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Assessing Enamel Wear of Monolithic Ceramics With Micro-CT and Intra-oral Scanner

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ABSTRACT

Objective: This in vitro study aimed to investigate enamel wear against 3 monolithic ceramics using 2 methods of measurement.
Methods: Three groups of standard flat monolithic ceramic specimens including zirconia-reinforced lithium silicate glass (Vita Suprinity, VITA Zahnfabrik), yttria-stabilised tetragonal zirconia (Lava Esthetic Zirconia), and lithium disilicate glass (IPS e.max Press, Ivoclar Vivadent) were prepared, with human enamel used as the control group. Each specimen was subjected to the 2-body wear test at 49 N for 250,000 cycles. Enamel antagonists were evaluated with micro-computed tomography (CT) and intra-oral scanner, allowing 3-dimensional images of vertical wear and volumetric loss of enamel antagonists to be calculated. One-way analysis of variance followed by Student–Newman–Keuls post hoc tests were used to examine the differences in vertical wear/volumetric loss amongst the groups. Paired t tests and intra-class correlations were used to compare vertical wear/volumetric loss between the micro-CT and intra-oral scanner groups.
Results: No significant difference in vertical wear was found amongst all groups. More volumetric loss was found in all test groups than in the control group ($P < .001$), but no significant difference was found amongst the test groups. There was a moderate positive correlation ($r = 0.535$, $P = .033$) between the vertical wear and volumetric loss. No significant difference between the 2 methods of measurement was found.
Conclusions: Monolithic ceramics induce more enamel wear than natural teeth. Both micro-CT and intra-oral scanners can be used for measuring tooth wear with similar performance.

Introduction

Dental ceramics have been extensively used in restorative dentistry as a material of choice for indirect restorations because they possess excellent aesthetic properties, colour stability, and biocompatibility.[1–3] However, there have been concerns regarding its abrasiveness against natural enamel.[4,5] The nature and mechanisms of wear are complex, as multifactorial processes are influenced by many factors including masticatory forces, contact area, surface texture, material microstructure, and fracture resistance.[6] The vertical wear in the enamel of posterior teeth within normal conditions was estimated to be around 15 to 40 μm per year, and that is accepted as physiologic wear,[7] but when opposed by different materials then the rate of wear might be accelerated.[8] Many in vitro and in vivo studies have shown that conventional feldspathic porcelain can cause iatrogenic wear to the opposing enamel over time, thus leading to exposure of dentine with tooth sensitivity, loss of surface anatomy, and occlusal disharmonies. In order to solve this problem, major advancements in dental ceramics such as the development of lithium disilicate glass and yttria-stabilised tetragonal zirconia have taken place over the last decade.[9,10] Apart from the chemical composition and processing, the finishing method can also affect the wear

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characteristics of dental ceramics. It has been shown that conventional fired feldspathic porcelain restorations are more abrasive than the ones fabricated by the computer-aided design/computer-assisted manufacturing (CAD/CAM) technique.[11–13] In addition, studies have shown that glazing, the conventional finishing method for ceramic restorations, does not always produce a less abrasive ceramic surface when compared with simple polishing.[11,14–17] In fact, many researchers have found that polished zirconia surfaces could produce minimal wear to the antagonist enamel[16,17] and suggested polishing to be the preferred method for finishing CAD/CAM ceramics.[18]

Amongst the modern CAD/CAM ceramics, lithium disilicate glass ceramic (IPS e.max Press, Ivoclar Vivadent) is the most widely used material for indirect restorations with good aesthetic outcome and ability to bond with the underlying tooth structure.[3] However, its mechanical properties might not be ideal when heavy occlusal loading is anticipated. Therefore, a new type of lithium silicate glass ceramics reinforced with zirconium dioxide particles (Vita Suprinity, VITA Zahnfabrik) has been introduced into the market and was claimed to have better mechanical properties.[18,19] On the other hand, although yttria-stabilised zirconia is known to be the strongest ceramic material, its aesthetic properties are far from ideal. In order to improve its translucency and aesthetics, scientists have modified the composition by adding the cubic form of zirconia as well as increasing the yttria content, and 3M Lava Esthetic Zirconia is one of those new forms of zirconia with high translucency.

