

Article

Effect of Sports and Energy Drinks on Surface Roughness of Dental Restorative Materials: An In Vitro Study

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Abstract

This study evaluated the effect of sports and energy drinks on the surface roughness of three commonly used restorative dental materials: resin-based composites (RBCs), resin-modified glass ionomer cements (RMGICs), and conventional glass ionomer cements (GICs). Sixty-three A2-shade specimens of each material were fabricated, stored in distilled water for 24 h, and then immersed in six commercially available beverages or distilled water (control) for 6, 30, or 60 h. Surface roughness was assessed after each immersion period using contact profilometry, and the effects of material type, immersion medium, and exposure time were compared. Surface roughness increased with longer immersion times for all materials, although the magnitude of change varied significantly among material types. RBCs showed the greatest resistance to surface degradation, whereas RMGICs and particularly GICs exhibited progressively higher roughness values over time. Beverages generally produced greater surface roughness than distilled water, with sugar-containing formulations showing higher roughness values than their sugar-free counterparts. Prolonged exposure to sports and energy drinks may adversely affect the surface integrity of restorative materials. Resin-based composites demonstrated the highest resistance to roughness changes, whereas glass ionomer cements were the most susceptible. Increased surface roughness may contribute to plaque accumulation, staining, and material wear, potentially compromising the long-term clinical performance of restorations.

Keywords: resin-based composite; glass ionomer; sports drinks; energy drinks; surface roughness; contact profilometry

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1. Introduction

Surface roughness is a fundamental physical property that describes the microtopography of a material surface and is usually characterised by parameters such as the arith-

metic mean roughness (Ra). It reflects the vertical deviations of a surface from its ideal form and is widely used to evaluate the quality of dental restorative materials after finishing and polishing procedures. Clinically, surface roughness directly influences plaque accumulation, bacterial adhesion, wear behaviour, staining susceptibility, and the longevity of restorations [1,2]. Even minor variations at the micrometre level may significantly alter the biological and mechanical performance of restorative materials [3,4].

From a clinical perspective, well-defined surface roughness values are essential for evaluating the quality of restorative materials. A surface roughness below 0.2 μm is widely regarded as optimal, as it effectively limits bacterial adhesion and biofilm accumulation [5,6]. In contrast, roughness values exceeding approximately 0.3 μm may become perceptible to patients, potentially influencing their subjective assessment of restoration quality [3]. When roughness exceeds 0.7–1.4 μm , a significant increase in bacterial retention has been observed, which may contribute to marginal discolouration, secondary caries, and periodontal disease [1,2].

Over the past decades, resin-based composite materials have been widely used in contemporary restorative dentistry, largely due to their favourable aesthetic properties and continuous improvements in mechanical performance [7,8]. Among the parameters determining their clinical success, surface roughness plays a central role. It is well established that inadequate surface smoothness facilitates plaque accumulation, increases the risk of gingival irritation, and may contribute to the development of secondary caries [3,9]. In addition, roughened surfaces compromise the optical properties of restorations by reducing gloss and light reflectivity, while simultaneously increasing susceptibility to extrinsic discolouration [3,5,10].

Glass ionomer-based restorative materials occupy a distinct position in restorative dentistry due to their unique combination of physicochemical and biological properties. They are characterised by their ability to adhesively bond to dental hard tissues, release fluoride, and exhibit desirable biocompatibility, which contributes to their anticariogenic potential [6,11]. However, their mechanical properties are a limitation, as they exhibit relatively low fracture toughness and wear resistance, and are susceptible to surface degradation over time. These characteristics are directly relevant to surface roughness, as inferior wear resistance and, additionally, moisture sensitivity at the early stage of the setting process may lead to surface deterioration, increasing roughness and compromising both aesthetic and functional outcomes [11–13].

Sports drinks, due to their low pH and organic acid content, represent a significant extrinsic factor influencing the structural integrity of restorative materials [14,15]. Preserving the smoothness of restorative materials is crucial for ensuring their durability and optimal performance, and moreover, a well-polished surface improves aesthetic outcomes and enhances patient satisfaction [16]. The presence of erosive agents in sports drinks can accelerate hydrolytic degradation of polymer-based materials, weakening the filler-matrix bond and increasing the loss of inorganic particles from the surface. This process results in the formation of microdefects and porosities, which further increase roughness values. Over time, repeated exposure to such conditions may push surface roughness beyond clinically acceptable thresholds, enhancing bacterial adhesion and biofilm accumulation, and ultimately affecting both the functional and aesthetic longevity of the restorations [17,18]. In the case of cement-based materials, acid exposure enhances surface erosion of the restoration, leading to mass loss and greater ion release, which may be accompanied by potential deterioration of mechanical properties [19,20].

The presented study was designed to address existing gaps in the literature. Most previous research has focused on a single material type and differences between sports drinks and other acidic drinks [21,22]. This study aimed to evaluate the effects of sports and energy drinks on the surface roughness of commonly used restorative materials by

comparing resin-based composites (RBCs), resin-modified glass ionomer cements (RMGICs), and conventional glass ionomer cements (GICs), as well as sugar-containing and sugar-free beverages, using multiple surface roughness parameters (Ra, Rq, Rz, and Rp).

2. Materials and Methods

This research paper is one of three parts of a series of studies analysing the effect of sports and energy drinks on the properties of dental materials; hence, the methodology section may present similarities.

2.1. Materials

This study evaluated six commercially available restorative materials in shade A2. The materials tested were the microhybrid resin-based composite Gradia Direct, the nanohybrid resin-based composite Filtek Z550, the resin-modified glass ionomers (RMGICs) Fuji II and Riva LC, and the conventional glass ionomers (GICs) Fuji IX and Riva SC. The compositions of the materials are presented in Table 1.

Table 1. Characteristics of restorative materials.

