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RESEARCH AND EDUCATION

Effect of different dental ceramic systems on the wear of human enamel: An in vitro study

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ABSTRACT

Statement of problem. The wear of tooth structure opposing different advanced dental ceramic systems requires investigation.

Purpose. The purpose of this in vitro study was to compare the wear of advanced ceramic systems against human enamel antagonists.

Material and methods. Four ceramic systems (IPS e.max Press, IPS e.max CAD, Noritake Super Porcelain EX-3, and LAVA Plus Zirconia) and 1 control group containing human enamel specimens were used in this study (n = 12). All specimens were fabricated as disks 11 mm in diameter and 3 mm thick. The mesiopalatal cusps of the maxillary third molars were prepared to serve as the enamel styluses. All specimens were embedded individually in 25 mm^3 autopolymerizing acrylic resin blocks. Wear was measured with a cyclic loading machine and a newly designed wear simulator. All enamel styluses (cusps) were scanned using the Activity 880 digital scanner (SmartOptics). Data from the base line and follow-up scans were collected and compared with Qualify 2012 3-dimensional (3D) and 2D digital inspection software (Geomagic), which aligned the models and detected the geometric changes and the wear caused by the antagonist specimen. One-way ANOVA was used to analyze the collected data.

Results. After 125 000 bidirectional loading cycles, the mean loss of opposing enamel volume for the enamel disks in the control group was 37.08 μm^3, the lowest mean value for IPS e.max Press system was 39.75 μm^3; 40.58 μm^3 for IPS e.max CAD; 45.08 μm^3 for Noritake Super Porcelain EX-3 system; and 48.66 μm^3 for the Lava Plus Zirconia system. No statically significant differences were found among the groups in opposing enamel volume loss (P=.225) or opposing enamel height loss (P=.149). In terms of opposing enamel height loss, Lava Plus Zirconia system showed the lowest mean value of 27.5 μm. The mean value for the IPS e.max CAD system was 27.91 μm; 29.08 μm for the control enamel; 33.25 μm for the IPS e.max Press system; and 34.75 μm for the Noritake Super Porcelain EX-3 system.

Conclusions. Within the limitations of this in vitro study, no differences were found in the linear and volumetric reduction of enamel cusps abraded against enamel disks and all other ceramic specimens. All ceramic systems exhibited high durability and were wear-friendly to opposing enamel. (J Prosthet Dent 2016;115:230-237)

The search for tooth-colored restorations with high strength, enhanced marginal integrity, and improved esthetics in the posterior region of the mouth has led to dental ceramics with improved physical and mechanical properties.[1-7] Ideally, loads placed on the occlusal surfaces of teeth should be kept at a level commensurate with normal physiologic wear and aging.[8] Compared with the mean annual occlusal wear of human tooth enamel (15-38 μm),[9] dental ceramics are considered wear-resistant and tend to damage the opposing enamel, the damage varies according to the ceramic material used.[9-12] The results of several studies have indicated that ceramic materials cause more wear on opposing enamel tooth structure than on cast gold alloy.[13-16] Variations in ceramic composition, microstructure, and fusing temperatures did

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Clinical Implications

Antagonistic enamel wear against the studied ceramic materials exhibited wear rates within the range of normal enamel, although the in vitro model cannot simulate the oral environment with all its biologic variables.

not correlate well with enamel wear.[8,17] However, a significant difference in the amount of opposing enamel wear has been found among different types of restoration.[18–20]

Results of a clinical trial of lithium disilicate glass ceramic restorations showed that they were wear resistant and wear friendly to the opposing enamel in a manner similar to that of the feldspathic ceramics typically used for veneering metal ceramic or ceramic crowns.[21] Conversely, glazing of heat-pressed crowns before insertion has resulted in a significantly lower volume loss when compared with the mean volume loss of enamel after 1 year of clinical performance.[22]

