

Article

Tongue Pressure Declines Early on in Patients with Malocclusion

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Abstract: (1) Background: The tongue plays a key role in the stomatognathic system in carrying out oral functions. The aim of this study was to identify the association between tongue pressure and orthodontic parameters. (2) Methods: This study is a cross-sectional multicentered cohort study with IRB approval. During routine orthodontic initial examinations, the following data were recorded: age, sex, angle classification, overjet (OJ), overbite (OB), arch sizes, tongue width, and maximum tongue pressure (MTP). The association between MTP and orthodontic parameters was analyzed using Pearson's correlation analysis and the Student's t-test. (3) Results: There is a positive correlation between MTP and age between ages 10 and 20 ($R = 0.47$, $p < 0.01$). There is a negative correlation with MTP and age between 20 and 40 ($R = -0.30$, $p < 0.05$). There are negative correlations between MTP and OJ ($R = -0.278$, $p < 0.01$) and OB ($R = -0.374$, $p < 0.01$). While there is no statistical significance between MTP and tongue width, there is a statistically significant difference between age and tongue width ($R = 0.22482$, $p < 0.05$). There is no statistical significance between MTP and sex, angle classification, arch length, intercanine width, and intermolar width. (4) Conclusion: An earlier decline in MTP is observed with patients with malocclusion. This implies that patients with malocclusion should seek early treatment for the malocclusion.

Keywords: tongue pressure; malocclusion; age



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1. Introduction

The tongue has a dynamic role in the stomatognathic system not only playing a key role in growth and development but also carrying out daily functions such as speech and nutrient intake. The balance of the forces of the tongue, cheek, and lips help stabilize the dental arches to reach an equilibrium [1–3]. However, this equilibrium can change with unbalanced forces such as habits including but not limited to tongue thrusting and finger sucking [3,4]. Thus, the force of the tongue is critical to the equilibrium equation. Changes in tongue force can be seen in dysarthria [5] and dysphagia [6], which are associated with an apparent decrease in chewing efficiency [7], swallowing [8], malnutrition [9], and sarcopenia [10].

Previous research has focused on maximum tongue pressure (MTP) in the vulnerable population such as children and older adults. Children with skeletal Class II malocclusion were shown to have a lower MTP [11]. In older adults, there has been a correlation shown between tongue pressure and malnutrition [9], sarcopenia, sarcopenic dysphasia [10,12],

and general frailty [13]. It was observed that MTP decreased with age in the older population [14]. It has also been shown that tongue pressure is stable from age 20 to 50; then, it becomes significantly lower by age 70 [15–17].

In malocclusion cases, Angle Class II and Class III malocclusion have a lower MTP compared to that of the established norms [18]. Angle class III has a lower swallowing tongue pressure secondary to the spatial relationship to the jaw [19]. Orthodontic treatment also can change parts of the equilibrium such as cheek pressure and tongue pressure [20–22]. Thus, when treating patients with malocclusion, one must consider the ramification of the changes in the tongue pressure since this can lead to a change in the stomatognathic equilibrium.

However, there is a gap in knowledge between the pediatric and older adult. The purpose of this study was to analyze the association between MTP and orthodontic parameters in people with malocclusion from the pediatric to the adult age group. This is especially relevant now as there has been an increase in adults seeking orthodontic treatment [2].

2. Materials and Methods

This protocol was reviewed and approved by the institutional review board of Harvard School of Dental Medicine (IRB19-1863). Patients seeking orthodontic treatment at the Dental Center of Iwate Medical University, School of Dental Medicine (Iwate, Japan), Rei Orthodontic Clinic (Tokyo, Japan), Shimpō Clinic (Tokyo, Japan), and Nagasaki Dental Clinic (Yokohama, Japan) were recruited. Inclusion criteria were (1) healthy individuals (American Society of Anesthesiologist (ASA I or II), (2) age from 12 to 40 with permanent dentition (including wisdom teeth and congenitally missing teeth), and (3) seeking orthodontic treatment. Exclusion criteria were patients who had (1) previous orthodontic treatments, (2) ankyloglossia, (3) systematic disease, (4) neurological/cognitive disorders, and (5) history of cancer of the head and neck. The study aims, contents, and method were explained to the patients, and the patients who had an interest in participating in the study signed the consent form.