Material	Type	Composition	Manufacturer	Material
Gradia Direct	Di-microhybrid composite	UDMA 20%–25%, bismethacrylate 1%–5%, DMA 1%–5%	GC, Tokyo, Japan	Gradia Direct
Filtek Z550	nanohybrid composite	Bis-GMA, UDMA, Bis-EMA, TEGDMA and PEGDMA; filler loading 82% weight, 68% volume	3M ESPE, Maplewood, MN, USA	Filtek Z550
Fuji II	resin-modified glass ionomer	Powder: fluoro-alumino-silicate glass (80%–95%), polybasic carboxylic acid Liquid: polyacrylic acid (25%–50%), water (50%–75%), HEMA (25%–50%), and UDMA (1%–5%).	GC, Tokyo, Japan	Fuji II
Riva LC	resin-modified glass ionomer	Powder: fluoro-alumino-silicate glass, polyacrylic acid Liquid: water, polyacrylic acid, tartaric acid, HEMA, DMA	SDI, Victoria, Australia	Riva LC
Fuji IX	glass ionomer	Powder: fluoro-alumino-silicate glass, polyacrylic acid Liquid: water, polyacrylic acid, tricarboxylic acid	GC, Tokyo, Japan	Fuji IX
Riva SC	glass ionomer	Powder: fluoro-alumino-silicate glass, polyacrylic acid Liquid: water, polyacrylic acid, tartaric acid	SDI, Victoria, Australia	Riva SC

UDMA: urethane dimethacrylate; DMA: dimethacrylate; Bis-GMA: bisphenol A glycol dimethacrylate; Bis-EMA: ethoxylated bisphenol A glycol dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; PEGDMA: poly(ethylene glycol) dimethacrylate; HEMA: (2-hydroxyethyl methacrylate).

2.2. Sample Preparation

For each restorative material, 63 disk-shaped specimens (15 mm in diameter × 1 mm in thickness) were prepared using customised silicone moulds. A total of 378 samples representing the six restorative materials were analysed.

To obtain flat surfaces, each specimen was covered on both the upper and lower sides with a polyester matrix strip (Finc, Przylęki, Bydgoszcz, Poland) and a 1 mm thick microscope glass slide. Light finger pressure was applied to the glass slide, and any excess material was removed. To ensure full polymerisation, each resin-modified sample was irradiated 9 times for 20 s (180 s in total) using an LED curing lamp with an 8 mm tip diameter (Woodpecker LED.H, Guilin Woodpecker Medical Instrument Co., Guilin, China). To standardise the light-curing process, the curing lamp tip was positioned directly against the glass slide, maintaining a consistent 1 mm distance between the light source and the specimen.

To provide standardised liquid-to-powder proportions, all glass ionomer and resin-modified glass ionomer materials were dispensed into the moulds using pre-dosed capsules and an applicator gun.

To ensure a smooth and standardised surface, each sample was polished using a 2-step polishing system, Diacomp plus Twist (EVE Ernst Vetter GmbH, Kletern, Germany) and SuperPolish paste (Kerr Dental, Brea, CA, USA).

2.3. Immersion Protocol

The test solutions were categorised into three groups: hypertonic, isotonic, and hypotonic beverages. Each category consisted of one sugar-containing drink and one sugar-free alternative. Altogether, seven immersion solutions were used in the study: distilled water (control group); the hypertonic beverages Red Bull Energy Drink and Red Bull Energy Drink Sugar-free; the isotonic beverages OSHEE Isotonic Drink and OSHEE Zero; and the hypotonic beverages Unisport Nutrend and Unisport Nutrend Zero. The Unisport solutions were prepared strictly according to the manufacturer's instructions before immersion of the specimens.

Before specimen immersion, the pH of each solution was measured three times using a Hanna edge™ pH HI 2002 m (Hanna Instruments Inc., Woonsocket, RI, USA), and the mean values were recorded. Detailed characteristics of the tested solutions are shown in Table 2. The lowest pH values were observed in hypotonic drinks, while hypertonic and isotonic beverages exhibited higher pH values.

Three disk-shaped specimens of each restorative material were placed in separate containers filled with 100 mL of the respective immersion solution at room temperature (23 ± 1 °C). Prior to immersion in the test solutions, all specimens were stored in distilled water for 24 h. The samples were then immersed in the seven solutions for 6, 30, and 60 h each, yielding a total of 21 exposure conditions for each material. For each experimental condition, three specimens of each material were tested.

After immersion, all specimens were rinsed with distilled water and gently dried using cellulose wadding.

Table 2. Characteristics of immersion solutions.

Solution	Abbreviation	Composition	Mean pH	Manufacturer
RedBull Energy Drink	RB	water, sucrose, glucose, citric acid, carbon dioxide, taurine, sodium carbonates, magnesium carbonates, caffeine, niacin, pantothenic acid, vitamin B6, vitamin B12, caramel, riboflavin	3.11 ± 0.01	Red Bull GmbH, Am Brunnen, Austria

RedBull Energy Drink Sugar-free	RB0	water, citric acid, carbon dioxide, taurine, sodium carbonates, magnesium carbonates, caffeine, sucralose, acesulfame K, niacin, pantothenic acid, vitamin B6, vitamin B12, xanthan gum, caramel, riboflavin	3.12 ± 0.01	Red Bull GmbH, Am Brunnen, Austria
OSHEE Isotonic (multifruit flavour)	OS	water, glucose, citric acid; sodium citrate, potassium sorbate, sodium benzoate; potassium citrate, aspartame, acesulfame K; gum arabic, glycerol esters of plant resins; niacin, vitamin B6, biotin; brilliant blue FCF	3.32 ± 0.04	Oshee, Cracow, Poland
OSHEE Zero (multifruit flavour)	OS0	water, citric acid; sodium citrate, potassium sorbate, magnesium lactate, potassium sorbate, sodium benzoate, gum arabic, glycerol esters of plant resins, sucralose; potassium citrate, niacin, vitamin B6, biotin; brilliant blue FCF	3.18 ± 0.03	Oshee, Cracow, Poland
Unisport (orange flavour)	UN	sugar, water, citric acid, orange emulsion, sodium chloride, magnesium gluconate, taurine, L-carnitine, L-alanine, acesulfame K, monopotassium phosphate, sucralose, potassium sorbate, sodium benzoate	2.81 ± 0.05	Nutrend, Olomouc, Czech Republic
Unisport Zero (peach and maracuja flavour)	UN0	water, citric acid, polydextrose, sodium chloride, magnesium gluconate, taurine, L-carnitine, L-alanine, acesulfame K, monopotassium phosphate, sucralose, green tea extract, potassium sorbate, sodium benzoate, colouring agent E102	2.68 ± 0.03	Nutrend, Olomouc, Czech Republic
Distilled water	WD	-	7.05 ± 0.20	Hipernet, Warsaw, Poland

2.4. Contact Profilometry Test

In the contact profilometry test, 3 disk-shaped samples were used for each group. Specimens were positioned horizontally on a flat surface, then a diamond-tipped probe was placed and dragged across the material over a 4 mm range. This test was repeated three times on each sample, maintaining a 60-degree rotation after each measurement. The tests were performed using a Mitutoyo Surftest SJ-410 contact profilometer (Mitutoyo Corporation K.K., Kawasaki, Japan).