Zirconia holds a unique place among oxide ceramics and is available for fabricating different types of restorations in combination with computer-aided design/computer-aided manufacturing (CAD/CAM) techniques.[23–26] Long-term clinical studies suggest that its performance is equivalent to that of metal ceramic crowns,[27] in spite of a recent in vivo study that showed the opposite.[28] When monolithic translucent and shaded experimental zirconia specimens were examined, they yielded superior wear behavior and lower antagonistic wear compared with monolithic lithium disilicate, veneering porcelain, or enamel specimens.[20,29,30] An in vitro study reported that monolithic zirconia produced similar enamel wear to conventional feldspathic porcelain.[31] Park et al[32] reported significantly less wear of the antagonistic tooth against different CAD/CAM anatomic contour zirconia ceramics than the veneering ceramic. Polished monolithic zirconia showed significantly lower wear on enamel antagonists than that produced by glazed monolithic specimens.[20,31–33] More interestingly, polished zirconia specimens that were glazed by using a glaze spray showed less enamel wear than airborne-particle abraded zirconia that was glazed using a layering technique with glaze ceramic.[33] Staining and glazing the zirconia substructure caused more antagonistic tooth wear than polishing.[32]

The vertical force impulses evoked in the molar region are 20 to 30 N, and horizontal mastication forces have been measured to be approximately 35% of the vertical ones. The sliding movement was found to be 0.8 mm with a sliding speed of 40 mm/s and a complete masticatory cycle frequency of 1.6 Hz.[14]

A 2-body wear contact of bidirectional back-and-forth sliding movements in which a stylus runs against a flat surface with no lifting of the stylus has been shown to build up more homogenous forces and avoid the uncontrolled force impulses seen in configurations that involve lifting the specimens.[34–38] However, a review of previous data showed a large variation in relation to wear test method qualification, applied force, lateral movement, number and frequency of cycles, number of specimens, and selected materials and techniques.[34–48]

The purpose of this in vitro study was to investigate the wear of advanced ceramic systems against human enamel antagonists in a newly designed wear simulating device (TA-317C multiple sample vertical friction wear device) developed by one of the authors (R.Z.). The null hypothesis was that no difference would be found in the resulting wear of specimen or antagonist materials when IPS e.max Press, IPS e.max CAD, Noritake Super Porcelain EX-3, LAVA Plus Zirconia, or enamel disks were worn against enamel styluses (cusps).

MATERIAL AND METHODS

The study included 5 groups (n=12): IPS e.max Press (EP), IPS e.max CAD (EC), Noritake Super Porcelain EX-3 (SP), LAVA Plus Zirconia (LPZ), and enamel (E). EP specimens (Ivoclar Vivadent Inc) were fabricated with low-translucency lithium disilicate provided in the form of pressable ingots by processing in the dental laboratory with the lost-wax technique. Specimens were prepared by contouring the soft wax (ABF-wax; Metalor Dental Inc) into disks 11 mm in diameter and 3 mm in thickness according to the manufacturer's instruction. All wax specimens were attached to wax sprues (Lincoln Dental Supply Inc) and invested (IPS Press VEST investment material; Ivoclar Vivadent Inc). The reaction layers formed on the disks during the press procedure were removed in an ultrasonic bath (IPS e.max Press Invex Liquid; Ivoclar Vivadent Inc). Sprues were removed with fine diamond disks (no. 2751; Dedeco Intl, Inc) in a laboratory using a micromotor unit at a speed of up to 20 000 rpm (Ultimate XL; NSK Nakanishi Inc) to prevent overheating and chipping of the disks.

To assure surface smoothness and parallelism before the wear tests, all specimens were finished with an applied force of 66.7 N at a speed of 350 rpm for 2 minutes with different grits of silicon carbide grinding paper (120, 240, 320, 600 grit; Buehler) and Ecomet 250 (Buehler) under running water. The specimens were then cleaned for 1 minute with a steam jet (11706; Triton SLA) and glazed according to the manufacturers' specifications.