The following data were collected by calibrated orthodontists at each research location: age, sex, angle classifications, OJ, OB, MTP, arch length, intercanine width, and intermolar width. MTP was measured using a balloon type probe (TPM-02, JMS Co., Ltd., Hiroshima, Japan) machine (Figure 1). This balloon type measurement has been widely used in many areas of research [7,9–15,23]. Arch length, intercanine width, and intermolar width were measured using 3Shape digital software (3Shape, Copenhagen, Denmark). Each examiner measured 3 times for each case, and the averaged data were used for the statistical analysis (Figure 2).

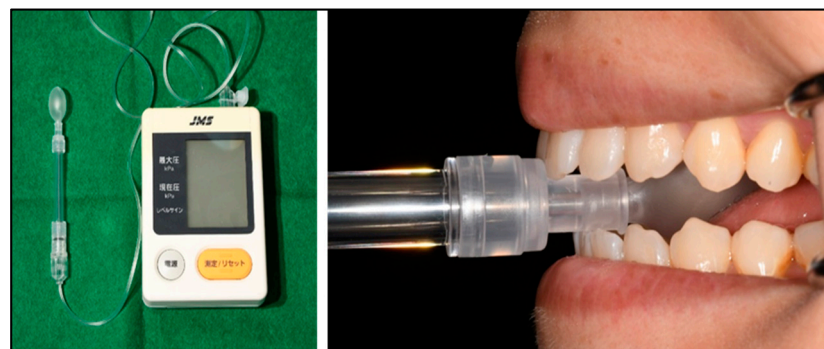


Figure 1. Measurement of Maximum Tongue Pressure (MTP). The device is composed of a measurement box, probe, and connecting tube. The balloon type probe was inflated with air at an initial pressure of 19.6 kPa by turning on the switch for pressurization. The diameter of the balloon was approximately 18 mm, and the volume was 3.7 mL.

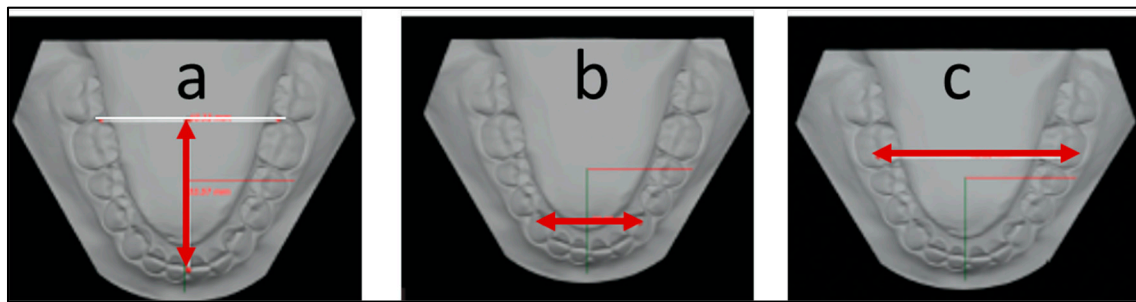


Figure 2. Measurement of maxilla and mandibular arch sizes. (a) arch length, (b) intercanine width, and (c) intermolar widths.

For the statistical analysis, SPSS software ($\alpha = 0.05$, SPSS ver. 24, IBM, Armonk, NY, USA) was used for Pearson's correlation analysis, Student's t-test, and One-way ANOVA. Sample size calculations were conducted using the expected population standard deviation and precision of error with 95% confidence level.

3. Results

In total, 111 patients were recruited, and 86 patients completed all data acquisition. Thus, 86 patients' data were used for analysis either in group 1 (<20) and group 2 (20~40) (Table 1).

Table 1. Age and sex demographics of the participants.

	Male		Female		Total	
	n	Age	n	Age	n	Age
<20 age group	12	16.2 $\pm$ 0.99	18	14.9 $\pm$ 3.13	30	14.6 $\pm$ 1.87
20–40 age group	16	29.4 $\pm$ 4.70	40	27.7 $\pm$ 5.18	56	29.4 $\pm$ 3.86
All age	28	23.7 $\pm$ 7.54	58	23.7 $\pm$ 7.53	86	23.7 $\pm$ 7.49

There was a positive correlation between MTP and age between the ages of 10 and 20 (Figure 3a, $R = 0.47$, $p < 0.05$ (0.00948)). There was a negative correlation with MTP and ages 20 to 40 (Figure 3b, $R = -0.30$, $p < 0.05$ (0.02428)). Furthermore, MTP in the 31–40 age group was significantly lower than that of the 21–30 age group (Figure 4, $p < 0.05$ (0.01524)). There were negative correlations between MTP and OJ (Figure 5a, $R = -0.278$, $p < 0.01$ (0.00954)) and OB (Figure 5b, $R = -0.374$, $p < 0.01$).

