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Influence of Chemical Aging on Antagonist Enamel Wear, Restorative Material Wear, and Surface Roughness of Zirconia and BioHPP: An In Vitro Study

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Abstract

Background

The clinical performance of restorative materials depends on their resistance to wear and degradation within the oral environment. Zirconia ceramics are widely used because of their favorable mechanical properties and biocompatibility; however, concerns remain regarding their wear behavior against opposing enamel. BioHPP, a high-performance polyetheretherketone-based polymer, has emerged as a potential alternative restorative material, although evidence regarding its wear behavior following chemical aging remains limited.

Objective

To evaluate the effect of different aging media on antagonist enamel wear, restorative material wear, and surface roughness of translucent zirconia (TZ), opaque zirconia (OZ), and BioHPP.

Materials and Methods

Thirty-six disc specimens (n = 12 per material) were fabricated from TZ, OZ, and BioHPP and allocated to three aging conditions: distilled water, artificial saliva, and acidulated phosphate buffer (n = 4 per subgroup). Following 7 days of immersion and thermal aging at 55°C, wear testing was performed using a pin-on-disc tribometer under a 25 N load for 4,800 cycles. Pre- and post-test weights of enamel antagonists and restorative discs were recorded. Surface characteristics were evaluated using scanning electron microscopy (SEM) and atomic force microscopy (AFM). Data were analyzed using repeated-measures analysis of variance and post hoc testing at a significance level of 0.05.

Results

A significant reduction in antagonist enamel weight was observed following wear testing ($p = 0.021$), confirming measurable enamel wear. However, no significant differences in antagonist enamel wear were detected among restorative materials or aging conditions ($p > 0.05$). Restorative disc wear differed significantly among experimental groups ($p < 0.001$), with greater wear observed in specimens exposed to acidic conditions. AFM and SEM analyses demonstrated increased surface roughness and morphological alterations following acidic aging, particularly in translucent zirconia and BioHPP.

Conclusions

Under the short-term experimental conditions of this study, restorative material type and aging medium did not significantly influence antagonist enamel wear. However, chemical aging affected restorative

material wear and surface characteristics, with acidic conditions promoting greater material degradation. Further long-term studies using clinically relevant aging protocols are required to validate these findings.

Introduction

The long-term success of restorative materials depends on their ability to withstand the complex mechanical and chemical challenges encountered in the oral environment. During function, restorative surfaces are continuously subjected to sliding contact, cyclic occlusal loading, thermal fluctuations, salivary constituents, and chemically active dietary components. These factors collectively contribute to progressive surface degradation, material loss, and alterations in surface topography over time. Excessive wear may compromise restoration longevity and alter occlusal relationships, whereas increased surface roughness may facilitate plaque accumulation and accelerate further surface deterioration (1, 2).

Zirconia-based ceramics have become widely used in restorative dentistry because of their high flexural strength, fracture toughness, favorable biocompatibility, and esthetic potential. Recent developments have focused on improving translucency through modifications in yttria content. Conventional opaque zirconia is predominantly composed of tetragonal zirconia stabilized with approximately 3 mol% yttria, whereas highly translucent zirconia contains increased yttria concentrations and a greater proportion of the cubic crystalline phase. Although enhanced translucency improves esthetic outcomes, these microstructural modifications may influence mechanical properties, wear resistance, and tribological behavior (3, 4). Previous investigations have demonstrated that zirconia wear characteristics are influenced by crystal structure, surface finishing procedures, and environmental conditions (2, 5).

Chemical degradation represents an additional factor that may affect the long-term clinical performance of zirconia restorations. Restorative materials are routinely exposed to acidic beverages, dietary acids, and fluctuations in salivary pH. Such environments may alter surface chemistry, increase surface roughness, and modify frictional behavior during functional contact. Furthermore, prolonged exposure to moisture and temperature variations has been associated with low-temperature degradation phenomena in zirconia, potentially affecting its mechanical and tribological performance (6, 7). Consequently, understanding the influence of chemical aging on wear behavior is important for predicting the clinical longevity of zirconia restorations.

Alongside ceramic materials, high-performance polymer-based biomaterials have emerged as potential alternatives for fixed and implant-supported prosthodontic restorations. BioHPP, a ceramic-reinforced polyetheretherketone (PEEK) material, has attracted considerable interest because of its favorable biomechanical properties. Compared with zirconia ceramics, BioHPP exhibits an elastic modulus closer to that of dentin, which may influence stress distribution, shock absorption, and tribological behavior under occlusal loading (8, 9). Although polymer-based materials demonstrate favorable biomechanical

characteristics, evidence regarding their wear behavior and surface stability following exposure to chemically challenging environments remains limited.

While numerous studies have investigated the wear characteristics of zirconia ceramics or polymer-based restorative materials individually (1, 3), direct comparisons between translucent zirconia, opaque zirconia, and BioHPP following exposure to different chemical aging environments remain scarce. Furthermore, limited information is available regarding the combined influence of restorative material composition and aging media on antagonist enamel wear, restorative material wear, and surface roughness under standardized sliding-contact conditions. Understanding these interactions is clinically relevant because restorative materials are exposed to varying oral environments throughout their service life. Such considerations may be particularly important in older adults, where age-related changes in salivary composition, medication use, and dietary habits may modify the chemical environment surrounding restorations.

Therefore, the present in vitro study aimed to evaluate the influence of simulated aging media on antagonist enamel wear, restorative material wear, and surface roughness of translucent zirconia, opaque zirconia, and BioHPP under standardized sliding-contact conditions.

