,91].

In the context of the epidemiology of TMDs, a 60% threshold has been grounded in empirical data: it represents twice the prevalence estimated by meta-analyses (~30% in 2020) [10,11], while simultaneously being corroborated by selected studies reporting values near or exceeding 60% in large population samples (n > 500) [95–97]. Although such values lie at the upper boundary of known data, they are observable in specific populations or under broad definitions of symptoms.

Therefore, the adoption of a 60% saturation threshold is methodologically justified and appropriate within the framework of modelling limited growth functions. This approach helps to avoid distortions arising from linear extrapolation and enhances the accuracy of predictions concerning the epidemiological dynamics of the phenomenon.

2.6. Omission of Gender Factor

Gender differences were not included in the model. A 2024 meta-analysis [10] found no statistically significant differences in TMD prevalence between men and women. Although female sex hormones may influence pain symptom severity, their role in TMD aetiology remains unclear [61,62].

2.7. Comparison with INED Data

The obtained results were compared with the exported data from the Institut national d'études démographiques (INED). The data referred to the projections available in May 2025, based on the Medium Scenario for the entire world [98].

2.8. Data Analysis

Analyses were conducted using the R Statistical language (version 4.1.1; R Core Team, 2021) on Windows 10 Pro 64 bit (build 19045), using the packages *metafor* (version 3.8.1; [99]), *dplyr* (version 1.1.2; [100]), *ggplot2* (version 3.4.0; [101]), readxl (version 1.4.5; [102]), scales (version 1.4.0; [103]), tidyr (version 1.3.1; [104]), and purr (version 1.0.4; [105]).

3. Results

Based on the conducted analyses, it was observed that, by 2030, the global prevalence of TMDs will reach 39%. In 2040, it will exceed 40%, reaching 44% by 2050. In subsequent years, it is projected to be 47% in 2075 and 49% in 2100. Detailed data are presented in Table 2 and Figure 1.

Table 2. Projected prevalence of TMDs for the years 2050, 2075, and 2100, including 95% confidence intervals.

Year	Projected Proportion	95% CI
2020	0.34 *	[0.29; 0.39] *
2030	0.39	[0.34; 0.44]
2040	0.41	[0.36; 0.46]
2050	0.44	[0.39; 0.49]
2075	0.47	[0.42; 0.52]
2100	0.49	[0.44; 0.54]

*—The data were added to illustrate the current state based on the work of [10].

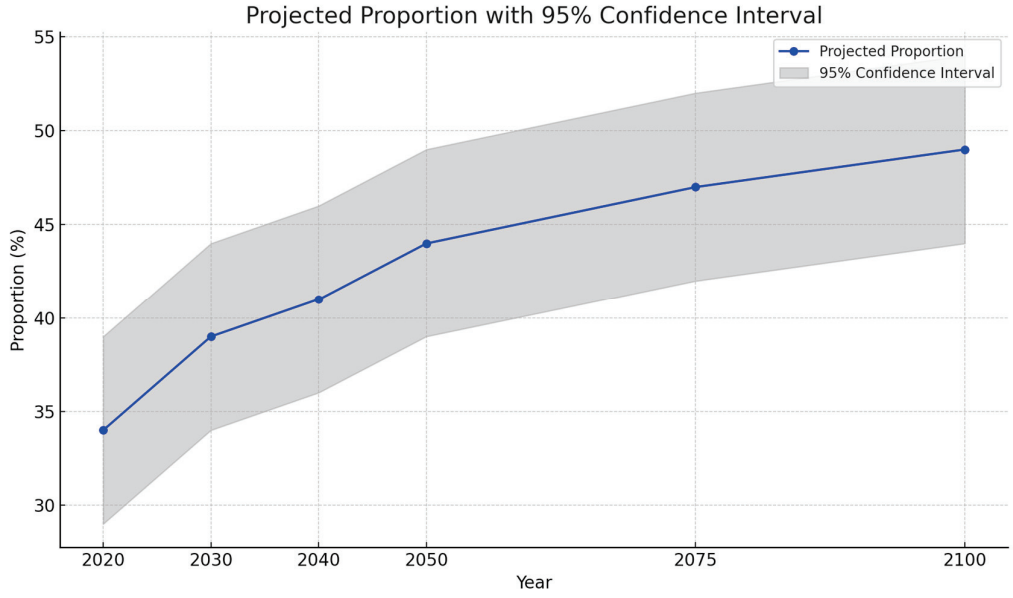

Figure 1. Graphical representation of the projected prevalence of TMD for the years 2050, 2075, and 2100, including 95% confidence intervals.

The results were compared with INED data [98]. According to estimates, the global population is projected to reach 9664 million people by 2050, 10,250 million by 2075, and 10,180 million by 2100 [98]. A comparison of the percentage data (Table 2) with INED projections suggests that, by 2050, at least one symptom of TMD will be present in approximately 4252.16 million people worldwide. By 2075, this number is expected to rise to 4817.50 million, and, by 2100, to 4988.20 million people globally.

In 2050, the estimated prevalence of TMDs in North America is projected to be 44%, while, in South America, it will reach 51%, representing the highest prevalence globally. In comparison, the prevalence in Europe is estimated at 37%, in Asia at 32%, in Africa at 43%, and in Australia at 43% (Figure 2). Due to a lack of detailed data for Africa and Australia, these figures have been averaged based on global estimates, as shown in Supplementary Material S1.

