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Randomized clinical study of wear of enamel antagonists against polished monolithic zirconia crowns

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Abstract

Objectives—To test the hypothesis that there is no difference in the *in vivo* maximum wear of enamel opposing monolithic zirconia crowns, enamel opposing porcelain fused to metal crowns and enamel opposing enamel.

Methods—Thirty patients needing single crowns were randomized to receive either a monolithic zirconia or metal-ceramic crown. Two non-restored opposing teeth in the same quadrants were identified to serve as enamel controls. After cementation, quadrants were scanned for baseline data. Polyvinylsiloxane impressions were obtained and poured in white stone. Patients were recalled at six-months and one-year for re-impression. Stone models were scanned using a tabletop laserscanner to determine maximum wear. Statistical analysis was performed using Mann-Whitney U to determine any significant differences between the wear of enamel against zirconia and metal-ceramic crowns.

Results—Sixteen zirconia and 14 metal-ceramic crowns were delivered. There were no statistical differences in mean wear of crown types ($p = 0.165$); enamel antagonists ($p = 0.235$) and enamel controls ($p = 0.843$) after one year.

Conclusion—Monolithic zirconia exhibited comparable wear of enamel compared with metal-ceramic crowns and control enamel after one year.

Significance—This study is clinically significant because the use of polished monolithic zirconia demonstrated comparable wear of opposing enamel to metal-ceramic and enamel antagonists.

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Conflict of interests

There are no conflicts of interest associated with this research project.

Keywords

Monolithic zirconia; Wear of enamel; Laserscanner

1. Introduction

Zirconia became popular in dentistry because of this material's excellent mechanical properties [1], which include high strength, fracture toughness [2–4], and biocompatibility [5,6]. Zirconia was mainly used as a substructure for ceramic-ceramic restorations and required veneering ceramics to obtain proper esthetics because of their high opacity. In general, these ceramic-ceramic restorations exhibited superior esthetic properties compared with their metal-ceramic counterparts [7–9].

Despite the excellent physical properties of zirconia, veneer chipping has been identified as a major cause of failure. A systematic analysis of zirconia-based FDPs shows a survival rate of 94.3% [10]. However, when technical complications such as chipping of the veneer ceramic are included, their survival decreases to 76.4% [10]. Heintze [11] performed a systematic review to analyze the survival of zirconia (90%) and metal (97%) supported FDPs after three years. He concluded that veneer chipping was a major cause of failure. The mean long-term survival rate of zirconia frameworks at 10 years is 91.5% [12] with failures attributed to marginal deficiencies and veneer chipping.

To overcome veneer chipping, dental manufacturers developed monolithic zirconia prostheses, which rely on the toughness and strength of the material to eliminate the need for the fracture-susceptible veneering ceramic. Veneer fractures in ceramic-ceramic restorations are believed to be the result of differences in the thermal expansion coefficients of the core ceramic and veneer ceramic and nonuniformity of condensation during ceramic build-up [13].

One major concern with the use of monolithic zirconia as a restorative material is the abrasive nature against opposing enamel because of this material's hardness and surface roughness [14–19]. Several *in vitro* and *in vivo* studies were conducted to determine the wear of enamel against zirconia. Numerous *in vitro* studies showing wear of zirconia against different antagonists, including enamel, have shown zirconia to be comparable to other restorative materials in terms of wear of opposing enamel [17,20–24]. However, *in vitro* studies are hard to compare with each other because of differences in surface finish of material, type of material, method of wear and type of wear analysis used. The limited clinical studies which have been published describe how monolithic zirconia is a viable restorative material in that the wear of antagonist enamel is within the range of acceptable limits [25–28]. However, since there is a limited number of clinical studies available, there is need for more clinical analyses to further validate the wear compatibility of zirconia with enamel.

The purpose of this study was to test the hypothesis that there is no difference in the *in vivo* maximum wear of enamel opposing monolithic zirconia crowns, enamel opposing porcelain fused to metal crowns and enamel opposing enamel.