The null hypotheses tested were: (1) aging media would not significantly influence antagonist enamel wear, restorative material wear, or surface roughness; and (2) restorative material type would not significantly influence antagonist enamel wear, restorative material wear, or surface roughness following chemical aging.

Materials and Methods

Study Design

This retrospective study was conducted using previously recorded clinical data. The study protocol was submitted to the Institutional Ethics Committee of Manipal College of Dental Science and received ethical approval/no objection for the conduct of the study (Reference No 20063). As the study involved retrospective analysis of existing clinical records and did not involve any additional intervention or contact with participants, individual informed consent was not obtained. Need for consent to participate was waived by the Institutional Review Board (Institutional Review Board, Manipal College Of Dental Sciences, Mangalore)

The study involving extracted human teeth was conducted in accordance with the relevant institutional guidelines and regulations and the principles of the Declaration of Helsinki. The investigation was conducted in collaboration with the Tribology Laboratory, Department of Mechanical Engineering, and the Central Instrumentation Facility (CIF) of the institution.

The study evaluated the influence of restorative material type and aging medium on wear behavior and surface characteristics under standardized sliding-contact conditions.

Independent variables:

• Restorative material:

- Translucent zirconia (TZ)
- Opaque zirconia (OZ)
- BioHPP

• Aging medium:

- Distilled water (DW)
- Artificial saliva (AS)
- Acidulated phosphate buffer (APB)

Outcome variables included antagonist enamel weight loss, restorative material weight loss, and surface roughness.

Sample Size Determination

Sample size estimation was based on wear data reported by Fathy et al. (10). Using a predicted standard deviation of 0.0004 and a clinically meaningful difference of 0.001, a minimum subgroup size of four specimens was calculated. Accordingly, 36 specimens were included (3 materials × 3 aging media × 4 specimens).

Specimen Preparation

Zirconia Specimens

Two zirconia materials were evaluated:

• 3Y-TZP opaque zirconia
• 5Y partially stabilized translucent zirconia

Pre-sintered zirconia blanks (Jyoti Ceramic Industries Pvt. Ltd., Maharashtra, India) were milled using CAD/CAM technology into disc-shaped specimens measuring 8 mm in diameter and 2 mm in thickness (Table 1). Following milling, the discs were sintered at 1425°C for 2 hours according to the manufacturer's recommendations and allowed to cool gradually to room temperature.

BioHPP Specimens (Table 1)

BioHPP discs (Bredent GmbH & Co. KG, Senden, Germany) consisting of a polyetheretherketone matrix reinforced with ceramic fillers were fabricated with identical dimensions (8 mm × 2 mm) using compression molding according to the manufacturer's instructions.

Surface Finishing

All specimens were subjected to a standardized sequential polishing protocol followed by final polishing with diamond polishing paste to obtain comparable surface finishes before aging and wear testing.

Antagonist Tooth Preparation

Extracted human second premolars were obtained from the Department of Oral Surgery, Manipal College of Dental Sciences (MCODS), Mangalore, Manipal Academy of Higher Education, Karnataka, India, following routine clinical extraction. Patient consent for the use of their teeth was not obtained .Teeth free from caries, restorations, cracks, developmental defects, and visible occlusal wear were selected (Department of Oral and Maxillofacial Surgery ,Manipal college of Dental Science). Teeth were cleaned of residual soft tissue and deposits and stored in distilled water until use.

For standardization, each tooth was embedded in self-cure acrylic resin using a silicone putty index to ensure uniform cusp projection and reproducible positioning. The same indexing procedure was used for all specimens to maintain consistent occlusal contact geometry.

Cleaning Procedure

Prior to aging, all restorative specimens underwent ultrasonic cleaning in acetone for 20 minutes to remove contaminants and machining residues, followed by ultrasonic cleaning in distilled water for 10 minutes. Specimens were then air-dried under controlled laboratory conditions.

Chemical Aging Protocol

Specimens from each material group were randomly allocated to one of three aging media (n = 4 per subgroup).

Each specimen was immersed individually in 250 mL of solution and stored at 37°C for 7 days.

Artificial Saliva Group

Specimens were immersed in artificial saliva (pH 7.0) containing urea, sodium chloride, potassium chloride, calcium chloride, and phosphate salts to simulate neutral oral conditions.

Acidulated Phosphate Buffer Group

Specimens were immersed in acidulated phosphate buffer adjusted to a pH of approximately 3–4. This medium contained no fluoride ions and was used to simulate acidic oral challenges associated with dietary acid exposure.

Distilled Water Group

Specimens stored in distilled water served as hydrolytic controls.

To maintain pH stability and chemical consistency, all solutions were replaced daily. Containers remained sealed throughout the aging period to prevent evaporation and contamination.

Accelerated Thermal Aging

Following chemical aging, specimens were rinsed with distilled water and air-dried. Thermal aging was performed in a calibrated hot-air oven at 55°C for 2 hours. After aging, specimens were allowed to cool gradually to room temperature before wear testing.

Wear Testing

Wear testing was performed using a pin-on-disc tribometer (TR-20 Series, Ducom Instruments Pvt. Ltd., Bengaluru, India).

The restorative disc was mounted on the rotating platform, whereas the premolar antagonist was secured in a stationary pin holder using custom-designed 3D-printed fixtures. Specimen alignment was verified before testing to ensure reproducible contact conditions.