In the EC group (Ivoclar Vivadent Inc), the low-translucency lithium disilicate that is provided in the form of CAD/CAM blocks was designed and milled into

Table 1. Wear test parameters

Test Parameter	Value
Sliding movement	0.8 mm
Sliding speed	40 mm/s
Abrasive load per specimen	13.5 N
Cycle frequency	2.5 Hz (150 cycles/min)
Number of cycles	125000
Contact duration	0.04 s
Dwell time	0.35 s

rods measuring 11 mm in diameter and 17 mm in length with an E4D processor (D4D). The rods in their crystalline intermediate block stage were then cut with a precision saw (Isomet 1000; Buehler) into 11×3 mm-diameter disks. Specimens were finished and glazed in a similar manner to those of the EP group. In the SP group, feldspathic porcelain disks were fabricated with Super Porcelain EX-3 (Noritake Dental Supply, Co) by placing the porcelain mix into a stainless steel mold (11×3 mm). After the initial setting was achieved, the disks were carefully removed from the mold and fired in a furnace (Programat P300/G2; Ivoclar Vivadent Inc), finished as with the previous groups, and glazed according to the manufacturer's specifications. For the LPZ group, disks were monolithic yttrium-stabilized zirconium oxide (Y-TZP; Lava Plus; 3M ESPE), which were fabricated in the requested diameter (11×3 mm) by the manufacturer under supervision of 1 of the authors (R.E.), finished as the previous groups, and glazed according to the manufacturer's specifications.

Ceramic disks from all groups were adjusted to simulate clinical usage. The disks were held in a metal block with double-sided mounting square stickers (Scotch Magic 810; 3M Co) in a minilathe (Unimat 3; Emco). A high-speed handpiece with a fine diamond rotary instrument (4380U0; Brasseler) was held parallel to the disk surfaces and mounted to the lathe feed table. A single stroke in a single direction was applied to the glazed surfaces of the disks under cooling water. The lathe feed table was then turned 180 degrees to adjust the other halves of the disks. A new rotary instrument was used for each set of 6 disks. For repolishing, a slow-speed handpiece with a lithium disilicate polishing rotary instrument (W17DM; Brasseler) was held parallel to the disk surfaces and mounted to the lathe feed table. Four strokes in a single direction were applied to repolish the adjusted disk surfaces. A new rotary instrument was used each time.

Extracted intact human mandibular third molars were collected from the oral surgery department at Tufts University School of Dental Medicine. Institutional review board approval of the protocol was not necessary for the use of the human-derived specimens. The largest teeth with flatter lingual surface were selected, cleaned (Cavitron GEN-119; Dentsply Intl) to remove saliva and debris, and placed in 0.05 % thymol and distilled water at room temperature over a period of 2 weeks. Enamel disks were prepared (11×3 mm) from the lingual surfaces of the teeth by using a slow- speed hand-piece and trephine bur (no. 04-9485-01; ACE Surgical Supply Inc) to serve as the control group. The outmost surfaces of these enamel disks were then ground with 2500 grade wet/dry silicon carbide paper (Buehler) and polished (with 6 μm followed by 1-μm diamond suspension) to obtain flat surface enamel specimens. Enamel stylus specimens were prepared by cutting the mesiopalatal cusp of the maxillary third molars under water with a saw (Isomet 1000 Precision; Buehler).

Figure 1. TAXTPlus texture analyzer with TA-317C multiple sample vertical friction wear device in plastic container filled with artificial saliva, which was fixed to feed table of cyclic loading machine. Movable upper arm of device with metallic weight rods carried enamel styluses, while fixed lower arm carried ceramic and enamel disk specimens.

All specimens were then embedded individually in 25mm^3 autopolymerizing acrylic resin blocks (Caulk Orthodontic Resin; Dentsply Intl) by using a silicone mold (President Putty; Coltène/Whaledent Inc) that ensured the precise horizontal alignment of the external surfaces of the disks, leaving the top 2 mm of each disk uncovered with resin. Specimens were then randomly assigned to groups (www.random.org). A cyclic loading machine (TAXTPlus texture analyzer; Texture Technologies Corp) and a newly designed wear device (TA-317C multiple sample vertical friction wear device) were used for wear simulation, which allowed the testing of 5 specimens simultaneously with but independently of the parameters shown in Table 1. The parameters were determined based on previously published criteria and the manufacturer's standards.[34–36] In order to generate