To date, there are no established standard methods for quantifying in vivo tooth wear. According to a recent systematic review,[20] tooth wear caused by dental materials is virtually assessed by laboratory studies such as 2- or 3-body wear simulation tests[21] and then measured by surface profilometers and laboratory scanners.[11,13,22] With the advent of digital technology, new methods such as micro-computed tomography (CT) and intra-oral scanners are now available for measuring wear. Micro-CT, in addition to its ability to assess the wear quantitatively, can measure the mineral density and thickness of different structures of the tooth specimens, whilst intra-oral scanners have become popular in practice and are able to assess tooth wear at the chairside. Although different variables and parameters of digital methods for measuring tooth wear have been documented,[23,24] no studies directly comparing different digital methods on in vitro enamel wear have been found.

Thus, this study aimed to investigate the antagonistic enamel wear of 3 monolithic ceramics in vitro using a micro-CT and intra-oral scanner. The rationale for performing the study was to assess whether the new generation of CAD/CAM ceramic materials could cause significant wear on the opposing enamel and also whether chairside intra-oral scanners are a good alternative for wear measurements. The null hypothesis was that there would be no significant difference in the antagonistic enamel wear amongst 3 ceramics and human enamel and no significant difference in wear measurement between micro-CT and intra-oral scanner.

Method and materials

Sample size calculation

Volumetric loss of the opposing enamel was chosen as the primary outcome measure in this study. The sample size was calculated using G*power 3.1.9.4[25] to detect a difference of 0.5 (SD = 0.2) mm^3 in volumetric loss with a power of 80% at an α level of 0.05 (2-tailed), indicating that a sample size of 3 was needed.

Specimen preparation

Ethical approval for the study was obtained (Institutional Review Board of Hong Kong Ref Number UW-17–048). Enamel antagonists were prepared from extracted human maxillary premolars, which had been immersed in 0.05% thymol for 24 hours. The antagonists were sectioned along the midline in the vertical plane and then horizontally at a height of 10 mm, retaining the buccal cusp by using a precision linear saw (IsoMet 5000, Buehler) at 3500 rpm under water irrigation. Each antagonist was examined under 2.5× magnification for any obvious cracks, caries, or enamel abnormalities before it was evaluated using micro-CT (Skyscan 1172, Bruker) in the longitudinal midplane to ensure that the enamel thickness (1.0–1.5 mm) and bone mineral density (2.3 ± 0.1 mg/cm^3) are consistent amongst all the antagonists.

Table 1 shows the composition of the 3 ceramics used in the study. All ceramic specimens (n = 4) were prepared in a standard size (8 mm × 10 mm × 5 mm) per manufacturer recommendations. Human enamel specimens were also sectioned into the same size as the control. All specimens were then sequentially polished by a grinder-polisher (EcoMet 250, Buehler) at 66.7 N and 350 rpm for 2 minutes followed by 240-, 320-, and 600-grit silicon carbide papers. The specimens were then subjected to ultrasonic cleaning in deionised water for 1 minute. The enamel specimens were measured by micro-CT to ensure the consistency of enamel thickness (≥1200 μm) and bone mineral density (2.3 ± 0.1 mg/cm^3).

Wear simulation

The test/control specimen (B) was first embedded into a plastic cylindrical holder (A) using epoxy resin with the help of a flat horizontal jig. The buccal cusp of an enamel antagonist (C) was then fixed on another plastic holder (D) using epoxy resin, and that was then mounted against the test/control specimen inside the wear simulator (Figure 1). The wear simulator used had been granted a patent from the USA, UK, Europe, Hong Kong, and China. It consists of 4 chambers to replicate simultaneous wear (sliding) movement for 2-body wear tests. The parameters of the simulator settings were 250,000 cycles, force of 49 N, sliding movement of 1.5 mm, height of 10 mm, and frequency of 1 Hz.[26–28]

Before the tests started, 30% glycerine was added between the test surfaces to act as a lubricant to simulate the saliva in the intra-oral environment. There was 2-body contact of a back-and-forth sliding movement in which the enamel antagonist was moved over the test surface with no lifting of the enamel cusp. A load cycle of 250,000 at 1 Hz under 49 N

Table 1 – Composition of tested monolithic ceramics.

