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RESEARCH AND EDUCATION

Two-body wear performance of dental colored zirconia after different surface treatments

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ABSTRACT

Statement of problem. Colored zirconia is widely used in dental clinical practice; however, data pertaining to its wear resistance after different surface treatments are sparse.

Purpose. The purpose of this in vitro study was to evaluate the 2-body wear resistance of dental colored zirconia after different glazing and polishing treatments.

Material and methods. Standardized specimens were prepared from dental zirconia (internal and external staining and no staining) and subjected to different surface treatments. The stained zirconia and control ceramics were polished with a Robinson brush and polishing paste or polishing kits, while the nonstained zirconia was airborne-particle abraded and glazed. The specimens were then abraded against steatite antagonists using a pin-on-disk wear tester. The wear depth for the specimens was measured using confocal microscopy. Wear areas on the steatite antagonists were measured by using an optical microscope. Scanning electron microscopy (SEM) was used to evaluate the wear pattern of the zirconia specimens. All data were statistically analyzed with 1-way ANOVA and the Tamhane test for post hoc analysis (α=.05).

Results. The surfaces polished using the Robinson brush and paste showed no wear. The wear depth of the unglazed surfaces was 42.27 ±3.21 ∼84.15 ±2.57 µm and 87.75 ±9.36 and 91.76 ±13.58 µm for the glazed surfaces. The antagonist wear area was 1.79 ±0.21 ∼2.69 ±0.34 mm^2 (unglazed) and 3.34 ±0.29 ∼4.51 ±0.88 mm^2 (glazed). SEM revealed chipping fractures, and peeling cracks were observed on the glazed zirconia surfaces, indicating a combination of fatigue and abrasive wear.

Conclusions. The results of this in vitro study suggest that highly polished zirconia shows the least wear, including antagonist wear. Furthermore, glazed zirconia can be significantly more abrasive than polished zirconia. The wear properties of internally and externally stained zirconia are similar. (J Prosthet Dent 2016;116:584-590)

Since the end of the 1990s, partially stabilized zirconia has been promoted as suitable for dental use because of its excellent mechanical properties and biocompatibility.[1] However, the chipping and fracture of zirconia veneers have been reported.[2-5] Failures are more frequent in the veneer material, as reported in a recent systematic review of 3-year clinical trials of zirconia partial fixed dental prostheses, which found a 27% incidence of chipping in the veneer porcelain and a 1% incidence of fracture in the framework.[6] The most prevalent technical complication was chipping of the veneering porcelain, followed by framework fracture, loss of retention, and marginal discrepancies.[7] Crowns with obvious chipping and fractures can be replaced; however, those with inconspicuous chipping and fractures are frequently ignored by clinicians. Consequently, the rough surfaces formed will cause excess abrasion of antagonists.[8-10]

Anatomic contour zirconia restorations without veneers were proposed to resolve the chipping problem.[11] The absence of a veneer may minimize the chipping and wear of the material and antagonists as shown in an vitro study.[12,13] For mimicking the appearance of natural teeth, white zirconia is colored. Currently, 3 main methods are available for obtaining shaded zirconia for dental purposes. In the first method, metal oxides are mixed with ZrO_2 powder at the production stage to obtain precolored blocks. In the second method, green-stage frameworks are infiltrated with specific coloring liquids before sintering. In the third method, zirconia is painted with liners that require firing in a traditional

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Clinical Implications

Polishing zirconia surfaces with a Robinson brush and paste is recommended in clinical practice. Suitable surface treatments for zirconia are crucial for the safe and effective use of anatomic contour zirconia crowns.

dental ceramic furnace after sintering.[14] However, treatment with coloring substances, usually metal oxides, has been reported to decrease the mechanical properties of zirconia.[15] Although numerous ceramics stained by novel methods have been developed and used in clinical practice in recent years, data concerning their wear resistance are limited.