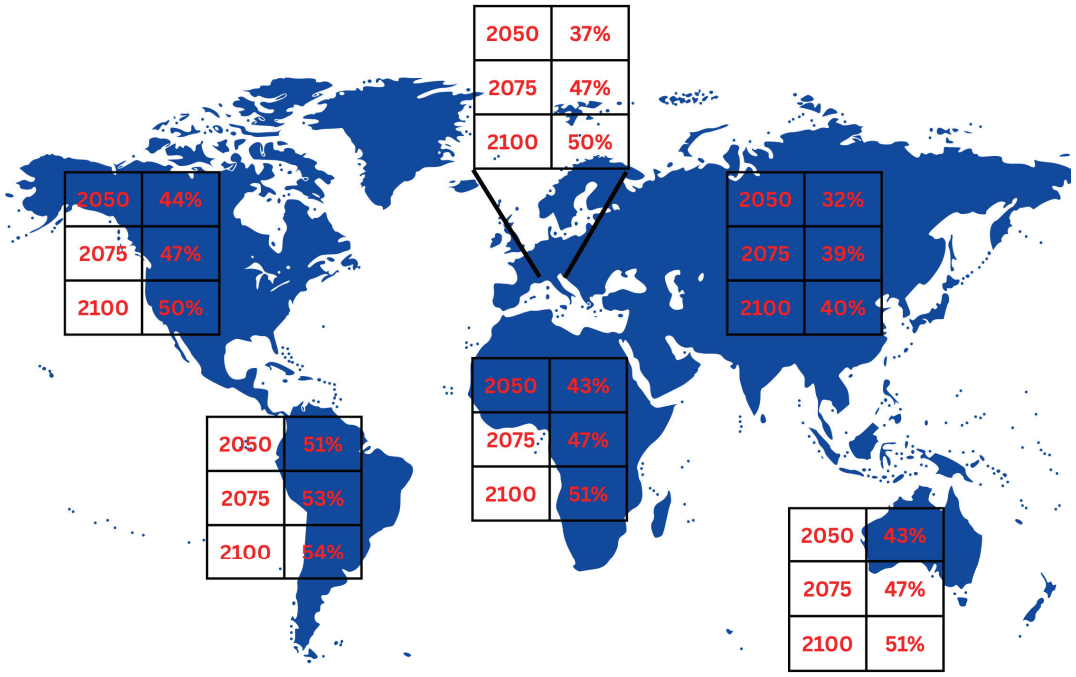

Figure 2. Graphical representation of TMD prevalence for the years 2050, 2075, and 2100 by continent.

In the following decades, a systematic increase in TMD prevalence is expected. By 2100, South America, Africa, and Australia are projected to exceed a 50% prevalence of TMDs in the population. Europe is expected to approach 50%, and Asia will near 40% (Figure 2). Detailed data on age distribution are presented in Table 3.

Table 3. Projected TMD prevalence for the years 2050, 2075, and 2100 by age group and continent.

Region	Age Group	Projected Proportion	95% CI	Projected Proportion	95% CI	Projected Proportion	95% CI	Projected Proportion	95% CI
		2030		2050		2075		2100	
Africa	0–18	0.31	[0.26; 0.36]	0.40	[0.35; 0.45]	0.45	[0.40; 0.50]	0.49	[0.44; 0.54]
Africa	18–60	0.43	[0.38; 0.48]	0.49	[0.44; 0.54]	0.52	[0.47; 0.57]	0.55	[0.50; 0.60]
Africa	60+	0.37	[0.32; 0.42]	0.42	[0.37; 0.47]	0.45	[0.40; 0.50]	0.48	[0.43; 0.53]
Asia	0–18	0.29	[0.24; 0.34]	0.34	[0.29; 0.39]	0.37	[0.32; 0.42]	0.39	[0.34; 0.44]
Asia	18–60	0.42	[0.37; 0.47]	0.42	[0.37; 0.47]	0.44	[0.39; 0.49]	0.45	[0.40; 0.50]
Asia	60+	0.36	[0.31; 0.41]	0.35	[0.30; 0.40]	0.36	[0.31; 0.41]	0.37	[0.32; 0.42]
Australia	0–18	0.31	[0.26; 0.36]	0.40	[0.35; 0.45]	0.45	[0.40; 0.50]	0.49	[0.44; 0.54]
Australia	18–60	0.43	[0.38; 0.48]	0.49	[0.44; 0.54]	0.52	[0.47; 0.57]	0.55	[0.50; 0.60]

Table 3. *Cont.*

Region	Age Group	Projected Proportion	95% CI	Projected Proportion	95% CI	Projected Proportion	95% CI	Projected Proportion	95% CI
		2030		2050		2075		2100	
Australia	60+	0.37	[0.32; 0.42]	0.42	[0.37; 0.47]	0.45	[0.40; 0.50]	0.48	[0.43; 0.53]
Europe	0–18	0.25	[0.20; 0.30]	0.38	[0.33; 0.43]	0.44	[0.39; 0.49]	0.48	[0.43; 0.53]
Europe	18–60	0.43	[0.38; 0.48]	0.49	[0.44; 0.54]	0.52	[0.47; 0.57]	0.55	[0.50; 0.60]
Europe	60+	0.34	[0.29; 0.39]	0.40	[0.35; 0.45]	0.44	[0.39; 0.49]	0.47	[0.42; 0.52]
North America	0–18	0.38	[0.33; 0.43]	0.43	[0.38; 0.48]	0.46	[0.41; 0.51]	0.50	[0.45; 0.55]
North America	18–60	0.43	[0.38; 0.48]	0.48	[0.43; 0.53]	0.52	[0.47; 0.57]	0.54	[0.49; 0.59]
North America	60+	0.37	[0.32; 0.42]	0.41	[0.36; 0.46]	0.44	[0.39; 0.49]	0.47	[0.42; 0.52]
South America	0–18	0.35	[0.30; 0.40]	0.41	[0.36; 0.46]	0.45	[0.40; 0.50]	0.49	[0.44; 0.54]
South America	18–60	0.56	[0.51; 0.61]	0.56	[0.51; 0.61]	0.57	[0.52; 0.62]	0.57	[0.52; 0.62]
South America	60+	0.56	[0.51; 0.61]	0.56	[0.51; 0.61]	0.56	[0.51; 0.61]	0.56	[0.51; 0.61]

Detailed results of the analyses can be found in Supplementary Material S4.

4. Discussion

The primary aim of this study was to determine the prevalence of TMDs in the year 2050. A secondary objective was to estimate the prevalence for the years 2030, 2075, and 2100. In response to the titular question, "Quo Vadis Temporomandibular Disorders?", the answer proposed is that TMDs are on a trajectory to exceed the 40% prevalence threshold worldwide. It is suggested that, by 2050, approximately 44% of the global population will be affected. This is expected to increase steadily, reaching 47% by 2075 and approaching 50% by the year 2100. The present article serves as a hypothesis which may be validated by future research.

TMD is an umbrella term that encompasses a range of diagnoses sharing common features such as pain, dysfunction, and restricted movement, although these conditions may have distinct aetiologies and require different therapeutic approaches [9,10,48,61,106]. It is important to emphasise that this analysis and its associated projections refer to TMDs in terms of this collective designation. The results presented here concern the occurrence of at least one TMD symptom within the studied population, based on data used as the foundation for the primary analysis [10].

Another key source instrumental in forming this analysis was the study by Holden et al. [34], which focused on myopia. It suggested that, by 2050, approximately 50% of the global population may experience myopia. Scientific literature indicates associations between refractive errors and TMDs, which provides a basis for comparing the findings of the two conditions [107–112]. Therefore, the 44% prevalence projected for 2050 in the current study may be considered a plausible and realistic hypothesis.

Even at present, some studies report TMD prevalence rates exceeding 40% [106,113, 114], and, in certain populations, figures as high as 60% have been observed [96,115,116].