Material	Classification	Composition	Shade	Manufacturer	Lot number
Vita Suprinity	Zirconia-reinforced lithium silicate glass ceramic	Silicon dioxide SiO_2 = 56%–64% Lithium oxide Li_2O = 15%–21% Zirconia ZrO_2 = 8%–10%	A3-High translucency	VITA ZahnfabrikH. Rauter GmbH & Co. KGPostfach 1338 D-79,704 Bad Säckingen	LOT62904
3M Lava Esthetic Zirconia	Zirconia ceramic	Cubic polycrystalline zirconia ZrO_2 with 5 mol% yttria	A3	3M, St Paul, MN 55,144 –1000, USA	LOT649548
IPS e.max Press	Lithium disilicate glass ceramics	SiO_2 = 57%–80% Li_2O = 11%–19%, K_2O = 0%–13% P_2O_5 = 0%–11% ZrO_2 = 0%–8% ZnO = 0%–8%	Multi A3 Medium translucency	Ivoclar Vivadent AG, Schaan, Liechtenstein	LOTVL1764

force with the sliding movement of 1.5 mm was set. Debris from the test area was cleaned every 50,000 cycles using a soft-bristled toothbrush under suction.

Surface roughness and wear measurement

Before and after the wear simulation, surface roughness (Ra) of the specimens was measured by a calibrated profilometer (Surtronic 3+, Taylor-Hobson; ± 0.02 μm) using a stylus tip with a radius of 5.0 μm. Three random areas on each specimen were measured and the mean value of each group was calculated.

Vertical wear (mm) and volumetric loss (mm^3) of the enamel antagonists were measured before and after the wear test using the following 2 methods (Figure 2):

1. Each specimen was mounted and scanned in a fixed and reproducible position in a micro-CT (Skyscan 1172) with the power set at 80 kVp, the current set at 112 μA, and an exposure time of 370 ms. The acquired images before and after the wear simulation were superimposed for the following measurements. For vertical wear, each horizontal slice was a 13-μm increment and measurements were taken from the tip of the tooth to the enamel dentinal junction. The volumetric measurement was calculated by CTAn version 1.16.1.0 and CTvol Realistic 3D-Visualization version 2.3.2.0.
2. Each specimen was scanned by a calibrated intra-oral scanner (3M True Definition scanner) according to the manufacturer’s guidelines. The data were saved into the stereolithography format. The images were superimposed. Vertical wear and the volumetric measurements were taken using the default imaging software (Materialise Magics 19.01).

Data analysis

Data were analysed with statistical analysis computer software (SPSS 25.0, IBM). Normality and homogeneity of variance were checked by Kolmogorov–Smirnov test and modified Levene test, respectively. One-way analysis of variance (ANOVA) was

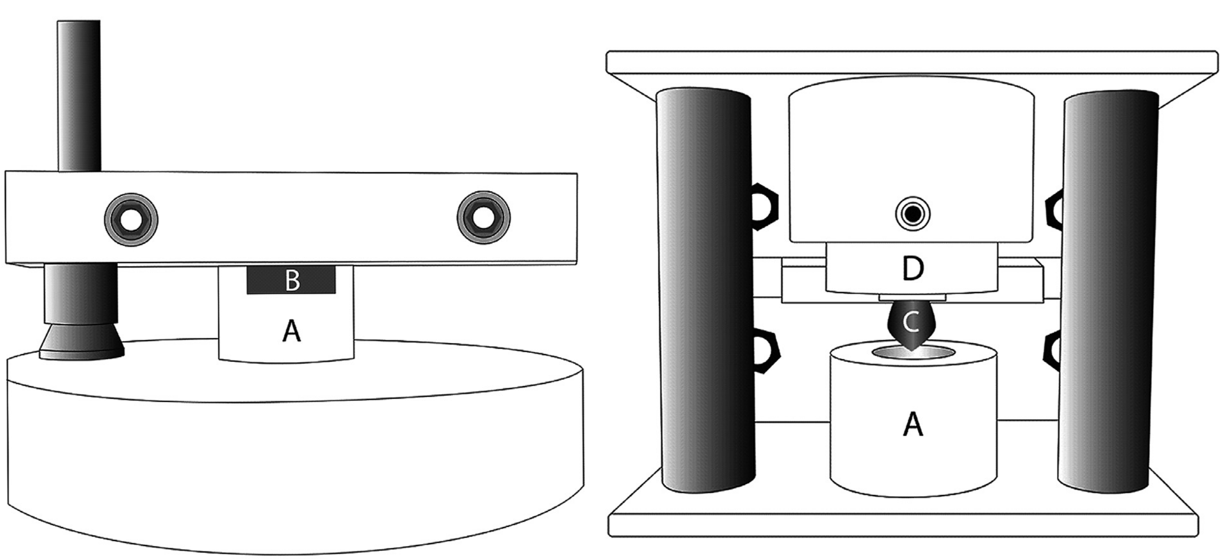

Fig. 1 – Placement of ceramic specimen (B) into a plastic holder (A) using a horizontal jig. Mounting of the specimen holder (A) against a tooth cusp (C) embedded in another holder (D).

