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Article *in* Journal of Prosthetic Dentistry · July 2015

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THE WEAR OF POLISHED AND GLAZED ZIRCONIA AGAINST ENAMEL

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Statement of problem. The wear of tooth structure opposing anatomically contoured zirconia crowns requires further investigation.

Purpose. The purpose of this in vitro study was to measure the roughness and wear of polished, glazed, and polished then reglazed zirconia against human enamel antagonists and compare the measurements to those of veneering porcelain and natural enamel.

Material and methods. Zirconia specimens were divided into polished, glazed, and polished then reglazed groups (n=8). A veneering porcelain (Ceramco3) and enamel were used as controls. The surface roughness of all pretest specimens was measured. Wear testing was performed in the newly designed Alabama wear testing device. The mesiobuccal cusps of extracted molars were standardized and used as antagonists. Three-dimensional (3D) scans of the specimens and antagonists were obtained at baseline and after 200 000 and 400 000 cycles with a profilometer. The baseline scans were superimposed on the posttesting scans to determine volumetric wear. Data were analyzed with a 1-way ANOVA and Tukey Honestly Significant Difference (HSD) post hoc tests (α=.05)

Results. Surface roughness ranked in order of least rough to roughest was: polished zirconia, glazed zirconia, polished then reglazed zirconia, veneering porcelain, and enamel. For ceramic, there was no measureable loss on polished zirconia, moderate loss on the surface of enamel, and significant loss on glazed and polished then reglazed zirconia. The highest ceramic wear was exhibited by the veneering ceramic. For enamel antagonists, polished zirconia caused the least wear, and enamel caused moderate wear. Glazed and polished then reglazed zirconia showed significant opposing enamel wear, and veneering porcelain demonstrated the most.

Conclusions. Within the limitations of the study, polished zirconia is wear-friendly to the opposing tooth. Glazed zirconia causes more material and antagonist wear than polished zirconia. The surface roughness of the zirconia aided in predicting the wear of the opposing dentition. (J Prosthet Dent 2013;109:22-29)

CLINICAL IMPLICATIONS

Polished zirconia is more wear friendly to opposing enamel than veneering porcelain. Therefore, polished anatomically contoured zirconia restorations can be indicated in high load bearing areas. The glazing of crowns should be avoided unless there is a high esthetic demand. In these situations, zirconia should be polished and then reglazed.

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Metal ceramic (MC) and cast metal crowns have been used in dentistry with considerable success.[1] Increase in the cost of metals and the demand for highly esthetic restorations have led to increased interest in ceramic restorations without any metal. Efforts have been directed at developing high strength ceramics with improved marginal quality, esthetics, and wear properties.[2,3] Most recently, high strength milled alumina and zirconia have been developed for use as a core material in posterior ceramic crowns.

Zirconia, specifically yttrium-stabilized tetragonal zirconia polycrystal (Y-TZP), was chosen as a core material to help prevent bulk fracture of ceramic restorations.[4] An important property of zirconia is its transformation toughening and an ability to slow crack propagation and improve fracture resistance. Zirconia has a flexural strength of 900 to 1200 MPa and a fracture toughness of 9 to 10 MPa·m$^{0.5}$.[5-7] With its superior mechanical properties, zirconia has been used for multiunit and complete arch frameworks, implant abutments, and complex implant superstructures for fixed and removable prostheses.[2,7]

Clinical trials have shown that despite a low frequency of core fracture in zirconia supported partial fixed dental prostheses (FDPs), they have a higher rate of porcelain veneer fracture than MC FDPs.[8] Additional studies of zirconia-supported implant restorations have reported chipping of veneering porcelain.[9,10] These failures can be attributed to the mismatch of the coefficient of thermal expansion between the zirconia and the veneered porcelain.[11] In an effort to reduce these failures, highly sintered monolithic or anatomically contoured zirconia crowns were developed. The elimination of the veneering porcelain layer improved the clinical success and reliability of zirconia restorations.[12] As zirconia is more wear resistant than many other dental ceramics,[13] the clinical advantages of occlusal zirconia should be considered for wear-prone patients.