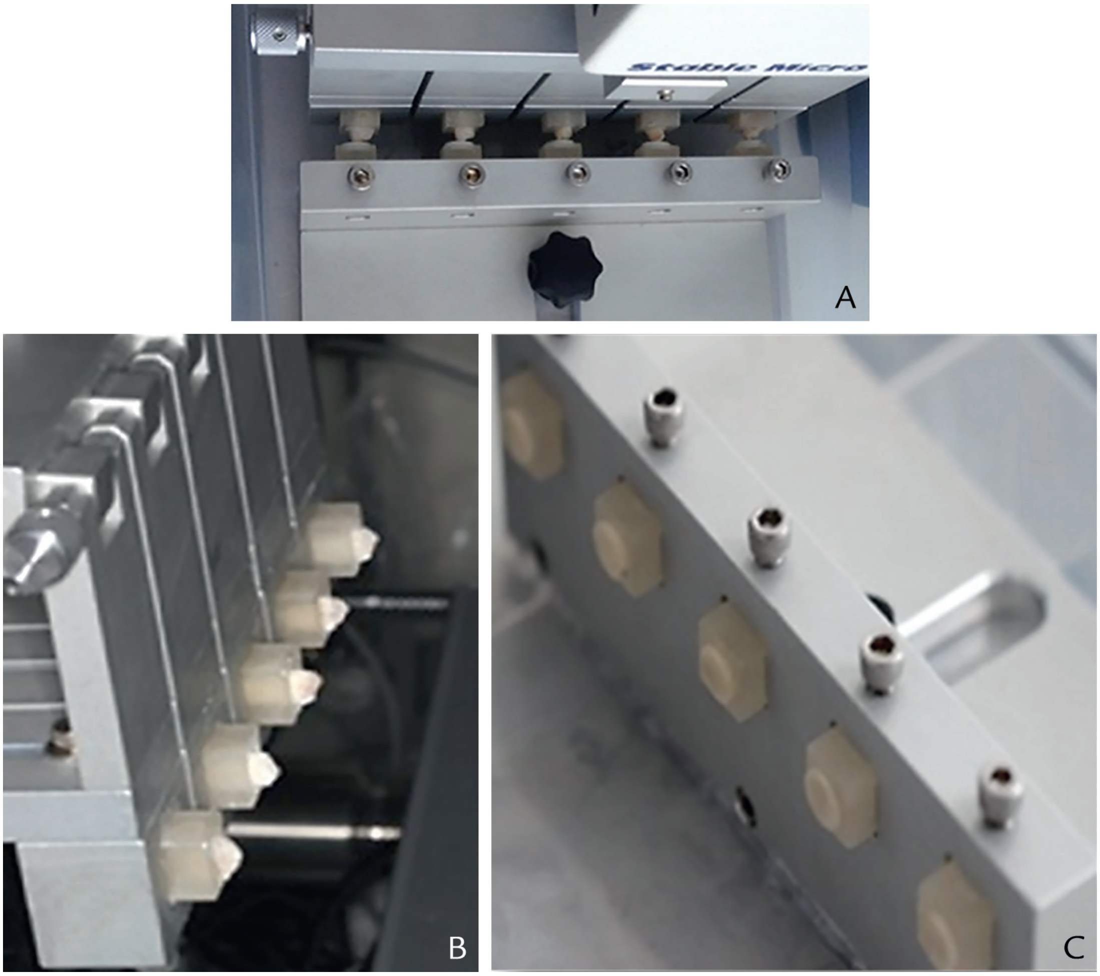

Figure 2. A, TA-317C multiple specimen vertical friction wear device. B, Mounted enamel stylus specimens on upper arm. C, Mounted ceramic and enamel disks specimens on lower arm.

clinically relevant circumstances, the forces exerted by the electromechanical actuator were controlled and regulated by connecting the activator to a computer during all movements of the device parts.

The TAXTPlus texture analyzer is normally calibrated 2 ways, both of which were done at the laboratory before the tests were conducted. However, the use of the TAXTPlus texture analyzer did not rely on the load cell to either measure a force or apply a force. The instrument was also not used in a way that necessitated knowledge or logging of the absolute or relative position of the mounted fixtures to the height of the base. The instrument was used to stroke up and down 0.8 mm at 40 mm/second (Table 1) and to carry the TA-317C multiple sample vertical friction wear device. This device held a set of static weights in a 'normal force' position. The weights were translated to consistent lateral "applied forces" because of the shape of the fixture and the rotational pivot of the device arm along the swing pin.