Zirconia is the hardest dental ceramic, and the wear of natural teeth opposing zirconia restorations is an issue of concern. Although IPS e.max Press, e.max CAD, Noritake Super Porcelain, and LAVA Plus Zirconia exhibited high durability and were wear-friendly to opposing enamel in an in vitro study, zirconia crowns and metal ceramic crowns led to more wear of antagonist enamel than natural enamel.[16,17] Preis et al[18,19] reported that polishing could effectively decrease the surface roughness of white zirconia and decrease the wear of natural antagonists. In clinical practice, zirconia is polished using fine polishing paste and polishing compound. However, no study has evaluated the effects of the type of polishing instruments on the wear patterns of zirconia, and antagonist wear must be evaluated to maintain oral homeostasis.[20]

The purpose of this study was to evaluate the effects of different staining methods and polishing instruments on the wear patterns of zirconia. The null hypotheses were that no difference would be found in the wear of zirconia stained by different modes under the same surface treatment conditions and that the wear of zirconia stained by the same method would not be influenced by different surface treatments.

MATERIAL AND METHODS

A total of 110 presintered zirconia disks (diameter, 10 mm; thickness, 2 mm) were provided by a single manufacturer (Upcera). Of these, 80 disks were cut from pure white zirconia blocks and 30 from precolored A2 blocks. All disks were abraded with 400-grit, wet SiC abrasive paper to ensure that the test surfaces were under the same condition and then divided into 4 main groups according to the coloring process used. First was an internal staining group, which included all the precolored zirconia disks (n=30). The disks were sintered at 1480°C in an air environment for a holding time of 2 hours (SJG-16; Luoyang Shenjia Kiln Co Ltd). Second was an external staining group, which included white zirconia disks immersed into A2 coloring liquid (Upcera) for 5 minutes and dried with an infrared lamp for 30 minutes (n=30). The sintering program was the same as that for the internal staining group. All other white zirconia disks were fully sintered by the same sintering program. Then, 20 of the disks were subjected to glaze with A2 color, while the remaining 30 were not colored and used as a control group. The specimens of all groups except the glazed group were further randomized into 3 subgroups (n=10 per subgroup) using simple random method according to the following surface treatments: polishing with a polishing kit (ZrO_2 polisher; Komet Dental) and polishing with a Robinson brush and paste (Zenostar; Wieland Dental). The polishing tools used in this study are illustrated in Fig. 1. The specimens were polished using a low-speed handpiece at 6000 rpm. A third subgroup did not undergo any treatment and was used as a control. In the glazed group, the zirconia disks were first airborne-particle abraded with 110-μm aluminum oxide particles (Renfert GmbH) under a 2-MPa pressure at a distance of 10 mm for 15 seconds, followed by ultrasonic cleaning in distilled water for 5 minutes (VS350; Silfradent). Two glazing materials were selected. In 1 subgroup, the zirconia disks were first glazed with Zenostar Magic Glaze Flu, followed by coloring with A2 Zenoflex dimension (Wieland Dental). In the other subgroup, zirconia disks were first colored by IPS e.max Ceram Shades, followed by glazing with IPS e.max Ceram (Ivoclar Vivadent AG). Firing programs were set according to the manufacturer's recommendations. The 11 zirconia experimental groups consisted of internal staining zirconia polished with polishing kits (IK), internal staining zirconia polished with brush and paste (IB), internal staining zirconia without polishing (IC), external staining zirconia polished with polishing kits (DK), external staining zirconia polished with brush and paste (DB), external staining zirconia without polishing (DC), white zirconia polished with polishing kits (CK), white zirconia polished with brush and paste (CB), white zirconia without polishing (CC), zirconia with staining with colorants and glazing (SG), and zirconia with glazing and staining with colorants (GS). The abbreviations for all experimental groups with different surface treatments and the materials used in this study are listed in Table 1. The 110-specimen arrangement is presented in Figure 2. To simulate standardized wear, steatite balls (Upcera) prepared from magnesium silicate were used as antagonists.[19,21,22] A sphere radius of 1.5 mm was selected, because individual human cusp radii vary between 0.6 and 4 mm.[23,24] The specimens were tested using a laboratory-made pin-on-disk wear instrument (QH-1; Tsinghua University). The vertical load was set as 5 N for 2×10^4 cycles at a frequency of 1.6 Hz, thus simulating a human masticatory

Figure 1. Polishing instruments and zirconia specimens. A, B, Komet polishing diamond. C, Robinson brush and Zenostar paste. D, Airborne-particle abraded and glazed zirconia specimens (Ivoclar; Shade, A2; Group SG).