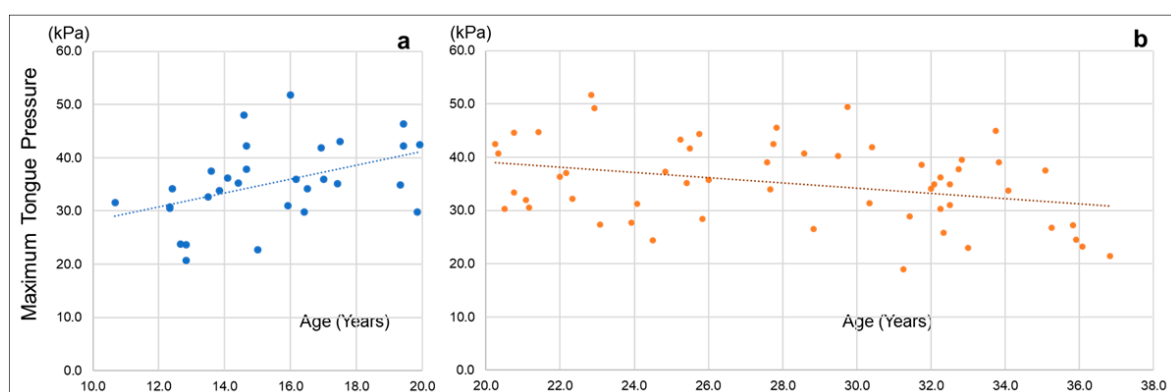


Figure 3. Correlation between MTP and age in two age groups. (a) Group under 20. (b) Group over 20.

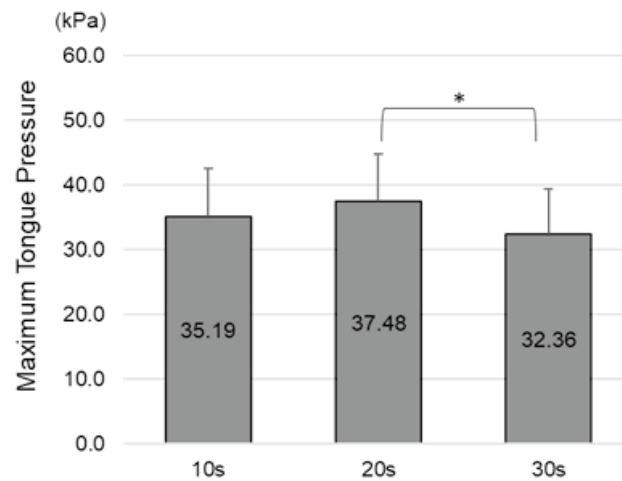


Figure 4. Average MTP among three age groups. * $p < 0.05$.