The applied force (13.5 N) was a function of the static weights that were mounted on the fixture. The TAXTPlus texture analyzer had a stepper motor that made discrete 1-μm steps. During the test sequence, it moved 800 steps (0.8 mm) in each direction for 125 000 cycles (total of 250 000), which is equivalent to 1 year of clinical wear in the occlusal contact area.[49]

The ceramic and control enamel specimens were fixed on the lower base of the device, while the upper arms carried the antagonist enamel stylus specimens. A plastic container (Sterilite) was fixed to the feed table of the cyclic loading machine and filled with artificial saliva that covered the surfaces of the specimens (Fig. 1). The debris from the test chamber was cleaned every other set of cycles with a tooth brush and a manual suction pump.

The procedure was run in the form of 2-body contact of bidirectional back-and-forth sliding movements in which a stylus ran against a flat surface with no lifting of the stylus (Fig. 2). All enamel styluses and mesiopalatal cusps were scanned with a 3-dimensional (3D) digital scanner (Activity 880 digital scanner; Smart Optics Sensortechnik GmbH). The scanner performed an automatic calibration, which was repeated every time the specimens

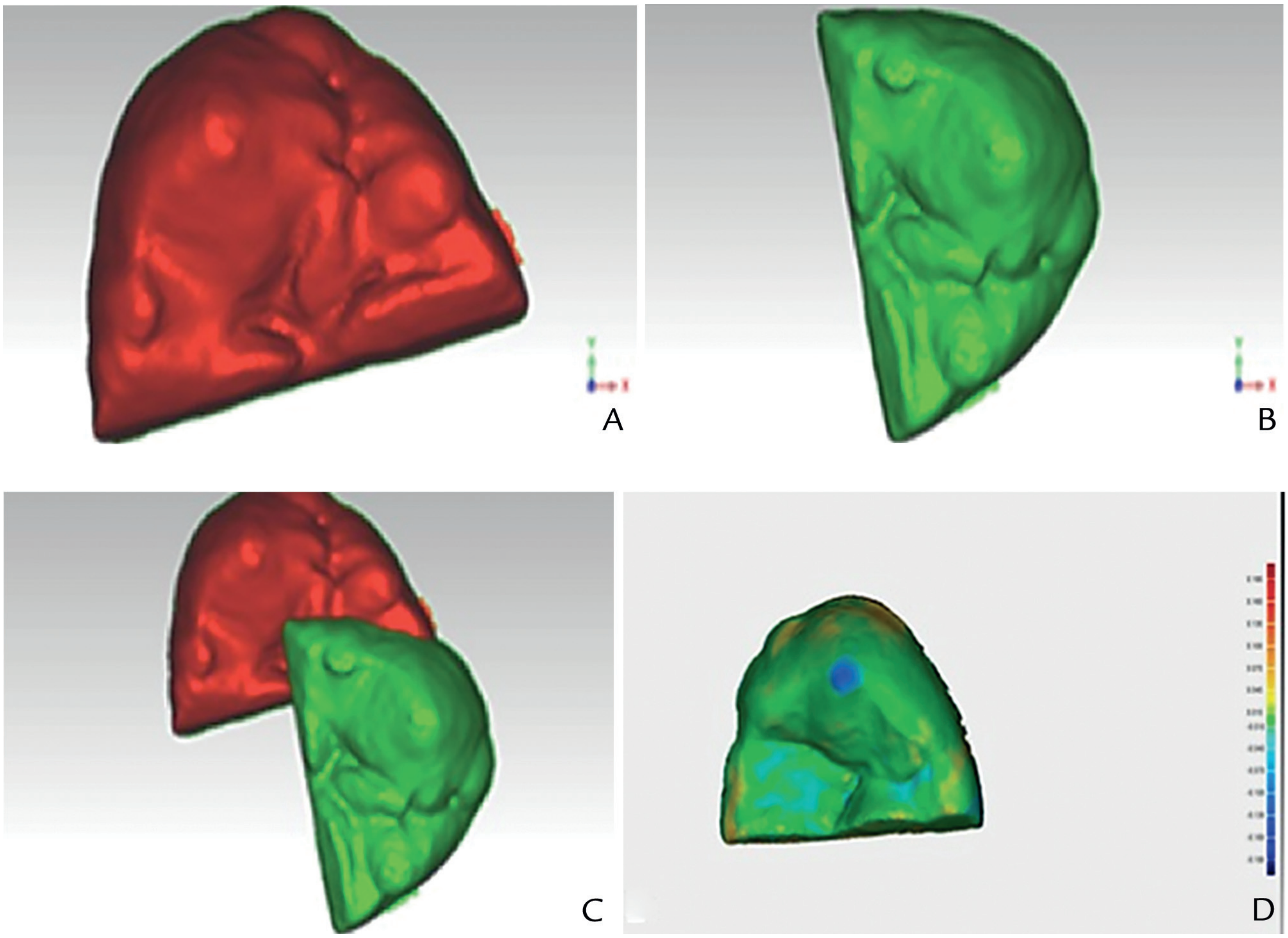

Figure 3. A, Baseline scan. B, Follow-up scan. C, Aligning scanned cusps with Qualify 2012 3D digital inspection software, which generated color-mapped models of each enamel cusp to detect geometric changes. D, 3D cusp comparison to detect volume loss of enamel cusp (stylus).

were scanned. The manufacture claims the accuracy of the scanner to be ±20 μm. The specimens were not powdered as recommended by the manufacturer.