Table 1. Abbreviations of all experimental groups with different surface treatments and materials used

Group	Stain Mean	Surface Treatment
IK (internal staining specimens polished by kits)	I: Precolored block with internal colorants[a]	K: Polish kits (Step 1/2:235945; Step 2/2:213760)[d]
IB (internal staining specimens polished by brush and paste)		B: Polish brush and paste[b]
IC (internal staining specimens without polishing)		C: As control
DK (external staining specimens polished by kits)	D: Dipping dye with liquid[a]	K: Polish kits[d]
DB (external staining specimens polished by brush and paste)		B: Polish brush and paste[b]
DC (external staining specimens without polishing)		C: As control
GS (glazed and shaded specimens)	S: Staining with colorants[b]	G: Glaze[b]
SG (shaded and glazed specimens)	S: Staining with colorants[c]	G: Glaze[c]
CK (nonstaining specimens polished by kits)	C: White block as control[a]	K: Polish kits[d]
CB (nonstaining specimens polished by brush and paste)		B: Polish brush and paste[b]
CC (nonstaining specimens without polishing)		C: As control

[a]Upcera; [b]Wieland; [c]Ivoclar Vivadent; [d]Komet.

cycle.[19,25] During this simulation, the specimens were immersed in artificial saliva.[16]

The wear depth (μm) and surface roughness (Ra) (μm) of the zirconia specimens were determined using confocal microscopy (LEXT OLS4000; Olympus). The wear area (mm^2) on the steatite antagonists was quantified using light microscopy (BX50; Olympus Corp). The detailed microstructure of the zirconia surfaces was observed using SEM (SSX-550; Shimadzu).

All calculations and statistical analyses were made with software (SPSS for Windows v13.0; SPSS Inc). Mean values and standard deviations were calculated and analyzed using 1-way ANOVA and the Tamhane test for post hoc analysis (α=.05).

RESULTS

The mean Ra (Fig. 3) was similar among zirconia ceramics without surface treatment, with values of

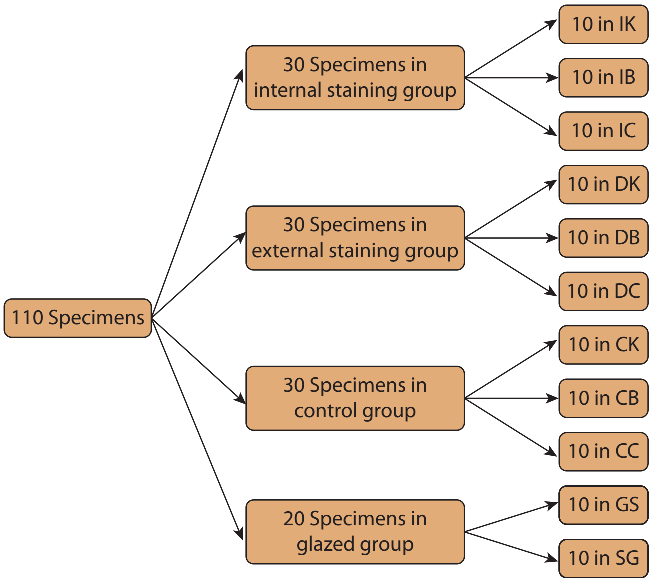

Figure 2. Experimental design.

0.23 ±0.01 μm (DC) and 0.25 ±0.01 μm (CC), but it was markedly lower after polishing as follows: 0.15 ±0.01 μm (DK) and 0.16 ±0.01 μm (IK), 0.09 ±0.01 μm (CB) and 0.12 ±0.01 μm (DB). No significant differences were found between the 2 stained groups and the control group (Table 2). The mean Ra of specimens polished using the Komet kits was significantly higher than that of specimens polished using the Robinson brush and paste in the internal staining group, external staining group, and control group ($P<.05$), while that of glazed specimens was significantly higher than that of the other tested specimens ($P<.05$).

None of the zirconia ceramics polished by the Robinson brush and paste showed any measurable wear after simulation (Fig. 3). Against the steatite antagonists, specimens in the 2 glazed subgroups showed a wear depth of 91.76 ±13.58 μm (SG) and 87.75 ±9.36 μm (GS), which was significantly greater ($P<.05$) than that in the other groups (Table 3). Polished specimens showed significantly less ($P<.05$) wear depth than untreated specimens in the internal staining group, external staining group, and control group. Furthermore, glazed zirconia was significantly more ($P<.05$) abrasive than the polished specimens, with no significant differences between the 2 stained groups (Table 2).