Similar to other ceramics, however, zirconia is highly likely to wear the enamel or dentin of an opposing tooth.[14-16] Several studies have suggested that ceramic substrates produce more wear on opposing tooth structure than enamel.[17-19] Anatomically contoured zirconia crowns have zirconia directly opposing natural teeth without a layer of intervening veneering porcelain. The reported hardness of zirconia ranges from around 1378 to 1354 Hv compared to the reported hardness of veneering porcelain at 481 to 647 Hv.[20,21] Despite some evidence that ceramic hardness is not correlated with its wear potential,[22,23] the wear of natural dentition and other restorations opposing zirconia is a concern. A recent in vitro study measuring the wear of zirconia against enamel and steatite antagonists, however, concluded that zirconia produced less wear of the steatite antagonists than veneering porcelain. The study did not measure the amount of wear of the enamel antagonists.[24,25]

Many anatomically contoured zirconia crowns are glazed and stained superficially during fabrication to improve their esthetic properties.[26] At insertion, the occlusal adjustment of ceramic crowns may roughen the occluding surface, the adjusted area of which will require polishing.[27] In vitro studies have reported that polishing ceramic materials decreases their roughness and decreases opposing enamel wear.[27,28] Additionally, polished ceramics produce less wear of opposing enamel than glazed ceramics.[29] A possible explanation is that the glazed surface is quickly worn away to reveal the rough surface of unpolished ceramic beneath.[30,31] Therefore, polishing ceramics before glazing may help prevent opposing enamel wear.

The purpose of this study was to investigate the wear of polished, glazed, and polished then reglazed zirconia against enamel in a newly designed Alabama wear testing device.[32-34] Additionally, the roughness of ceramics was measured before testing as ceramic roughness has been correlated with wear.[35,36] The null hypotheses were: (1) there would be no difference in the resulting wear of specimen or antagonist materials when zirconia (with varied surface treatments), a veneering porcelain, and a flat enamel are worn against an enamel antagonist; and (2) there would be no difference in the roughness of the substrates.

MATERIAL AND METHODS

Specimen Preparation

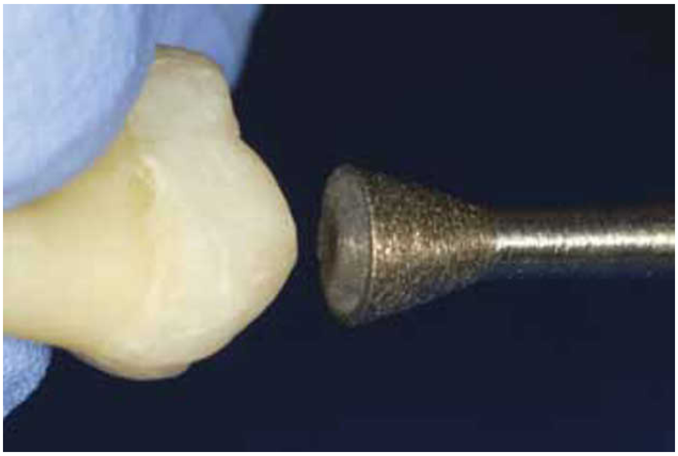
The study included 5 groups (n=8): polished zirconia (PZ), glazed zirconia (GZ), polished then reglazed zirconia (PGZ), veneering porcelain (VP), and enamel (E). A sample size of 8 was selected based on the specimen capacity of the modified Alabama wear testing device. A power analysis was not performed; however, previous testing with this device has shown significant differences among ceramic materials with sample sizes of 8. For groups PZ, GZ, PGZ, and VP, ceramic blocks with the dimensions of 7 × 11 × 6 mm were prepared by the manufacturer (Ivoclar Vivadent, Schaan, Liechtenstein). All zirconia specimens (Monolithic Zirconia; Ivoclar Vivadent) were airborne-particle abraded with alumina at 0.34 MPa, steam cleaned, and then prepared according to the following directions.

PZ specimens were polished sequentially with an NTI green coarse polisher, an NTI blue refining polisher for initial shine, and an NTI yellow high shine polisher for a wet shine (CeraGlaze Porcelain Adjusting & Polishing Lab Set; Axis Dental, Coppell, Texas). The polished specimens were treated with intraoral fine polish (DiaShine; VH Technologies, Lynnwood, Wash) to achieve a high gloss. GZ specimens received a coat of FCZ glaze and were then fired as described in Table I. PGZ specimens were polished as described for Group PZ and then glazed as described for Group GZ.

