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# An evaluation of dental paste-like bulk-fill composite wear using intra-oral scanner

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This study evaluates the wear resistance of dental paste-like bulk-fill composites compared to conventional paste-like composite resins using an intraoral scanner and 3-D analyzing software. Six different dental composite materials, including five bulk-fill composites and one conventional composite, were tested alongside natural human enamel as a control group. A computer-controlled chewing simulator for wear testing. A one-way ANOVA test was used to identify any significant differences between the means of the tested dental composite materials $\alpha$=0.05. The results showed variability among bulk-fill composites, with some demonstrating wear resistance similar to conventional composites ($p$<0.05). Human enamel displayed the lowest wear values, but some bulk-fill composites matched this resistance($p$>0.05). Significant variability was observed among bulk-fill composites but the results were comparable to those of conventional composites. The enamel control group demonstrated the lowest wear values, with some bulk-fill composites showing similar wear resistance. This study provides valuable information about the wear resistance of contemporary bulk-fill composite materials, commonly used in current clinical practice, contributing to enhancing clinical procedures.

*Keywords*: Bulk fill composite, Dental composites, Intraoral scanner, Two-body wear

## INTRODUCTION

In the oral cavity, wear refers to the progressive material loss from surfaces, a complex phenomenon influenced by various factors[1]. These include the abrasive nature of food, forces exerted during mastication, brushing, and parafunctional habits such as bruxism and clenching[2,3]. Enamel tissue experiences wear from the moment it erupts into the oral cavity and contacts the opposing tooth[4]. Similarly, dental restorations undergo wear from the moment of their placement. Both natural enamel and dental restorations are subject to the forces of occlusion and mastication, resulting in gradual material loss over time[5-7]. This understanding of wear from the initial contact highlights the significance of wear resistance in the selection of dental materials for restorative treatments.

Bulk-fill resin composites have seen increased use in posterior restorations due to their superior curing thickness compared to conventional composites[8]. However, the limited resistance of these resin composites to mechanical forces in posterior regions remains a significant concern for clinicians. The oral environment presents challenges to the durability of restorative materials, particularly in areas exposed to heavy occlusal forces. The wear of resin composites can be influenced by several factors, including the properties of the filler particles, the composition of the resin matrix, and the quality of the filler-matrix bond[9-12].

In assessing dental wear, technological advancements have enabled the implementation of novel measuring methods such as intraoral scanning and 3D evaluation[13,14]. The intraoral scanners facilitate the accurate capture of the geometry of dental surfaces, allowing for a non-invasive and highly detailed representation of the oral cavity[15]. Intraoral scanners, increasingly used in clinical settings, have also become an integral part of scientific research studies without the need for complex laboratory devices and software, and without causing damage to the samples[16]. Moreover, the data obtained can be analyzed by a multitude of computer programs. This approach offers the advantages of cost-effectiveness and ease of application[17]. Subsequently, the use of 3D analyzing software enables the thorough evaluation of wear patterns and material loss on both natural enamel and dental restorations[14]. This innovative approach is particularly significant in understanding the wear resistance of different materials both in vitro and under the challenging conditions of the oral environment.

Numerous studies have sought to compare the wear properties of bulk-fill and conventional composites[9-11,18-21]. However, the literature reveals a limited number of wear studies conducted using intraoral scanners. Therefore, this study aims to evaluate the wear resistance of paste-like bulk-fill resin composites and conventional paste-like resin composite following thermo-mechanical loading, using an intraoral scanner and 3-D analyzing software. The null hypotheses are as follows: 1) The wear resistance of the bulk-fill resin composite groups will not significantly differ from each other. 2) The wear resistance of the bulk-fill resin composite groups will not significantly differ from the conventional posterior resin composite. 3) The wear resistance of the bulk-fill resin composite groups will not significantly differ from the enamel control group.