With unglazed zirconia, the wear area on the steatite antagonists was 2.69 ±0.35 (IC) and 1.79 ±0.21 mm^2 (IB). With glazed zirconia, the antagonist wear area was 4.51 ±0.88 mm^2 (GS) and 3.34 ±0.29 mm^2 (SG). No significant difference was found among the 2 stained groups and the control group (Table 2). The antagonist wear against the polished and control zirconia was significantly less ($P<.05$) than that against glazed and stained zirconia (Table 3). Zirconia polished with the Robinson brush and

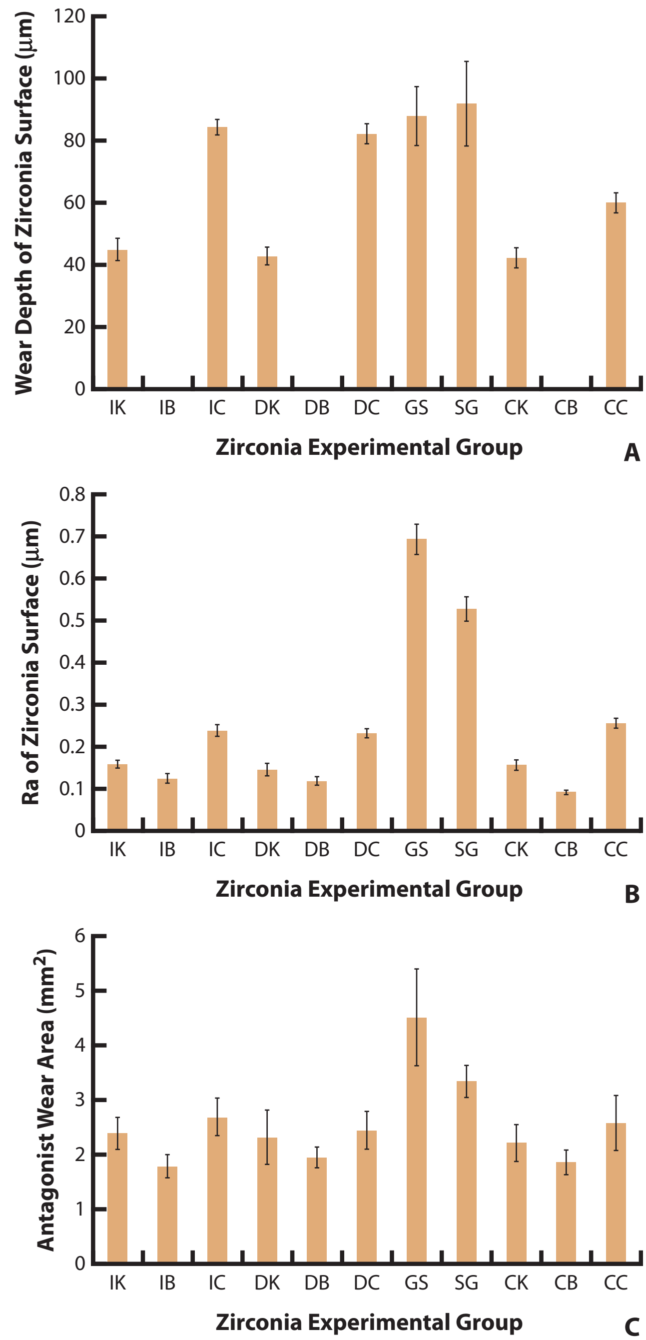

Figure 3. Wear depth of zirconia surface (μm) (A), Ra of zirconia surface (μm) (B), and antagonist wear area (mm^2) (C) in IK, IB, IC, DK, DB, DC, GS, SG, CK, CB, and CC groups. No difference was found between IK and DK, IB and DB, IC and DC ($P>.05$). Significant difference was found between IK and ID, DK and DB, and CK and CB ($P<.001$). Group GS or SG was significantly different from other groups in Ra of zirconia surface (μm) and antagonist wear area (mm^2). For key to groups, see Table 1.

paste resulted in the smallest wear areas on the antagonists (1.79 ±0.21 mm^2), while glazed zirconia resulted in the largest wear areas (4.51 ±0.88 mm^2).

