Yenidunya *et al. BMC Oral Health* (2025) 25:614
https://doi.org/10.1186/s12903-025-05988-2

BMC Oral Health

RESEARCH

Open Access

Gastric acid challenge: Mechanical proficiency and surface gloss of tooth-colored restorative materials

Ozge Gizem Yenidunya[1*], Tugba Misilli[2] and Ebru Yilmaz[1]

Abstract

Background To evaluate surface microhardness, roughness, and gloss changes of tooth-colored restorative materials [a direct composite (G-aenial A'Chord), an indirect composite (Gradia Plus), an ormocer (Admira Fusion), a giomer (Beautifil II), and an alkasite (Cention N)] after exposure to simulated gastric acid.

Methods A total of 110 disc-shaped specimens (22 discs of each material) were prepared using silicone molds (8 mm×2 mm) and exposed to either gastric acid or artificial saliva (control). Surface roughness (Ra), gloss (GU), and microhardness (VHN) were measured at baseline and after 96-hour of immersion in the solutions and the respective changes (ΔRa, ΔGU, ΔVHN) were calculated. Intergroup comparisons were performed using ANOVA (Tukey post hoc) or Kruskal-Wallis tests (Bonferroni correction). Independent samples t-test or Mann-Whitney U test was used for comparisons of each material across immersion media, while paired t-test was applied for time-dependent analyses.

Results In the gastric acid medium, changes in all parameters led to significant differences among restorative materials, while in the artificial saliva medium, significant differences were observed in ΔVHN and ΔGU. The statistically significant difference between immersion media was observed in both ΔVHN and ΔRa values for the giomer group, and in only ΔVHN values for the alkasite and indirect composite groups. In the gastric acid medium, the decrease in VHN and GU values was significant across all subgroups, while the increase in Ra was statistically significant only in the giomer and alkasite groups.

Conclusions While the giomer group exhibited the most significant changes in roughness and microhardness following exposure to gastric acid, all tested materials executed clinically admissible results regarding surface gloss.

Clinical trial number Not applicable.

Keywords Gastric acid, Surface gloss, Surface microhardness, Surface roughness, Tooth-colored restorative materials

*Correspondence:
Ozge Gizem Yenidunya
gizemyndny@outlook.com
[1]Department of Restorative Dentistry, Faculty of Dentistry, Pamukkale University, Denizli 20160, Turkey
[2]Department of Restorative Dentistry, Faculty of Dentistry, Çanakkale Onsekiz Mart University, 17100 Çanakkale, Turkey

Background

The durability and long-term clinical success of dental restorations are significantly contingent upon a comprehensive understanding of the properties inherent to restorative materials, as well as the fundamental principles and mechanisms involved in their interaction with the surrounding medium. Dental practitioners, pursuing the "latest and sophisticated" biomaterials should always be mindful of the longevity of restorative materials use, particularly during the dental treatment of individuals with medical conditions (i.e. gastro-esophageal reflux disease (GERD), bulimia nervosa, etc.) that alter the oral environment [1].

In GERD, which is an involuntary response that is not coordinated by the autonomic nervous system, gastric juice reaches the oral cavity due to relaxation of the upper sphincters of the esophagus [2]. The prevalence of GERD in Turkey has been documented to be 23%, comparable to that observed in Western countries [3]. Bulimia nervosa is an eating disorder characterized by recurrent episodes of binge eating (consumption of unusually large quantities of food), followed by compensatory behaviors such as self-induced vomiting, fasting, abuse of laxatives, excessive exercise [4]. In patients suffering from such medical conditions, the regurgitated gastric acid, primarily composed of hydrochloric acid (HCl), can be regarded as a corrosive acid capable of erosion and loss of dental hard tissues, as well as impacting the properties of restorative materials [5]. Although restorative materials have undergone remarkable evolution, showcasing enhanced optical and functional characteristics in recent decades, the extent to which these properties are affected by erosive acid cycle remains an unanswered question.

The increasing adoption of biomimetics and bioemulation principles in aesthetic dentistry has led to a rise in the utilization of tooth-colored restorative materials [6]. Resin composites have admitted as the foremost restorative materials in dental practice for many years due to their pre-eminencent mechanical strength and aesthetic properties [7]. Though resin composites can be applied directly to restore posterior teeth, their versatility has extended to include applications of indirect restoration as well. As for the indirect resin composites, the advantages of these materials include superior physical and mechanical properties, easier achievement of ideal contours and anatomy, higher degree of conversion and surface hardness due to the laboratory procedures based on various combinations of light, heat, pressure, and vacuum in the extra-oral polymerization process, and improved biocompatibility by virtue of the lower monomer elution [8, 9]. Ormocers, the acronym for organically modified ceramics, have been used in clinical practice for over three decades and are based on urethane dimethacrylate (UDMA) modifications developed to reduce shrinkage by using large matrix monomers with few crosslinks [10]. These materials comprise inorganic Si-O-Si networks derived from polysiloxanes crosslinked with polyfunctional urethane and thioether (meth)acrylate, prepared by the sol-gel technique [10, 11]. The bioactive material, entitled 'giomer', has surface pre-reacted glass ionomer (SPRG) fillers, which are produced through the pre-reaction of fluoroboroaluminosilicate glass particles with a polymer-containing acid, resulting in the formation of a glass ionomer phase prior to its dispersion into the resin matrix [12]. A giomer-based nanohybrid composite tested in this study blend the aesthetic and mechanical characteristics of resin composites with the bioactive properties of glass ionomers. From a clinical point of view, this material contains nanofillers (10–20 nm) with a total filler content of 83.3% by weight (68.6% volume), making it appropiate for all restoration classes in both anterior and posterior regions [13]. A new category of filling material 'alkasite' can release hydroxide, calcium, and fluoride ions from its alkaline (calcium fluorosilicate glass) fillers [14, 15]. This self-adhesive restorative which can be applied in bulk, both with or without light-curing, can neutralize the acidic environment around restorations and facilitate remineralization process [16].

Given that the choice of an appropriate restorative material plays a key role in the durability and longevity of dental restorations, particularly in patients with a highly acidic oral environment, dental professionals have a responsibility to meticulously evaluate and select materials that can withstand the acidic challenges [17]. While knowledge of the physical and optical properties of dental materials is essential for the evaluation of their clinical behavior, surface roughness, hardness, and gloss parameters stand out as the most commonly tested surface properties [2]. This study endeavors to evaluate the effect of simulated gastric juice on different tooth-colored restorative materials, with a particular emphasis on surface roughness, microhardness, and gloss, in the context of rehabilitating patients suffering from erosive challenges induced by HCl. The null hypotheses of this research were that there would be no difference in the tested parameters (microhardness, surface roughness, gloss): (1) among the tooth-colored restorative material groups in the gastric acid medium, (2) between the gastric acid and artificial saliva for each material group, and (3) within each group before and after gastric acid challenge.