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## MATERIALS AND METHODS

This study was conducted in compliance with the decision number 2023/102 of the Medipol University Non-Interventional Clinical Research Ethics Committee and adheres to the principles of the Helsinki Declaration. The materials tested encompassed five paste-like bulk-fill composite materials: Filtek Bulk Fill Posterior Restorative-FBR (3M Dental Products, St. Paul, MN, USA), x-tra fill-XTF (VOCO, Cuxhaven, Germany), Sonicfill-SCF (Kerr, Orange, CA, USA), Admira Fusion x-tra-AFX (VOCO), Tetric EvoCeram Bulk Fill-TEB (Ivoclar Vivadent, Schaan, Liechtenstein), and one conventional paste-like composite, Clearfil Majesty

Table 1 The composition of the tested materials and application methods

| Material type | Material | Shade | Lot number | Matrix composition | Filler % by weight | Recommended thickness | Recommended curing time and light intensity for each layer | Number of layer of samples | Manufacturer |
|---|---|---|---|---|---|---|---|---|---|
| Bulk-fill paste-like | Tetric EvoCeram Bulk-fill (TEB) | IVA (Universal) | T39247 | Bis-GMA, UDMA (%17–18), Barium glass, $YbF_3$, prepolimer, additives, catalysts, stabilizers, and pigments | 76–77 | 4 mm | 10 s≥1,000 mW/cm$^2$ | 1 (4 mm) | Ivoclar Vivadent, Schaan, Liechtenstein |
| | Filtek Bulk Fill Posterior Restorative (FBR) | A2 | N719050 | AUDMA, AFM, UDMA, DDDMA, $YbF_3$, silan treated ceramic/slica/ zirconia, EDMAB, Benzotriazol, Titanium dioxide, water | 76.5 | 5 mm | 20 s≥1,000–2,000 mW/cm$^2$ | 1 (4 mm) | 3M Dental Products, St. Paul, USA |
| | Admira Fusion x-tra (AFX) | Universal | 1813298 | Organically modified silicic acid, Silicon dioxide nanofillers (~20–50 nm) and silicon oxide-based hybrid fillers (~1 μm) | 84 | 4 mm | 20 s≥1,000 mW/cm$^2$ | 1 (4 mm) | VOCO, Cuxhaven, Germany |
| | x-tra fill (XTF) | Universal | 1749292 | Inorganic filler in a methacrylate matrix (Bis-GMA, UDMA, TEG-DMA) | 86 | 4 mm | 10 s≥800 mW/cm$^2$ | 1 (4 mm) | VOCO |
| | Sonic Fill (SF) | A2 | 1012336 | Bis-GMA, TEGDMA, EBPDMA, UDMA, $SiO_2$, glass, oxide | 83.5 | 4 mm | 10 s≥1,000 mW/cm$^2$ | 1 (4 mm) | Kerr, Orange, CA, USA |
| Conventional paste-like | Clearfil Majesty Posterior (CMP) | A2 | 180052 | Bis-GMA, TEG-DMA, hydrophobic aromatic dimethacrylate, Glass ceramics, surface-treated aluminamicro filler 1.5 mm 20 nm | 92 | 1.5 mm | 20 s>300 mW/cm$^2$ | 3 (1.5 mm+ 1.5 mm+ 1 mm) | Kuraray, Okayama, Japan |

Bis-GMA: bisphenol A-glycidyl methacrylate, UDMA: urethane dimethacrylate, $YbF_3$: ytterbium fluoride, AUDMA: aliphatic urethane dimethacrylate, DDDMA: dodecyl methacrylate, EDMAB: ethyl 4-dimethylaminobenzoate, TEG-DMA: triethylene glycol dimethacrylate, EBPDMA: ethoxylated bisphenol A dimethacrylate, $SiO_2$: silicon dioxide

Posterior-CMP (Kuraray Noritake Dental, Okayama, Japan). Recently extracted human permanent central incisor teeth were used as a control group in the study.