The wear mechanism was clarified on the basis of micromorphologic analysis using SEM. Figure 4A shows

Table 2. Tamhane post hoc analysis according to mode of staining: Wear depth and surface roughness (Ra) values for zirconia surfaces and antagonist wear area

Staining Method (n)	Group	Wear Depth of Zirconia Surface (mean, µm)	Ra of Zirconia Surface (mean, µm)	Antagonist Wear Area (mean, mm²)
I (30)	IK	43.00[b]	0.17[a]	2.29[a]
	IB			
	IC			
D (30)	DK	41.56[b]	0.17[a]	2.23[a]
	DB			
	DC			
S (20)	GS	89.75[c]	0.61[b]	3.92[b]
	SG			
C (30)	CK	34.03[a]	0.17[a]	2.21[a]
	CB			
	CC			

Different superscript letters indicate groups with statistically significant differences (P<.05).

Table 3. Tamhane post hoc analysis according to surface treatment: Wear depth and surface roughness (Ra) values for zirconia surfaces and antagonist wear area

Surface Treatment (n)	Group	Wear Depth of Zirconia Surface (mean, µm)	Ra of Zirconia Surface (mean, µm)	Antagonist Wear Area (mean, mm²)
K (30)	IK	43.28[b]	0.15[b]	2.30[b]
	DK			
	CK			
B (30)	IB	0.00[a]	0.11[a]	1.86[a]
	DB			
	CB			
G (20)	GS	89.75[d]	0.61[d]	3.92[c]
	SG			
C (30)	IC	75.32[c]	0.24[c]	2.57[b]
	DC			
	CC			

Different superscript letters indicate groups with statistically significant differences (P<.05).

the microstructures of an intact zirconia surface in group DC. Irregular textures as a result of grinding with abrasive paper (400 grit SiC) can be observed. Figure 4B shows the microstructure of an intact zirconia surface polished using Komet kits in group DK; the shallow cracks could be removed. Figure 4C shows the microstructure of an intact zirconia surface polished with the Robinson brush and paste in group DB. Most cracks could be removed by the Robinson brush and paste; consequently, a surface with a fine-grained and homogeneous texture could be observed. Figure 4D, which is Figure 4C at a higher magnification, reveals the base of small cracks within the furrows; the width of the cracks was approximately 3 to 4 µm, consistent with the particle size of the polishing paste.

Figure 5 show many scale-like desquamations and large-sized debris in the wear area in group GS. The glaze is crushed but not completely stripped. In the glazed zirconia, fatigue wear was the most common pattern and was characterized by chipping fractures and peeling cracks similar to fish scales. There was a zone of compression in the head of the antagonist, where it slid over the glazed zirconia surface. Plastic deformation of the glazed layer was also observed. Furthermore, flake-like chipping after stripping and cracks were observed on glazed zirconia surfaces when they slid against the steatite, indicating a combination of fatigue-related and abrasive wear.

DISCUSSION

The first null hypothesis stating that there is no difference in the wear patterns of zirconia stained by different modes under the same surface treatment conditions was accepted. The findings supported rejecting the second null hypothesis, which proposed decreased wear after adequate polishing.

Enamel-based antagonists are closer to actual clinical conditions, although differences in enamel with regard to morphology and structure complicate standardized wear testing. Some have attempted to standardize enamel cusps by grinding and embedding; however, the wear performance results were not satisfactory.[20,26] Equally shaped and structured antagonists such as spheres allow the standardization of antagonistic conditions, thus providing valid quantification of wear performance results.[27] Although steatite spheres may not be considered ideal substitutes for human enamel because of their mechanical and tribologic properties,[28] their suitability as antagonist materials for in vitro studies on wear resistance has been documented.[29] Therefore, we chose steatite spheres instead of enamel spheres as antagonists in this study. Although machine polishing results in a significantly higher surface gloss than manual polishing, we chose manual polishing to simulate clinical conditions.