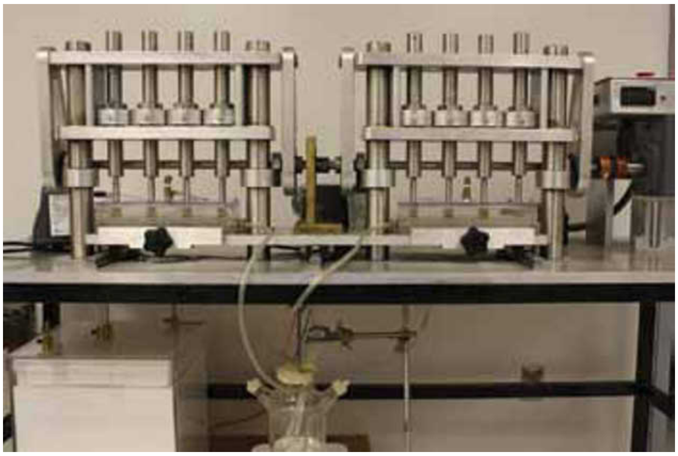
A commercially available veneering ceramic material (Ceramco3; Dentsply Prosthetics, York, Pa) was included in the study as a control. The

Table I. Firing parameters of ceramics and glazes

Firing Parameters	Pre-Dry (min)	Low Temp (°C)	Heat Rate (°C/min)	Vac	Vac Start (°C)	Vac Stop (°C)	Hi Temp (°C)	Hold (s)	Cool
Zirconia	6	425	55	Full	480	1000	1000	0	0
Glaze	6	425	38	Full	480	1000	1000	0	0
Ceramco	3	650	70	No	X	X	935	30	0
Overglaze	3	650	52	No	X	X	935	30	0



1 Standardizing antagonist cusps.



2 Alabama wear testing device.

specimens were layered and fired according to the manufacturer's instructions. Their surface was then ground flat with 400 grit paper on a polishing wheel and finished with a fine diamond rotary instrument (30 micron red stripe; Brasseler, Savannah, Ga). All specimens were airborne-particle abraded with 50 µm alumina at 0.21 MPa and cleaned in an ultrasonic bath. The Ceramco3 overglaze was mixed to a creamy consistency, painted onto the surface, and fired according to the parameters in Table I. An enamel group was also included as a control for which an approval was obtained from the University of Alabama at Birmingham (UAB) Institutional Review Board. Nearly flat specimens were obtained from the labial surface of freshly extracted human central incisors. The incisors were cleaned in an ultrasonic bath and polished with pumice. The ceramic blocks and control teeth were mounted into brass holders with acrylic resin. Parallelism between the specimens and the surface of the brass holders was maintained during mounting.