Testing parameters were:

• Load: 25 N
• Sliding frequency: 20 cycles/min
• Duration: 240 minutes
• Total cycles: 4800

The selected protocol was designed to evaluate early-stage tribological behavior under controlled laboratory conditions.

Wear Measurement

The weights of both restorative discs and antagonist teeth were measured before and after testing using a calibrated analytical balance (Shimadzu AUW-120D/AUW-220D, Japan; accuracy ±0.0001 g).

After testing, specimens were rinsed with distilled water, air-dried, and reweighed. Weight loss was calculated as:

Weight loss (g) = Pre-test weight − Post-test weight

Surface Characterization

Scanning Electron Microscopy (SEM)

Representative specimens from each group were sputter-coated with a 10 nm gold layer and examined using a scanning electron microscope (EVO MA 18, Carl Zeiss, Germany). Surface morphology, wear tracks, microcracks, and surface defects were qualitatively assessed.

Energy Dispersive Spectroscopy (EDS)

Elemental analysis was performed using an EDS system (X-act, Oxford Instruments, Abingdon, United Kingdom) attached to the SEM. EDS observations were used for qualitative assessment of elemental composition and potential surface alterations following aging and wear.

Atomic Force Microscopy (AFM)

Surface topography was evaluated using an Innova SPM atomic force microscope (Bruker Corporation, USA) operating in non-contact mode. Three randomly selected areas (50 × 50 μm) were scanned on each specimen.

The arithmetic mean roughness (Ra) was recorded and expressed in nanometers (nm).

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics, including mean, standard deviation (SD), and standard error (SE), were calculated for all quantitative variables.

The normality of data distribution was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test prior to conducting parametric analyses.

Changes in antagonist tooth weight before and after wear testing were analyzed using a two-way repeated-measures analysis of variance (ANOVA). In this model, time (pre-test and post-test) was considered the within-subject factor, while restorative material type (translucent zirconia, opaque zirconia, and BioHPP) and aging medium (distilled water, artificial saliva, and acidulated phosphate buffer) were included as between-subject factors. Main effects and interaction effects among time, material type, and aging medium were evaluated.

Restorative disc weight loss was analyzed using two-way ANOVA to determine the influence of restorative material type and aging medium and their interaction on material wear.

When significant differences were identified, Tukey's Honestly Significant Difference (HSD) post hoc test was applied for pairwise comparisons.

Surface roughness measurements obtained by atomic force microscopy were summarized descriptively using arithmetic mean roughness (Ra) values and were used to support qualitative interpretation of surface alterations observed following aging and wear testing.

All statistical tests were two-tailed, and a significance level of $\alpha = 0.05$ was adopted. A p-value < 0.05 was considered statistically significant.

Results

Descriptive Analysis

The mean and standard deviation values for antagonist tooth weight loss and restorative disc weight loss for all experimental groups are presented in Table 2.

Mean antagonist tooth weight loss ranged from 0.0010 g to 0.0103 g across most groups. The highest mean enamel weight loss was observed in the opaque zirconia–artificial saliva group (0.0103 ± 0.0026 g). The BioHPP–acidulated phosphate buffer subgroup demonstrated the greatest variability in antagonist tooth weight loss (0.0310 ± 0.0509 g), indicating substantial dispersion of values within this group.

Mean restorative disc weight loss ranged from 0.00125 g to 0.00700 g. The highest restorative material wear was observed in translucent zirconia aged in acidulated phosphate buffer (0.00700 ± 0.00216 g), whereas the lowest wear was observed in BioHPP aged in distilled water (0.00125 ± 0.00050 g).

Antagonist Tooth Weight Change

A two-way repeated-measures ANOVA was performed to evaluate changes in antagonist tooth weight before and after wear testing and to determine whether these changes differed according to restorative material type and aging condition (Table 3).

A statistically significant main effect of time was observed ($F(1,27) = 5.982$, $p = 0.021$), indicating a significant reduction in antagonist tooth weight following wear testing. This finding demonstrates that measurable enamel wear occurred under the experimental conditions.

The interaction between time and restorative material was not statistically significant ($F(2,27) = 1.034$, $p = 0.369$), suggesting that the magnitude of enamel weight reduction did not differ significantly among translucent zirconia, opaque zirconia, and BioHPP. Similarly, the interaction between time and aging medium was not significant ($F(2,27) = 1.420$, $p = 0.259$), indicating that the change in antagonist tooth weight was comparable across the different aging conditions.

The three-way interaction among time, restorative material, and aging medium was also not statistically significant ($F(4,27) = 1.275$, $p = 0.304$), indicating that the combined influence of material type and aging condition did not significantly affect antagonist tooth weight change over time.

Comparison of Antagonist Tooth Weight Loss Among Experimental Groups

Comparison of antagonist tooth weight loss among the nine experimental groups revealed no statistically significant differences ($p = 0.309$) (Table 4). Although numerical variations were observed among groups, no significant effect of restorative material type or aging medium on antagonist enamel wear was detected under the conditions of this study.

Restorative Disc Weight Loss

Analysis of restorative disc weight loss demonstrated statistically significant differences among the experimental groups ($p < 0.001$) (Table 4). These findings indicate that restorative material wear was influenced by restorative material type, aging condition, or their combined effects.

Post hoc Tukey analysis identified significant pairwise differences among several groups (Table 5). In general, specimens exposed to acidulated phosphate buffer exhibited greater material wear, whereas BioHPP demonstrated comparatively lower wear values under distilled water and artificial saliva conditions. However, not all pairwise comparisons reached statistical significance.