Methods

The restorative materials [a direct composite (G-aenial A'Chord - GC Corp., Tokyo, Japan), an indirect composite (Gradia Plus - GC Corp., Tokyo, Japan), an ormocer (Admira Fusion - VOCO GmbH, Cuxhaven, Germany), a giomer (Beautifil II - Shofu Inc., Kyoto, Japan), and an alkasite (Cention N - Ivoclar Vivadent, Schann,

Table 1 Restorative materials used in this study

Material/Abbreviation	Composition	Manufacturer	Lot number
G-aenial A'Chord (GA) [Direct composite]	Filler particles (82 wt%): barium glass, prepolymerized silica Matrix: Bis-MEPP, UDMA	GC Corp., Tokyo, Japan	2306051
Gradia Plus (GP) [Indirect composite]	Filler particles: ceramic filler Matrix: 1%-5% Bis-GMA, 5%-10% TEGDMA, 1%-%5 UDMA	GC Corp., Tokyo, Japan	230123B
Admira Fusion (AF) [Ormocer]	Filler particles (84 wt%): barium, aluminum, organically modified silicic acid (10%–25%), silicon oxide Matrix: Ormocer (organically modified ceramic)	VOCO GmbH, Cuxhaven, Germany	2347561
Beautifil II (BE) [Giomer]	Filler particles (83.3 wt% / 68.6 vol%): multifunctional glass filler and S-PRG filler based on aluminofluoro-borosilicate glass Matrix: Bis-GMA (7.5 wt%) / TEGDMA (5 wt%)	Shofu Inc., Kyoto, Japan	082140
Cention N (CN) [Alkasite]	Powder: calcium fluoro-silicate glass, barium glass, calcium-barium-aluminum fluoro-silicate glass, iso-fillers, ytterbium trifluoride, initiators, pigments Liquid: dimethacrylates (UDMA, DCP, PEG-400 DMA), initiators, stabilizers, additives	Ivoclar Vivadent, Schann, Liechtenstein	Z0563R

Bis-MPEPP: bisphenol-A-polyethoxy methacrylate; Bis-GMA: bisphenol-A-glycidyl dimethacrylate; TEGDMA: triethylene glycol dimethacrylate; UDMA: urethane dimethacrylate; DCP: Tricyclodecan-dimethanol dimethacrylate; PEG-400 DMA: Polyethylene glycol 400 dimethacrylate.

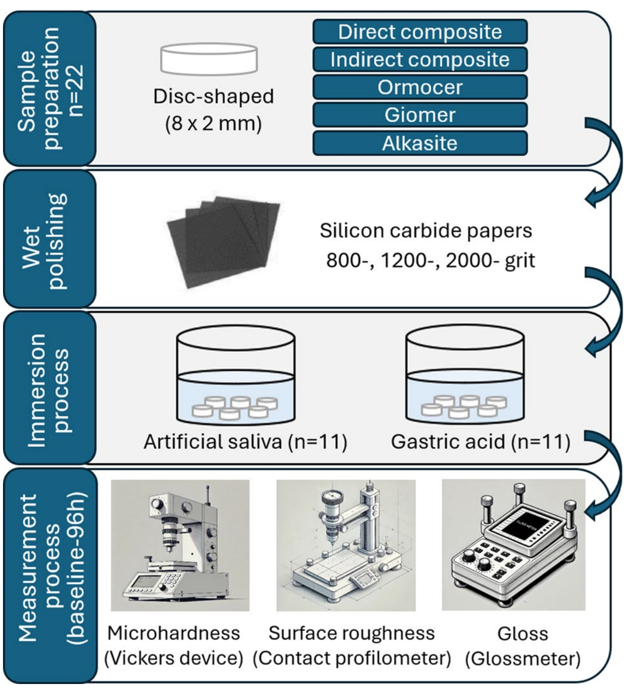

Fig. 1 Flowchart of study design and experimental procedures

Liechtenstein)] tested in this randomized *in vitro* study and their compositions are listed in Table 1. Based on power analysis performed using G*Power 3.1 software (Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany), the sample size was determined as 11 per group with an error probability of α = 0.05, an effect size d = 0.66, and 95% power.

A total of 110 disc-shaped specimens (8 mm in diameter × 2 mm in thickness) were prepared from five different tooth-colored restorative materials (*n* = 22), as described in the study flowchart (Fig. 1). Considering the manufacturers' instructions, after inserting the material into a silicone mold, a Mylar strip (Hawe™ Transperent Strips, KerrHawe, Bioggio, Switzerland) and a thin glass slab were gently pressed onto the surface with a static load of ~ 20 N to extrude excess resin composite and achieve a smooth, flat, and porosity-free surface. All specimens, except those in the indirect composite subgroups, were photopolymerized using an LED curing unit (Bluephase PowerCure, Ivoclar Vivadent AG, Schaan, Liechtenstein) at a light intensity of 1.200 mW/cm², and the power of the curing unit was verified prior to each polymerization process using an integrated radiometer. As the indirect composite material has different recommended curing time and instrument, the specimens were heat-cured for 3 min with a pressure oven (Labolight Duo, GC Europe, Leuven, Belgium) in full mode. Using a 1:1 mixing ratio, alkasite material was mixed on a paper pad with a plastic spatula until a homogeneous consistency was achieved. The resulting mixture was then transferred into the mold, adapted using a condenser, and only the chemical + light activation mode was tested. The specimens were maintained in distilled water at 37 °C for 24 h to ensure complete polymerization.

All specimens were polished using a polishing machine equipped with silicon carbide papers of 800-, 1200-, and 2000- grit, each applied for 20 s under water cooling. Subsequently, the specimens underwent ultrasonic cleaning in distilled water for 5 min. The lower surface of each specimen was marked with a number and a code name to identify material.

For the experimental design, specimens were divided into two groups, each consisting of 11 samples, using a simple randomization method based on the immersion solution. Prior to the immersion process, baseline measurements of surface roughness, gloss, and microhardness were taken from the upper surfaces of the specimens. For surface roughness testing, a mechanical profilometer instrument (Perthometer M2, Mahr, Göttingen, Germany) was used, with a 0.25-mm cutoff value and 2-mm tracing length. Three measurements were taken at the center of each specimen along different orientations, and the mean surface roughness (Ra_1) was calculated and recorded in micrometers (μm). The calibration of the profilometer was checked with the help of a reference block with an Ra value of 3.22 μm before measurements of each specimen.