Surface Roughness Measurement

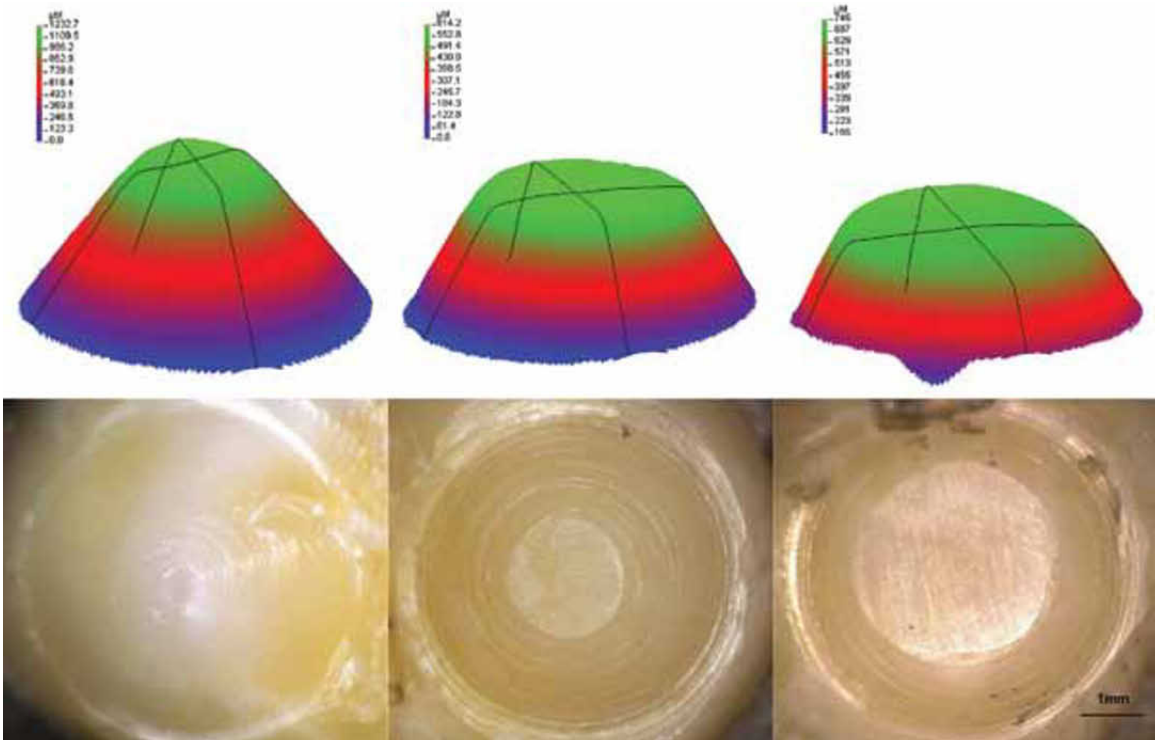
The pretest surface roughness (Ra) of all the specimens was determined (ISO 4288)[35] with an S16/3.5 sensor of a 3D optical profilometer (Proscan 2000; Scantron Industrial Products Ltd, Taunton, UK). As the surfaces of the specimens were assumed to be homogenous, an area in the middle of each specimen was selected for testing. A 0.7-µm length was measured with a 0.8-mm cutoff length and a 40 surface filter number selected for Group PZ and with a 2.5-mm cutoff length and a 125 surface filter number selected for Groups GZ, PGZ, VP, and E.

Wear Testing and Measurement

Prepared, standardized enamel cusps were used as antagonists in this study. Caries-free mandibular molars were obtained from the UAB School of Dentistry. Their mesiobuccal cusps were isolated by using a polishing wheel. A diamond rotary instrument (Sintered diamond part# 5014006OU; Brasseler, Savannah, Ga) with an internal cone (∅=0.36 mm) was used to standardize the enamel cusps (Fig. 1). The instrument produced an area on the tip of the cusps, which was uncut. The cusps were cleaned with pumice and mounted on a steel stylus with acrylic resin.

Wear testing was performed in the University of Alabama wear testing device (Fig. 2). In this device, a vertical force of 10 N is applied by the enamel antagonist. After the weighted antagonists were cycled onto the flat specimens, a synchronized platform moved 2 mm horizontally. After sliding 2 mm, the load was removed, the platform returned to its original position, and the cycle repeated. The test was performed at a frequency of 20 cycles/min and continued for 400 000 cycles. A 33% glycerine (Sigma Aldrich, St Louis, Mo) and 66% distilled water solution was continuously cycled through the device over the specimens.

Impressions of the enamel styli were made with vinyl polysiloxane light-body impression material (Im-



3 Scans and micrographs of antagonists (left to right: baseline, 200 000 and 400 000 cycles).

print 3 Light Body; 3M ESPE, Seefeld, Germany) at baseline, 200 000, and 400 000 cycles. These impressions were cast with low-expansion die stone (Silky-Rock; Whip Mix Corporation, Louisville, Ky) with a W/P ratio of 23 mL/100 g, spatulated for 20 seconds, and vacuum-mixed under 91 kPa for 30 to 40 seconds. The impressions were poured at an ambient temperature of 23 ±2°C and humidity of 34 ±1%, and casts were stored at a controlled temperature (37°C) and humidity until scanning.