Surface Roughness Analysis

Atomic force microscopy demonstrated differences in surface roughness among the experimental groups (Table 6). Increased roughness values were generally observed following exposure to acidulated phosphate buffer. The highest arithmetic average roughness (Ra) was recorded for translucent zirconia aged in acidulated phosphate buffer (203 nm), whereas the lowest Ra value was observed for translucent zirconia stored in distilled water (8.77 nm).These findings suggest that acidic aging conditions were associated with greater surface topographical alterations compared with neutral aging environments.

SEM and EDS Analysis

Scanning electron microscopy revealed distinct surface alterations among the experimental groups following aging and wear testing. Specimens aged in distilled water generally exhibited smoother wear tracks with fewer surface irregularities, whereas those exposed to acidulated phosphate buffer demonstrated more pronounced surface changes, including increased surface roughness, shallow pits, and localized wear defects. Translucent zirconia specimens aged in acidulated phosphate buffer showed more evident surface deterioration compared with specimens stored in distilled water and artificial saliva. BioHPP specimens exhibited wear tracks characterized by localized abrasion and surface deformation, while opaque zirconia generally displayed comparatively uniform wear patterns.

Qualitative energy dispersive spectroscopy analysis confirmed the elemental composition characteristic of each restorative material. No major qualitative compositional changes were observed following aging and wear testing. The EDS findings supported the SEM observations and indicated that the detected surface alterations were predominantly morphological rather than associated with substantial changes in elemental composition.

Discussion

The present in vitro study evaluated the influence of restorative material type and simulated aging media on antagonist enamel wear, restorative material wear, and surface characteristics under controlled sliding-contact conditions. The findings demonstrated a statistically significant reduction in antagonist tooth weight following wear testing, confirming that the experimental protocol produced measurable

enamel wear. However, neither restorative material type nor aging condition significantly influenced antagonist enamel wear. In contrast, restorative disc wear differed significantly among groups, indicating that restorative material degradation was influenced by material composition and aging environment. Surface characterization by SEM and AFM further demonstrated qualitative alterations in surface morphology and roughness following aging, particularly under acidic conditions.

The significant main effect of time observed in the repeated-measures ANOVA indicates that the wear simulation protocol was sufficient to induce measurable antagonist enamel loss. This finding is consistent with previous investigations demonstrating that repeated sliding contact can result in enamel wear through micro-abrasion, fatigue-related crack propagation, and progressive material removal at the contact interface (11–13). The loading conditions used in the present study (25 N and 4800 cycles) were selected to simulate early-stage occlusal interactions rather than peak masticatory forces and therefore provide insight into the initial tribological behavior of the restorative materials.

Despite measurable enamel wear, no statistically significant differences were detected among translucent zirconia, opaque zirconia, and BioHPP with respect to antagonist enamel weight loss. These findings suggest that, under the experimental conditions employed, restorative material composition alone was not a major determinant of antagonist enamel wear. Although zirconia ceramics possess high hardness and elastic modulus, previous studies have shown that antagonist wear is influenced more strongly by surface roughness and finishing procedures than by hardness alone (11, 14). Well-polished zirconia surfaces have been reported to cause less enamel wear than roughened, adjusted, or glazed zirconia surfaces (11, 14). The standardized polishing protocol used in the present study may therefore have minimized surface irregularities and contributed to the absence of significant differences among materials.

Similarly, the non-significant interaction between time and aging medium indicates that short-term chemical aging did not significantly alter antagonist enamel wear. Acidic environments have been reported to influence the surface stability of restorative materials and may contribute to degradation through chemical dissolution and surface alteration mechanisms (12, 15). However, the 7-day aging period combined with short-term thermal aging at 55°C may have been insufficient to induce changes of sufficient magnitude to affect enamel wear. These findings suggest that the early tribological performance of the tested materials may be relatively resistant to short-term chemical challenges when a polished surface is maintained.

The absence of a significant three-way interaction among time, restorative material, and aging medium further suggests that the combined effects of material composition and chemical aging did not significantly modify antagonist enamel wear. Previous investigations have indicated that contact mechanics, surface topography, and loading conditions may exert a greater influence on wear behavior than material composition alone during the early stages of wear (12, 14). The present findings are consistent with this concept and highlight the multifactorial nature of wear processes.

In contrast to antagonist enamel wear, restorative disc weight loss differed significantly among experimental groups. The highest wear was observed in translucent zirconia aged in acidulated phosphate buffer, whereas the lowest wear occurred in BioHPP stored in distilled water. These findings indicate that restorative materials responded differently to the aging environments and suggest that material degradation may occur even when antagonist enamel wear remains unaffected. Although not all pairwise comparisons reached statistical significance, a general trend toward increased wear under acidic conditions was observed.

Differences in restorative material wear may be related to their distinct microstructural characteristics. High-translucency zirconia contains increased yttria content and a greater proportion of cubic phase crystals, which improve optical properties but may reduce transformation toughening and resistance to environmental degradation compared with conventional 3Y-TZP zirconia (15, 16). Consequently, exposure to acidic conditions may contribute to greater surface deterioration and material loss. In contrast, BioHPP possesses a lower elastic modulus and greater resilience than ceramic materials, characteristics that may facilitate stress absorption and reduce wear under certain conditions (17, 18). Nevertheless, the substantial variability observed in some subgroups, particularly the BioHPP–acidulated phosphate buffer group, suggests heterogeneous material responses and warrants cautious interpretation of these findings.