The initial surface gloss of the specimens was measured with a glossmeter (Novo-Curve, Rhopoint Instruments, Bexhill-on-Sea, England) at a specular angle of 60°, in accordance with ASTM D523-14:2018 [18] and ISO 2813:2014 [19] standards. Specimens were shielded from external light exposure using a custom-made, black polytetrafluoroethylene mold. The glossmeter was calibrated with a calibration plate (Novocurve High Gloss Calibration Standard) having a reference value of 93.4. Four readings were obtained for each specimen using rotation around its center, and the average of the measurements was reported as a single value, expressed in Gloss Units (GU_1).

The hardness value of each specimen was assessed using a microhardness tester (METKON MH-3, Metkon Ind. Trade. Co. Ltd., Bursa, Turkey) equipped with a diamond Vickers indenter. A 200 g force was applied to the specimen's surface for 10 s to create a diagonal indentation, which was then measured under a microscope integrated with the device. The Vickers hardness number (VHN) was subsequently calculated based on the following formula:

$$HV = 1.8544 \times \ (P/d^2),$$

where *P* represents the applied load in kilograms-force (kgf), and *d* denotes the mean diagonal length of the indentation in millimeters (mm). Indentations were applied at three distinct points on each specimen, ensuring a minimum spacing of 1 mm between adjacent indentations. The mean values were then calculated and recorded as VHN_1.

To simulate an erosive challenge, a protocol involving immersion in a 0.06 M hydrochloric acid solution (an aqueous solution of 0.113% HCl, pH 1.2) was implemented. Meanwhile, the control specimens were stored in an artificial saliva medium (NaCl 125.6 mg L^{-1}, KCl 963.9 mg L^{-1}, KSCN 189.2 mg L^{-1}, KH_2PO_4 654.5 mg L^{-1}, urea 200.0 mg L^{-1}, $Na_2SO_4.10H_2O$ 763.2 mg L^{-1}, NH_4Cl 178.0 mg L^{-1}, $CaCl_2.2H_2O$ 227.8 mg L^{-1}, $NaHCO_3$ 630.8 mg L^{-1}). Each specimen was immersed in 5 mL of immersion solution for 96 h in an incubator (LabART LI-63D, Art Laborteknik Ltd. Co., Istanbul, Turkey) at 37 °C. The immersion duration was determined based on a previously published protocol, which indicates that 96 h of continuous exposure corresponds to approximately 10 years of clinical conditions [20, 21]. To ensure consistent pH levels, the immersion solutions were refreshed daily throughout the experiment.

Upon completion of the immersion period, surface roughness, gloss, and microhardness measurements were repeated following the previously described methodology and recorded as Ra_2, GU_2, and VHN_2 values, respectively. The changes in the respective parameters (ΔRa, ΔGU, ΔVHN) were calculated as the differences between the after 96-hour and baseline values.

Statistical analysis

Data were analyzed using SPPS (23.0) statistical software program (SPPS Inc., Chicago, IL, USA). The normality assumption was evaluated using the Shapiro-Wilk test. When the data showed normal distribution, ANOVA (with Tukey post hoc test) was employed to compare the changes in parameters among restorative materials in each immersion medium. When normality was not met, Kruskal-Wallis (with post hoc Bonferroni correction) tests were applied. Additionally, comparisons of each material across different immersion media were performed using the independent samples t-test for normally distributed data, or the Mann-Whitney U test for non-normally distributed data. Paired t-tests were performed to compare the differences between the after 96-hour and baseline values (Ra_2-Ra_1, VHN_2-VHN_1, and GU_2-GU_1) for each material*immersion medium subgroup. A *p*-value of less than 0.05 was considered statistically significant.

Results

Table 2 showed the microhardness reduction rates of the restorative materials. The one-way ANOVA revealed significant differences among the restorative materials in both immersion media ($p < 0.001$). According to the Tukey post hoc test, the highest microhardness change values (ΔVHN) were observed in the ormocer and giomer groups in both immersion media, with the giomer group exhibiting even greater values than the ormocer group in the gastric acid medium. These were followed by alkasite group. However, no statistically significant differences were detected between the alkasite and direct composite groups in artificial saliva or between the alkasite and indirect composite groups in the gastric acid medium. Similarly, no statistically significant differences were observed between the direct and indirect composite groups in either of the immersion media. The independent samples t-test, comparing the same restorative materials across different immersion media, showed that the indirect composite, giomer, and alkasite groups exhibited significantly higher ΔVHN values in the gastric acid medium compared to artificial saliva ($p < 0.001$, $p = 0.001$, and $p = 0.029$, respectively).

Table 2 Baseline and 96-hour microhardness values, reduction rates, and percentage changes of restorative materials in different immersion media

Groups			Direct composite	Indirect composite	Ormocer	Giomer	Alkasite	*P* value
Immersion Media	Artifical saliva	Baseline-96 h, VHN	59.53–54.07	57.34–53.14	71.77–51.37	83.41–65.20	45.50-37.18	
		% Change	%9.13	%7.30	%28.42	%21.79	%18.26	
		*ΔVHN (Mean ± SD)	5.46 ± 4.00^{AB}	$4.20 \pm 2.02^{A, y}$	20.40 ± 3.60^{C}	$18.22 \pm 3.06^{C, y}$	$8.32 \pm 3.23^{B, y}$	< ***0.001***
	Gastric acid	Baseline-96 h, VHN	59.30–52.60	58.07–47.02	71.71–50.97	83.45–57.29	45.77–33.62	
		% Change	%11.26	%18.99	%28.88	%31.16	%26.37	
		*ΔVHN (Mean ± SD)	6.70 ± 3.46^{A}	$11.05 \pm 4.08^{AB, x}$	20.74 ± 4.02^{C}	$26.15 \pm 5.76^{D, x}$	$12.15 \pm 4.34^{B, x}$	< ***0.001***
P value			0.444	***< 0.001***	0.836	***0.001***	***0.029***	

*Data represent the mean and standard deviation of the reduction in Vickers hardness (VHN) values.

A–C: Different uppercase letters indicate statistically significant differences among materials in the same immersion medium.

x–y: Different lowercase letters indicate significant differences for each material across different immersion media.