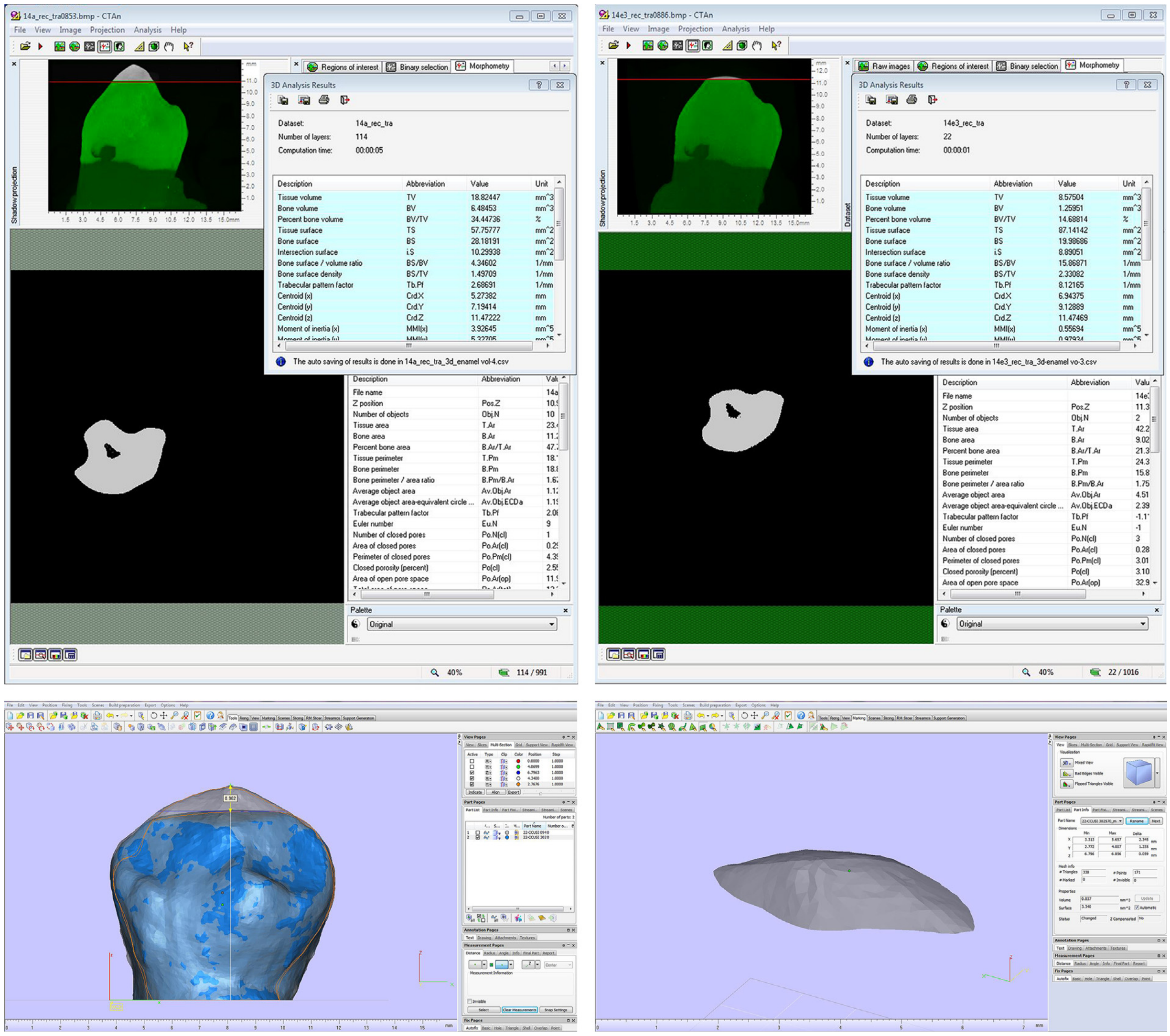

Fig. 2 – Micro-computed tomography image before (upper left) and after wear simulation (upper right). Superimposed 3-dimensional images of intra-oral scanner before and after wear simulations (lower left), Amount of enamel lost after image subtraction (lower right).