To determine antagonist enamel and ceramic wear, 3D scans of the stone casts, ceramic blocks, and enamel surfaces were obtained after 200 000 and 400 000 cycles with a noncontact surface profilometer (Proscan 2000; Scantron Industrial Products Ltd) (Fig. 3). The scans were performed with a resolution of 20 μm × 20 μm. The 2 profilometer scans of each cusp tip (baseline 200 000 cycles and 400 000 cycles) were superimposed (ProForm Software; Scantron Industrial Products Ltd) and aligned to measure the volumetric loss of enamel (frame size = 2 mm × 2 mm). A similar procedure was used to determine the ceramic wear by superimposing the 3D scans of the ceramics against a flat reference surface. After testing, representative ceramic and antagonist specimens were examined with light microscopy (VHX-600; Keyence Co, Osaka, Japan)

A 2-way analysis of variance (ANOVA) (α=.05) for material and number of cycles was used to determine significant differences and interactions within the volumetric wear data. Individual 1-way ANOVAs (α=.05) and Tukey Honestly Significant Difference (HSD) tests were performed at each cycle time to determine significant differences and pairwise comparisons among material group means. A 1-way ANOVA (α=.05) and Tukey HSD tests were performed for the roughness data.

RESULTS

The mean and standard deviation surface roughness (Ra) of the specimens is listed in Table II. The 1-way ANOVA demonstrated significant differences between the Ra values of the different substrates (df=4, F=65.09, *P*<.001). The Tukey HSD test analysis divided materials into the following 3 categories according to roughness: polished zirconia had the least rough surface (0.17 ±0.07 μm); both polished then reglazed zirconia (0.69 ±0.1 μm) and glazed zirconia (0.76 ±0.12 μm) had intermediate roughness values; both the veneering porcelain (1.6 ±0.16 μm) and enamel (2.6 ±1.1 μm) control groups had significantly higher Ra values than the zirconia groups.

The mean and standard deviation volumetric wear of the ceramic and enamel specimens is listed in Table II. The 2-way ANOVA showed significant differences among materials (*P*<.001) and number of cycles (*P*<.001) and a significant interaction between the 2 variables (*P*=.002) (Table III). The 1-way ANOVAs demonstrated significant differences among the wear values of the different materials (*P*<.001) at both cycle times. The Tukey analysis divided materials into the following groups: (1) Polished zirconia showed no signs of wear after 200 000 or 400 000 cycles. (2) Enamel and polished then reglazed zirconia showed statistically similar amounts of wear, with 0.24 ±0.08 mm^3 and 0.27 ±0.06