However, as noted in a recent meta-analysis concerning the global prevalence of TMDs [10], geographic variability and related factors play a crucial role. These include genetic predispositions [117–119], anthropological characteristics [14,120], disparities in access to healthcare [121,122], the incidence of bruxism [18,21], and population-specific differences in pain perception [123,124].

In light of these considerations, the assumption adopted in this study—that, by 2050, approximately 44% of the global population may exhibit at least one TMD symptom—appears to be both realistic and well-founded in the existing epidemiological data.

4.1. Geographic Differences in the Prevalence of TMD

The geographical variation in the prevalence of functional disorders of the masticatory system, known as TMDs, is a complex, multifactorial phenomenon. Among the key determinants of this variation are genetic predispositions, which are increasingly recognised as a significant component in the aetiopathogenesis of TMDs [117–119]. At the same time, environmental and cultural factors, as well as differing population exposures to risk factors such as bruxism, are also highlighted.

Recent meta-analyses point to a significant co-occurrence of bruxism and TMDs [18,19]. The global average prevalence of both conditions occurring together is approximately 17%, though this figure varies widely by region. In North America, the prevalence reaches as high as 70%; in South America, it is 24%; in Europe, 14%; and, in Asia, only 9% [18]. These differences may reflect both the distinct aetiological factors and variations in diagnostic methodologies employed in different regions [10].

One potential factor influencing these differences is the variation in pain perception and tolerance [123,124]. Global epidemiological studies covering 52 countries have shown that the average prevalence of chronic pain is 27.5%, with rates ranging from 9.9% to 50.3% depending on the country [125]. Furthermore, numerous scientific reports indicate differences in pain thresholds between ethnic groups. For instance, studies conducted in the United States have found that members of racial and ethnic minority groups tend to have a lower pain tolerance and greater sensitivity to pain stimuli [126].

Another important aspect is the accessibility and quality of healthcare, which can significantly affect epidemiological data. The literature highlights the substantial variation in healthcare spending between countries and regions, which does not always correlate with the quality of medical services or treatment outcomes [127]. Increasingly, research emphasises the need for systemic health policy interventions aimed at reducing regional disparities in access to healthcare services [128,129].

In summary, the observed geographical differences in the prevalence of TMDs may result from an interplay of biological, cultural, environmental, and systemic factors. This phenomenon requires further multi-centre epidemiological studies and an interdisciplinary research approach to deepen our understanding of the pathomechanisms of TMD and to develop more effective preventive and therapeutic strategies.

4.2. The 44% of the Population with TMD by 2050—What Comes Next?

Contemporary diagnostic and therapeutic approaches to the management of TMDs are demonstrating increasing efficacy and precision. Technological advancements, the expansion of medical knowledge, and the adoption of interdisciplinary strategies are contributing to a deeper understanding of the aetiopathogenesis of TMD and the optimisation of treatment pathways [27,130–132]. As outlined in the introduction to this paper, the current spectrum of available treatment modalities for TMDs encompasses both conservative strategies and more invasive interventions, selected individually based on the patient's clinical phenotype [25–28].

Despite significant progress in this field, there remains a pressing need for continued intensive clinical and experimental research aimed at further refining diagnostic, therapeutic, and preventive methods. Particular emphasis should be placed on the development of strategies grounded in personalised medicine, taking into account genetic, environmental, and psychological factors that influence the clinical manifestation of TMD [8,10,16,17,117,119,130,132].

In the coming years, the advancement of artificial intelligence (AI) is likely to play a pivotal role, as its application in medicine becomes increasingly widespread [133–135]. Within the context of TMD, AI-based technologies may significantly enhance diagnostic processes, for example, through the analysis of imaging data (e.g., MRI, CBCT), symptom patterns, or data collected via digital tools [136,137]. Furthermore, machine-learning algorithms may, in the future, assist in therapeutic decision-making and the identification of high-risk patients, thereby enabling the implementation of early preventive interventions [133–137].

4.3. Limitations of the Forecast

Although this forecast is based on available data and reasonable assumptions, it is subject to a number of significant methodological limitations, which have been discussed in detail in the Introduction and the Materials and Methods sections. However, it is important to emphasise these issues explicitly here.

One of the main limitations of this analysis is the necessity of applying averaged global epidemiological values to estimate forecasts for entire continents such as Africa, Australia, and—in some cases—North America. This approach was necessitated by the lack of sufficiently detailed local source data, which represents a common challenge in modelling and prognostic studies of this kind [34].

An additional limitation involves the use of averaged urbanisation indices for the aforementioned regions, which may not fully capture the internal diversity within each continent. Despite these shortcomings, it should be noted that the substitution of missing data with estimated or averaged values is a widely accepted practice in population analyses and epidemiological forecasting, provided that such substitutions are properly documented and interpreted [34].

Another limitation of the analysis is the omission of sex-related differences. This decision was based on the findings of a recent meta-analysis, which did not reveal statistically significant differences in the prevalence of TMD between women and men [10]. Nevertheless, in light of the ongoing debate regarding the potential influence of hormonal factors on the pathophysiology of TMDs [61,62], as well as reports indicating a higher prevalence of the disorder among women, this omission should be acknowledged as a potential limitation that may influence future findings and their interpretation.

It should be clearly emphasised that the presented projection constitutes a prognostic hypothesis which—like any prediction based on statistical modelling—may or may not be confirmed by future empirical data. Its accuracy may be influenced by numerous dynamic and unpredictable external factors that were not accounted for in the present meta-analysis. Potential confounding variables include, among others, global health crises (e.g., pandemics), international conflicts, and political and regulatory changes (both those facilitating and those limiting access to healthcare services), as well as shifts in the demographic structure of the population. A significant impact may also arise from the advancements in the diagnosis and treatment of TMDs, including the development of new, more effective therapeutic approaches. In light of these considerations, the results presented herein should be interpreted as an approximation of a potential epidemiological trajectory rather than as a definitive or unchallengeable prediction.

In light of the above, the results presented here should be interpreted with caution—as an approximation of a potential trend, rather than a definitive prediction. They are intended to serve more as a starting point for further research than as a conclusive statement regarding the future prevalence of TMDs.

5. Conclusions

- By the year 2050, the global prevalence of TMDs is projected to reach 44%, which, according to estimates, corresponds to approximately 4,252,160,000 individuals.
- By 2030, 39% of the population is projected to experience TMDs. By 2075, the global TMD prevalence is expected to rise to 47%, and, by 2100, it could increase further to 49% of the global population.
- Urbanisation may exert varying effects on the prevalence of TMDs depending on the geographical region. The strongest association has been observed in Asian countries, where an increase in urbanisation levels correlated with a statistically significant decrease in TMD prevalence. In the Americas and Europe, this relationship was weak or not demonstrated. On a global scale, the analysis did not confirm a significant impact of urbanisation on TMD epidemiology, which may suggest the importance of environmental and cultural determinants in its aetiopathogenaesis.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jcm14134414/s1, Supplementary Material S1—Exported Data; Supplementary Material S2—Analysis of the Impact of Urbanisation on TMD Prevalence; Supplementary Material S3—Annual Growth Model; Supplementary Material S4—Detailed Results.