*Specimen preparation*

Bulk-fill composite materials were applied in a single layer, while conventional composites were applied in three horizontal layers. These were placed into custom-made cylindrical Teflon molds (4 mm in height and diameter), adhering to the manufacturers' instructions. The composition of the tested materials and application methods are detailed in Table 1. The molds were then covered with a Mylar strip and a 1 mm thick glass plate, which was pressed to the mold's height to extrude excess material. Each layer was cured using a Light-emitting diode (LED) light-curing unit (SDI Radii Plus, SDI Limited, Bayswater, Australia), ensuring a light intensity equal to or exceeding 1,000 mW/cm$^2$, as measured by a radiometer (Hilux Ledmax curing lightmeter, Benlioglu Dental, Ankara, Turkey). Subsequently, all specimens were removed from the molds, and the lower surface of each specimen was marked with a permanent marker. The upper surface was then meticulously polished using aluminum oxide discs from coarse to fine (Sof-Lex, 3M ESPE, St. Paul, MN, USA). Each disc was applied for 15 s to achieve the desired level of polishing. In the enamel control groups, the labial surfaces of the first incisors were used to achieve flat surfaces similar to the specimens of restorative materials. Additionally, the enamel surfaces were polished following the same protocol as used for the restorative materials. Following the polishing step, the specimens underwent a thorough cleaning process in an ultrasonic bath filled with distilled water for 10 min. Before the wear simulation, specimens were stored in distilled water for 24 h at 37°C. They were then fixed and embedded in the middle of round Polyvinyl Chloride (PVC) molds using a chemically cured acrylic resin. To create enamel specimens, the roots of permanent incisors were sectioned from the cementoenamel junction, then they were mounted horizontally on PVC molds using a chemically cured acrylic resin. Care was taken to align the teeth in a manner that ensured the labial surface was as flat as possible.

Natural human tooth cusps were employed as antagonists. For this purpose, unerupted third maxillary molars were sectioned into three parts with a low-speed cutting machine (Micracut 175, Metkon Instruments, Bursa, Turkey). The first section was made at the tooth cervix to remove the root, leaving a crown approximately 5-mm high. The second section was made buccolingually at the middle of the mesiodistal aspect, and the third section was made mesiodistally at the middle of the buccolingual aspect. The sharper maxillary buccal cusps were selected, embedded into the holder with auto-polymerizing resin, and approximately 2 mm of the tooth cusp was exposed. The 56 antagonists were then divided into seven groups ($n$=8) using a random number chart.

*Wear test*

The specimens were securely mounted in a computer-controlled dual-axis chewing simulator (Esetron chewing simulator, Ankara, Turkey). The parameters for the wear test conducted are detailed in Table 2. Throughout the loading period, the samples were examined twice daily.

*Quantitative surface analysis*

Following the wear simulation, samples underwent a quantitative surface analysis using a CAD/CAM three-dimensional scanner (Trios 4, 3Shape, Copenhagen, Denmark). Wear studies conducted using the Trios 3 have reported its effectiveness in evaluating wear[22,23].

Table 2 Configuration of the parameters set for the wear method

| Parameter | Value |
|---|---|
| Dwell time | 60 s |
| Cold/hot bath temperature | 5°C–55°C |
| Number of cycles | 1,200,000 (5 years of oral fuction*) |
| Force | 5 kg |
| Height | 6 mm |
| Lateral movement | –0.3 mm |
| Descending speed | 30 mm/s |
| Lifting speed | 55 mm/s |
| Feed speed | 30 mm/s |
| Return speed | 55 mm/s |
| Frequency | 1.3 Hz |

*Rosentritt M, Preis V, Behr M, *et al*. Two-body wear of dental porcelain and substructure oxide ceramics. Clin Oral Investig 16, 935–943 (2012).

Further research has demonstrated that the accuracy of the Trios 4 is superior compared to other oral cameras and to the Trios 3[24]. Therefore, Trios 4 system used for this study. A three-dimensional stereolithography CAD file (STL) file was obtained from each worn surface. The three-dimensional mesh was generated from the STL file with computer-aided design software (MeshLab(v2021.07)). For depth measurement, the circumference of the worn surface on the mesh was cut and removed. The remaining mesh was converted into a 3D object with the "convex hull" process, and its volume was calculated as $mm^3$ (Fig. 1).