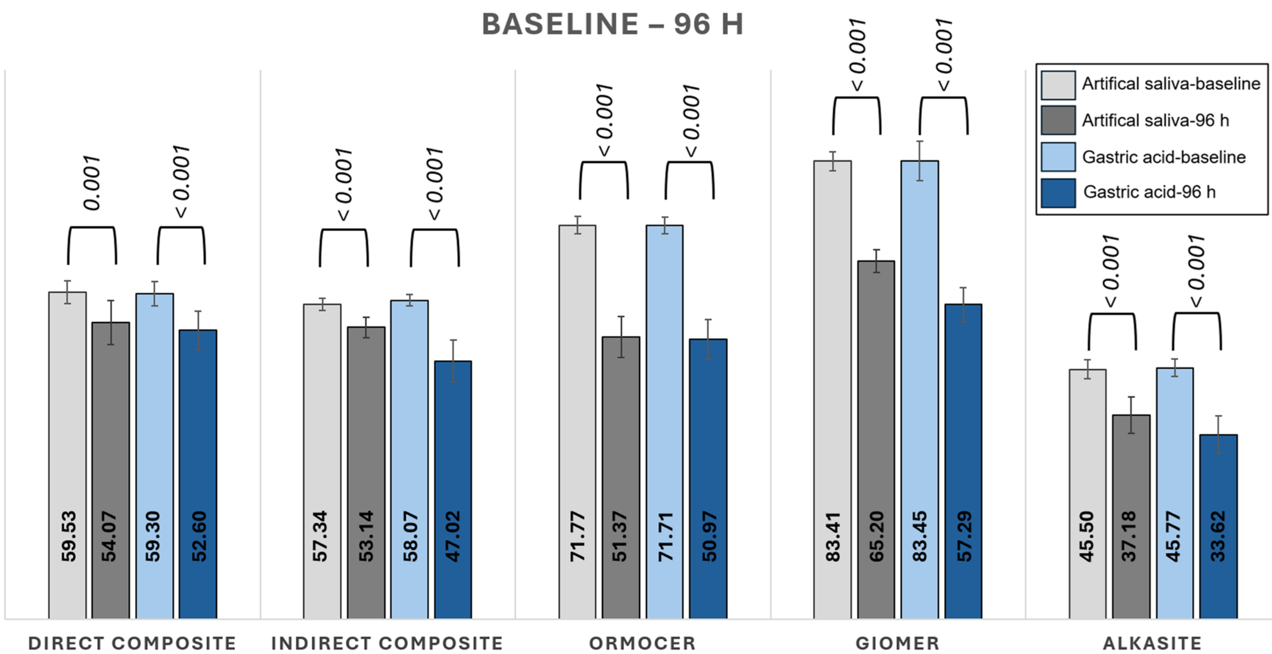

Fig. 2 Differences in microhardness (VHN) from baseline to after 96-hour immersion, with mean, standard deviation, and paired t-test results for all subgroups

The results of the paired t-test, which evaluated the time-dependent differences in microhardness values for each composite group within each storage medium, were presented in Fig. 2. Accordingly, a significant decrease in VHN values over time was observed in all subgroups (except for direct composite*artifical saliva with $p = 0.001$; $p < 0.001$ for all other groups).

Surface roughness changes of the restorative materials were displayed in Table 3. The Kruskal-Wallis test (with post hoc Bonferroni correction), which evaluated changes in Ra values (ΔRa) among different materials within each medium, revealed that the gastric acid medium led to significantly higher ΔRa values for the giomer and alkasite groups ($p < 0.001$), with no significant difference observed between them. Also, no significant differences were found between the ormocer, direct composite, and indirect composite groups ($p > 0.05$). On the other hand, when each material group was compared across different media using the Mann-Whitney U test, higher changes were observed in the giomer group in gastric acid compared to artificial saliva ($p < 0.001$).

The time-dependent differences in surface roughness values for each material group within each medium, as analyzed by the paired t-test, were shown in Fig. 3. As a result, a significant increase in Ra values was observed for the giomer and alkasite groups in the gastric acid medium ($p = 0.001$ and $p = 0.002$, respectively).

Table 4 exhibited the gloss reduction rates of the restorative materials employed. The one-way ANOVA revealed statistically significant differences among restorative materials in both artificial saliva and gastric acid media ($p < 0.001$ and $p = 0.010$, respectively). According to the Tukey post-hoc test, in the artificial saliva medium, the greatest ΔGU values were observed in direct composite

Table 3 Baseline and 96-hour surface roughness values and changes of restorative materials in different immersion media

Groups			Direct composite	Indirect composite	Ormocer	Giomer	Alkasite	*P* value
Immersion Media	Artifical saliva	Baseline-96 h, Ra	0.10–0.12	0.10–0.10	0.12–0.13	0.14–0.14	0.18–0.22	
		% Change	%14.57	%5.36	%10.19	%7.16	%23.98	
		*ΔRa	0.00 (-0.01)-0.10	0.01 (-0.03)-0.02	0.00 (-0.01)-0.07	0.02^{y} (-0.05)-0.03	0.02 (-0.04)-0.14	0.701
	Gastric acid	Baseline-96 h, Ra	0.10–0.11	0.09–0.10	0.12–0.13	0.13–0.22	0.19–0.26	
		% Change	%17.34	%17.26	%6.09	%62.80	%47.10	
		*ΔRa	0.00^{A} (-0.02)-0.12	0.01^{A} (-0.02)-0.05	0.01^{A} (-0.03)-0.02	$0.08^{B, x}$ 0.05–0.12	0.07^{B} 0.00-0.21	< ***0.001***
***P* value**			0.893	0.330	0.814	***< 0.001***	0.167	

*Data are the median (minimum- maximum) values of changes in surface roughness (Ra, in µm).

A–C: Different uppercase letters indicate statistically significant differences among materials in the same immersion medium.

x–y: Different lowercase letters indicate significant differences for each material across different immersion media.