Four parameters were assessed, i.e., the arithmetic mean of all absolute values of the roughness profile deviations (R_a , μm), root mean square deviation of the profile (R_q , μm), roughness height based on the ten highest points of the profile (R_z , μm), and maximum surface peak height (R_p , μm).

Three profilometric traces were recorded from each specimen and averaged. The specimen was treated as the experimental unit ($n = 3$ per material $\times$ medium $\times$ time combination).

2.5. Statistical Analysis

The determined roughness parameters were analysed using a three-way analysis of variance (ANOVA) in the model with the interaction, including the following factors: material type (6 levels), immersion medium (7 levels), and exposure time (3 levels). All subgroups met the assumptions required by statistical methods. For the post-hoc analyses, the Tukey test was used. The plots display the estimated marginal means. The significance level was defined as $\alpha = 0.05$. The statistical analysis was performed using Statistica 13.3 (Statsoft, Cracow, Poland).

3. Results

3.1. Effect of Material Type

Surface roughness parameters (Ra, Rq, Rz, and Rp) significantly depended on the type of restorative material (Figure 1). Post-hoc analysis revealed statistically significant differences between most materials (Table S1).

The RBCs (Gradia and Filtek) exhibited the lowest roughness values and did not differ significantly from each other for any of the analysed parameters. In contrast, RMGICs (Riva LC and Fuji II) and conventional GICs (Riva SC and Fuji IX) demonstrated significantly higher roughness values compared with RBCs. Among all tested materials, Fuji IX and Riva SC showed the highest roughness parameters, indicating the greatest susceptibility to surface degradation.

These results suggest that glass ionomer-based materials, particularly conventional formulations, are more prone to surface alterations than resin composites.

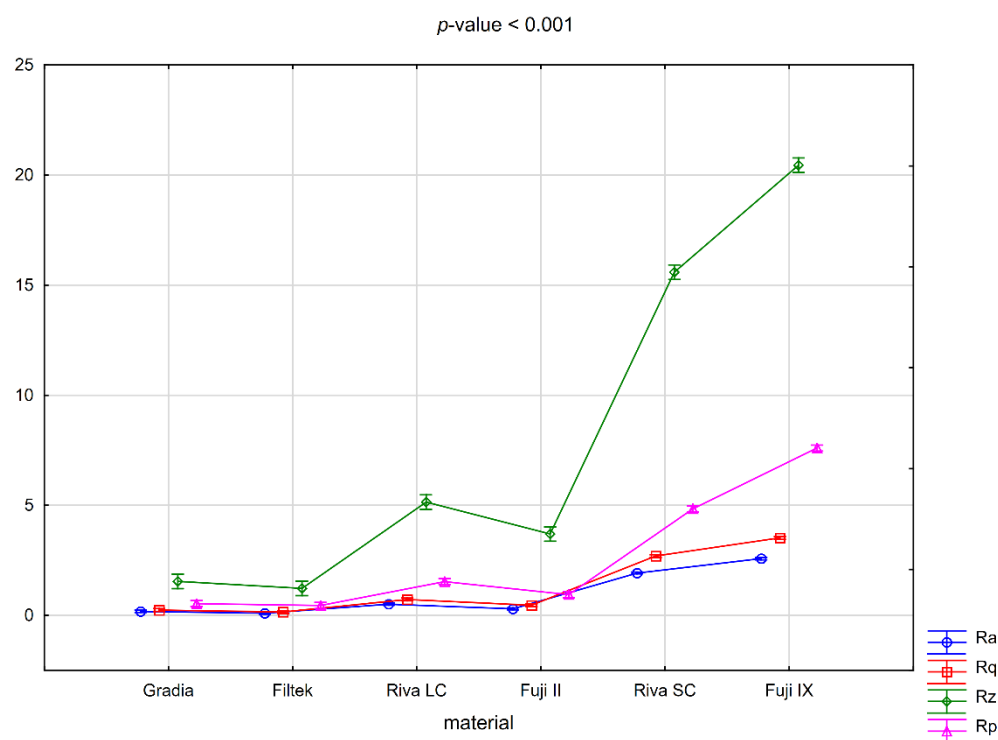


Figure 1. Comparison of selected roughness parameters [μm] of dental restorative materials following exposure to sports and energy drinks, depending on the type of material. The vertical bars indicate 0.95 confidence intervals.

3.2. Effect of Immersion Medium

The type of immersion medium significantly influenced the surface roughness parameters (Figure 2). Post-hoc comparisons confirmed statistically significant differences between several beverages and distilled water (Table S2).

Exposure to sports and energy drinks, both with and without sugar, generally resulted in higher roughness values compared with distilled water, although the magnitude of the effect varied depending on the beverage type. In particular, significant differences in Ra, Rq, Rz, and Rp were observed between OSHEE and OSHEE Zero, as well as between several acidic functional drinks and distilled water.

Distilled water generally produced the lowest roughness values, indicating minimal surface degradation under neutral conditions. Conversely, some acidic functional drinks,

especially those without sugar, were associated with significantly higher roughness values, suggesting a stronger erosive or hydrolytic potential.