*Statistical analysis*

The wear data, which followed a normal distribution, was analyzed using a one-way ANOVA test to identify any significant differences between the means of the tested dental composite materials. A Tukey's *post hoc* test was conducted for multiple comparisons to determine specific group differences. The significance level for all tests was set at $\alpha$=0.05, indicating a 5% probability of a Type I error. Statistical analyses were performed using GraphPad Prism version 8.2.1 for Mac (GraphPad Software, San Diego, CA, USA)

## RESULTS

The results of the ANOVA and Tukey's *post hoc* tests, as outlined in Table 3, revealed significant differences between the groups ($p$<0.05). The enamel control group exhibited the lowest wear values. In contrast, the XTF, AFX, and TEB groups showed significantly higher wear volumes (Fig. 2).

Compared to the conventional posterior composite

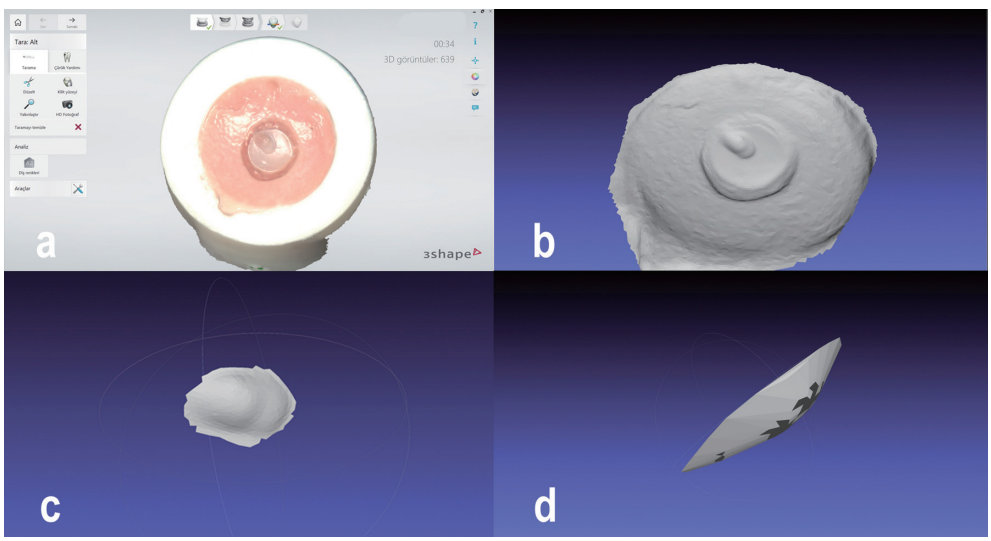



Fig. 1 a: Scanned specimen, b: raw stereolithography CAD file (STL), c: trimmed STL file around the wear area, d: 3D solid object which represents wear volume.

Table 3 Statistical analysis

| ANOVA | | Tukey's *post hoc* test | | | |
|---|---|---|---|---|---|
| | | Group | Mean wear ($mm^3$) | Std err | Diff.* |
| | | Enamel | 0.1466 | 0.02155 | A |
| | | FBR | 0.3465 | 0.1103 | AB |
| F | 6.060 | XTF | 0.9879 | 0.1479 | C |
| $p$ value | <0.0001 | SCF | 0.4989 | 0.1339 | ABC |
| $p$ value summary | **** | AFX | 0.9040 | 0.1694 | C |
| Significant diff. among means ($p$<0.05) | Yes | TEB | 0.8167 | 0.06822 | BC |
| R square | 0.4260 | CMP | 0.6472 | 0.1542 | ABC |

*Groups which have same letter have no significant differences.
FBR: Filtek Bulk Fill Posterior Restorative, XTF: x-tra fill, SCF: Sonicfill, AFX: Admira Fusion x-tra, TEB: Tetric EvoCeram Bulk Fill, CMP: Clearfil Majesty Posterior