used to examine the differences in vertical wear/volumetric loss amongst the 4 groups. Post hoc multiple comparisons using Student–Newman–Keuls tests were performed with Bonferroni adjustments. Paired t tests were used to compare the micro-CT and intra-oral scanner data. The level of agreement between the 2 methods was assessed by the intraclass correlation coefficient (ICC). The level of significance was set at .05.

Results

The surface roughness data showed that no significant differences was found amongst all groups before and after the wear simulation. Results of the vertical wear and volumetric loss of enamel antagonists are shown in Tables 2 and 3, respectively. Regarding vertical wear, no significant differences were found

Table 2 – Vertical wear (mm) of enamel antagonist by group.

Specimen	Micro-CT Mean (SD)	Intra-oral scanner Mean (SD)	Diff.	P value*
Human enamel	1.074 (0.005)	1.060 (0.043)	−0.014	.590
Vita Suprinity	1.093 (0.083)	1.095 (0.108)	0.002	.966
Lava Esthetic Zirconia	1.113 (0.084)	1.158 (0.031)	0.045	.483
IPS e.max Press	1.085 (0.017)	1.056 (0.007)	−0.029	.071
P value†	.826	.115		

* Paired t test.
† One-way analysis of variance.CT, computed tomography.

Table 3 – Volumetric loss (mm^3) of enamel antagonist by group.

Specimen	Micro-CT Mean (SD)	Intra-oral scanner Mean (SD)	Diff.	P value*
Human enamel	4.240^a (0.115)	4.108^a (0.043)	−0.133	.082
Vita Suprinity	5.043^b (0.100)	4.658^b (0.354)	−0.385	.137
Lava Esthetic Zirconia	5.025^b (0.098)	4.985^b (0.257)	−0.040	.774
IPS e.max Press	4.915^b (0.115)	4.593^b (0.229)	−0.323	.053
P value†	<.001	.003		

* Paired *t* test.
† One-way analysis of variance ($P < .05$). Values in the same column that have different superscript letters differ significantly from each other.CT, computed tomography.

amongst all 4 groups. On the other hand, a significant difference in volumetric loss was found amongst the 4 groups ($P < .001$). The volumetric loss of the 3 ceramics was significantly higher than the control group. However, there were no significant differences amongst the 3 ceramics ($P > .05$, 1-way ANOVA with Student–Newman–Keuls post hoc test). There was a moderate positive correlation (Pearson correlation $r = .535$; $P = .033$) between the vertical wear and volumetric loss. Comparing the data taken by the micro-CT and intra-oral scanner, there was no significant difference in both measured vertical wear and volumetric loss in all the groups. The ICC was 0.659 for vertical wear and 0.787 for volumetric loss.

Discussion

Although no significant differences in vertical wear were found amongst all 4 groups and between the 2 methods of wear measurement, a significant difference in the primary outcome, that is, volumetric loss, was found. Therefore, the null hypothesis was partially rejected. Wear, being a complex process, is determined by many physical, chemical, and biological factors. Amongst all the mechanical properties of restorative material, it was believed that surface hardness was one of the determining factors for enamel wear. However, other studies showed that fracture toughness, internal porosities, and surface defects might play a more important role.[5] Because the mechanical properties of tested ceramics are stronger than that of enamel, more volumetric loss of enamel than in the control group is expected. In the present study, volumetric loss was chosen as the primary outcome for a few reasons. Compared with vertical wear, volumetric loss measured the total loss of tooth substances in 3 dimensions. It is also a more sensitive parameter, and hence a smaller sample size was needed to detect any differences. It could also explain why no significant difference in vertical wear was found.