According to the data in Table 2 and Figure 3, there was no significant difference (P>.05) in wear resistance between the 2 staining methods (internal and external staining). However, while a significant difference was found in wear depth (P<.05) between stained and control zirconia, no significant difference (P>.05) was found between the 2 types with regard to antagonist wear area and roughness, indicating that treatment with coloring substances impaired wear resistance of the zirconia surfaces and had no effect on antagonists.

Grinding results in rough and grooved zirconia surfaces, and polishing and glazing can effectively decrease such roughness. Some have reported that the surfaces of glazed ceramic are smoother than those of polished ceramics.[30,31] In contrast, some investigations have concluded that the smoothness of polished ceramic surfaces is similar or better than that of glazed ones.[32,33] In this study, the final Ra value after completion of the 2 polishing steps was lower than that for the glazed layers. Zirconia polished with the Robinson brush and paste was

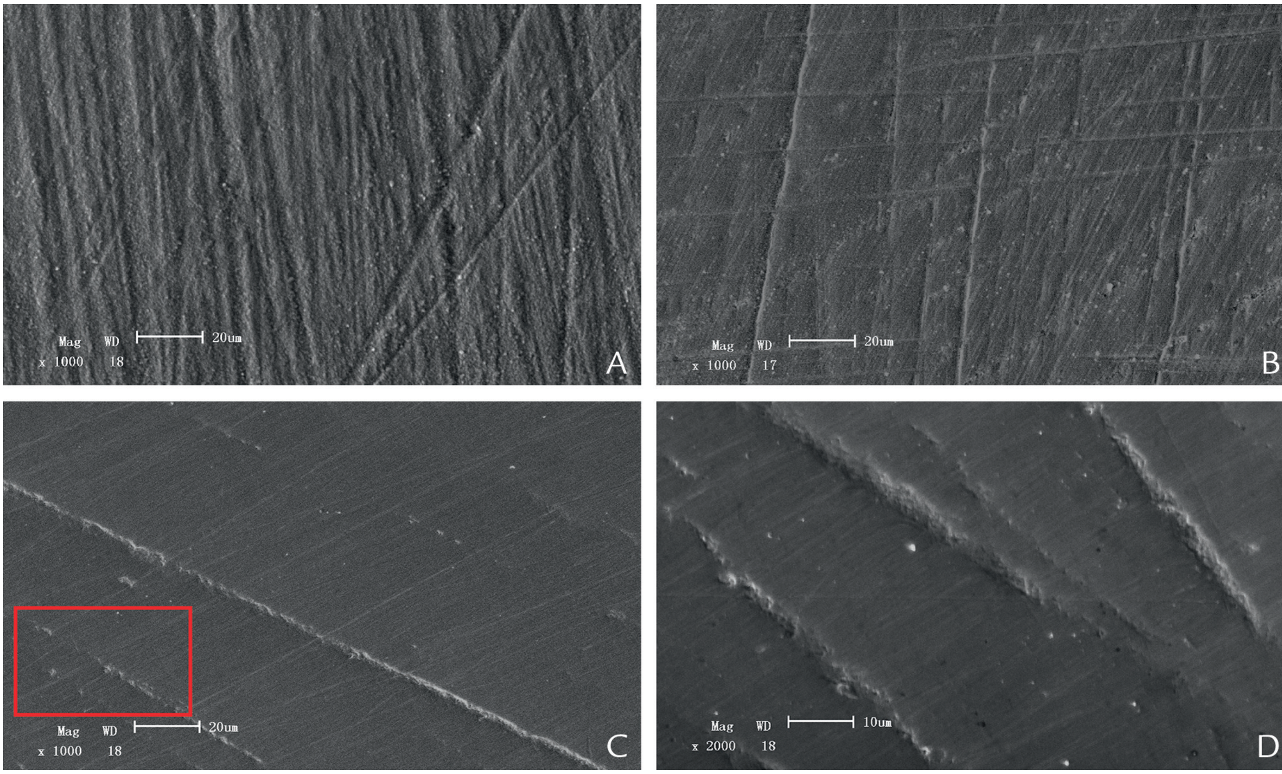

Figure 4. Scanning electron micrographs of zirconia surfaces. Surface abrasion due to polishing can be observed in groups DB and DK. Group DB shows more even and finer texture. A, Group DC (×1000 magnification). B, Group DK (×1000 magnification). C, Group DB (×1000 magnification). D, High magnification of cracks in Figure 2C (marked by red box; ×2000 magnification).