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Systematic Review

The Co-Occurrence of Temporomandibular Disorders in Patients Diagnosed with Tinnitus: A Systematic Review with Meta-Analysis

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Abstract: Background/Objectives: Persistent and distressing tinnitus and TMDs may significantly impair the quality of patients' lives. Problems are particularly severe for those who experience both. Although the exact causes of this association are not fully understood, several hypotheses connect TMD conditions with otological symptoms. **Methods:** The systematic review presented involved records published between 1 January 2004 and 27 November 2024, in the databases PubMed, Scopus, and Web of Science, according to the PRISMA guidelines. The search queries included "temporomandibular disorder" and "tinnitus". Inclusion and exclusion criteria were predefined according to PECOS. A risk of bias assessment and meta-analyses were performed. The study's protocol was registered in PROSPERO (CRD42024533293). **Results:** Eleven studies included in this review fulfilled all the predefined criteria. In a sample of 114,071 tinnitus patients, 50.99% (95% CI: 33.31–68.54) also had coexisting TMDs. Furthermore, tinnitus patients had more than 2.2 times higher odds of having TMDs compared to the control group ($p = 0.002$ for random effects). The absence of data regarding randomisation, blinding, and sample size justification was the most frequent risk of bias. **Conclusions:** Tinnitus frequently co-occurs in patients who suffer from TMDs. It is essential to expand the diagnostic evaluation of patients to confirm its presence and assess its impact on their quality of life. Additionally, dental consultation should be considered to evaluate patients about TMD signs and symptoms when suffering from tinnitus.

Keywords: tinnitus; temporomandibular disorder; temporomandibular joint

1. Introduction

Tinnitus is used to describe the continuous sensation of sounds inside the head or ear without any external acoustic stimulus in the auditory pathway [1]. It accompanies a variety of diseases affecting the auditory organ, and may coexist with some systemic or organ-associated conditions [2]. The perceived sound may be experienced centrally in the head, binaurally or monoaurally, and may present with various frequencies and intensities [3]. Patients identify the sensation of tinnitus as a ringing, buzzing, or whistling sound. Pathophysiological models assume that tinnitus may stem from the brain's inability to adapt to the fact that sensory information is not delivered from the inner ear—a key element in the aetiology of its onset. This, in turn, leads to the activation of a compensatory

mechanism in the brain, which results in increased neuronal activity along the auditory four-neuron pathway. This heightened activity is thought to be a maladaptive response, where the brain "fills in the gaps" with spontaneous neural firing, which patients perceive as tinnitus. Essentially, tinnitus may arise because the brain attempts to adjust to missing auditory input but ends up generating abnormal neural signals instead [4].

In 1995, Jastreboff performed the precise classification of tinnitus according to its nature, and differentiated it into subjective and objective [5]. In terms of epidemiology, subjective tinnitus is the most commonly observed form, and it derives exclusively from mechanical activity within the inner ear and impaired function of the central nervous system or of the vestibulocochlear nerve (CN VIII). The underlying causes of subjective tinnitus are most frequently otologic in character [2,6]. In contrast, objective tinnitus, also referred to as somatosound or pseudo-tinnitus, is a type of noise that is perceptible not only for the patient, but also for other individuals. In fact, objective tinnitus may be detected and recorded using measuring devices. Its underlying causes include cardiovascular disorders, intracranial hypertension, soft palate myoclonus, and myoclonic spasms of the middle ear muscles, and it may also be associated with temporomandibular joint disorders (TMDs). In the case of the latter, tinnitus has been reported in approximately 65% of patients [7]. Interestingly, the literature suggests that mandibular crowding may also potentially contribute to the occurrence of tinnitus [8,9].

Various experimental studies have emphasised that tinnitus is a diversified phenomenon and that it cannot be regarded as a disease, but rather as a subjective symptom. Conversely, temporomandibular disorders involve the complex musculoskeletal system of the jaw as well as the surrounding structures. Therefore, tinnitus and TMDs constitute two complex medical issues, which may interact in a number of respects [10]. Crucially, the impact of craniofacial health issues on the severity of tinnitus remains poorly understood. The pathophysiology of TMDs may be linked to otological disorders, due to the anatomical proximity of the cochlea and temporomandibular joint (TMJ), through the connections of the nerve and blood vessels. Furthermore, temporomandibular joint inflammation or mechanical damage may result in pressure on nerves and blood vessels, which in turn may contribute to a range of ear symptoms [11]. These involve a feeling of ear fullness (74.9%), ear pain (65.0%), increased otalgia (55.1%), tinnitus (52.2%), vertigo (40.9%), and dizziness (21.9%), as well as hearing loss (39.0%) [7].

TMDs have a multifactorial aetiology, involving both objective (biological) and subjective (psychosocial) factors. The development of TMDs may result from a combination of genetic predisposition, the mechanical overload of the masticatory muscles (e.g., excessive parafunctional activity such as bruxism), structural changes within TMJ (e.g., disc displacement, osteoarthritic changes), or trauma. Additionally, inflammatory processes and systemic conditions, such as rheumatoid arthritis, can contribute to TMDs. Psychosocial factors, including stress, anxiety, and pain-related central sensitisation, also play a significant role in the onset and persistence of symptoms [12,13]. TMDs are observed in approximately 34% of the population [14]. Hence, TMDs, which are quite common, may significantly affect the severity of tinnitus. Additionally, research results indicate that up to 57.5% of dental patients may experience such issues simultaneously [15]. Therefore, it is vital to approach TMD patients holistically, also taking into consideration the potential otological and audiological complaints [16]. Although, clinically, tinnitus is not a life-threatening condition, it significantly decreases the quality of patients' lives; thus, the diagnosis necessitates the interdisciplinary involvement of multiple specialists, particularly in the areas of audiology, neurology, dentistry, and psychiatry [17].