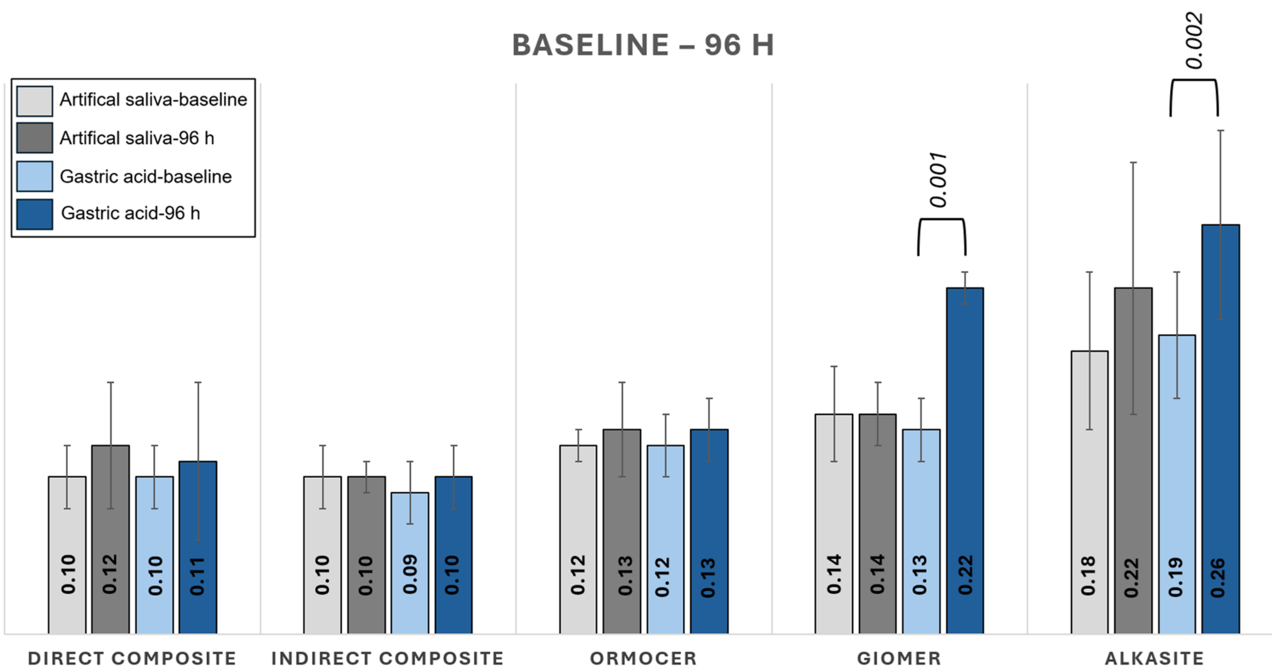

Fig. 3 Differences in surface roughness (Ra) from baseline to after 96-hour immersion, with mean, standard deviation, and paired t-test results for all subgroups

Table 4 Baseline and 96-hour gloss values, reduction rates, and percentage changes of restorative materials in different immersion media

Groups			Direct composite	Indirect composite	Ormocer	Giomer	Alkasite	*P* value
Immersion Media	Artifical saliva	Baseline-96 h, GU	40.13–29.11	33.79–33.03	27.30–22.30	19.48–17.26	32.64–23.45	
		% Change	%26.86	%1.62	%17.71	%8.61	%26.60	
		*ΔGU (Mean ± SD)	11.02 ± 5.41^{C}	0.76 ± 3.33^{A}	5.00 ± 3.34^{AB}	2.22 ± 4.27^{A}	9.19 ± 5.25^{BC}	< ***0.001***
	Gastric acid	Baseline-96 h	41.36–30.76	33.24–28.76	28.27–20.86	18.92–14.16	31.20-19.98	
		% Change	%24.85	%12.39	%25.33	%21.65	%34.61	
		*ΔGU (Mean ± SD)	10.60 ± 5.70^{AB}	4.48 ± 5.28^{A}	7.41 ± 3.45^{AB}	4.76 ± 4.47^{AB}	11.22 ± 5.61^{B}	***0.010***
P value			0.871	0.092	0.152	0.211	0.439	

*Data are the mean and standard deviation values of changes in gloss units (GU).

A–C: Different uppercase letters indicate statistically significant differences among materials in the same immersion medium.

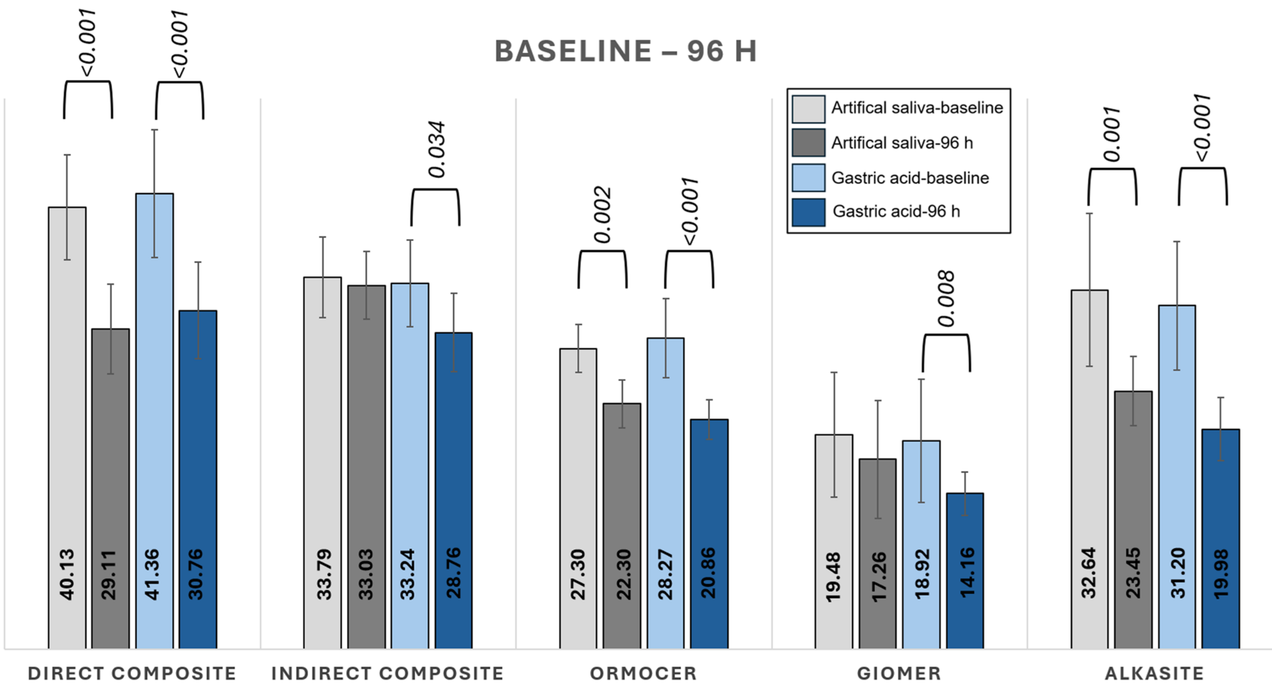

Fig. 4 Differences in surface gloss (GU) from baseline to after 96-hour immersion, with mean, standard deviation, and paired t-test results for all subgroups

and alkasite, followed by ormocer, giomer, and indirect composite groups. However, no significant differences were found between alkasite and ormocer, or between ormocer, giomer, and indirect composite groups ($p > 0.05$). In the gastric acid medium, gloss reduction was highest in the alkasite group, followed by the direct composite, ormocer, and giomer groups, with no statistically significant differences among these four groups ($p > 0.05$). The lowest gloss reduction was observed in the indirect composite group, and the only statistically significant difference was between the alkasite and indirect composite groups ($p = 0.048$). However, comparing each restorative material in different immersion media showed no statistically significant differences ($p > 0.05$).