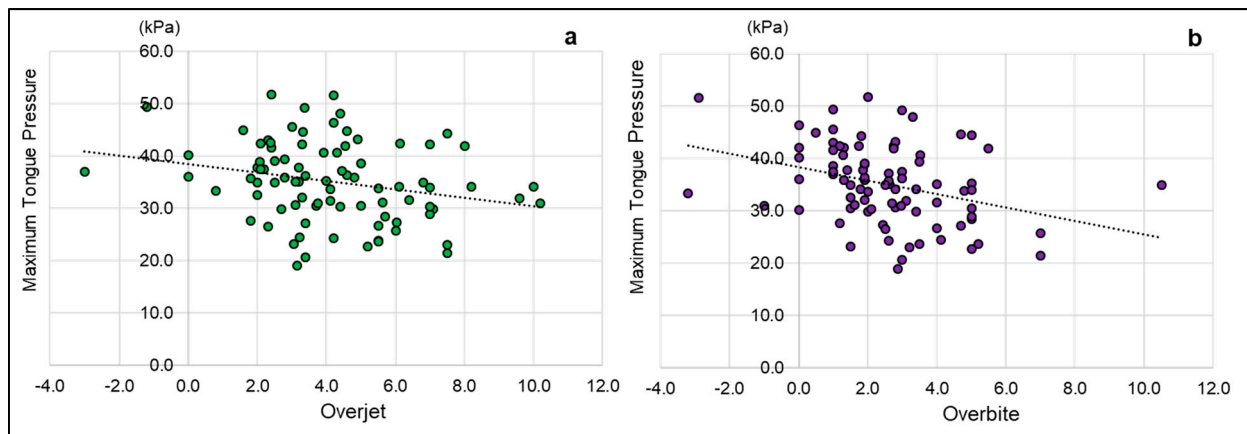


Figure 5. Correlation between MTP and overjet (a) and overbite (b).

While there was no statistical significance between MTP and tongue width, there was a statistically significant correlation between age and tongue width ($R = 0.22482$, $p < 0.05$ ($p = 0.03742$)) (Figure 6). There was no statistically significant correlation between MTP and arch size parameters; arch length, intercanine width, and intermolar width (Table 2).

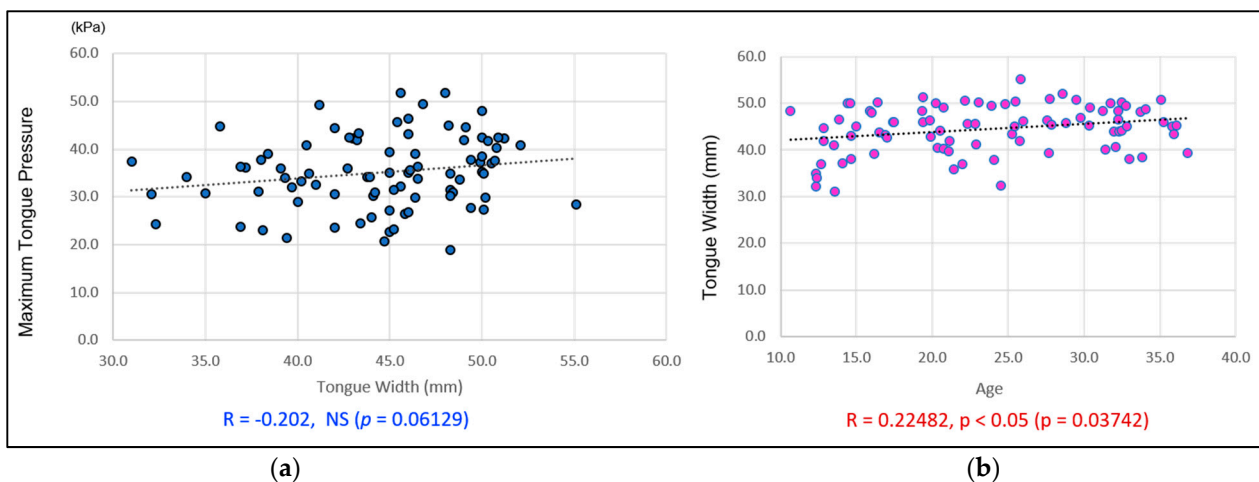


Figure 6. (a). Correlation between MTP and tongue width. (b). Correlation between tongue width and age.

Table 2. Correlation between MTP and arch size parameters.

	Maxilla			Mandibular		
	Arch Length	Inter canine Width	Inter molar Widths	Arch Length	Inter canine Width	Inter molar Widths
R	−0.053	−0.189	−0.155	−0.175	−0.152	0.002
<i>p</i> value	0.064	0.094	0.170	0.121	0.180	0.183

The average MTP of females was $34.36 \text{ kPa} \pm$ and $36.73 \pm$ for males, and the Student's *t*-test indicated no significant difference. The average MTP on angle classifications I, II, and III was 35.16 ± 7.76 , 34.12 ± 7.20 , and 37.27 ± 7.59 , respectively, and one-way ANOVA indicated no statistical significance.