TMJ is an integral part of the masticatory system; however, TMDs encompass a broader range of conditions, affecting not only the TMJ but also the associated muscles

and structures. According to the Diagnostic Criteria for Temporomandibular Disorders (DC/TMDs), the diagnostic process should include a thorough anamnesis, validated patient questionnaires, and a detailed clinical examination [18]. Clinical assessment involves the palpation of the masticatory muscles for tenderness, the evaluation of mandibular mobility, and the assessment of any associated symptoms, including pain and joint sounds. Imaging techniques, such as X-rays, computed tomography (CT), ultrasound (US), or magnetic resonance imaging (MRI), should only be used when necessary to confirm the diagnosis or to guide treatment decisions [19–21]. The diagnostic process of TMDs involves the careful analysis of information derived from the patient's subjective and objective examinations, which should subsequently lead to the identification of a specific disorder. In cases where a patient presents with a single disorder, the diagnosis is a relatively routine procedure. However, the clinician needs to take into consideration the fact that the patient may simultaneously suffer from more than one disorder, involving more than one structure, and that these may interact with each other [22].

When patients report otological symptoms, audiological diagnostics should be considered in order to assess the functioning of the auditory pathway, from the peripheral organ to the auditory centres located in the central nervous system. Moreover, neurological, cardiological, and psychiatric consultations are also recommended. Our systematic review aimed to evaluate the co-occurrence of TMDs in patients diagnosed with tinnitus.

2. Materials and Methods

2.1. Search Strategy and Data Extraction

The systematic review presented was conducted based on the records published between 1 January 2004 and 27 November 2024, according to the guidelines of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [23], and involved the databases PubMed, Scopus and Web of Science. The search queries were as follows:

- For PubMed: ("temporomandibular disorder" [MeSH Terms] AND ("tinnitus");
- For Scopus: TITLE-ABS-KEY ("temporomandibular disorder" AND "tinnitus");
- For Web of Science: TS = ("temporomandibular disorder" AND "tinnitus").

Two independent researchers reviewed the records for the title, abstract, and full text. The studies included in this review fulfilled all the predefined criteria according to PECOS ("Population", "Exposure", "Comparison", "Outcomes", and "Study design"), as shown in Table 1. A detailed search flowchart is included in the Section 3. The study protocol was registered in the international prospective register of systematic reviews PROSPERO (CRD42024533293).

The results of the meta-analysis were presented as forest plots using MedCalc Statistical Software, version 22.014 (MedCalc Software Ltd., Ostend, Belgium). The pooled prevalence and odds ratios of temporomandibular disorders in patients with tinnitus were calculated. Egger's test was used to assess potential publication bias in a meta-analysis.

2.2. Quality Assessment and Critical Appraisal for the Systematic Review of Included Studies

The risk of bias in each individual study was assessed according to the "Study Quality Assessment Tool" issued by the National Heart, Lung, and Blood Institute within the National Institute of Health [24]. Two independent researchers completed the questionnaires, and any disagreements were resolved through discussion.

The level of evidence was assessed using the classification of the Oxford Centre for Evidence-Based Medicine levels for diagnosis [25].

Table 1. Inclusion and exclusion criteria according to the PECOS.

Parameter	Inclusion Criteria	Exclusion Criteria
Population	patients with tinnitus—adults, both genders	patients with other neurological and hearing disorders
Exposure	temporomandibular disorders (TMDs)	other disorders of the oral cavity
Comparison	not applicable	
Outcomes	prevalence or odds ratio for TMDs in tinnitus patients	prevalence or odds ratio for tinnitus in TMD patients
Study design	case-control, cohort and cross-sectional studies	literature reviews, case reports, expert opinion, letters to the editor, conference reports
	published between 1 January 2004 and 27 November 2024	not published in English

3. Results

A total of 11 studies fulfilled the search criteria and were subsequently included in our critical review. The analysed papers provided data collected in six different countries. Figure 1 shows a detailed selection strategy of the records. The inclusion and exclusion criteria are presented in Table 1.

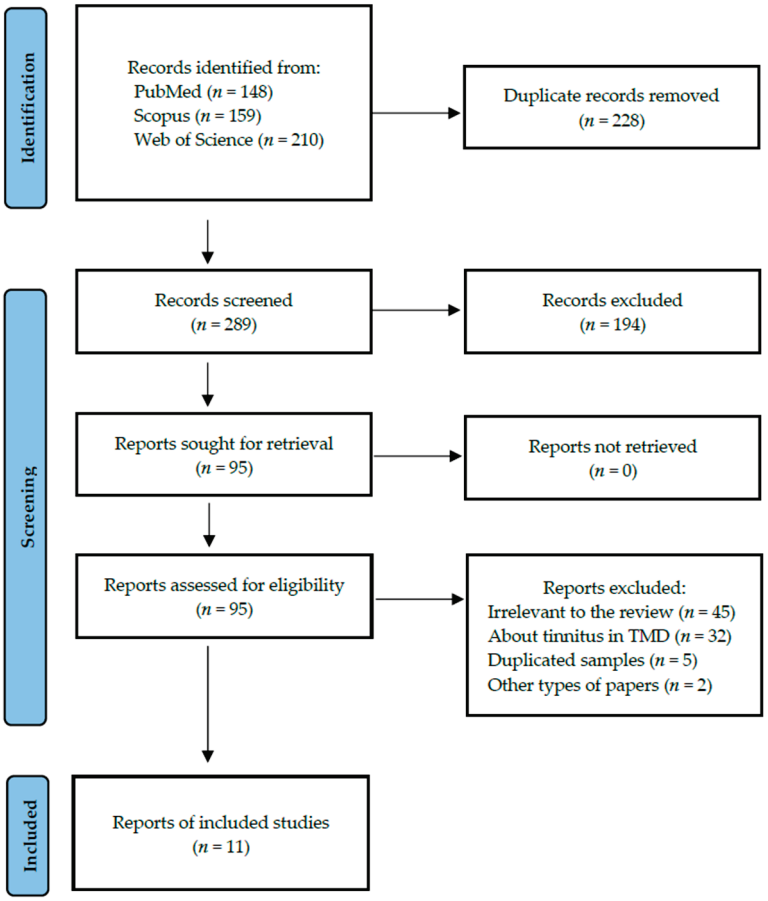

Figure 1. PRISMA flow diagram presenting search strategy.

Table 2 provides the details of the included studies, such as authors and year of publication, setting, study design, involved participants, tinnitus diagnosis, and clinical criteria for TMDs.

Table 2. Detailed characteristics of included studies.