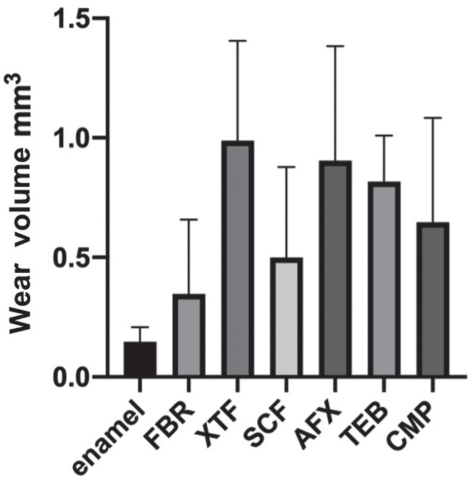



Fig. 2 Mean wear values and standard errors of tested groups.
FBR: Filtek Bulk Fill Posterior Restorative, XTF: x-tra fill, SCF: Sonicfill, AFX: Admira Fusion x-tra, TEB: Tetric EvoCeram Bulk Fill, CMP: Clearfil Majesty Posterior.

resin group, the bulk-fill composite groups exhibited similar wear values, with no significant difference noted ($p$>0.05). Among the bulk-fill composite groups, FBR presented significantly lower wear values than XTF and AFX ($p$<0.05).

## DISCUSSION

The findings of this study provide a detailed examination of the wear resistance of various dental composite materials, including both bulk-fill and conventional composites, in relation to human enamel. Upon scrutinizing the data, it was observed that the wear resistance among the bulk-fill composites exhibited significant variability, leading to the rejection of the first null hypothesis. Conversely, the second null hypothesis was upheld, as the wear values of the bulk-fill composite groups were found to be similar to those of the conventional posterior composite resin group. While the enamel control group showed the lowest wear values, it was not significantly different from some of the bulk-fill groups, leading to the partial acceptance of the third null hypothesis.

Wear testing studies on dental materials are inherently complex, given the multitude of influencing factors that can lead to a range of outcomes. Factors such as the type of wear, testing equipment used, applied load, choice of antagonist material and its shape, thermocycling, and the inherent characteristics of the tested material all play pivotal roles in shaping the results[6]. In this study, the chewing simulator employed effectively emulates the dynamics of chewing movements. Consistent with other researchers, a masticatory force of 49 N was applied at a frequency of approximately 1–1.6 Hz during the simulation, a value reported by Gibbs *et al.*[25] as the average masticatory force observed under normal chewing function. To ensure the removal of wear debris from the specimens' surface and to maintain wet conditions throughout the test, continuous thermal cycling was conducted between temperatures of 5°C and 55°C, which also contributed to additional aging of the specimens.

The literature reveals the use of various materials as antagonists, including stainless steel, natural teeth[10,11], magnesium steatite[26], and zirconium oxide[5,27]. In this study, natural tooth cusps were utilized to provide a more realistic representation of the clinical conditions. Furthermore, natural tooth cusps have been employed in various composite resin wear studies[10,11,28,29]. In this study, there was a considerable variation in the wear standard deviation among all the tested groups. This variability can be attributed to the heterogeneity observed in the human enamel antagonists, and the differences in thickness or geometry of the enamel layers, all of which may have impacted the results[28,29]. The diverse morphologies of natural teeth also had an influence on the wear rate. Nonetheless, the utilization of human enamel antagonists was imperative to maintain clinical relevance in the studies as mentioned before.

To enhance the clinical relevance and deepen the understanding of the performance of the tested composite resins, this study included a group of natural human enamel. Alsahafi *et al.*[10] anlayzed wear of bulk-fill composite resins after thermo-mechanical loading and showed that enamel was more resistant to wear than all composite resins tested. In contrast, Barakat evaluated wear resistance bulk-fill composites with human enamel and found no significant difference between FBR, SCF, TEB when compared with enamel[30]. In the present study the enamel control group displayed the lowest wear values, but the FBR and SCF groups demonstrated wear values similar to the enamel control group, suggesting that these bulk-fill composites may offer wear resistance comparable to natural enamel. However, other bulk-fill groups showed higher wear values, indicating variability within the category of bulk-fill composites.