Figure 4 illustrated the differences in GU values over time for each material in each immersion medium. In both artificial saliva and gastric acid media, significant decreases were observed in the direct composite ($p < 0.001$), ormocer ($p = 0.002$, $p < 0.001$, respectively), and alkasite groups ($p = 0.001$, $p < 0.001$, respectively) groups. However, for the indirect composite and giomer groups, this decrease was only detected in the gastric acid medium ($p = 0.034$, $p = 0.008$, respectively).

Discussion

This study aimed to evaluate the mechanical properties and surface gloss of five tooth-colored restorative materials by comparing specimens exposed to an endogenous erosion protocol with those preserved in artificial saliva as controls. The results showed that the microhardness, surface roughness, and gloss of the materials were affected at different levels by the chemical impact of simulated gastric acid. Hence, the first null hypothesis, which proposed that no differences would exist among the tooth-colored restorative material groups in the gastric acid medium, was rejected. The second null hypothesis, which proposed that there would be no difference between the gastric acid and artificial saliva media for each material group, was accepted for the gloss parameter. However, it was rejected for the microhardness and surface roughness parameters due to the different tendencies exhibited by spesific groups. The third null hypothesis, which proposed that there would be no difference within each group before and after gastric acid challenge, was also rejected. Gastric acid exposure resulted in differences in microhardness and gloss in all materials, while the changes in surface roughness were observed only in specific groups; therefore, the hypothesis was not valid for all material groups.

A consensus regarding the in vitro simulation of gastric acid and corresponding duration necessary to accurately replicate the clinical scenario remains elusive within the researchers. In the review of the literature, Cengiz et al. stated that continuous 24-hour exposure to gastric acid simulates the worst-case clinical scenario in terms of gastroesophageal reflux [22], while another study reported that immersion times of 6- and 24- hours correspond approximately to simulations of 2 and 8 years, respectively [23]. Considering that a recent study [5] has indicated that 45 min of exposure to gastric acid corresponds to one month of clinical situation, it can be stated that the 96-hour exposure period utilized in our study simulates a timeframe of over 10 years [20, 21].

It has been reported that higher filler content results in trends for increased hardness and stiffness [24]. Within the reported context, this finding is in line with the present study in which giomer and ormocer subgroups with high levels of fillers showed the highest hardness values. Acidic solutions can enhance the rate of hydrolysis of methacrylate ester bonds within the resin matrix of polymer-based materials, causing the organic matrix to swell. This swelling creates pores and intermolecular spaces, allowing fillers to leach out, which ultimately accelerates the breakdown of the polymer network and reduces the materials' physical properties, such as microhardness [17, 23]. All the materials assessed in the current investigation demonstrated a notable decrease in surface hardness subsequent to acid exposure, thereby manifesting a considerable effect size on this characteristic.

Giomer-based material demonstrated the most drastic changes in microhardness compared to other resin-based materials used in this study. Likewise, a previous study assessing the impact of gastric acid on the surface microhardness of various restorative materials found that Beautifil II exhibited a more pronounced reduction in microhardness compared to other materials [25]. As a possible explanation for this result, it has been suggested that the polymer matrix of the other tested materials exhibited greater acid resistance. In light of the microhardness reduction rates observed in the study, the lowest values were found in the direct and indirect composite groups as well as in the alkasite material. Within the indirect composite group, polymerization with the specialized device may have enhanced cross-linking, thereby increasing the hardness of the polymer matrix [22]. It is considered that this situation could potentially decrease interaction with the oral environment, thereby minimizing the microhardness reduction rate. Moreover, this outcome may also be attributed to the possible stability of these materials against oral solutions and erosive episodes, likely due to the low water absorption characteristics of the UDMA monomers they share in common [17]. Interestingly, the PEGDMA present in the composition of Cention N, being a hygroscopic monomer highly prone to degradation, is expected to result in the formation of a less stable polymer network, ultimately decreasing the hardness ratio [16]. In the context of the present study, it can be suggested that the alkasite restorative material was more affected by the gastric acid environment than by artificial saliva, due to its PEGDMA monomer content.

In the literature, surface roughness (Ra) values below 0.2 μm are recommended to reduce microbial colonization which may lead to secondary caries formation [26]. Based upon the data obtained from our study, it was determined that the giomer subgroup exposed to gastric acid and the alkasite material stored in both solutions showed roughness values exceeding the threshold of 0.2 μm. In particular, the alkasite restorative material (Cention N) used in this study, is composed of a separately packaged powder and liquid, which are manually mixed immediately before application. However, achieving a consistent powder-to-liquid ratio and a uniform mix each time can be challenging, which may be associated with the higher initial Ra values observed in this group. Furthermore, the results showed higher ΔRa values in the surface roughness changes of giomer and alkasite subgroups immersed in gastric acid compared to other tested materials. A possible explanation for this phenomenon is that alkasite and giomer are ion-releasing bioactive/bio-interactive "smart" materials that ionically interact with their surroundings, releasing ions at a higher rate when exposed to acidic conditions [27, 28]. Also, only the giomer-based restorative material exhibited a significant change in surface roughness following immersion in gastric acid solution compared to artificial saliva. This difference may be attributed to the greater susceptibility of fluorosilicate glass fillers to degradation by weak acids, as opposed to artificial saliva. This finding of the study aligns with those of Kooi et al. [29] and Cabadag et al. [30], who observed that giomer-based materials are particularly vulnerable to degradation in acidic environments. Therefore, it is not coincidental that the highest surface roughness change values after exposure to gastric acid were observed in these two bioactive materials, along with the differences in the rates of microhardness reduction between the immersion media, which were also evident in these two groups.

The surface gloss of esthetic restorations plays a crucial role in replicating dental structures with precision, both in terms of tooth proportions and visual perception. Gloss is, in essence, affected by various factors such as the surface roughness of the material, the size, shape, and distribution of filler particles, the refractive index differences between the filler and the resin matrix, the mechanical characteristics of the material, and the extent of monomer conversion in the resin phase [31, 32]. In a clinical setting, factors such as the operator, the type of movements, and the pressure applied to the instruments can also affect the final gloss of the surface [33]. To minimize these variables, all finishing/polishing procedures were performed by a single operator.