2. Materials and methods

2.1. Study design

A randomized, controlled, clinical trial was designed to analyze the wear of enamel by opposing polished monolithic zirconia crowns and by the polished veneer surfaces of metal-ceramic crowns. This single-blind pilot study involved a total of 30 teeth that required full coverage crowns that opposed natural antagonist teeth.

2.2. Study intervention

2.2.1. Participant recruitment—Participants that needed full coverage crowns were randomly assigned to receive either a polished (nonglazed) zirconia crown (Lava™ Plus, 3M ESPE, PZ), or a polished (nonglazed) veneer of metal-ceramic crown (GC Initial™, GC America; Argedent 62, Argen, USA, PV). All participants were over 21 years old with no contraindications to dental treatment. These participants were screened for low caries risk, the absence of periodontal disease and no temporomandibular disorders. Each participant needed a crown on either a first or second premolar or first or second molar in any arch. Inclusion criteria for abutment teeth included: [1] restorability with a crown:root ratio of at least 1:1; [2] presence of an opposing natural tooth which was non-restored or minimally restored; [3] the presence of two non-restored or minimally restored teeth opposing each other on the same quadrants as the crowned tooth and the opposing to serve as enamel controls. Minimally restored was defined as teeth which have no restoration greater than a Class II amalgam restoration. The opposing arch did not have a full coverage restoration or a partial denture. Two crowns were the maximum number of crowns for each participant. A random number table was formulated by the statistician to facilitate assignment of teeth to either material group. The clinical coordinator assigned to the study enrolled the participants and assigned them to the material groups. Patients were treated at the University of Florida College of Dentistry Dental Clinical Research Unit. Institutional Review Board approval for treating human subjects using the research protocol was obtained. All participants were required to sign an informed consent form prior to initiating the study.

2.2.2. Crown fabrication—One investigator prepared all the teeth to receive crowns based on design criteria for crown preparation. Provisional material (Protemp™ Plus, 3 M ESPE) was used to fabricate provisionals. Prepared teeth were scanned using a chairside oral scanner (3M True Definition™ Chairside Oral Scanner Digital Impression System, 3M, ESPE). Scans were sent to one laboratory for crown fabrication.

Crowns were received from the laboratory with a polished surface. All crowns were polished using porcelain polishers impregnated with diamond abrasives (Shofu Dura Polish Dia, Shofu Dental Corporation). Try-in and adjustment, if necessary, of each crown were made with a fine diamond bur (8369DF.31.025 FG Fine Football Dialite Diamond, Brassler, USA) on a high-speed handpiece. Crowns were polished with diamond impregnated porcelain polishers in the order of coarse, medium, and fine points (Dialite, Brassler, USA) until a fine lustre was achieved. All crowns were cemented with a resin cement (Rely X™ Unicem Self-Adhesive Resin Cement, 3M ESPE). Participants were not made aware of the type of crown they received.

A baseline examination was performed one week after cementation to ensure that the patient was comfortable with the crown and no further adjustments were needed. When no further adjustments were necessary, teeth were cleaned to remove plaque and saliva. A vinylpolysiloxane impression (Imprint 3, 3M ESPE) was made of the maxillary and mandibular quadrants, where the crown and the opposing tooth are located, to record the occlusal surfaces of each cemented crown and its antagonist tooth. These are the same quadrants where the enamel controls are also located. Photographs of the quadrants were made with occlusal contacts marked by articulating paper (Accufilm®II double sided articulating film, Parkell Prod Inc). The red paper was used to indicate maximum intercuspation while the black paper was used to indicate contacts in excursive movements. The post-cementation casts were poured with a white gypsum material (GC Fujirock, GC America) to enable optimal scanned image contrast. The participants were asked to return at 6 months and one year. Quadrants were re-impressed during both time periods.

2.2.3. Wear quantification—The maximum wear was quantified as the maximum loss in height. A 3D Laserscanner (CS2, Straumann, Germany) was used to scan the casts at baseline, six months and one year along the x, y and z axes of the casts. These period scans were superimposed against one another using tripodization by identifying three points on the occlusal anatomy which are expected to remain stable (*i.e.* marginal ridges). The matching of the two scans was conducted by the software to achieve a match with a standard deviation (SD) less than 25 μm. The scanning accuracy for this type of scanner is reported to be 20 μm [29,30]. The matching process was repeated until an acceptable SD was achieved. After proper matching was achieved between the period scans, the maximum wear of the crowns and teeth at these time periods were compared and recorded. The wear areas were compared with the clinical photographs to confirm intra-oral contact areas.