Study	Setting	Study Design	Study Group (F/M, Age)	Control Group	Tinnitus Diagnosis	TMD Diagnosis
Attanasio et al., 2015 [26]	Italy	cross-sectional	55 (NR), mean 41.8	n/a	chronic subjective tinnitus lasted at least for the last 12 months	Wilkes Classification Stages I and II
Cimino et al., 2022 [27]	Italy	cross-sectional	79 (37/42), 44.41 ± 11.7	n/a	episode of sound perception in the absence of external sources for more than 5 min at least 2 times a week	according to the Diagnostic Criteria for TMDs (DC/TMD) Axis I protocol
Didier et al., 2023 [1]	Italy	cross-sectional	47 (NR), NR	n/a	somatosensory tinnitus	according to the diagnostic criteria for TMD Axis I (DC/TMD), as any condition associated with pain and dysfunction of the masticatory muscles or TMJ
Edvall et al., 2019 [28]	Sweden	cross-sectional	2482 (1222/1260)	n/a	according to Tinnitus Sample Case History Questionnaire	self-reported TMJ problems
Hilgenberg et al., 2012 [29]	Brazil	case-control	100 (84/16), mean 39.16 ± 12.01	100 (65/35), mean 34.33 ± 10.72	use of the Protocol of Tinnitus and Hyperacusis of HC-FMUSP	according to the research diagnostic criteria for TMDs (RDC/TMD) Axes I and II
Morais & Gil, 2012 [30]	Brazil	cross-sectional	20 (14/6), mean 32.1	n/a	identification of the tinnitus pitch and loudness by means of acuphenometry	checklist of TMD signs and symptoms
Pavaci et al., 2019 [31]	Italy	case-control	130 (55/75), mean 53.1 ± 13.97	100 (46/54), mean 46.16 ± 12.95	hyperacusis questionnaire (HQ) and the tinnitus handicap inventory (THI) in a self-administered way	not specified
Peleg et al., 2022 [16]	Israel	cross-sectional	51 (24/27), 51.26 ± 17.97	n/a	tinnitus for at least 6 months as reported by a patient; confirmed based on physical and an audiometric examination	according to the diagnostic criteria for TMDs (DC/TMD) Axes I and II
Stohler et al., 2019 [32]	the United Kingdom	case-control	109,783 (55,909/53,874), 54.7 ± 15.9	109,783 (55,909/53,874), age-matched	first-time-diagnosed tinnitus	not specified
Tullberg & Ernberg, 2006 [33]	Sweden	cross-sectional	120 (56/64), 47 ± 13	n/a	not specified	presence of TMD symptoms and signs
Vielsmeier et al., 2012 [3]	Germany	cross-sectional	1204 (451/753), 52.97 ± 13.28	n/a	according to Tinnitus Sample Case History Questionnaire	self-reported TMJ problems

Legend: F, female; M, male; n/a, not applicable; TMDs, temporomandibular disorders; TMJ, temporomandibular joint.

Our meta-analyses comprised all 11 studies (8 cross-sectional and 3 case-control studies) that reported TMD prevalence in patients suffering from tinnitus.

The pooled prevalence of TMDs in tinnitus patients is shown in Figure 2. According to the sample of 114,071 tinnitus patients, 50.99% (95%CI: 33.31–68.54) presented with co-occurring TMDs (Table 3). Moreover, considering the case-control approach, the odds of developing a TMD were more than 2.2 times higher in tinnitus patients as compared to the controls (p-value = 0.002 for random effects)—Figure 3 and Table 4.

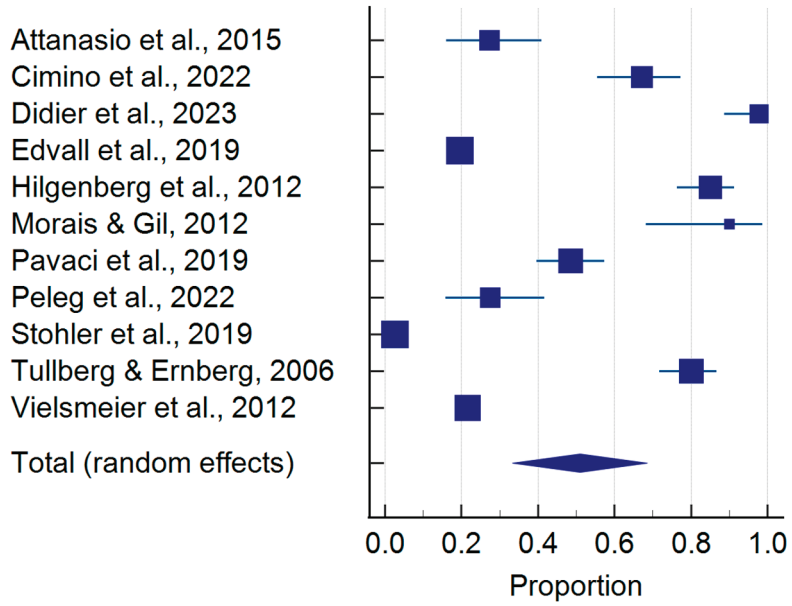

Figure 2. Pooled prevalence of temporomandibular disorders in tinnitus patients (squares—proportions for individual studies; diamond—polled proportion) [1,3,16,26–33].

Table 3. Detailed results of meta-analysis considering pooled prevalence of temporomandibular disorders in tinnitus patients.

Study	Sample Size	Proportion (%)	95% CI	Weight (%)
Attanasio et al., 2015 [26]	55	27.273	16.138 to 40.962	8.97
Cimino et al., 2022 [27]	79	67.089	55.601 to 77.252	9.10
Didier et al., 2023 [1]	47	97.872	88.706 to 99.946	8.90
Edvall et al., 2019 [28]	2482	19.581	18.036 to 21.198	9.40
Hilgenberg et al., 2012 [29]	100	85.000	76.469 to 91.355	9.16
Morais & Gil, 2012 [30]	20	90.000	68.302 to 98.765	8.31
Pavaci et al., 2019 [31]	130	48.462	39.610 to 57.385	9.22
Peleg et al., 2022 [16]	51	27.451	15.893 to 41.745	8.94
Stohler et al., 2019 [32]	109,783	2.501	2.410 to 2.595	9.41
Tullberg & Ernberg, 2006 [33]	120	80.000	71.719 to 86.745	9.20
Vielsmeier et al., 2012 [3]	1204	21.678	19.380 to 24.114	9.39
Total (random effects)	114,071	50.988	33.305 to 68.544	100.00
Egger's test (publication bias)		Intercept	95% CI	p-value
		16.3805	10.1555 to 22.6055	0 = 0.0002