Surface characterization findings supported the wear measurements. AFM analysis demonstrated increased roughness values in specimens exposed to acidulated phosphate buffer, with the highest roughness recorded for translucent zirconia aged under acidic conditions. SEM observations similarly revealed greater surface irregularities, localized defects, and more pronounced wear features in specimens exposed to acidic aging media compared with those stored in distilled water or artificial saliva (Figs. 1–4). These observations suggest that acidic environments can adversely affect surface integrity even during relatively short aging periods. The presence of surface irregularities and increased roughness may be attributed to localized surface degradation and alterations in material microstructure following chemical exposure (12, 15). Qualitative EDS analysis did not reveal substantial changes in elemental composition, indicating that the observed alterations were predominantly morphological rather than compositional in nature.

Based on these findings, the null hypotheses were partially rejected. The hypothesis that aging medium would not influence wear behavior was rejected for restorative material wear, as significant differences were observed among experimental groups. Similarly, the hypothesis that restorative material type would not influence tribological performance was rejected for restorative disc wear. However, for antagonist enamel wear, no statistically significant differences were detected among restorative materials or aging conditions. The hypothesis regarding the absence of interaction between restorative material type and aging medium was accepted with respect to antagonist enamel wear, as no significant interaction effects were observed.

From a clinical perspective, the present findings suggest that differences in restorative material degradation do not necessarily correspond to differences in antagonist enamel wear during short-term simulated function. Restorative materials may exhibit varying degrees of surface deterioration and material loss following chemical aging while producing similar levels of antagonist enamel wear. Consequently, both restorative material longevity and preservation of opposing dentition should be considered independently during restorative material selection.

Several limitations of the present study should be acknowledged. First, the relatively small subgroup sample size may have limited the ability to detect subtle differences among restorative materials and aging conditions, particularly for antagonist enamel wear outcomes. Second, wear assessment was based on gravimetric measurements, which may be less sensitive to localized wear than three-dimensional profilometric or volumetric analyses. Third, the aging protocol consisted of a 7-day immersion period followed by short-term thermal aging and therefore represents only an accelerated simulation of early clinical exposure rather than long-term intraoral service. Furthermore, the wear simulation was performed under unidirectional sliding contact using a fixed load and limited number of cycles, which cannot fully replicate the complex oral environment characterized by multidirectional loading, salivary dynamics, enzymatic activity, temperature fluctuations, and prolonged chemical exposure (14). Future studies incorporating larger sample sizes, extended aging periods, thermocycling protocols, and volumetric wear assessment techniques are required to better characterize the long-term tribological behavior of these restorative materials.

Conclusion

Within the limitations of this in vitro study, antagonist enamel wear was not significantly influenced by restorative material type or short-term chemical aging conditions. Although measurable enamel wear occurred during wear simulation, no statistically significant differences were detected among translucent zirconia, opaque zirconia, and BioHPP. In contrast, restorative material wear was significantly affected by material type and aging condition, with greater wear generally observed following exposure to acidulated phosphate buffer. Surface characterization demonstrated increased roughness and morphological alterations under acidic aging conditions, particularly in translucent zirconia specimens. These findings suggest that short-term chemical aging may influence restorative material degradation to a greater extent than antagonist enamel wear. Further studies incorporating larger sample sizes, extended aging periods, thermocycling protocols, and volumetric wear assessment methods are required to confirm the long-term clinical relevance of these observations.

Declarations

Clinical implication:

Within the limitations of this study, the tested restorative materials did not produce significantly different levels of antagonist enamel wear under the experimental conditions employed. Consequently, restorative

material selection should not be based solely on concerns regarding short-term antagonist enamel wear but should also consider factors such as mechanical properties, surface finishing protocols, esthetic requirements, and clinical indications. The observed differences in restorative material wear and surface degradation following acidic aging suggest that intraoral environmental conditions may influence long-term restorative performance. These findings may be particularly relevant in older adults and patients with increased exposure to acidic oral conditions, where maintaining restorative longevity and preserving occlusal harmony are important clinical considerations.

Data Availability Statement

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

Author Contributions

Conceptualization: (RR, SR)
Methodology: (RR, SR)
Investigation: (RR, SR)
Data curation: (RR, SR)
Formal analysis: (RR, SR)
Writing – original draft: (RR, SR)
Writing – review & editing: (RR, SR, MM,TBS,UYP,SS,PK,AS,SM, VK, PB)

Ethics Approval and Consent to Participate

This study was conducted using previously recorded clinical data. Therefore, Patient consent was not obtained to use their teeth for the study. Need for consent to participate was waived by the Institutional Review Board (Institutional Review Board, Manipal College Of Dental Sciences, Mangalore)The study protocol was submitted to the Institutional Ethics Committee of Manipal College of Dental Science and received ethical approval/no objection for the conduct of the study (Reference No 20063). As the study involved retrospective analysis of existing clinical records and did not involve any additional intervention or contact with participants, individual informed consent was not obtained. The study involving extracted human teeth was conducted in accordance with the relevant institutional guidelines and regulations and the principles of the Declaration of Helsinki.

Consent for Publication

Not obtained.

Conflict of Interest

The authors declare no conflict of interest.

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Tables

Tables 1 to 6 are available in the Supplementary Files section.