4. Discussion

It has been shown that the population's MTP starts to decrease after the age of 60 [15–17]. In this study, we focused on pediatric and adult populations with malocclusion who were seeking orthodontic treatment. There was a positive correlation between MTP and age from age 10 to 20 (Figure 3a. $R = 0.47$, $p < 0.05$ (0.00948)). There was a negative correlation with MTP and ages 20–40 (Figure 3b. $R = -0.30$, $p < 0.05$ (0.02428)). Furthermore, MTP in the 31–40 age group was significantly lower than that of the 21–30 age group. This nonlinear biphasic result revealed that the MTP of patients with Angle classification I, II, and III malocclusions started to decrease at an earlier age (31–40) than that of the normal population (61–70) [1,15,24]. This early loss of MTP is significant, since previous research shows that a decrease in MTP is correlated with dysarthria [5], dysphagia [6], malnutrition [9], and sarcopenia [10]. Thus, early treatment of all malocclusions may benefit by preserving MTP or preventing the early decline in MTP.

There was a negative correlation between MTP and OJ (Figure 5a). Severe OJ is 7 mm or greater and is usually associated with skeletal and or Angle Class II malocclusion [25,26]. A zero or negative overjet is associated with skeletal and or Angle Class III malocclusion. While patients with an anterior open bite fill the space with the tongue, a patient with severe OJ fills the space with the lower lip instead of the tongue. This may be the reason there is a negative trend between going from negative to positive overjet.

There was a negative correlation between MTP and OB (Figure 5b). Negative OB is defined as an anterior open bite. Common reasons for an anterior open bite are habits such as tongue, finger, as well as playing musical instruments [27]. A probable reason for observing a higher MTP in the negative OB is due to the tongue thrust habit that compensates and establishes a seal for normal oral function such as speech and swallowing. With a positive OB, which is a deep and possibly impinging bite, there is no need for the tongue to seal the space for speech and swallowing. Thus, this may explain why patients with negative overbite and tongue thrusting have a stronger MTP than that of positive OB patients.

While there was no statistical significance between MTP and tongue width, there was a statistically significant difference between age and tongue width ($R = 0.22482$, $p < 0.05$ ($p = 0.03742$)). This observation may be explained with the loss of tonality as humans age [28]. The loss of muscle tone may relax the tongue. This is often seen in obstructive sleep apnea, where the tongue relaxes into a retruded position while in a supine position causing the obstruction of the airway [29]. For the other dental parameters such as sex, angle classification, arch length, intercanine width, and intermolar width, there was no statistical significance when compared to MTP. A higher sample size may explicate an association.

There were several limitations to the present study due to the cross-sectional design and investigation in a single ethnicity. A subsequent study should be a longitudinal study to measure the change in MTP over time to confirm and eliminate the limitations of a cross-sectional study. Moreover, including skeletal classification and dental space analysis with a greater sample size per subgroup will help elucidate more correlations and help to establish

the population norms. However, when establishing a population norm, an additional factor to consider is the ethnicity of the participants. A Class III malocclusion in Asians is usually due to a prognathic mandible while for European Americans, a lower percentage of Class III would be due to prognathic mandible [30]. Another consideration is that African Americans are usually bimaxillary prognathic leading to spacing and concomitant tongue habits [31]. Therefore, separate MTP norms should also be investigated based on ethnicity.

5. Conclusions

With the exception of an anterior open bite, an earlier decline in MTP was observed in patients with malocclusion compared to that of the established healthy MTP norms. This suggests that patients with malocclusion should seek early treatment for the malocclusion.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Harvard Faculty of Medicine, Office of Human Research Administration (protocol code IRB19-1863. 11 April 2019).