2.3. Statistical analysis

All analyses were performed using the R statistical software package (V3.2.4, The R Foundation for Statistical Computing, Vienna, Austria). Since the sample size was small ($N < 15$ per group for all comparisons), the non-parametric Mann-Whitney *U* test was used to compare wear between the zirconia and metal-ceramic crown types at six months and one year. To compare antagonist wear to control wear between the two groups, the difference between antagonist wear and control wear as the outcome for each patient was calculated. The mean wear of the two control teeth was used as the control wear for that patient.

3. Results

Thirty [30] teeth in 25 enrolled participants (20 females, 5 males and no more than two crowns per participant), were included in this study and were seen from 2013 to 2017. There were 16 monolithic zirconia crowns (PZ) and 14 metal-ceramic crowns (PV) analyzed. The consort diagram (Fig. 1) shows a more detailed distribution of the participants. Wear between the monolithic zirconia and metal-ceramic crowns were compared at six months and one year (Fig. 2). There were no significant differences observed at any time point (6 months $p = 0.958$; 1 year $p = 0.367$). The wear of the enamel opposing both types of crowns was also compared to determine if one material wore the opposing enamel more than the other (Fig. 3). There were no significant differences observed for antagonist enamel wear across all time periods (6 months p = 0.776; 1 year p = 0.534). The opposing enamel wear was then compared to the wear between two opposing enamel surfaces (control wear) to determine if either material caused an increase in opposing enamel wear. This was computed for by the difference between antagonist wear and control wear for each participant. The mean between the two controls were subtracted from the antagonist enamel wear of the crowns. In Fig. 4, negative numbers indicate more control wear than antagonist wear and positive values indicate more antagonist tooth wear. The p values are 6 months p = 0.864 and 1 year p = 0.093 indicating no significant difference between the control enamel wear and the antagonist enamel wear. Greater opposing enamel wear was observed for the metal ceramic than the zirconia crown for the first six months. This trend changed for the first-year data with an increase in wear for the enamel opposing zirconia crowns. Fig. 5a and b are representative images retrieved from the laserscanner for wear comparison at one year. Fig. 5b shows the crowned tooth on the lower left second molar, the left first molar is serving as the enamel control. The left most image is the baseline image while the middle image is the one year image. The right most image is the superimposed image of the two scans and red marks indicate differences between the two images or possibly wear. In this superimposed image, the red marks are located in peripheral areas which are not indicative of wear because the teeth do not contact in those areas. Fig. 5a shows the antagonist teeth to the crown and the control. The superimposed image shows more distinct red marks which are possible areas of wear (arrows). No wear facets are visible on any of these scans.

4. Discussion

Wear is a complicated phenomenon to measure. As a result of veneer chipping associated with zirconia substrates, dental manufacturers are marketing monolithic zirconia restorations for full coverage restorations. This has brought about wide concern of excessive enamel wear opposing this hard and possibly abrasive dental material. However, as of 2015, there have only been *in vitro* studies analyzing the wear of enamel against zirconia antagonists. The problem with *in vitro* wear analysis is wear machines cannot replicate complex masticatory movements. Chewing patterns vary between individuals and are dependent on multiple factors such as muscle tone, joint dyscrasia, oral health, etc. [31]. There is a need for long-term clinical studies to determine the wear potential of a dental material.