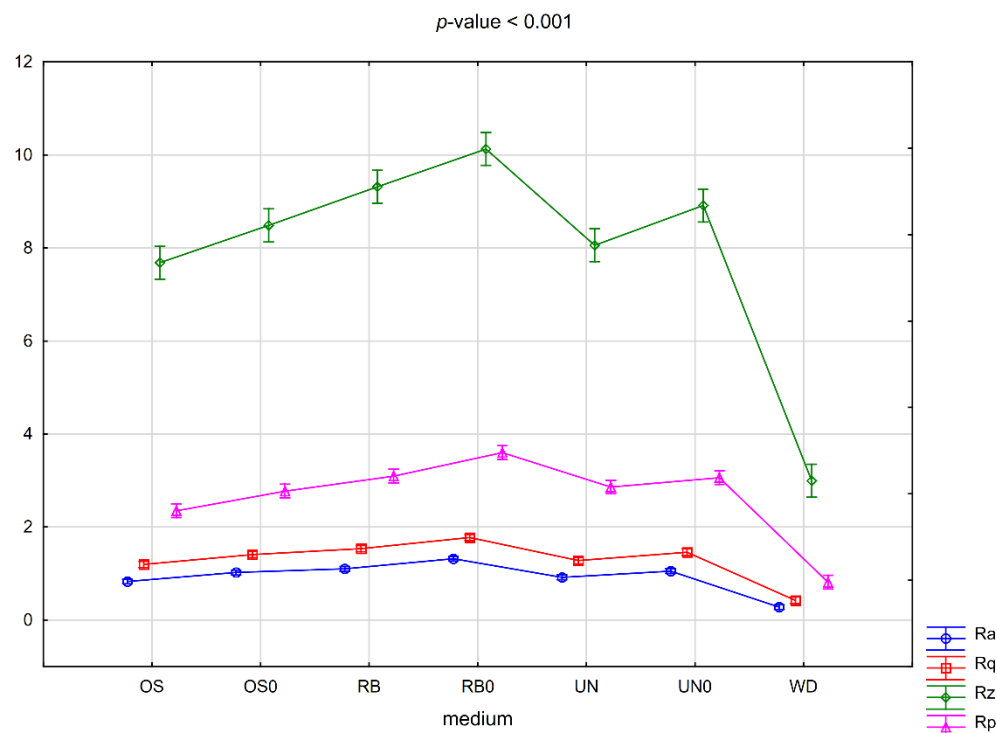


Figure 2. Comparison of selected roughness parameters [μm] of dental restorative materials following exposure to sports and energy drinks, depending on the type of medium (OSHEE, OSHEE Zero, Unisport Nutrend, Unisport Nutrend Zero, Red Bull Energy Drink, Red Bull Energy Drink Zero). The vertical bars indicate 0.95 confidence intervals.

3.3. Effect of Exposure Time

Exposure time significantly affected all analysed roughness parameters (Figure 3). Post-hoc analysis demonstrated significant increases in surface roughness between 6 h and 30 h, as well as between 6 h and 60 h (Table S3).

Furthermore, significant differences were also observed between 30 h and 60 h, indicating a progressive increase in surface roughness with prolonged exposure. These findings confirm a time-dependent deterioration of the surface morphology of the restorative materials.

3.4. Interaction Between Material Type and Exposure Time

A significant material $\times$ time interaction was observed for all roughness parameters (Figure 4). Post-hoc comparisons (Table S4) demonstrated that RBCs (Gradia and Filtek) exhibited relatively stable roughness values over time, with no statistically significant differences between the examined exposure periods.

In contrast, glass ionomer-based materials showed pronounced time-dependent changes. Particularly notable increases in roughness were observed for Riva SC and Fuji IX, especially after 60 h of exposure, confirming their greater susceptibility to prolonged environmental challenge.

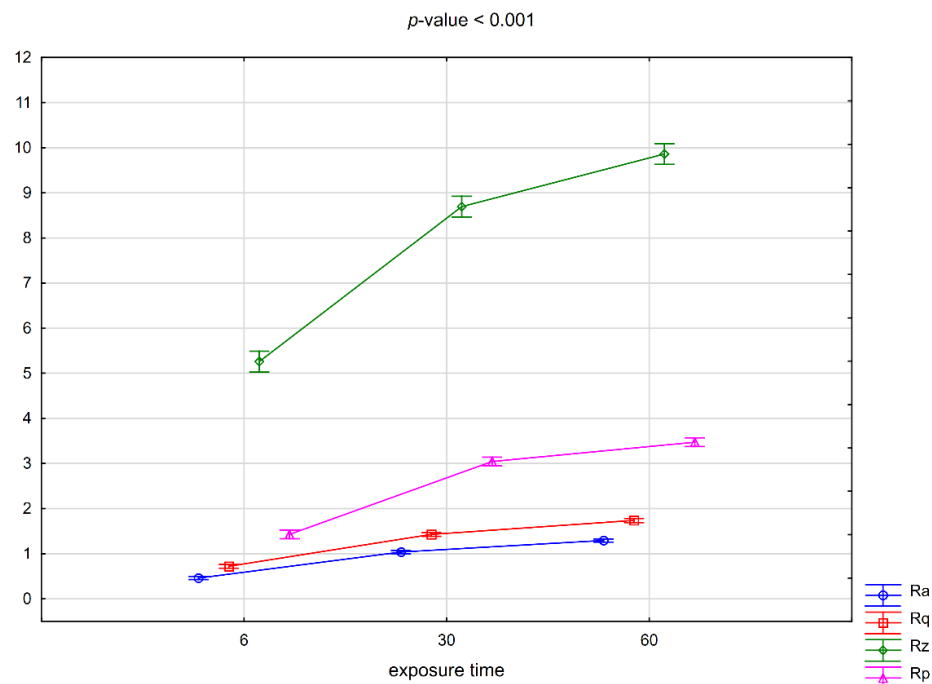


Figure 3. Comparison of selected roughness parameters [μm] of dental restorative materials following exposure to sports and energy drinks, depending on the exposure time. The vertical bars indicate 0.95 confidence intervals.