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

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

References

1. Lambrechts, H.; De Baets, E.; Fieuws, S.; Willems, G. Lip and tongue pressure in orthodontic patients. *Eur. J. Orthod.* **2010**, *32*, 466–471. [[CrossRef](#)] [[PubMed](#)]
2. Proffit, W.R. *Contemporary Orthodontics*, 6th ed.; Elsevier: Philadelphia, PA, USA, 2019.
3. Thomas, M.; Graber, R.L.V., Jr. *Orthodontics Current Principles and Techniques*, 3rd ed.; Mosby: St. Louis, MO, USA, 2000; 1040p.
4. Proffit, W.R. Lingual pressure patterns in the transition from tongue thrust to adult swallowing. *Arch. Oral Biol.* **1972**, *17*, 555–563. [[CrossRef](#)]
5. Solomon, N.P.; Clark, H.M.; Makashay, M.J.; Newman, L.A. Assessment of Orofacial Strength in Patients with Dysarthria. *J. Med. Speech-Lang. Pathol.* **2008**, *16*, 251–258. [[PubMed](#)]
6. Hirota, N.; Konaka, K.; Ono, T.; Tamine, K.; Kondo, J.; Hori, K.; Yoshimuta, Y.; Maeda, Y.; Sakoda, S.; Naritomi, H. Reduced Tongue Pressure Against the Hard Palate on the Paralyzed Side During Swallowing Predicts Dysphagia in Patients With Acute Stroke. *Stroke* **2010**, *41*, 2982–2984. [[CrossRef](#)]
7. Takahashi, M.; Koide, K.; Arakawa, I.; Mizuhashi, F. Association between perioral muscle pressure and masticatory performance. *J. Oral Rehabil.* **2013**, *40*, 909–915. [[CrossRef](#)]
8. Namasivayam-MacDonald, A.M.; Morrison, J.M.; Steele, C.M.; Keller, H. How Swallow Pressures and Dysphagia Affect Malnutrition and Mealtime Outcomes in Long-Term Care. *Dysphagia* **2017**, *32*, 785–796. [[CrossRef](#)]
9. Iwasaki, M.; Motokawa, K.; Watanabe, Y.; Shirobe, M.; Inagaki, H.; Eda, H.; Ohara, Y.; Hirano, H.; Shinkai, S.; Awata, S. A Two-Year Longitudinal Study of the Association between Oral Frailty and Deteriorating Nutritional Status among Community-Dwelling Older Adults. *Int. J. Environ. Res. Public Health* **2020**, *18*, 213. [[CrossRef](#)]
10. Maeda, K.; Akagi, J. Decreased Tongue Pressure is Associated with Sarcopenia and Sarcopenic Dysphagia in the Elderly. *Dysphagia* **2015**, *30*, 80–87. [[CrossRef](#)]
11. Kurabeishi, H.; Tatsuo, R.; Makoto, N.; Kazunori, F. Relationship between tongue pressure and maxillofacial morphology in Japanese children based on skeletal classification. *J. Oral Rehabil.* **2018**, *45*, 684–691. [[CrossRef](#)]
12. Machida, N.; Tohara, H.; Hara, K.; Kumakura, A.; Wakasugi, Y.; Nakane, A.; Minakuchi, S. Effects of aging and sarcopenia on tongue pressure and jaw-opening force. *Geriatr. Gerontol. Int.* **2017**, *17*, 295–301. [[CrossRef](#)]
13. Satake, A.; Kobayashi, W.; Tamura, Y.; Oyama, T.; Fukuta, H.; Inui, A.; Sawada, K.; Ihara, K.; Noguchi, T.; Murashita, K.; et al. Effects of oral environment on frailty: Particular relevance of tongue pressure. *Clin. Interv. Aging* **2019**, *14*, 1643–1648. [[CrossRef](#)] [[PubMed](#)]