Comparing the 3 tested ceramics, it is not surprising to see no significant difference in enamel wear between the Vita Suprinity and IPS e.max Press, which are both lithium disilicate–based glass ceramics with similar chemical composition and mechanical properties. However, although the Lava Esthetic Zirconia ceramic is a polycrystalline material with intrinsically higher hardness and fracture toughness than the lithium disilicates, its enamel wear is not significantly greater. The finding could probably be due to the similar surface roughness amongst all tested ceramics and enamel before and after the wear simulation, and this phenomenon is in line with other similar studies.[14,18,20] Unlike previous generations of ceramics on which the surface roughness increases over time, which exacerbates the antagonistic enamel wear, the surface roughness of the 3 tested ceramics was maintained after the wear simulation. That could partly be explained by the well-controlled manufacturing process which results in highly homogenous ceramic ingots/blocks with minimal internal porosities. The overall findings from our study are supported by other researchers who found that those ceramic materials had a similar rate of enamel wear.[29–32] Regarding the clinical implications, dentists should notice that the tested modern CAD/CAM ceramics do wear the opposing teeth over time, and that should be taken into account when long-term ceramic indirect restorations/prostheses are being planned.

It should be stressed that all in vitro wear simulation methods vary greatly in terms of the experimental setup and setting of wear parameters; hence, it is difficult not only to compare the results across different studies but also to translate the results to the clinical situation. Therefore, there is a great need to standardise the wear simulation methods and parameters such as 2-body or 3-body wear, the size/dimensions of the specimens, surface finish, antagonist and control group selection, amount of force, and number of cycles.[26,27] For example, the thickness of enamel and the bone mineral density of the antagonists could greatly affect the wear results. Therefore, in the present study, all tooth specimens were screened to ensure that the enamel was thick enough (>1.2 mm) with consistent bone mineral density (2.3 ± 0.1 mg/cm^3). Although the wear simulator used in this study has not been validated, all the parameters chosen are closely matched with similar studies.[12,13] Also, apart from the wear measurement methods, the outcome variables for measuring the wear should be standardised.[28] Surface profilometry, scanning microscopy, laser scanning, or digital imaging have been used in different studies. In the present study, the 2 new methods—micro-CT and intra-oral scanner—were tested. Although the mechanism and technology used by the 2 methods are different, their results are comparable. In addition, the ICCs (0.659 for vertical wear, 0.787 for volumetric loss) showed a moderate level of agreement.[33] Our results are in agreement with a similar study that also showed a quantitative agreement between depth and volume measurements by intraoral scanning and micro-CT methodologies[34] and that implies that both methods could be used for measuring tooth wear. However, it should be noted that micro-CT has been shown as a reliable method for measuring not only wear but also enamel thickness and mineral content, which could not be achieved by most intra-oral scanners.[35] On the other hand, intra-oral scanners are becoming popular and available in clinical practice, and that facilitates monitoring of tooth wear longitudinally.[36] Recent development in intra-oral scanners could also be able to detect certain demineralisation of tooth structure using fluorescent technology, and that requires more exploration for wear measurement.[34] Regarding the outcome variables, some of the studies measured the vertical wear and then calculated the volumetric loss indirectly. Our study measured both the vertical wear and volumetric loss of tooth enamel. The 2 parameters were chosen because, whilst volumetric loss can provide information on overall loss of enamel, vertical wear is more clinically relevant, which affects the vertical dimension of occlusion and occlusal stability.

To the best of our knowledge, this is the first study to evaluate the mineral content and thickness of the enamel antagonist, thus confirming the wear within the enamel. Previous studies potentially fall short on the possible nonhomogeneity of the enamel specimens. Along with measuring in vitro the vertical wear and volumetric loss independently and by 2 methods of measurement, our study allows for further work looking at the wear of various other materials[37] against enamel and opposing each other and also variations within the type of wear, such as an erosive component. One limitation of this study was that an assumption was made that the wear was flat in nature and measurements were made in that plane. The study also looked at a limited choice of materials in that it was specific to monolithic ceramics and also the surface finish was polished. Finally, although the sample size used is greater than the estimated one, it is still considered small. Further studies on other ceramics and possible veneering ceramics, and also different surface finishing procedures, could be performed.

Conclusions

Within the limitations of this in vitro study, no significant differences in vertical antagonistic enamel wear amongst the 3 monolithic ceramics and the control group were found. Significantly more volumetric antagonistic enamel loss was found in all 3 ceramic groups than in the control group, but no significant differences were found amongst the 3 monolithic ceramics. There was a moderate positive correlation between vertical wear and volumetric loss. No significant difference was found between the 2 methods of measurement.

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Conflict of interest

None disclosed.

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