In comparison to the conventional posterior composite resin group, all bulk-fill composite groups exhibited similar wear values, with no significant difference observed. This finding aligns with some previous studies[11,31], such as one that investigated the wear of four types of bulk-fill composites and one type of conventional composite and found comparable wear resistance between bulk-fill and conventional composites. However, the literature on this topic is not entirely consistent. For instance, a study conducted by Osiewicz *et al.*[20] reported a higher wear rate in bulk-fill resin composites compared to conventional ones. In contrast, Alsahafi *et al.*[10] found that bulk-fill composite resins exhibited higher wear resistance than conventional composite resin. Asadian *et al.*[18] compared wear characteristics by using weight loss method for bulkfill composites and found that SCF and FBR showed similar wear values with control group Z 250. These conflicting results, along with the findings of the current study,

highlight the complexity of wear behavior in dental composites. Researchers suggest that wear properties can vary significantly depending on specific material formulations, filler content, and testing methodologies employed in each study[9,10,20]. This underscores the need for further research using standardized testing methods to provide a more comprehensive understanding of the wear resistance of different dental composite materials. It also suggests that clinicians should consider the specific properties and performance characteristics of individual products when selecting a composite material for dental restorations.

However, it is crucial to highlight that within the bulk-fill composite groups, XTF and AFX demonstrated significantly higher wear values than FBR group. In parallel, Sahadi *et al.*[19] compared multiple-peak and single-peak dental curing lights comparison on the wear resistance of bulk-fill composites and showed that FBF always showed the least volume loss, regardless of which LCU was used. A study by Shimokawa *et al.* compared wear resistance of conventional and bulk-fill composites (which includes FBR, AFX, TEB and SCF) and showed that AFX showed higher wear than other bulkfill composites. The higher wear of Admira Fusion x-tra was attributed to the higher surface roughness ratio, which causes more material mass loss from the rough surface after wear. Factors such as the silanization quality of the matrix and the irregular size and shape of the filler particles will cause further wear of this composite[32]. Tagtekin *et al.*[33] reported that filler size, load, and filler-matrix interactions may have a greater effect on mechanical properties than matrix structure. They explained that the spherical filler shape of AFX can increase the wear functional area with the antagonist during occlusal attrition simulated by the two-body abrasion test, resulting in a higher wear. This suggests that while bulk-fill composites as a category may exhibit wear resistance similar to conventional composites, there are still notable differences in performance between individual products. These disparities could be ascribed to variations in the composition of the materials, encompassing the characteristics of the filler particles, the composition of the resin matrix, and the quality of the filler-matrix bond. Each of these factors can significantly sway the wear resistance of the composite material, underscoring the importance of meticulous material selection in clinical practice. Li *et al.*[21] evaluated wear resistance of bulk-fill dental resins cured by different light-curing settings and found that material type has the most significant influence on wear behavior. Hu *et al.*[34] showed that the wear rate of samples with a filler percentage below 60% was lower and the wear rate increased rapidly in composites with a filler content of 80%–87.5%. Increasing the coefficient of friction between the filler and the matrix particles and the weak bond between the filler and the matrix can cause mass loss from the surface of samples with high filler content, which can lead to higher surface roughness in them[35]. This finding emphasizes that while the category of composite (bulk-fill or conventional) is an important consideration, the specific properties and performance of individual products within these categories should also be taken into account.

This study, while comprehensive, does have several limitations. Despite meticulous efforts, the methodology employed could not fully replicate the intricate and dynamic oral environment. The study was unable to simulate the impact of three-body wear, a phenomenon that occurs when food or other particles intervene between the teeth during mastication. Moreover, the study did not account for other factors that could influence wear resistance, such as the technique and quality of the restoration placement, the patient's oral hygiene practices, diet, and parafunctional habits like bruxism.

The shape of the samples were prepared as flat discs in accordance with ISO/TS 14569-2:2001 "Guidance on testing of wear Part 2: Wear by two- and/or three body contact" standards[36]. This led to an inability to mimic the occlusal geometry, a factor that could have potentially influenced the wear results obtained. Furthermore, it is crucial to note that the inherent variability in natural tooth structure can introduce a degree of uncertainty to the results. This variability was evident in the wear standard deviation among the tested groups, which can be attributed to the heterogeneity observed in the human enamel antagonists.

Future studies could consider using standardized antagonists to reduce this variability, while also conducting additional tests with natural tooth cusps to maintain clinical relevance. Additionally, future research could explore the impact of three-body wear and other factors not considered in this study to provide a more comprehensive understanding of the wear resistance of different dental composite materials.