The perceptibility and acceptability thresholds employed to assess the tolerability of variations observed in this study represent a potential limitation, as they introduce a gray area open to debate. It is essential to be discussed these thresholds to determine which differences in surface gloss significantly impact the aesthetic outcome of dental restorations. The wide range of reported values is influenced by the subjective criteria of evaluators, the tools used for assessment, and the coordinate systems applied [34]. A previous study has identified the perceptibility and acceptability limits for surface gloss within a range of 6.4 to 35.7 GU [35]. In the present study, although all alkasite, direct composite groups, and the ormocer subgroup immersed in gastric acid exhibited the gloss variations above the perceptible limit (PT = 6.4 GU), none of the materials displayed values exceeding the acceptable threshold (AT = 35.7 GU).

Based on the American Dental Association (ADA) professional product review, an expert panelist identified 40–60 GU as the typically preferred gloss range [36]. Cook and Thomas further noted that gloss levels below 60 GU are generally regarded as poor, while gloss levels between 60 and 80 GU are deemed acceptable [37]. In our study, the highest gloss values were recorded in the direct and indirect composite groups, respectively, whereas the lowest gloss value was observed in the giomer-based material. However, it is noteworthy that even the highest gloss values in the direct and indirect composite groups remained below the poor gloss threshold of 60 GU, which can likely be attributed to the use of 2000- grit sandpaper as the final step in the polishing process for all tested specimens. Consistent with our study, Lassila et al. investigated how various polishing protocols (laboratory-machine polishing with different silicon carbide paper grits: 320-, 800-, 1200-, 2000-, 4000-, chairside-hand polishing using a series of Sof-lex spiral, and abrasive polishing points) affect the surface gloss of different restorative resin composites and concluded that achieving an acceptable gloss range of 60–80 GU is only possible with the use of 4000- grit abrasive for polishing [38]. In addition to these differences, it should be note that even composites classified within the same category can exhibit considerable differences in filler size, shape, volume or weight fraction, and resin matrix composition. These variations make it challenging to directly compare restorative materials and isolate the impact of specific components on optical properties like surface gloss [32].

This *in vitro* study provides considerable insights regarding the resultant surface alterations of tooth-colored restorative materials under acidic conditions, which may jeopardize the aesthetic and physical characteristics of restorations. Regrettably, the heterogeneity of experimental designs concerning intrinsic erosion makes it difficult to compare outcomes and accurately adapt them to the clinical environment. Additionally, the continuous immersion model used in this study does not fully replicate intraoral conditions, where factors such as saliva and other protective mechanisms may alter material degradation. As the conclusions are based on laboratory experimentation, further studies incorporating more dynamic oral conditions are warranted to better reflect clinical scenarios and provide reliable recommendations for dental practitioners.

Conclusions

Within the limitations of this study, the following conclusions can be drawn:

1. Regarding the microhardness parameter, all restorative materials tested exhibited a significant decrease in VHN over time, with the giomer group showing the greatest microhardness reduction after exposure to gastric acid.
2. The greatest changes in surface roughness due to gastric acid exposure were observed in the giomer and alkasite groups. Notably, alkasite materials stored in both mediums and giomer specimens exposed to gastric acid displayed roughness values exceeding the critical threshold of 0.2 µm.
3. While all alkasite, direct composite groups, and the ormocer subgroup immersed in gastric acid exhibited gloss reduction rates above the perceptible threshold, it was determined that gastric acid caused a significant reduction in the gloss values of all restorative materials tested.

Abbreviations

GERD Gastro-esophageal reflux disease
HCl Hydrochloric acid
UDMA Urethane dimethacrylate
SPRG Surface pre-reacted glass ionomer
Ra Surface roughness
µm Micrometers
GU Gloss units
VHN Vickers hardness number
PEGDMA Polyethylene glycol dimethacrylate
ADA American Dental Association

Acknowledgements

Not applicable.

Author contributions

Research concept and design: O. G. Y., T. M.; Collection and/or assembly of data: O. G. Y., T. M., E. Y.; Data analysis and interpretation: O. G. Y., T. M.; Writing the article: O. G. Y.; Critical revision of the article: T. M., E. Y.; Final approval of article: O. G. Y., T. M., E. Y.

Funding

Financial support for the study was provided by the authors.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical approval

Since the study protocol is an in vitro study, it does not require ethical approval.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 13 December 2024 / Accepted: 11 April 2025
Published online: 21 April 2025