Data from the base line and follow-up scans were collected, superimposed by the software and compared with 3D digital inspection software (Qualify 2012; Geomagic Inc). This software generated color-mapped models of each enamel cusp and then aligned the models to detect the geometric changes that illustrate the wear caused by the antagonist specimen (Fig. 3). Using the same software, the linear reduction of the enamel cusps was also detected by aligning the profiles of the cusps' scans and comparing those 2 dimensionally (Fig. 4). A data report indicating the enamel volume and height loss in μm was then created for each experimental specimen. One investigator (R.E.) performed all testing.

A power calculation was conducted using software (Advisor version 7.0; nQuery). Assuming an effect size of Δ^2 = 0.485 (the effect size that was observed in a pilot study using 3 specimens per group), a sample size of 12 (n = 12) per group was adequate to obtain a type I error rate of 5% and a power greater than 99%.

Descriptive statistics (means, SDs, minima, and maxima) were calculated. One-way analysis of variance (ANOVA) was used to assess statistical significance. All analyses were conducted by using software (SPSS Statistics for Windows, v19.0; IBM Corp) (α=.05).

RESULTS

Descriptive statistics are shown in Tables 2 and 3, and data are side-by-side box plots in Figures 5 and 6. The mean volume loss of opposing enamel for enamel disks of the control group was 37.08 μm^3, which was the lowest mean value among the groups; IPS e.max Press system was 39.75 μm^3; IPS e.max CAD was 40.58 μm^3; Noritake Super Porcelain EX-3 system was 45.08 μm^3; and the Lava Plus Zirconia system was 48.66 μm^3 (Table 2).

In terms of opposing enamel height loss, the Lava Plus Zirconia system showed the lowest mean value of 27.5 μm. The mean value for the IPS e.max CAD system was 27.91 μm, 29.08 μm for the control enamel, 33.25 μm for the IPS e.max Press system, and 34.75 μm for the

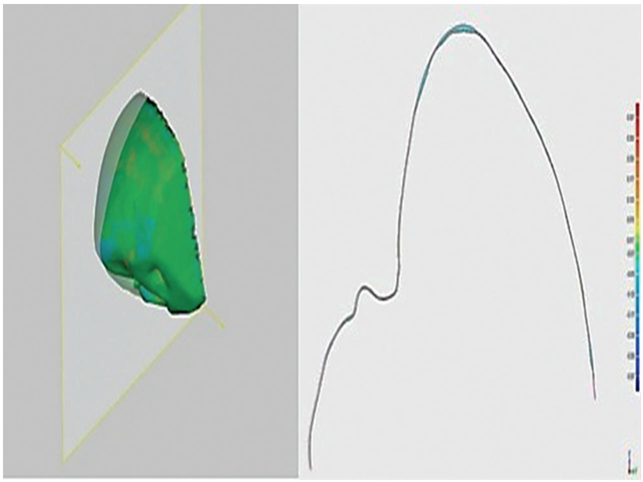

Figure 4. 2D Cusp alignment and comparison with 3D digital inspection software Qualify 2012 to detect linear reduction of enamel cusp (stylus).