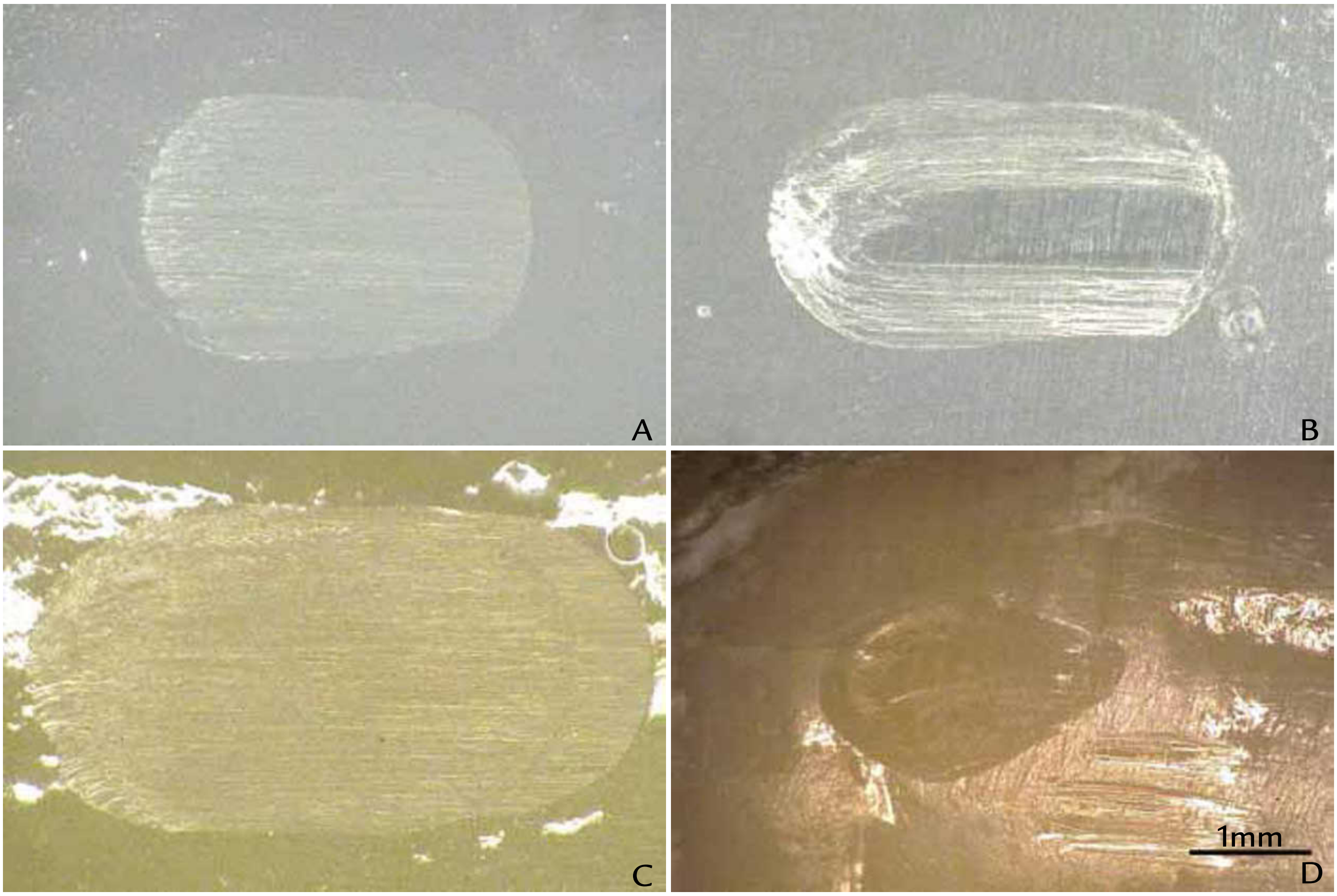
Table II. Volumetric wear of substrates and antagonists and roughness of substrates

		Volumetric Wear of Ceramic Substrates		Volumetric Wear of Enamel Antagonists	
	Ra of substrates (μm)	Wear at 200 000 cycles (mm^3)	Wear at 400 000 cycles (mm^3)	Wear at 200 000 cycles (mm^3)	Wear at 400 000 cycles (mm^3)
Polished zirconia	0.17 ±0.07^{A}	0.17 ±0.07^{A}	0.00 ±0.00^{A}	0.11 ±0.04^{A}	0.21 ±0.05^{A}
Glazed zirconia	0.76 ±0.12^{B}	0.76 ±0.12^{B}	0.62 ±0.16^{C}	0.87 ±0.21^{C,D}	1.18 ±0.20^{C,D}
Polished then reglazed zirconia	0.69 ±0.1^{B}	0.69 ±0.1^{B}	0.49 ±0.10^{B,C}	0.59 ±0.10^{C}	0.88 ±0.12^{C}
Veneering porcelain	1.60 ±0.16^{C}	1.60 ±0.16^{C}	0.42 ±0.11^{D}	1.46 ±0.50^{D}	2.15 ±0.50^{D}
Enamel	2.60 ±1.10^{C}	2.60 ±1.10^{C}	1.29 ±0.10^{B}	0.29 ±0.21^{B}	0.49 ±0.20^{B}

Similar superscripted letters represent statistically similar groups in each column

Table III. 2-way ANOVA table for wear of ceramic and enamel substrates

	df Effect	MS Effect	*df* Error	MS Error	F	*P*
Material	3	4498	28	115	39	<.001
Number of cycles	1	4241	28	19	228	<.001
Material × Cycles	2	123	28	19	6.6	.016