Figures

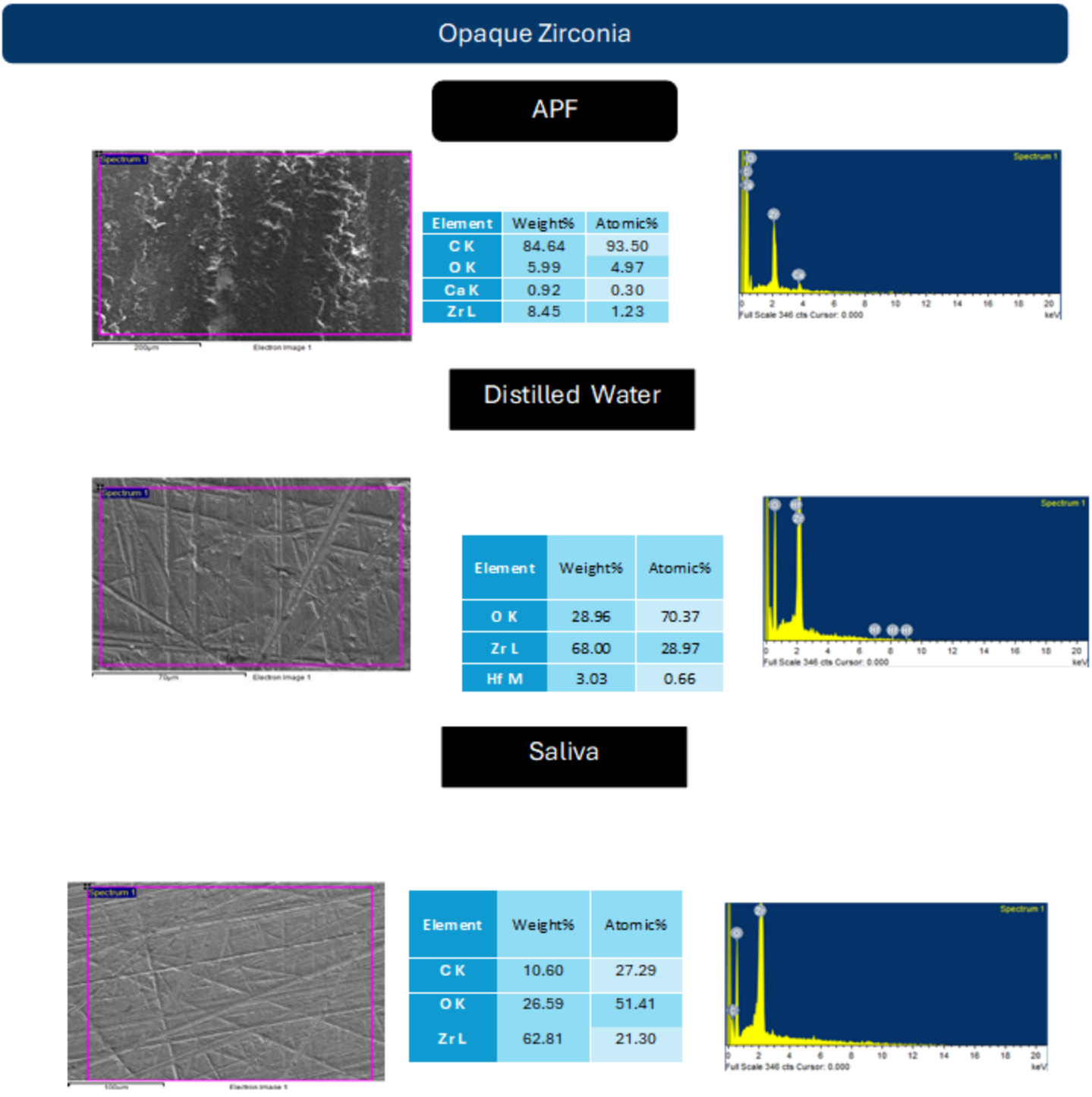


Figure 1

SEM micrographs and EDS elemental analysis of **Opaque zirconia (OZ)** specimens following aging in acidulated phosphate buffer (APB), distilled water (DW), and artificial saliva (AS) .