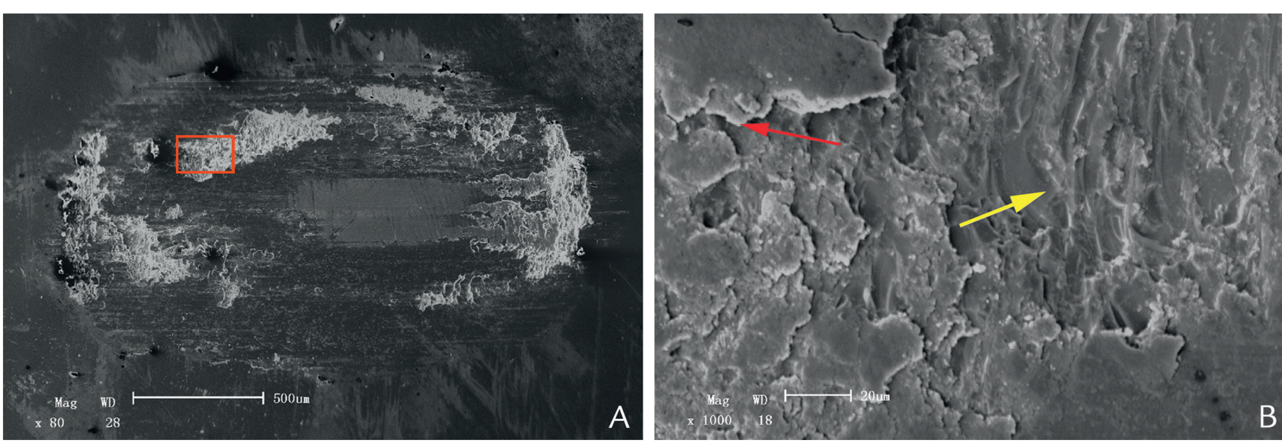

Figure 5. Scanning electron micrographs of glazed zirconia surfaces in group GS. A, Wear trace (×80 magnification). B, High magnification of red block in A showing wear of glazed zirconia against steatite antagonist: chipping fractures (marked by red arrow) and peeling cracks similar to fish scales (marked by yellow arrow; ×1000 magnification).

associated with the least amount of wear and the smallest antagonist wear area, while glazed zirconia showed opposite findings. These findings were similar to those of Janyavula et al[34] and Kontos et al[35] and indicate that adequate polishing may be a better time-saving method compared with glazing in clinical practice.

In this study, SEM images of zirconia polished with the Robinson brush showed a surface with a more fine-grained and homogeneous texture compared with those of zirconia polished with Komet kits. Higher magnification showed that the width of the cracks was approximately 3 to 4 μm, consistent with the particle size of the polishing paste. The zirconia substructure should be polished before any surface treatment, because the rough surface that appears after wear of the stain may accelerate further wear.[29]

Glazed zirconia shows greater wear compared with polished zirconia, although the surface of glazed zirconia is smooth before wear testing. Although glazing results in a smooth, esthetic, and hygienic surface, the glaze layer can be easily removed during function or by occlusal adjustment, thus causing more abrasive wear of the opposing teeth. The rough surface of the underlying ceramic material can cause aggressive damage once exposed.[35]

In a previous study on Cercon base, airborne-particle abrasion before glazing did not increase the wear rate compared with antecedent polishing. This was probably because the glaze may have filled the rough zirconia surface, and the deeper glaze layers may have been protected by sticking zirconia.[21] In addition, roughening zirconia surfaces by airborne-particle abrasion may be beneficial for effective bonding to the glaze layer.[19]

The authors suspect that stress abrasion may be further aggravated by chemical reactions, besides vertical load and friction cycle frequencies and time. Therefore, further studies are required to investigate the long-term survival rate and wear mechanisms of glazed zirconia under fatigue stress and the effects of acid medium.

CONCLUSIONS

Within the limitations of this in vitro study, the findings suggest that monolithic zirconia polished with the Robinson brush and paste shows the least wear depth and smallest antagonist wear area. Furthermore, glazed zirconia can be more abrasive than polished zirconia. Finally, the wear properties of internally and externally stained zirconia are similar.

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