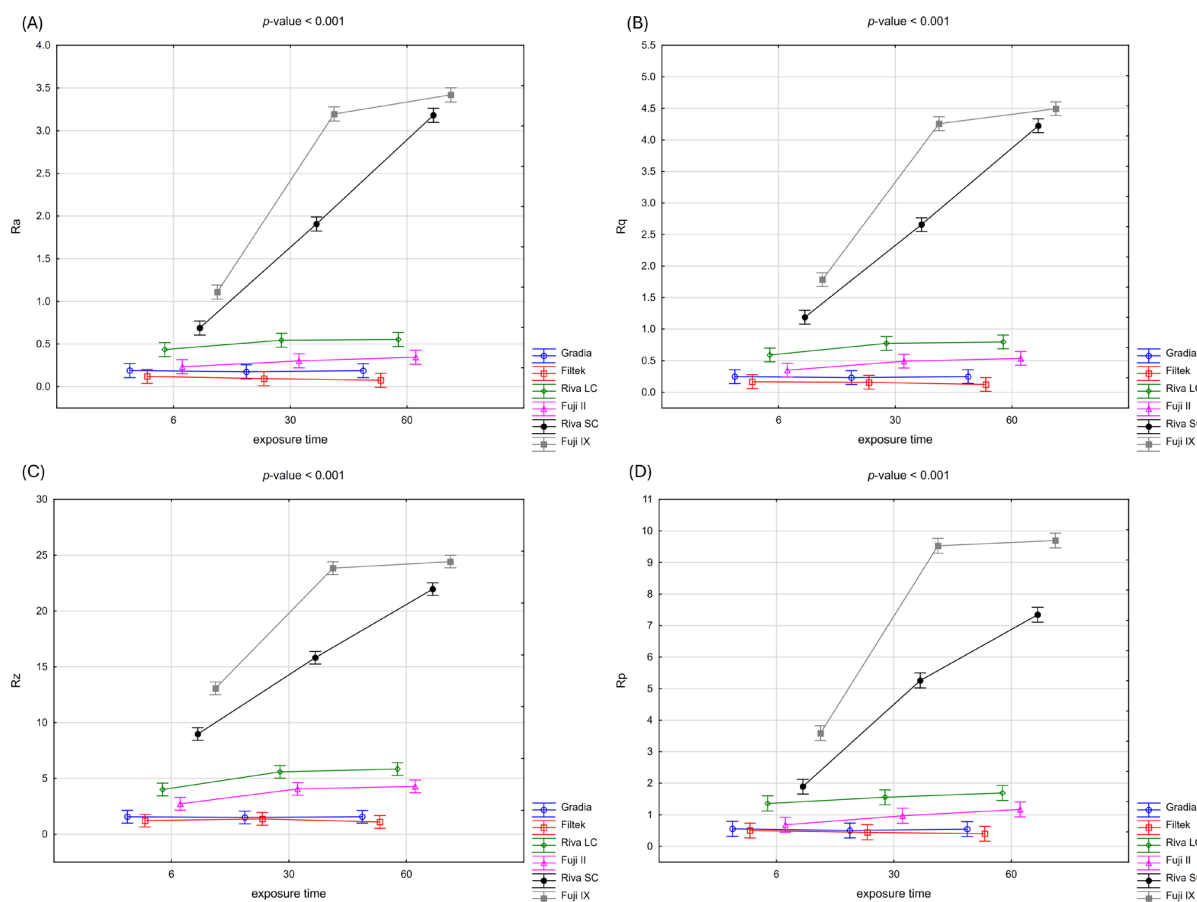


Figure 4. Comparison of selected roughness parameters [μm] of dental restorative materials: (A) Ra, (B) Rq, (C) Rz, and (D) Rp, following exposure to sports and energy drinks, depending on the inter-

action between the type of material and the exposure time. The vertical bars indicate 0.95 confidence intervals.

3.5. Interaction Between Medium and Exposure Time

The interaction between immersion medium and exposure time also significantly affected surface roughness (Figure 5). Post-hoc analysis (Table S5) revealed that several acidic functional drinks caused progressively higher roughness values with increasing exposure time.

In many cases, roughness parameters measured after 60 h were significantly higher than those observed at 6 h, particularly for drinks such as OSHEE and Red Bull. In contrast, samples stored in distilled water exhibited comparatively smaller changes over time, indicating a less aggressive effect on the surface structure.

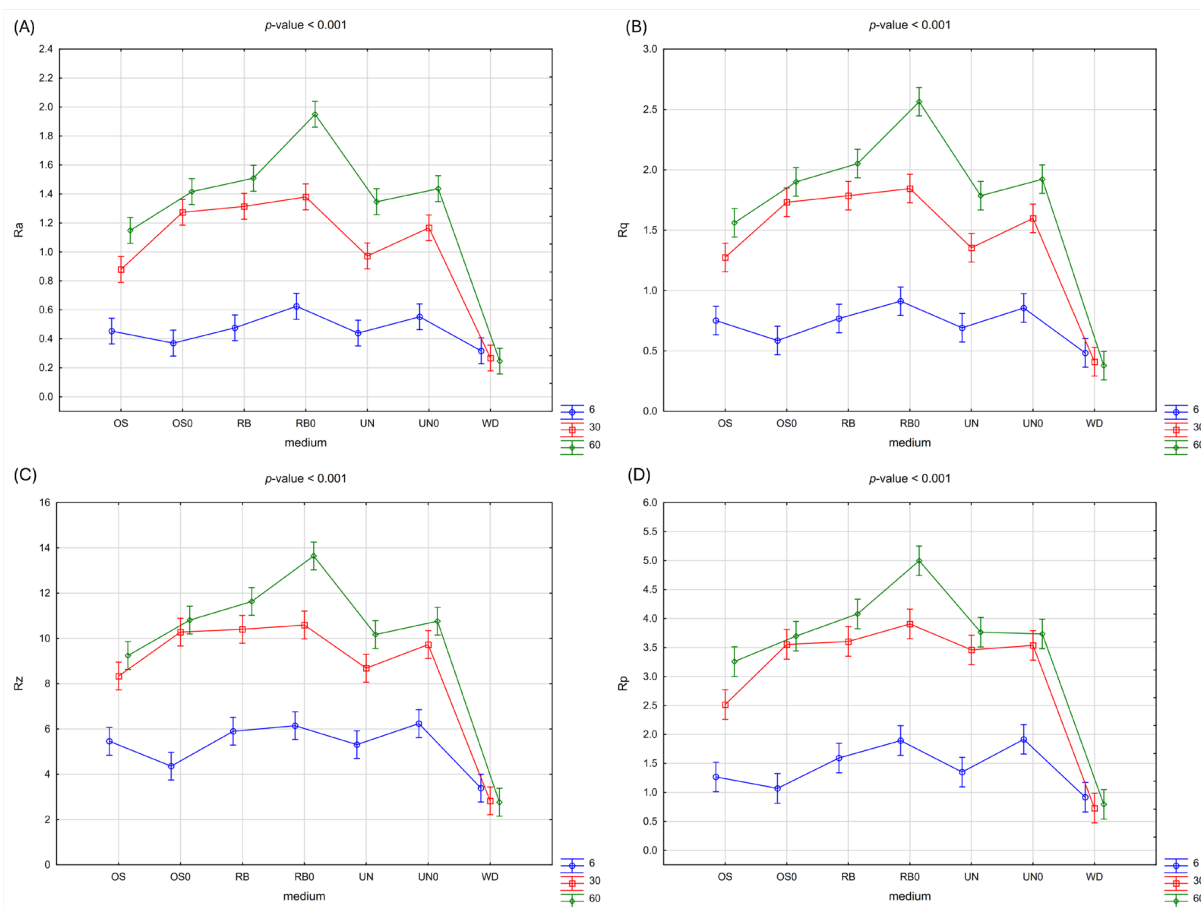


Figure 5. Comparison of selected roughness parameters [μm] of dental restorative materials: (A) Ra, (B) Rq, (C) Rz, and (D) Rp, following exposure to sports and energy drinks, depending on the interaction between the type of medium (OSHEE, OSHEE Zero, Unisport Nutrend, Unisport Nutrend Zero, Red Bull Energy Drink, Red Bull Energy Drink Zero) and the exposure time. The vertical bars indicate 0.95 confidence intervals.