## CONCLUSIONS

From this study, the following could be concluded:

1. Significant variability was observed among bulk-fill composites, but the results were comparable to those of conventional composites.
2. The enamel control group demonstrated the lowest wear values, with some bulk-fill composites showing similar wear resistance.

## REFERENCES

1) Mair LH, Stolarski TA, Vowles RW, Lloyd CH. Wear: Mechanisms, manifestations and measurement. Report of a workshop. J Dent 1996; 24: 141-148.
2) Mair LH, Padipatvuthikul P. Wear mechanisms in the mouth. P I Mech Eng J-J Eng 2010; 224: 569-575.
3) Grippo JO, Simring M, Schreiner S. Attrition, abrasion, corrosion and abfraction revisited: A new perspective on tooth surface lesions. J Am Dent Assoc 2004; 135: 1109-1118; quiz 63-65.
4) Craddock HL, Youngson CC. Eruptive tooth movement —The current state of knowledge. Br Dent J 2004; 197: 385-391.
5) D'Arcangelo C, Vanini L, Rondoni GD, De Angelis F. Wear properties of dental ceramics and porcelains compared with human enamel. J Prosthet Dent 2016; 115: 350-355.

6) Lee A, He LH, Lyons K, Swain MV. Tooth wear and wear investigations in dentistry. J Oral Rehabil 2012; 39: 217-225.
7) Yilmaz EÇ. Effect of sliding movement mechanism on contact wear behavior of composite materials in simulation of oral environment. J Bio- Tribo-Corros 2019; 5: 63.
8) Boaro LCC, Lopes DP, de Souza ASC, Nakano EL, Perez MDA, Pfeifer CS, *et al*. Clinical performance and chemical-physical properties of bulk fill composites resin —A systematic review and meta-analysis. Dent Mater 2019; 35: E249-E264.
9) Abdulmajeed AA, Suliman AA, Selivany BJ, Altitinchi A, Sulaiman TA. Wear and color stability of preheated bulk-fill and conventional resin composites. Oper Dent 2022; 47: 585-592.
10) Alsahafi TA, Walter R, Nunes M, Sulaiman TA. Wear of bulk-fill composite resins after thermo-mechanical loading. Oper Dent 2023; 48: 416-424.
11) Asadian F, Hoseini AP, Ahmadian L, Rafeie N, Rezaei S, Moradi Z. In vitro attrition wear resistance of four types of paste-like bulk-fill composite resins. BMC Oral Health 2022; 22: 360.
12) DeLong R, Pintado MR, Douglas WH, Fok AS, Wilder AD Jr, Swift EJ Jr, *et al*. Wear of a dental composite in an artificial oral environment: A clinical correlation. J Biomed Mater Res B Appl Biomater 2012; 100: 2297-2306.
13) O'Toole S, Osnes C, Bartlett D, Keeling A. Investigation into the accuracy and measurement methods of sequential 3D dental scan alignment. Dent Mater 2019; 35: 495-500.
14) Wulfman C, Koenig V, Mainjot AK. Wear measurement of dental tissues and materials in clinical studies: A systematic review. Dent Mater 2018; 34: 825-850.
15) Mayer J, Stawarczyk B, Vogt K, Hickel R, Edelhoff D, Reymus M. Influence of cleaning methods after 3D printing on two-body wear and fracture load of resin-based temporary crown and bridge material. Clin Oral Investig 2021; 25: 5987-5996.
16) Sfondrini MF, Gandini P, Malfatto M, Di Corato F, Trovati F, Scribante A. Computerized casts for orthodontic purpose using powder-free intraoral scanners: Accuracy, execution time, and patient feedback. Biomed Res Int 2018; 2018: 4103232.
17) Luqmani S, Jones A, Andiappan M, Cobourne MT. A comparison of conventional vs automated digital peer assessment rating scoring using the Carestream 3600 scanner and CS Model+ software system: A randomized controlled trial. Am J Orthod Dentofacial Orthop 2020; 157: 148-155. e1.