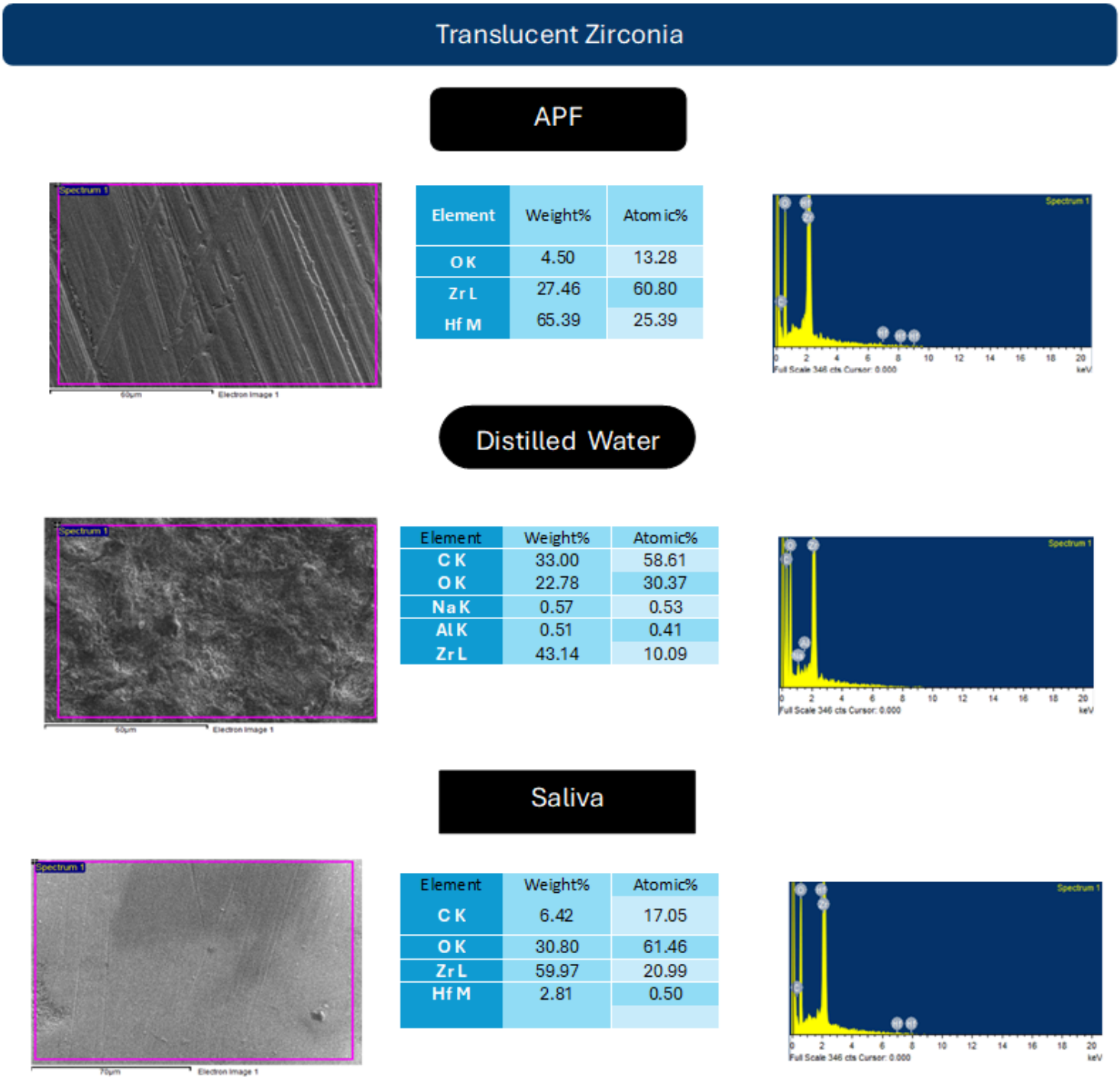


Figure 2

SEM micrographs and EDS elemental analysis of translucent zirconia (TZ) specimens following aging in acidulated phosphate buffer (APB), distilled water (DW), and artificial saliva (AS) .