3.6. Interaction Between Material Type and Medium

A significant material $\times$ medium interaction was observed (Figure 6). Post-hoc comparisons confirmed that the effect of sports and energy drinks on roughness depended strongly on the type of restorative material (Table S6). For RBCs, the type of beverage had little effect on surface roughness, with most comparisons showing no statistically significant differences. In contrast, RMGICs and conventional GICs exhibited significant rough-

ness increases after exposure to several acidic functional drinks, particularly OSHEE, Red Bull, and Unisport Nutrend.

Among all materials, Riva SC and Fuji IX demonstrated the most pronounced changes in roughness parameters depending on the immersion medium.

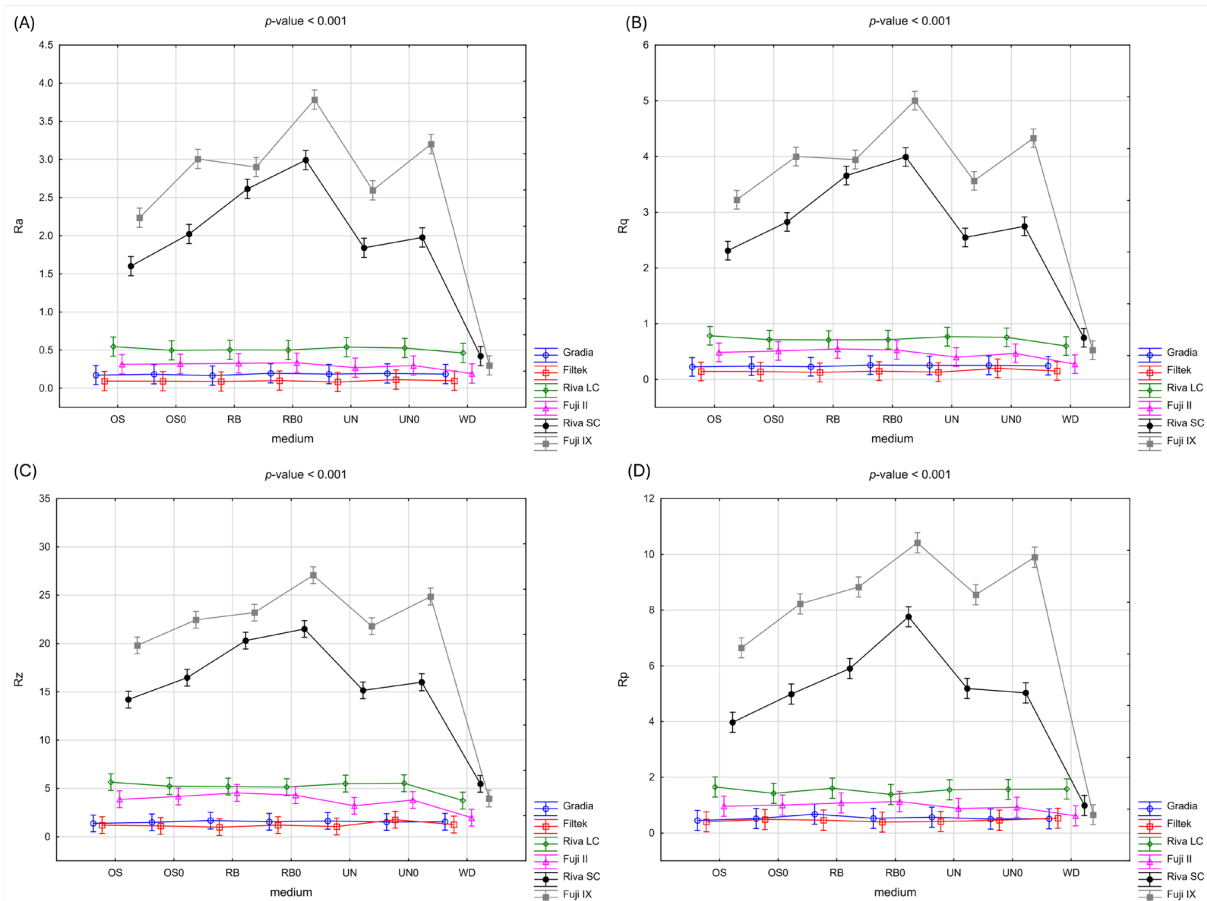


Figure 6. Comparison of selected roughness parameters [μm] of dental restorative materials: (A) Ra, (B) Rq, (C) Rz, and (D) Rp, following exposure to sports and energy drinks, depending on the interaction between the type of material and the type of medium (OSHEE, OSHEE Zero, Unisport Nutrend, Unisport Nutrend Zero, Red Bull Energy Drink, Red Bull Energy Drink Zero). The vertical bars indicate 0.95 confidence intervals.

3.7. Three-Way Interaction (Material $\times$ Medium $\times$ Time)

A significant three-way interaction between material type, immersion medium, and exposure time was observed (Figure 7). The combined effect of glass ionomer-based materials, sports and energy drinks, and prolonged exposure resulted in the greatest increases in surface roughness parameters.

The most pronounced roughness changes were observed for conventional GICs after 60 h of exposure to acidic functional drinks, whereas RBCs maintained relatively stable surface characteristics across all experimental conditions.

Detailed descriptive statistics and ANOVA results are available in the Supplementary Materials (Tables S7 and S8).