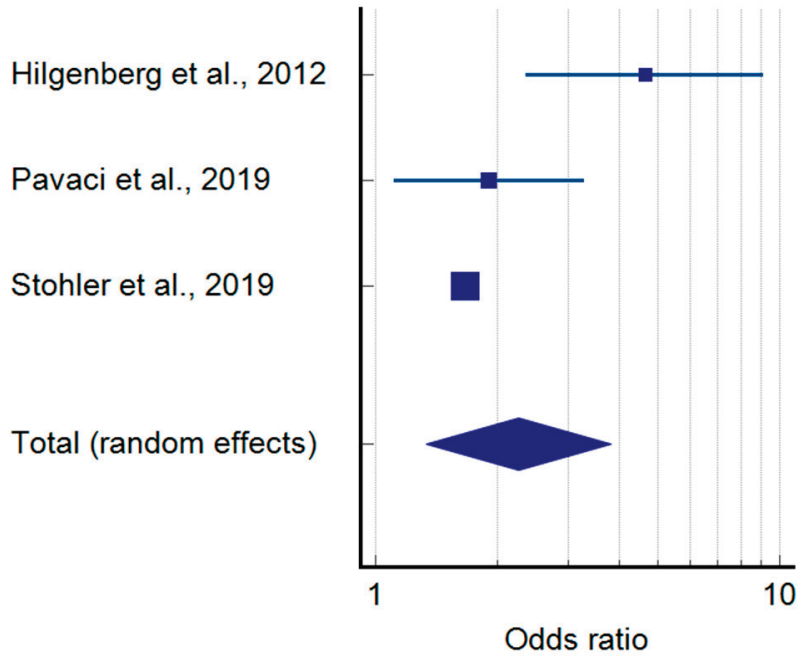

Figure 3. Pooled odds ratio of temporomandibular disorders in tinnitus patients based on case-control studies (squares—odds ratios for individual studies; diamond—polled odds ratio) [29,31,32].

Table 4. Detailed results of meta-analysis considering pooled odds ratio of temporomandibular disorders in tinnitus patients.

Study	Tinnitus	Controls	Odds Ratio	95% CI	*p*-Value	Weight (%)
Hilgenberg et al., 2012 [29]	85/100	55/100	4.636	2.359 to 9.112		25.66
Pavaci et al., 2019 [31]	63/130	33/100	1.909	1.112 to 3.277		30.25
Stohler et al., 2019 [32]	2746/109,783	1662/109,783	1.669	1.569 to 1.775		44.09
Total (random effects)	2894/110,013	1750/109,983	2.259	1.334 to 3.827	0.002	100.00
Egger's test (publication bias)			Intercept	95% CI		
			1.9433	−15.4477 to 19.3343	0.3906	

The summarised quality assessment is illustrated in Figure 4. The most common sources of bias were the lack of information on randomisation (in all studies), blinding (in 10 studies), and justification for sample size (in 9 studies). The critical appraisal was conducted by assigning points to each criterion based on potential risk (scoring: 1—low risk; 0.5—unspecified; 0—high risk). According to our analysis, 5 studies (45.5%) were classified as having "good" quality (≥80% of the total score), while 6 studies (54.5%) were categorized as having "intermediate" quality (≥60% of the total score).

All studies included corresponded to the third or fourth level of evidence (case-control and cross-sectional studies) as defined by the Oxford Centre for Evidence-Based Medicine's classification for diagnostic research [25].

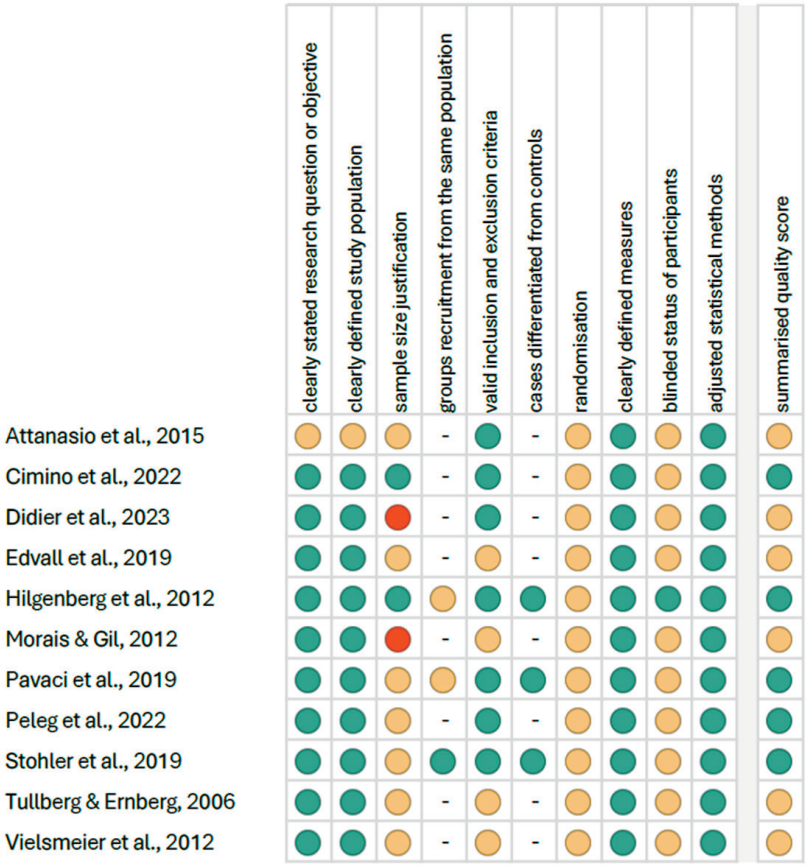

Figure 4. Quality assessment, including the main potential risk of bias (risk level: green—low, yellow—unspecified, red—high; quality score: green—good, yellow—intermediate, red—poor) [1,3,16,26–33].

4. Discussion

Tinnitus is the sensation of sound that occurs despite the absence of an external acoustic stimulus, and it is more frequently subjective than objective in nature. According to the literature review conducted, tinnitus may also accompany temporomandibular disorders (TMDs), which affect the complex musculoskeletal system of the jaw, as well as the surrounding structures. Although tinnitus and TMDs are two separate and complex medical issues, they frequently coincide. Although the exact causes of the association are not fully understood, several hypotheses can be put forward. The coexistence of TMDs and tinnitus may result from the proximity of the middle ear and the temporomandibular joint (TMJ) [34–36]. This close anatomical and functional relationship between the two structures is facilitated by the anterior malleolar ligament (AML), the sphenomandibular ligament (SML), and the discomalleolar ligament (DML). Furthermore, unlike the AML, the DML plays a pivotal role in the mobility of the malleus, the structure which contributes to TMJ function and plays a role in cases of forward displacement of the intervertebral disc. The above-mentioned ligaments extend during the TMJ movement, thereby affecting middle ear structures, such as the eardrum and malleus [37]. The relationship between TMJ and the middle ear depends on the performance of specific ligaments, their structure (collagenous or elastic), and the width of the petrotympanic fissure. In addition, the overactivity of the masseter muscles may be associated with the development of tinnitus and TMDs, since these structures, connected to the TMDs, share trigeminal innervation with the muscles involved in the function of the Eustachian tube, including the lateral and medial pterygoid muscle [38]. Interestingly, disturbed pressure regulation in the Eustachian tube may constitute a significant factor in increasing the risk of tinnitus [38].