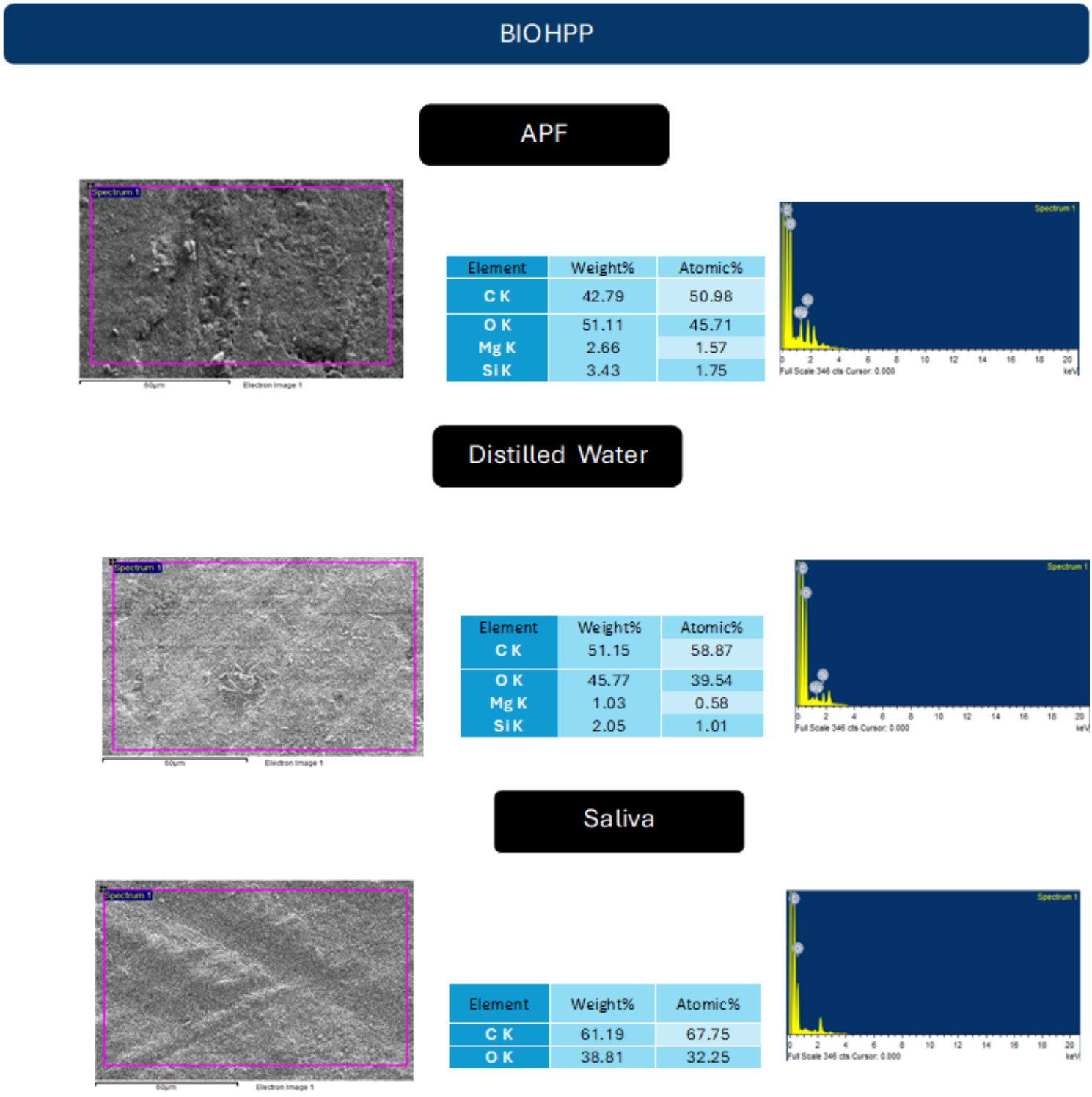


Figure 3

SEM micrographs and EDS elemental analysis of translucent zirconia (TZ) specimens following aging in acidulated phosphate buffer (APB), distilled water (DW), and artificial saliva (AS) .

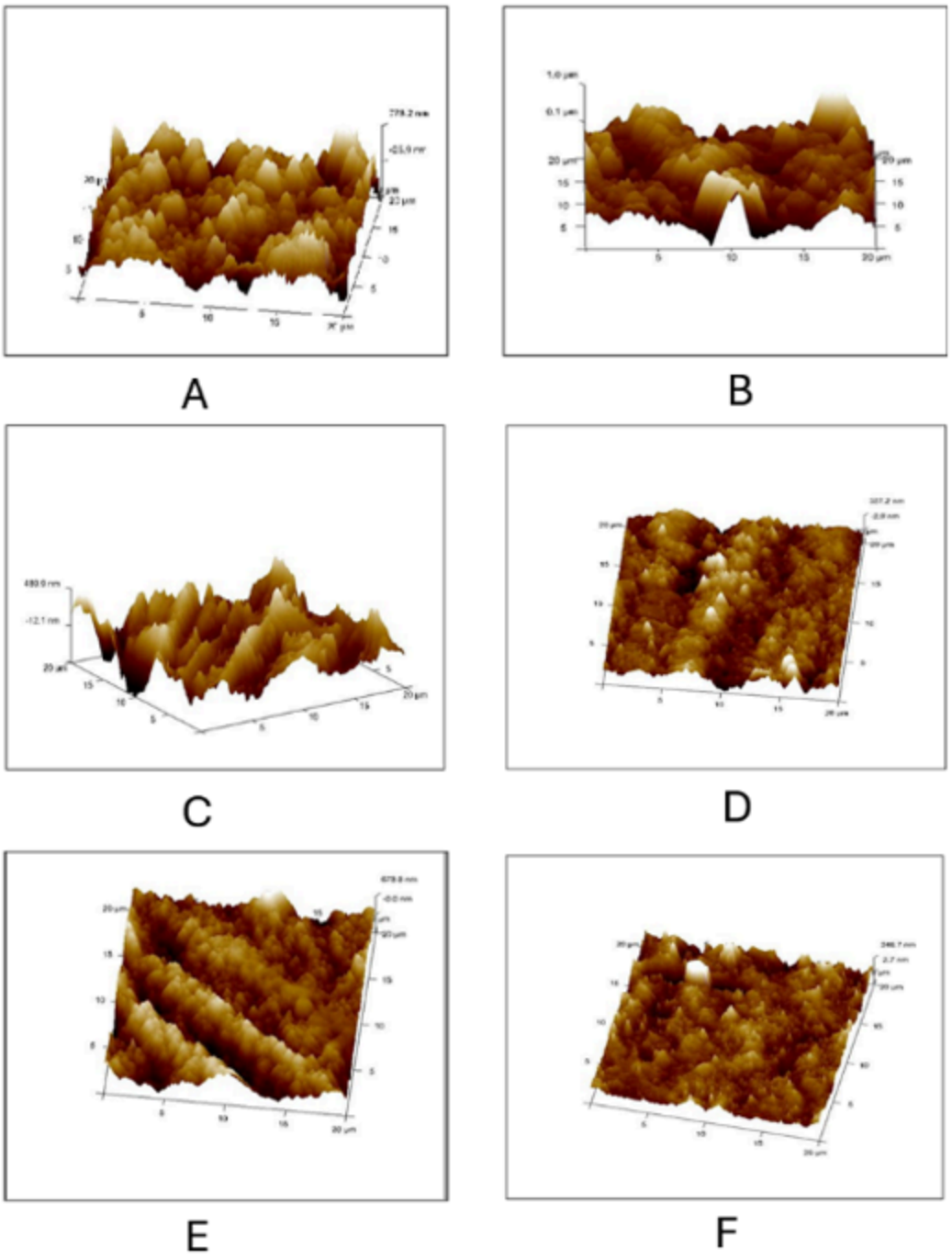


Figure 4

Representative AFM three-dimensional surface topography of restorative materials following aging and wear testing.

(A) BioHPPaged in acidulated phosphate buffer;

(B) BioHPPaged in artificial saliva.

(C) Opaque zirconia zirconiaaged in acidulated phosphate buffer;

(D) Opaque zirconia aged in artificial saliva;

(E) Translucent zirconia aged in acidulated phosphate buffer;

(F) Translucent zirconia aged in artificial saliva.

Specimens aged in acidic media exhibited increased surface irregularities and peak–valley variations compared with those stored in neutral conditions, indicating surface degradation and increased roughness.

Supplementary Files

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- Tables.docx