To date, there are five clinical studies which examined the wear potential of monolithic zirconia against different antagonists, including this current study (Table 1) [25–27]. This table compares all clinical studies in terms of the different variables employed in each. For surface finish of zirconia, all clinical studies, except one, utilized a polished surface. The preference for the surface finish was, at least for this study, based on literature findings. *In vitro* studies have shown that polished zirconia produces less wear on enamel antagonists than glazed zirconia [14–17,22]. Kim et al. [17] reported that polished zirconia showed less enamel wear than feldspathic porcelain and heat-pressed ceramics. In addition, the rate of enamel wear was dependent on the surface roughness of the zirconia. Jung et al. [18] reported that polished zirconia showed less enamel wear than feldspathic porcelain and polished zirconia with glazing. Park et al. [23] concluded that polished zirconia showed the least volume loss of enamel while the stained and glazed zirconia showed the highest volume loss. These studies indicate that polished zirconia full coverage crowns, without glazing, cause less wear the antagonist enamel. In addition, the glazed zirconia surface has been shown to have significant wear after 6 months [18,23,32]. Contrasting studies reveal that zirconia against enamel causes more wear compared with zirconia against gold or against zirconia [24]. *In vitro* wear analysis of zirconia revealed that zirconia demonstrated less wear compared with lithium disilicate ceramic [33]. Enamel wear for both these types of ceramics was comparable with the enamel-enamel wear observed. Further, glazed zirconia causes more material loss on the surface. These two occurrences can be explained by the fact that a polished zirconia surface produces a quantifiably smoother surface than the glazed zirconia, therefore proving to be less abrasive to the opposing enamel. Rougher surfaces have been correlated with increased wear of the opposing dentition [34]. The increased material loss is explained by the glaze layer wearing away from the surface, leaving a rougher surface, which perpetuates greater antagonist enamel wear.

All the clinical studies utilized an indirect method for measuring wear which required making an impression of the teeth and developing a replica either in acrylic or gypsum. These replicas were then compared using either a 3D non-contact profilometer or a 3D laserscanner. As a result of the two-step process involved with creating a replica, there can be inherent errors in the data which can produce inconsistencies or inaccuracies [35]. The setting expansion for the stone used for this study was 0.12%, and the linear dimensional change for the impression used was 1.5%. Additionally, the accuracy for the scanners/ profilometer used were in the range of 5 µm–20 µm This can account for slight differences in wear values measured (Table 1).

Lambrechts, et al. [36], documented normal clinical enamel to enamel wear per year for molars (38 µm, 28 µm for steady state) and premolars (18 µm,15 µm for steady state). The authors describe that wear is critical during the first year where there is initial increased wear [36]. This wear then plateaus into a steady state where equilibrium is reached. However, this can vary depending on the patient’s occlusal condition, diet, quantity and quality of saliva, and the presence of parafunctional habits. This is the reason for incorporating an enamel-enamel control that is patient specific where the enamel antagonist wear for each material can be compared with the enamel-enamel wear within the same conditions. Three [26,27], including this study, out of the five studies employed enamel-enamel controls. For enamel versus enamel in patients with zirconia crowns, the enamel wear values are: 26.2 µm [27], 95 µm [26] and 61.6 µm for this study, However, there are differences among the three studies in that the time period is different with Stober’s [26] study at 2 years and the others at 1-year analysis and that the higher valued studies all report maximum wear whereas Munde’s [27] study reported mean wear.

A comparison of enamel wear against zirconia among the 1-year studies shows Munde at 84.5 µm, Cardelli [28] at 76 µm and the current study at 70.3 µm. These values are all comparable with each other. However, compared with Munde’s enamel-enamel control (26.2 µm) for the same patients, the enamel wear against zirconia is higher. There was no enamel-enamel control for Cardelli’s study. For this current study the enamel control was 61.6 µm which is comparable to the enamel-zirconia wear. For the studies reporting 2-year wear, the antagonist enamel wear reported for Lohbauer [25] was 204 µm and Stober was 151 µm.

While these values by themselves seem comparable, Lohbauer's conclusion that zirconia is enamel friendly is hard to validate because the study is missing enamel-enamel controls. In Stober's study, they state that the wear of enamel vs. zirconia is greater than that compared with enamel vs. enamel (95 µm) for the same patient.