Noritake Super Porcelain system (Table 3). This study showed no statically significant differences among the groups in opposing enamel volume loss (*P*=.225, F value=1.5, *df*=4 and 55) and height loss (*P*=.149, F value=1.8, *df*=4 and 55).

DISCUSSION

Results of the present study demonstrated no statistically significant differences among the groups in opposing enamel volume and height loss; therefore, data supported the null hypothesis. Even though data from randomized control clinical trials with a validated method for wear quantification are rare, in vivo studies have shown that ceramic materials are wear resistant[10,16] and they may damage the opposing enamel.[34–37] However, clinical wear measurements in general are complicated, expensive, and time-consuming and can result in relatively high standard deviations due to the biological spread between the studied individuals in terms of dietary habits, dysfunctional occlusion, occlusal force, and bruxism.[21]

The results of previous in vitro studies, in which a specific material and the antagonist wear of the human enamel were examined, have been inconsistent, mainly because the test parameters differed widely.[20–25,29,33–37] Most studies used flat polished ceramics and prepared enamel specimens from extracted molars as their antagonists, with test chambers filled with water and integrated sliding movements in the wear generating processes. However, large variations have been noted in relation to force actuators, applied forces, numbers of cycles, frequencies of cycles per test, and numbers of specimens.[41,43,48] Therefore, laboratory data may not be verified directly with clinical data, which could also be a limiting factor in the present study.

Table 2. Descriptive statistics for volume loss

Group	n	Mean Volume Loss (μm^3)	±SD	Minimum	Maximum
EP	12	39.75	7.33	29	55
EC	12	40.58	13.26	25	72
SP	12	45.08	16.64	23	82
LPZ	12	48.66	14.85	31	81
E	12	37.08	11.88	16	56
Total	60	42.23	13.38	16	82

E, enamel; EC, IPS e.max CAD; EP, IPS e.max Press; LPZ, LAVA Plus Zirconia; SP, Noritake super porcelain EX-3.
P=.225; F value = 1.5; *df* = 4 and 55; Levene significance = 0.21.

Table 3. Descriptive statistics for height loss

Group	n	Mean Height Loss (μm)	±SD	Minimum	Maximum
EP	12	33.25	8.2	18	44
EC	12	27.91	6.8	18	44
SP	12	34.75	13.2	21	63
LPZ	12	27.50	7.4	17	41
E	12	29.08	4.6	20	36
Total	60	30.50	8.8	17	63

E, enamel; EC, IPS e.max CAD; EP, IPS e.max Press; LPZ, LAVA Plus Zirconia; SP, Noritake super porcelain EX-3.
P=.149; F value = 1.8; *df* = 4 and 55; Levene significance = .06.

The findings of the current study showed no significant difference between the evaluated materials and the control enamel group, which is in agreement with the findings of Amer et al[31] and incompatible with some of the previous studies.[10,11,19,28,30,40–42] This study also demonstrated that the use of monolithic zirconia does not cause significant enamel wear and is within the range of normal enamel as found in other studies.[28,30,31] However, some researchers have reported less wear depth to human enamel with monolithic zirconia compared with glass ceramic and feldspathic porcelain.[28,30]

In this study, the all ceramic disks were fabricated following the respective manufacturers' recommendations and then adjusted using a high-speed handpiece with a diamond rotary instrument in a manner similar to that used by most clinicians when delivering a restoration. This adjustment, along with the consequent low-speed polishing, have resulted in the removal of the superficial glazing layer from the top of the ceramic disks, which may play a role in decreasing the wear of their opposing cusps.[31,32] Previous studies have shown that a rough external surface is needed for perfect glazing.[43] When the antagonist cusp has worn the glazed top layer, the cusp hits the rough surface of the ceramic layer, resulting in increased enamel wear.[31,33,44]

Wear increases with the increasing number of cycles.[24] However, in vitro wear test methods demonstrate an even linear pattern with a steep increase in wear at the initial phase and a flattening of the curve after.[38] In the present study, the force exerted by the cyclic loading device was not controlled during all movements of the