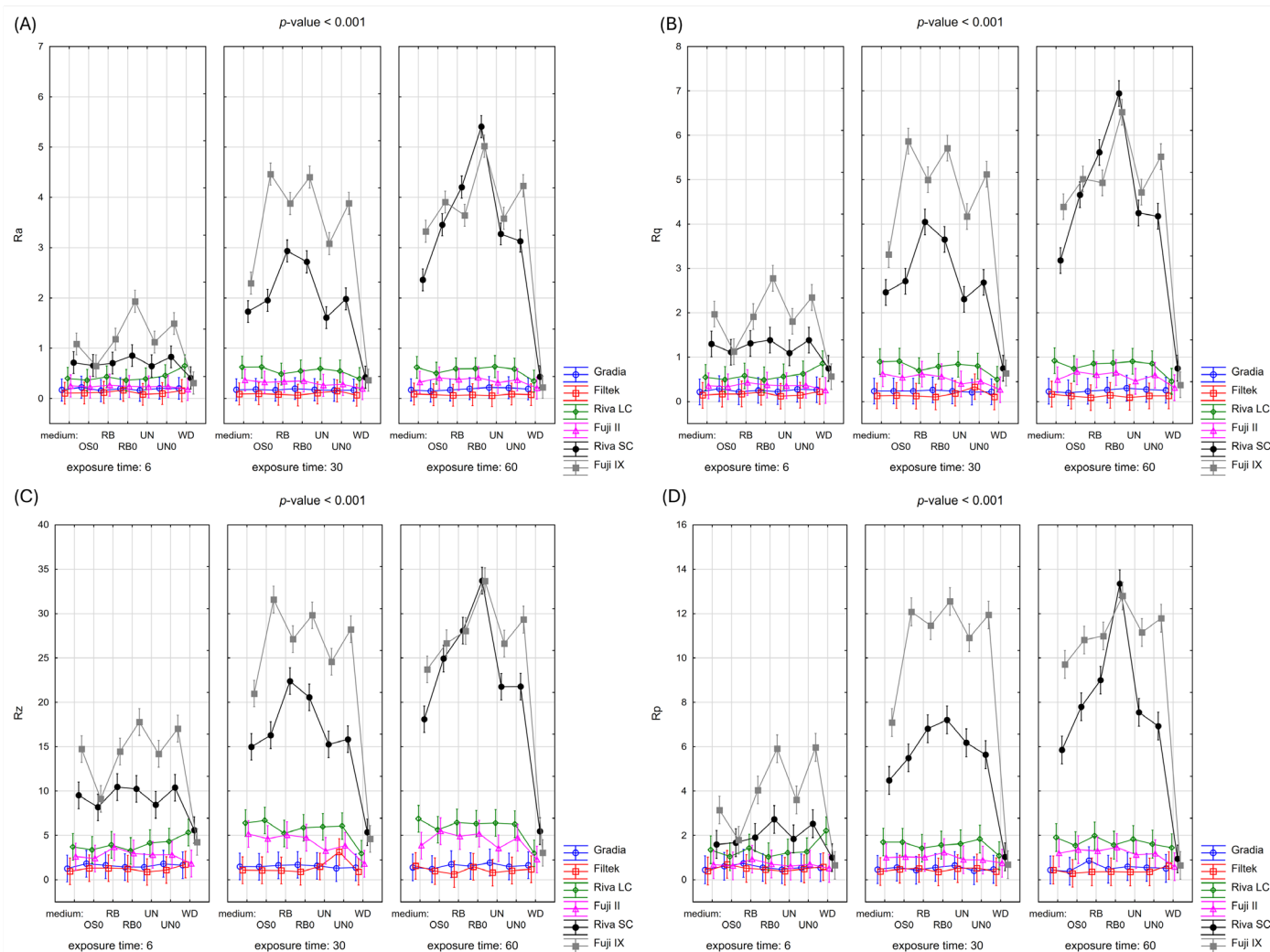


Figure 7. Comparison of selected roughness parameters of dental restorative materials: (A) Ra, (B) Rq, (C) Rz, and (D) Rp, following exposure to sports and energy drinks, depending on the interaction between the type of material, the type of medium (OSHEE, OSHEE Zero, Unisport Nutrend, Unisport Nutrend Zero, Red Bull Energy Drink, Red Bull Energy Drink Zero) and the exposure time. The vertical bars indicate 0.95 confidence intervals.

4. Discussion

The presented study was conducted by immersing samples of A2 shade filling materials in various sports and energy drinks. Presented exposure times of 6, 30 and 60 h were intended to replicate the cumulative exposure associated with regular acidic functional drink consumption (approximately 5–10 min weekly) over durations of one, five, and ten years. The control group consisted of samples stored in distilled water rather than artificial saliva, since there were no significant differences in the results obtained between those media [23].

To represent a wide variety of available acidic functional beverages, this study reviewed one hypertonic, one isotonic, and one hypotonic drink, along with their respective sugar-free versions, for a total of six tested solutions. The selection of these beverages was driven by rising consumption of sports drinks among adolescents, increased dietary awareness, and a growing preference for sugar-free alternatives [24,25]. The findings of this study showed that the type of immersion medium significantly influenced the surface roughness parameters of dental materials. Exposure to both sugar-containing and sugar-free sports and energy drinks generally produced greater surface roughness values than

exposure to distilled water. The greatest changes were observed in RMGICs and GICs after immersion in sugar-free acidic functional drinks, particularly OSHEE Zero, Red Bull Zero, and Unisport Nutrend Zero. The presented results agree with the studies by Elmarakby et al. [26] and Al-Samadani [6], which state that exposure to sports drinks results in adverse effects on the surface roughness of dental materials. A key factor in the erosive potential of acidic functional beverages is their titratable acidity levels. In this study, the pH of the tested solutions ranged from 2.68 to 3.32, confirming their high erosive capacity. A common characteristic of the tested solutions was the presence of citric acid, a highly corrosive compound [27]. Such acids could break down the organic matrix, consequently weakening the mechanical properties of restorative materials [15].

The selection of Ra, Rq, Rz, and Rp parameters allowed for a comprehensive assessment of surface alterations induced by immersion in sports and energy drinks. While Ra is the most commonly reported roughness parameter in dental materials research and provides information on the average surface irregularity, it does not fully characterize the morphology of the surface profile. Therefore, additional parameters were included to capture different aspects of topographical changes. Rq, being more sensitive to large deviations from the mean line, enables the detection of pronounced surface defects that may result from erosive degradation. Rz reflects the vertical distance between the highest peaks and deepest valleys of the profile and is particularly useful for identifying localised surface damage. In contrast, Rp characterises the height of the highest surface peak, providing information on the presence of prominent asperities that may influence plaque accumulation, wear behaviour, and surface gloss. The combined use of these parameters offers a more detailed characterisation of material degradation than the use of Ra alone and allows for a better understanding of the mechanisms underlying surface changes following exposure to acidic sports beverages [28].