14. Suzuki, H.; Ayukawa, Y.; Ueno, Y.; Atsuta, I.; Jinnouchi, A.; Koyano, K. Relationship between Maximum Tongue Pressure Value and Age, Occlusal Status, or Body Mass Index among the Community-Dwelling Elderly. *Medicina* **2020**, *56*, 623. [[CrossRef](#)] [[PubMed](#)]
15. Utanohara, Y.; Hayashi, R.; Yoshikawa, M.; Yoshida, M.; Tsuga, K.; Akagawa, Y. Standard Values of Maximum Tongue Pressure Taken Using Newly Developed Disposable Tongue Pressure Measurement Device. *Dysphagia* **2008**, *23*, 286–290. [[CrossRef](#)] [[PubMed](#)]
16. Nicosia, M.A.; Hind, J.A.; Roecker, E.B.; Carnes, M.; Doyle, J.; Dengel, G.A.; Robbins, J. Age Effects on the Temporal Evolution of Isometric and Swallowing Pressure. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **2000**, *55*, M634–M640. [[CrossRef](#)] [[PubMed](#)]
17. Robbins, J.; Levine, R.; Wood, J.; Roecker, E.B.; Luschei, E. Age effects on lingual pressure generation as a risk factor for dysphagia. *J. Gerontol. Ser. A Biol. Sci. Med. Sci.* **1995**, *50*, M257–M262. [[CrossRef](#)]
18. Menezes, L.D.F.; Rocha Neto, A.M.D.; Paulino, C.E.B.; Laureano Filho, J.R.; Studart-Pereira, L.M. Tongue pressure and endurance in patients with Class II and Class III malocclusion. *Rev. CEFAC* **2018**, *20*, 166–174. [[CrossRef](#)]
19. Ruan, W.-H.; Su, J.-M.; Ye, X.-W. Pressure from the lips and the tongue in children with class III malocclusion. *J. Zhejiang Univ. Sci. B* **2007**, *8*, 296–301. [[CrossRef](#)]
20. Küçükkeleş, N.; Ceylanoğlu, C. Changes in lip, cheek, and tongue pressures after rapid maxillary expansion using a diaphragm pressure transducer. *Angle Orthod.* **2003**, *73*, 662–668. [[CrossRef](#)]
21. Taslan, S.; Biren, S.; Ceylanoğlu, C. Tongue Pressure Changes Before, During and After Crib Appliance Therapy. *Angle Orthod.* **2010**, *80*, 533–539. [[CrossRef](#)]
22. Koletsis, D.; Makou, M.; Pandis, N. Effect of orthodontic management and orofacial muscle training protocols on the correction of myofunctional and myoskeletal problems in developing dentition. A systematic review and meta-analysis. *Orthod. Craniofacial Res.* **2018**, *21*, 202–215. [[CrossRef](#)]
23. Egashira, R.; Mizutani, S.; Yamaguchi, M.; Kato, T.; Umezaki, Y.; Oku, S.; Tamai, K.; Obata, T.; Naito, T. Low Tongue Strength and the Number of Teeth Present Are Associated with Cognitive Decline in Older Japanese Dental Outpatients: A Cross-Sectional Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 8700. [[CrossRef](#)] [[PubMed](#)]
24. Hara, K.; Tohara, H.; Kenichiro, K.; Yamaguchi, K.; Ariya, C.; Yoshimi, K.; Nakane, A.; Minakuchi, S. Association between tongue muscle strength and masticatory muscle strength. *J. Oral Rehabil.* **2019**, *46*, 134–139. [[CrossRef](#)] [[PubMed](#)]
25. Shalish, M.; Gal, A.; Brin, I.; Zini, A.; Ben-Bassat, Y. Prevalence of dental features that indicate a need for early orthodontic treatment. *Eur. J. Orthod.* **2013**, *35*, 454–459. [[CrossRef](#)] [[PubMed](#)]
26. Cangialosi, T.J.; Riolo, M.L.; Owens, S.E., Jr.; Dykhouse, V.J.; Moffitt, A.H.; Grubb, J.E.; Greco, P.M.; English, J.D.; James, R. The ABO discrepancy index: A measure of case complexity. *Am. J. Orthod. Dentofac. Orthop.* **2004**, *125*, 270–278. [[CrossRef](#)]
27. Lentini-Oliveira, D.A.; Carvalho, F.R.; Rodrigues, C.G.; Ye, Q.; Hu, R.; Minami-Sugaya, H.; Carvalho, L.B.; Prado, L.B.; Prado, G.F. Orthodontic and orthopaedic treatment for anterior open bite in children. *Cochrane Database Syst. Rev.* **2014**, *9*. [[CrossRef](#)]
28. Volpi, E.; Nazemi, R.; Fujita, S. Muscle tissue changes with aging. *Curr. Opin. Clin. Nutr. Metab. Care* **2004**, *7*, 405–410. [[CrossRef](#)]
29. Cori, J.M.; O'Donoghue, F.J.; Jordan, A.S. Sleeping tongue: Current perspectives of genioglossus control in healthy individuals and patients with obstructive sleep apnea. *Nat. Sci. Sleep* **2018**, *10*, 169–179. [[CrossRef](#)]
30. Ishii, N.; Deguchi, T.; Hunt, N.P. Craniofacial differences between Japanese and British Caucasian females with a skeletal Class III malocclusion. *Eur. J. Orthod.* **2002**, *24*, 493–499. [[CrossRef](#)]
31. Adesina, B.A.; Otuyemi, O.D.; Kolawole, K.A.; Adeyemi, A.T. Assessment of the impact of tongue size in patients with bimaxillary protrusion. *Int. Orthod.* **2013**, *11*, 221–232. [[CrossRef](#)]