18) Asadian F, Shahidi Z, Moradi Z. Evaluation of wear properties of four bulk-fill composites: attrition, erosion, and abrasion. Biomed Res Int 2021; 2021: 8649616.
19) Sahadi BO, Price RB, Andre CB, Sebold M, Bermejo GN, Palma-Dibb RG, *et al*. Multiple-peak and single-peak dental curing lights comparison on the wear resistance of bulk-fill composites. Braz Oral Res 2018; 32: e122.
20) Osiewicz MA, Werner A, Roeters FJM, Kleverlaan CJ. Wear of bulk-fill resin composites. Dent Mater 2022; 38: 549-553.
21) Li EG, Waddell JN, Choi JJE. Wear resistance of bulk-fill dental resins cured by different light-curing settings. Biotribology 2021; 28: 100197.
22) Marchand L, Sailer I, Lee H, Mojon P, Pitta J. Digital wear analysis of different CAD/CAM fabricated monolithic ceramic implant-supported single crowns using two optical scanners. Int J Prosthodont 2022; 35: 357-364.
23) Michou S, Vannahme C, Ekstrand KR, Benetti AR. Detecting early erosive tooth wear using an intraoral scanner system. J Dent 2020; 100: 103445.
24) Schmalzl J, Roth I, Borbely J, Hermann P, Vecsei B. The impact of software updates on accuracy of intraoral scanners. BMC Oral Health 2023; 23: 219.
25) Gibbs CH, Mahan PE, Lundeen HC, Brehnan K, Walsh EK, Sinkewiz SL, *et al*. Occlusal forces during chewing —Influences of biting strength and food consistency. J Prosthet Dent 1981; 46: 561-567.
26) Preis V, Behr M, Kolbeck C, Hahnel S, Handel G, Rosentritt M. Wear performance of substructure ceramics and veneering porcelains. Dent Mater 2011; 27: 796-804.
27) Zhang F, Spies BC, Vleugels J, Reveron H, Wesemann C, Muller WD, *et al*. High-translucent yttria-stabilized zirconia ceramics are wear-resistant and antagonist-friendly. Dent Mater 2019; 35: 1776-1790.
28) Stawarczyk B, Özcan M, Schmutz F, Trottmann A, Roos M, Hämmerle CHF. Two-body wear of monolithic, veneered and glazed zirconia and their corresponding enamel antagonists. Acta Odontol Scand 2013; 71: 102-112.
29) Stawarczyk B, Özcan M, Trottmann A, Schmutz F, Roos M, Hämmerle C. Two-body wear rate of CAD/CAM resin blocks and their enamel antagonists. J Prosthet Dent 2013; 109: 325-332.
30) Barakat OA. Comparative evaluation of wear resistance of different bulk-fill composite and surface roughness with antagonist human enamel and porcelain. Egypt Dent J 2020; 66: 1383-1395.
31) Yilmaz EÇ, Sadeler R. Investigation of two- and three-body wear resistance on flowable bulk-fill and resin-based composites. Mech Compos Mater 2018; 54: 395-402.
32) Shimokawa C, Giannini M, Andre CB, Sahadi BO, Faraoni JJ, Palma-Dibb RG, . In vitro evaluation of surface properties and wear resistance of conventional and bulk-fill resin-based composites after brushing with a dentifrice. Oper Dent 2019; 44: 637-647.
33) Tagtekin DA, Yanikoglu FC, Bozkurt FO, Kologlu B, Sur H. Selected characteristics of an Ormocer and a conventional hybrid resin composite. Dent Mater 2004; 20: 487-497.
34) Hu X, Marquis PM, Shortall AC. Influence of filler loading on the two-body wear of a dental composite. J Oral Rehabil 2003; 30: 729-737.
35) Han JM, Zhang H, Choe HS, Lin H, Zheng G, Hong G. Abrasive wear and surface roughness of contemporary dental composite resin. Dent Mater J 2014; 33: 725-732.
36) ISO/TS14569-2:2001. Guidance on testing of wear Part 2: Wear by two- and/or three body contact. Dental materials. 1 ed2001. p. 32.