4 Wear tracks from ceramic and enamel surfaces. A, glazed. B, polished then reglazed. C, veneering porcelain. D, enamel.

Table IV. 2-way ANOVA table for wear of enamel antagonists

	df Effect	MS Effect	*df* Error	MS Error	F	*P*
Material	4	8564	35	162	53	<.001
Number of cycles	1	2387	35	8.5	280	<.001
Material × Cycles	4	16.34	35	8.5	1.9	.129

mm^3 at 200 000 cycles and 0.49 ±0.1 mm^3 and 0.42 ±0.11 mm^3 at 400 000 cycles. (3) Glazed zirconia had more wear than enamel or polished then reglazed zirconia with a mean volume loss of 0.38 ±0.1 mm^3 at 200 000 cycles and it had similar wear to polished then reglazed zirconia but more than enamel with a mean volume loss of 0.62 ±0.16 mm^3 at 400 000 cycles. (4) Veneering porcelain showed the highest volume loss at 0.87 ±0.1 mm^3 at 200 000 cycles and 1.29 ±0.1 mm^3 at 400 000 cycles. Light micrographs of the worn ceramic and enamel substrates are presented in Figure 4.

The mean and standard deviation volumetric wear of the enamel antagonists is listed in Table II. The 2-way ANOVA showed significant differences among materials (*P*<.001) and number of cycles (*P*<.001) and no significant interaction between the 2 variables (*P*=.129) (Table IV). The 1-way ANOVAs demonstrated significant differences among wear values of the different materials (*P*<.001) at both cycle times. The Tukey test divided groups into 4 significantly different categories at both 200 000 cycles and 400 000 cycles. (1) Enamel opposing polished zirconia showed minimal wear with a mean volume loss of 0.11 ±0.04 mm^3 at 200 000 cycles and 0.21 ±0.05 mm^3 after 400 000 cycles. (2) Enamel to enamel showed slightly more wear than the polished zirconia with a mean volume loss of 0.29 ±0.21 mm^3 and 0.49 ±0.2 mm^3 at 200 000 and 400 000 cycles respectively. (3) Polished then reglazed zirconia and glazed zirconia showed similar wear, with a mean volume loss of 0.59 ±0.1 mm^3 and 0.87 ±0.21 mm^3 respectively at 200 000 cycles and 0.88 ±0.12 mm^3 and 1.18 ±0.2 mm^3 after 400 000 cycles. (4) Veneering ceramic was ranked as producing similar wear as the glazed group but more wear than the glazed then polished group. It produced the highest amount of wear of all the groups, with a mean volume loss of 1.46 ±0.5 mm^3 and 2.15 ±0.5 mm^3 at 200 000 and 400 000 cycles.

DISCUSSION

The results of this study indicated significant differences in the wear of zirconia and opposing enamel with different surface treatments; therefore, the first null hypothesis was rejected. Polished zirconia caused the least amount of enamel wear, glazed zirconia the most, and polished then reglazed zirconia was intermediate. Only polished zirconia caused less wear to enamel than enamel itself, and all treatments produced less wear than veneering porcelain. Polished zirconia had the least amount of wear, and the veneering porcelain demonstrated more wear than all other substrates. Enamel and glazed zirconia groups demonstrated intermediate wear.

The surface roughness (Ra) values of the zirconia specimens were also significantly different, so the second null hypothesis was also rejected. The polished zirconia surfaces were the smoothest, followed by the polished then reglazed and glazed surfaces. The veneering porcelain and enamel surfaces were significantly rougher than all other substrates. Among the ceramic groups, the surface roughness of the substrates appears to be a good predictor of the amount of resulting antagonist wear. Studies of other ceramics have suggested this relationship.[36,37]

All zirconia substrates in this study produced significantly less opposing enamel wear than veneering porcelain despite being more than twice as hard. Other studies have also concluded that ceramic hardness does not correlate with enamel wear.[22,23] Unlike the ductile metal alloys used for cast metal crowns, which show a correlation between hardness and resulting enamel wear, ceramics are brittle and wear of their surface occurs by fracture.[15] Fracture toughness (K_{IC}) is a critical property in ceramic wear, and materials with low fracture toughness are more likely to chip, sharpening the edges of the porcelain and producing abrasive wear particles.[15] The reported fracture toughness of zirconia is 9 to 10 MPa·m$^{0.5}$ and a veneering porcelain (Ceramco3) 0.73 MPa·m$^{0.5}$.[5,38] Therefore, in this study, it is likely that fragments from the veneering porcelain contributed both to the wear of the ceramic itself and the creation of third-body abrasive particles. The rough post-test porcelain surface can be observed in Fig. 4C. This material property helps explain both the relatively high wear of the veneering porcelain and its opposing enamel compared to the zirconia groups.