References

1. Kulkarni A, Rothrock J, Thompson J. Impact of gastric acid induced surface changes on mechanical behavior and optical characteristics of dental ceramics. J Prosthodont. 2020;29(3):207–18.
2. Tinastepe N, Malkondu O, Kazazoglu E. Hardness and surface roughness of differently processed denture base acrylic resins after immersion in simulated gastric acid. J Prosthet Dent. 2023;129(2):364–e1.
3. Bor S, Sarıtas Yuksel E. How is the gastroesophageal reflux disease prevalence, incidence, and frequency of complications (stricture/esophagitis/Barrett's esophagus/carcinoma) in Turkey compared to other geographical regions globally. Turk J Gastroenterol. 2017;28(Suppl 1):S4–9.
4. Gulakar TL, Comert GN, Karaman E, Cakan U, Ozel GS, Ahmet SO. Effect of simulated gastric acid on aesthetical restorative CAD-CAM materials' microhardness and flexural strength. Niger J Clin Pract. 2023;26(10):1505–11.
5. Elsaka S, Hassan A, Elnaghy A. Effect of gastric acids on surface topography and bending properties of esthetic coated nickel-titanium orthodontic archwires. Clin Oral Investig. 2021;25:1319–26.
6. Elraggal A, Afifi R, Abdelraheem I. Effect of erosive media on microhardness and fracture toughness of CAD-CAM dental materials. BMC Oral Health. 2022;22(1):191.
7. Eltoukhy RI, Elkaffas AA, Ali AI, Mahmoud SH. Indirect resin composite inlays cemented with a self-adhesive, self-etch or a conventional resin cement Luting agent: A 5 years prospective clinical evaluation. J Dent. 2021;112:103740.
8. Josic U, D'Alessandro C, Miletic V, Maravic T, Mazzitelli C, Jacimovic J, et al. Clinical longevity of direct and indirect posterior resin composite restorations: an updated systematic review and meta-analysis. Dent Mater. 2023;39:1085–94.
9. Bompolaki D, Lubisich EB, Fugolin AP. Resin-based composites for direct and indirect restorations: clinical applications, recent advances, and future trends. Dent Clin N Am. 2022;66(4):517–36.
10. Ilie N. The dependence on Hue, value and opacity of real-time-and post-curing light transmission in a nano-hybrid Ormocer. Materials. 2024;17(2):496.
11. Kolb C, Gumpert K, Wolter H, Sextl G. Highly translucent dental resin composites through refractive index adaption using zirconium dioxide nanoparticles and organic functionalization. Dent Mater. 2020;36(10):1332–42.
12. Pássaro AL, Olegário IC, Laux CM, Oliveira RC, Tedesco TK, Raggio DP. Giomer composite compared to glass ionomer in occlusoproximal ART restorations of primary molars: 24-month RCT. Aust Dent J. 2022;67(2),148– 58.
13. Ozer F, Patel R, Yip J, Yakymiv O, Saleh N, Blatz MB. Five-year clinical performance of two fluoride-releasing Giomer resin materials in occlusal restorations. J Esthet Restor Dent. 2022;34(8):1213–20.
14. Ilie N. Fracture and viscoelastic behavior of novel self-adhesive materials for simplified restoration concepts. J Mech Behav Biomed Mater. 2022;125:104970.
15. Theerarath T, Sriarj W. An Alkasite restorative material effectively remineralized artificial interproximal enamel caries *in vitro*. Clin Oral Investig. 2022;26(6):4437–45.
16. Mederos M, León ED, García A, Cuevas-Suárez CE, Hernández-Cabanillas JC, Rivera-Gonzaga JA, et al. *In vitro* characterization of a novel resin-based restorative material containing alkaline fillers. J Appl Oral Sci. 2024;32:e20230219.
17. Willers AE, Branco TB, Sahadi BO, Faraoni JJ, Dibb RGP, Giannini M. Effect of erosive challenge with HCl on restorative materials. Clin Oral Investig. 2022;26(8):5189–203.
18. ASTM D532-14. Standard test method for specular gloss. PA: American Society for Testing and Materials, West Conshohocken; 2018. pp. 1–5.
19. ISO 2813. Paint and varnishes-measurements of specular gloss of nonmetallic paint films at 20°, 60°, and 85°. International Organization for Standardization; 2014.
20. Sulaiman TA, Abdulmajeed AA, Shahramian K, Hupa L, Donovan TE, Vallittu P, et al. Impact of gastric acidic challenge on surface topography and optical properties of monolithic zirconia. Dent Mater. 2015;31(12):1445–52.
21. Hjerppe J, Shahramian K, Rosqvist E, Lassila LV, Peltonen J, Närhi TO. Gastric acid challenge of lithium disilicate–reinforced glass–ceramics and zirconia-reinforced lithium silicate glass–ceramic after Polishing and glazing—impact on surface properties. Clin Oral Investig. 2023;27(11):6865–77.
22. Cengiz S, Sarac S, Ozcan M. Effects of simulated gastric juice on color stability, surface roughness and microhardness of laboratory-processed composites. Dent Mater J. 2014;33(3):343–8.
23. Backer AD, Münchow EA, Eckert GJ, Hara AT, Platt JA, Bottino MC. Effects of simulated gastric juice on CAD/CAM resin composites—morphological and mechanical evaluations. J Prosthodont. 2017;26(5):424–31.
24. Gurgan S, Koc Vural U, Miletic I. Comparison of mechanical and optical properties of a newly marketed universal composite resin with contemporary universal composite resins: an *in vitro* study. Microsc Res Tech. 2022;85(3):1171–9.
25. Unal M, Candan M, Ipek I, Kucukoflaz M, Ozer A. Evaluation of the microhardness of different resin-based dental restorative materials treated with gastric acid: scanning electron microscopy–energy dispersive X-ray spectroscopy analysis. Microsc Res Tech. 2021;84(9):2140–8.
26. Bollenl CM, Lambrechts P, Quirynen M. Comparison of surface roughness of oral hard materials to the threshold surface roughness for bacterial plaque retention: a review of the literature. Dent Mater. 1997;13(4):258–69.
27. de Carvalho LF, e Silva MG, da Silva Barboza A, Badaró MM, Stolf SC, Cuevas-Suárez CE, et al. Effectiveness of bioactive resin materials in preventing secondary caries and retention loss in direct posterior restorations: A systematic review and meta-analysis. J Dent. 2025;152:105460.
28. Slimani A, Sauro S, Gatón Hernández P, Gurgan S, Turkun LS, Miletic I, et al. Commercially available ion-releasing dental materials and cavitated carious lesions: clinical treatment options. Materials. 2021;14:6272.
29. Kooi TJM, Tan QZ, Yap AUJ, Guo W, Tay KJ, Soh MS. Effects of food-simulating liquids on surface properties of Giomer restoratives. Oper Dent. 2012;37(6):665–71.
30. Cabadag OG, Gonulol N. The effects of food-simulating liquids on surface roughness, surface hardness, and solubility of bulk-fill composites. J Adv Oral Res. 2021;12(2):245–53.
31. Lippert VF, Bresciani E, Mota EG, Bittencourt HR, Kramer PF, Spohr AM. *In vitro* comparison of one-step, two-step, and three-step polishing systems on the surface roughness and gloss of different resin composites. J Esthet Restor Dent. 2024;36(5):785– 95.
32. Amaya-Pajares SP, Koi K, Watanabe H, da Costa JB, Ferracane JL. Development and maintenance of surface gloss of dental composites after Polishing and brushing: review of the literature. J Esthet Restor Dent. 2022;34(1):15–41.
33. Monterubbianesi R, Tosco V, Orilisi G, Grandini S, Orsini G, Putignano A. Surface evaluations of a nanocomposite after different finishing and Polishing systems for anterior and posterior restorations. Microsc Res Tech. 2021;84(12):2922–9.
34. Molina GF, Cabral RJ, Mazzola I, Burrow M. Surface gloss, gloss retention, and color stability of 2 nano-filled universal resin composites. Restor Dent Endod. 2022;47(4):e43.
35. Rocha RS, Fagundes TC, Caneppele TMF, Bresciani E. Perceptibility and acceptability of surface gloss variations in dentistry. Oper Dent. 2020;45(2):134–42.
36. ADA professional product review. Pol Syst. 2010;5:2–16.
37. Cook MP, Thomas K. Evaluation of gloss meters for measurement of moulded plastics. Polym Test. 1990;9:233–44.
38. Lassila L, Säilynoja E, Prinssi R, Vallittu PK, Garoushi S. The effect of Polishing protocol on surface gloss of different restorative resin composites. Biomater Investig Dent. 2020;7(1):1–8.

Publisher's note