This association is further corroborated by the somatosensory theory, whereby chronic pain or psychosocial disorders, such as depression or anxiety, trigger changes in the central nervous system, resulting in sensory hypersensitivity and an altered perception of auditory stimuli [36,39,40]. Moreover, recent studies also suggested that this connection could stem from increased intestinal permeability, disrupted gut microbiota, and abnormal metabolism of tryptophan, i.e., a biomarker of chronic musculoskeletal pain. It is of note that tryptophan is a precursor of serotonin and melatonin, which are critical in the activation of microglia (e.g., in the ES gastrointestinal tract) and participate in the regulation of chronic orofacial pain. The impaired metabolism of tryptophan may lead to increased pain sensitivity and depression which, in turn, affect both TMDs and tinnitus [41]. In fact, other studies conducted reported a link between depression, TMDs, and the development of tinnitus. Furthermore, researchers also suggest that another factor, i.e., TMJ herniation, may also potentially trigger tinnitus, although the disorder itself is rare [42]. The above-mentioned observations are in line with the findings of our meta-analysis, according to which more than 50% of patients with tinnitus also presented with TMDs, and show that there is a correlation between these disorders. Additionally, the relation between the two has also been pointed out by several other researchers in their reports.

An epidemiological study by Hilgenberg et al., investigating the coexistence of tinnitus and TMDs, found a strong correlation between the two disorders [29]. Other researchers found that 30.6% of dental patients suffering from TMDs also showed a history of tinnitus [27], whereas 22% of their studied group, diagnosed with tinnitus, presented with TMDs [3]. Furthermore, the prevalence of TMDs in tinnitus patients was 85%, which is consistent with the findings of similar studies. Additionally, they also observed that tinnitus was more common in women than in men. In terms of women, 54% of patients suffered from tinnitus with TMDs, while 33% presented with tinnitus without TMDs. Conversely, 46% of male participants experienced tinnitus with TMDs, whereas 67% developed tinnitus without TMDs [3].

Notably, the severity of tinnitus was affected by bruxism, and chronic facial pain was greater in patients with tinnitus and sleep bruxism. Tinnitus was more common when it co-occurred with painful TMDs; however, no correlation was found between somatosensory tinnitus and the development of TMDs. The results obtained by Edvall et al. [28] indicated that only 19% of individuals with existing tinnitus reported temporomandibular joint issues [28]. Conversely, a study by Peleg et al. [16] showed significant statistical differences between the presence of tinnitus and bilateral TMDs presenting with bruxism.

In terms of epidemiology, one of the studies found that the proportion of patients diagnosed simultaneously with TMDs and tinnitus was 85%. Bilateral tinnitus was observed in 47% of subjects, unilateral tinnitus was observed in 43%, and central tinnitus was observed in only 10% [27]. Another literature review showed that, in 79% of cases, tinnitus was reported on the right side, while it was reported on the left in 85% of cases, and 63% of individuals experienced bilateral tinnitus [33]. In turn, in a combined analysis of the tinnitus prevalence, a difference was reported in 24 women and 27 men. In the majority of cases, tinnitus was found bilaterally in both ears and was observed in 72.5% of cases [33].

In addition to tinnitus, clinical diagnosis reports the existence of a correlation between otological symptoms and TMD progression. In their study, Hildenberg et al. screened 785 patients for TMDs and excluded objective tinnitus. They showed that patients with TMDs and tinnitus presented with otalgia (27%), dizziness (52%), a sense of hearing loss (62%), and auditory hypersensitivity, combined with misophonia (26%) [29].

The study by Manfredini et al. [43] involved 238 patients with TMDs who were tested for tinnitus; the mean age of the subjects was 49.3 $\pm$ 13.5 years. The authors demonstrated that tinnitus was present in 30.4% of individuals with TMDs. This finding

differs from the observations of the study by Silva et al. [44], in which tinnitus was present in 61.3% of TMD cases. However, it is of note that the Manfredini study group was approximately half the size of the Silva study group, and the mean age was also different. The high prevalence of tinnitus in the study of Silva may be due to the difference in the age of the participants, where the maximum age was 88 years. Age-related processes, senile hearing loss, comorbidities, and inflammation of the ear and vestibular nerve all contribute to the increased sensation of tinnitus. In the analysed group, TMD patients most frequently reported otological symptoms, such as fullness in the ears (59%), hyperacusis with misophonia (80%), and dizziness occurring 1–2 times per week (27%) [39,40].

Both our analysis and the findings of studies from different sources reported different values in terms of the co-occurrence between tinnitus and TMDs. However, all studies confirmed a correlation between the two disorders. The study confirms a strong association between tinnitus and TMDs, but it does not establish a direct causal relationship. The cross-sectional nature of most studies prevents an understanding of the progression of TMD-related tinnitus. The meta-analysis includes studies with different methodologies, diagnostic criteria, and sample sizes, which may introduce variability in results. Standardised diagnostic tools for both TMDs and tinnitus are necessary to achieve better comparability. Most studies included rely on self-reported tinnitus rather than objective audiological assessments, which may introduce subjectivity in the findings.

Future research should focus on tracking patients over time to clarify whether TMDs precede or worsen tinnitus, and to assess the effectiveness of various interventions. Studies evaluating the impact of TMD treatments (e.g., occlusal splints, physiotherapy, cognitive behavioural therapy) on tinnitus symptoms could help develop targeted therapeutic approaches. Also, since depression, anxiety, and stress play significant roles in both TMDs and tinnitus, interdisciplinary studies integrating psychology, neuroscience, and dentistry can provide deeper insights.

5. Conclusions

On the basis of the aforementioned studies and analyses, it appears that tinnitus frequently co-occurs in patients who suffer from TMDs. Since persistent and distressing tinnitus may significantly impair the quality of patients' lives, it is essential to expand the diagnostic evaluation of this patient group so that it includes tinnitus. If tinnitus is observed in the patient's history and the tests confirm the presence of such a symptom, questionnaires assessing the impact of tinnitus on the quality of life should be applied. In addition, when investigating the cause of tinnitus, a dental consultation should be incorporated into the diagnostic protocol in order to assess for TMDs.

It also seems advisable to develop a common standard for the diagnostic management of patients presenting with TMDs and tinnitus. This would allow for a quicker assessment of the causes of tinnitus and the application of causal therapies, aiming to improve the patients' quality of life.

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