Polished zirconia demonstrated significantly less wear than glazed zirconia and produced less enamel wear. This phenomenon has been demonstrated in other ceramics.[27-30] Micrographs of the polished zirconia specimens after wear show no signs of surface damage. The initial roughness of glazed zirconia was higher than polished zirconia, and glazed ceramic demonstrates a higher coefficient of friction.[30] During wear testing, the 20 to 50 μm thick glaze layer is worn away.[30] The micrographs of the glazed specimens demonstrated loss of the surface glaze (Fig. 4A). At this point, the underlying surface of the ceramic becomes exposed, and the roughness of this surface is most critical for producing wear.[16] Additionally, worn particles from the glaze may act as third-body abrasives. Therefore, the greater wear of glazed zirconia can be explained by the loss of the soft glazed surface, and the greater wear of opposing enamel is explained by its contact with rough subsurface zirconia and the production of abrasive particles. These findings support clinical observations of the loss of glaze on ceramic crowns within 6 months of function.[31] Polishing then glazing zirconia demonstrated slightly less ceramic wear and enamel antagonist wear than glazing zirconia alone. The micrograph of the polished then reglazed zirconia shows an area where the glaze has been removed and the subsurface polished zirconia is exposed (Fig. 4B). This layer of polished zirconia may limit the progression of zirconia and enamel wear.

A recent study by Preis et al[24] examined the antagonist wear of glazed and polished zirconia and a veneering porcelain. The authors measured the wear of a standardized steatite ball against ceramics and concluded that zirconia is less abrasive than veneering porcelain, similar to the results of the present study. Steatite, however, is both harder and more wear resistant than enamel[39] and is not a perfect replacement for enamel in wear testing. Their study also examined wear against an enamel antagonist, but enamel wear was not quantified because of the assumed variability in measuring enamel cusp wear. The present study was able to quantify enamel wear by standardizing the enamel cusps. Other investigators have reported that standardizing cusps changes their wear properties.[30,40] Unlike previous studies, the cusps in this test were prepared without modifying the enamel on the cusp tips. Therefore, the substrates in this study closely approximate in vivo conditions.

Wear testing was performed in a newly designed Alabama wear testing device (Fig. 2). The modifications to this device included weight-controlled load delivery, incorporation of a 2-mm horizontal slide, and continuously flowing lubrication. The original device applied vertical and horizontal components of wear by pressing a spring-controlled piston onto each specimen and rotating 30 degrees.[32,33] The load delivery was changed to weight control to eliminate the variability of spring-controlled loading. Maximum values of single-tooth forces during mastication have ranged from 20 to 120 N.[41] A load of 10 N was selected for this study; however, force impulses with weight-controlled wear devices have been shown to produce 3 to 4 times the applied load.[34] The 30 degree rotation was replaced with a 2-mm horizontal slide to model the lateral movements of mastication, which have been reported up to 1.46 mm.[42] Channels were added to the lids of the specimen holders through which a lubricant was continuously pumped. The lubricant used in this study was a 33% glycerine (by weight) solution, which simulated stimulated saliva. The continuous flow of the lubricant provided the physiologically relevant function of washing away debris.

The limitations of this study include the relatively low value of the simulated occlusal force and the limited inclusion of physiologic parameters such as temperature and pH cycling. Future studies may examine the wear produced from high forces such as the maximum limits of mastication or forces of parafunction (bruxing). Additionally, physiological variables such as pH and temperature cycling should be examined. For conclusive evidence of the acceptability of anatomically contoured zirconia crowns, controlled clinical trials which measure opposing enamel wear must be conducted.

CONCLUSION

Within the limitations of the study, the use of monolithic anatomically contoured zirconia crowns can provide acceptable opposing tooth wear. Polished zirconia is more wear friendly to opposing enamel than veneering porcelain. Therefore, polished anatomically contoured zirconia restorations can be indicated in high load bearing areas. The surface roughness of the zirconia aided in predicting the wear of the opposing dentition. Highly polished zirconia is more desirable than the glazed zirconia, and if the esthetics demands a glazed restoration, polishing the surface before glazing is advised. Examining for any roughened areas and polishing the crowns before insertion are also beneficial.

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