The most prominent changes in roughness parameters were observed in conventional glass ionomer cements after 30 and 60 h of exposure to sports and energy drinks, confirming their greater vulnerability to long-term environmental challenges. On the other hand, composite materials (Gradia Direct and Filtek Z550) demonstrated relatively stable surface roughness over time, with no statistically significant differences observed among the evaluated exposure periods. However, Al-Samadani found that an immersion protocol extended to 1, 3, and 6 months led to significant changes in the surface roughness of composite materials [29]. This suggests that, depending on exposure time, all tested materials would present significant changes in surface roughness after immersion in acidic functional drinks. Although immersion in acidic beverages reduces mechanical resistance, the effect of distilled water is minimal. In Yazkan's research, after 1 week of immersion, there was no statistical significance in the distilled water group; however, the Red Bull and Burn group showed significant material degradation [22].

Glass ionomer-based restorative materials are well known in clinical dentistry for their strong adhesive and restorative properties. These materials also exhibit low cytotoxicity, caries-preventive effects due to fluoride release, and low thermal expansion [6]. Although their properties have improved, surface roughness remains a challenge affecting the longevity of these restorations. According to the obtained results, the interaction of glass ionomer materials, sports and energy drinks, and extended exposure produced the highest increases in surface roughness parameters. The greatest changes in roughness were observed after 60 h of exposure. The loss of matrix fragments exposes more filler particles to acidic attack, thereby accelerating degradation over time. Research conducted by Tanthanuch et al. [27] confirms the findings, stating that the glass ionomer restorative material immersed in the energy drink exhibited the greatest degree of degradation in comparison to composites. Al-Samadani [6] also observed significant changes in Ra values after 1 day, 1 week and 1 month of exposure, with the highest Δ Ra values after 1 month

of immersion. However, it should be noted that glass ionomer materials, due to their high buffering capacity through ion exchange and partial neutralisation of pH, may, in clinical conditions, have the potential to reduce the demineralisation of hard tissues, thereby supporting adjacent tooth structures from damage in the form of erosion or secondary caries [19].

Although RBCs performed much better than conventional GICs, composites showed a lower increase in surface roughness and maintained more stable results than RMGICs. Differences in resistance between glass ionomer- and resin-based materials may be attributed to their chemical composition. While glass ionomers consist mainly of fluoroaluminosilicate glass and polyacrylic acid, composites and RMGIs are modified by the addition of resins such as HEMA, Bis-GMA, UDMA, and TEGDMA. The inclusion of Bis-EMA and TEGDMA is associated with increased conversion, reduced solubility, and lower water sorption. Conversely, TEGDMA and UDMA are among the principal monomers released from materials stored in distilled water [30]. The presented results agree with those of Kose et al. [31], who found that composites showed minimal increases in surface roughness parameters compared with the substantial increase observed with Equia Forte glass ionomer.

On the other hand, prolonged exposure to sports and energy drinks leads to significant changes in the surface roughness of resin-based materials [29]. A major challenge with these materials, given their sensitivity to acidic functional drinks, is the process of water sorption. Because of their high acidity, these drinks can penetrate deeply into the organic matrix, promoting water uptake that results in particle loss and decreased surface integrity and microhardness [14,32]. Recent studies have highlighted the relationship between water sorption, nanomechanical properties, and restorative techniques in resin-based materials, emphasizing that environmental degradation influences not only surface roughness but also hardness, elastic modulus, and wear resistance [33]. Besides surface roughness, acidic beverages may also increase marginal microleakage, which is clinically relevant because it may promote secondary caries and restoration failure. Future studies should evaluate both surface degradation and marginal integrity under cyclic acidic challenges.

The greatest challenge in this study is that the complex conditions of the oral cavity cannot be fully reproduced in vitro. The immersion periods were selected as an experimental accelerated aging protocol intended to simulate prolonged acidic exposure under controlled laboratory conditions rather than to reproduce the complex oral environment. It remains unclear whether these effects occur to the same extent in vivo. The buffering capacity of saliva against sports drinks plays a crucial role in neutralising acids and maintaining stable pH values, thus minimising wear, abrasion, and fatigue of restorations. The experimental design did not include cyclic immersion with artificial saliva or intermittent pH recovery, which may reduce the erosive effects under clinical conditions. A further limitation is that baseline surface roughness was not assessed before immersion. Therefore, the present study compares post-immersion roughness values rather than true within-specimen changes, and intrinsic baseline differences between restorative materials cannot be excluded. Also, since the beverages differed in multiple physicochemical characteristics besides sugar content, the present study does not permit isolation of the specific contribution of sugar to the observed effects. Additionally, dietary habits, oral hygiene practices, and other patient-related factors could not be accounted for or evaluated. Consequently, further clinical studies are needed to better assess the performance and durability of these materials.

5. Conclusions

Within the limitations of this study, it can be concluded that immersion in sports and energy drinks negatively affects the roughness properties of dental restorative materials, thereby reducing their durability and clinical performance. The findings can be summarised as follows:

1. The type of immersion medium significantly influenced surface roughness. Exposure to both sugar-containing and sugar-free acidic functional drinks generally led to higher surface roughness values than distilled water, although sugar-free acidic functional drinks were associated with significantly higher roughness values, suggesting greater erosive and hydrolytic potential.
2. Exposure time had an adverse effect on all analysed roughness parameters, and a significant increase in surface roughness was observed across all exposure times. These findings indicate a progressive increase in surface roughness with longer exposure times.
3. The combination of prolonged exposure and acidic sports drinks resulted in the greatest increases in surface roughness parameters among conventional glass ionomer materials.
4. Resin-based composites exhibited the lowest roughness values and maintained relatively stable surface characteristics across all experimental conditions.

As surface roughness represents only one aspect of material degradation, further studies should also investigate the effects of acidic beverages on marginal integrity and other clinically relevant properties of restorative materials.

From a clinical perspective, cautious sports and energy drink consumption is recommended, and their frequent intake should be associated with more regular dental check-ups, as increased exposure to acids and sugars may raise the risk of enamel erosion and caries. Rinsing the mouth with water after consumption is recommended to help minimise the acidic effects on dental tissues.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/coatings16070881/s1>.

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