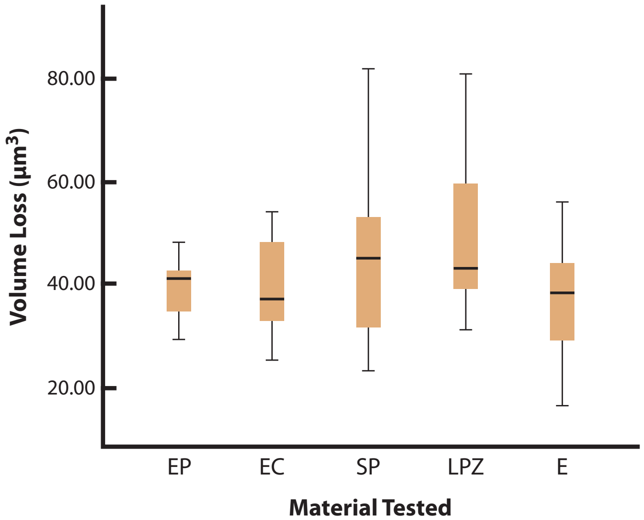

Figure 5. Box plots of enamel volume loss opposing ceramic and enamel disk specimens. EP, IPS e.max Press; EC, IPS e.max CAD; SP, Noritake super porcelain EX-3; LPZ, LAVA Plus Zirconia; E, enamel.

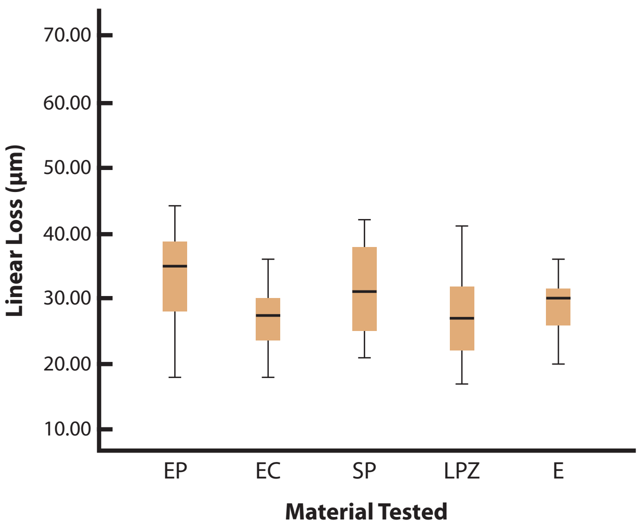

Figure 6. Box plots of enamel height loss opposing ceramic and enamel disk specimens. EP, IPS e.max Press; EC, IPS e.max CAD; SP, Noritake super porcelain EX-3; LPZ, LAVA Plus Zirconia; E, enamel.

stylus. The force applied by each stylus on its opposing disk was only measured once before the test was run, which could be considered a limitation of the study. In this study, specimens were not exposed to thermocycling or constant temperature. Heat application has been shown to be effective on composite resin materials in some studies, and somewhat insignificant in others.[45-47] Further studies are needed to assess this factor on ceramic systems.

In terms of biological spread, this study did not divide the extracted human teeth based on the patient's age and sex. Such factors have been proven to be influencing variables on the wear process of human tooth structure.[47] However, the cusps of extracted teeth were randomly assigned to the study groups, which could have minimized the biological variation. Physiologic occlusal masticatory forces were not simulated in this study. However, sliding is an essential component of a wear-testing method, as a material is stressed in terms of microfatigue only. This configuration has been shown to build up more homogenous forces and avoid the uncontrolled force impulses seen in configurations that involve lifting of the stylus.[42]

For higher accuracy, both volumetric (3D) and linear (2D) measurements were performed in this study (Figs. 3, 4). The differences in 2D and 3D rankings of the studied materials could be because 2D comparisons measure only the height loss at selected points on the longitudinal cross section of the cusps, putting the approach in question. In vitro studies could assist researchers in better standardizing the wear-test parameters so that a better correlation with clinical circumstances can be achieved.

CONCLUSIONS

Within the limitations of this in vitro study, it was concluded that there were no statically significant differences in linear and volumetric reduction of natural enamel cusps abraded against natural enamel surfaces and those abraded against evaluated ceramic materials by using a newly designed wear-simulating testing devices and an electro mechanical cyclic loading machine in a chamber filled with artificial saliva. All ceramic systems exhibited high durability and were wear-friendly to opposing natural enamel.

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