For the current study and Mundhe's study, metal-ceramic crowns were used as a second control. They reported an average enamel wear of 124 µm (for molars and premolars) opposing metal-ceramic crowns while our study demonstrated wear of antagonist enamel to metal-ceramic at 68 µm after one year. For Munde's study, the enamel vs. metal-ceramic wear was reported to be higher than zirconia *vs.* enamel wear (84.5 µm) or the enamel-enamel (26.2 µm) wear while for our study the enamel-enamel wear at 86.4 µm was comparable.

In general, the consensus among the studies, despite the differences in wear values, is that zirconia holds promise as a dental restorative material. The differences can be attributed to lack of enamel controls as well as to the inherent errors produced in creating replicas for measuring wear.

The phenomenon of transformation toughening occurs with Y-TZP ceramics when a reverse tetragonal to monoclinic transformation occurs within the crystalline phases. This is considered beneficial in that the material can actually "heal" itself. When tensile stresses are generated at the tip of a crack, the reverse tetragonal to monoclinic transformation occurs. This phase change at the tip of the crack is accompanied by volumetric expansion and subsequent compressive stresses around the crack tip. This volumetric expansion can result in partial closure of the crack and prevent its propagation through the entire structure [37]. Another phenomenon known as low-temperature degradation (LTD) induces tetragonal to monoclinic transformation at the surface of the specimen in the presence of moisture at 250 °C [38]. This can cause loss of strength and adverse effects on other mechanical properties such as roughening of the surface. Although this has not been shown to occur in vitro [37], long-term clinical studies need to be conducted to determine the effect LTD may have on the surface of these polished zirconia surfaces.

5. Conclusion

The results of this study demonstrate that polished monolithic zirconia does not cause accelerated wear of the opposing enamel. The wear of both metal-ceramic and monolithic zirconia is comparable and that there are no significant differences between the enamel antagonist wear and control enamel wear of the two materials. This is clinically significant because polished monolithic zirconia holds promise as a versatile restorative material because of this material's high strength and esthetic properties.

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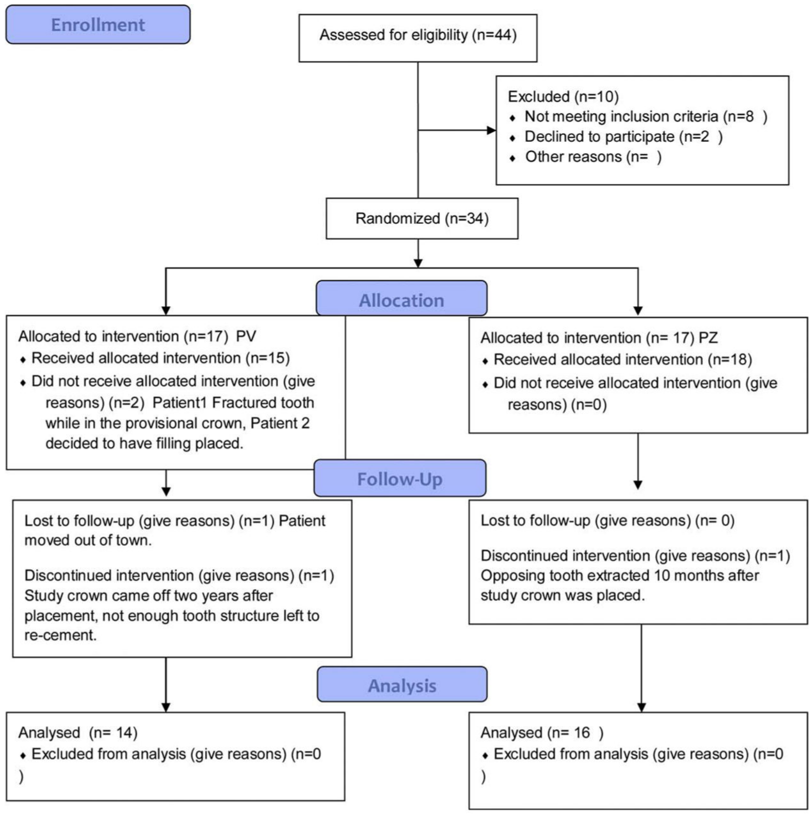

Fig. 1.

Consort diagram showing enrollment, allocation, follow up and analysis of participants.

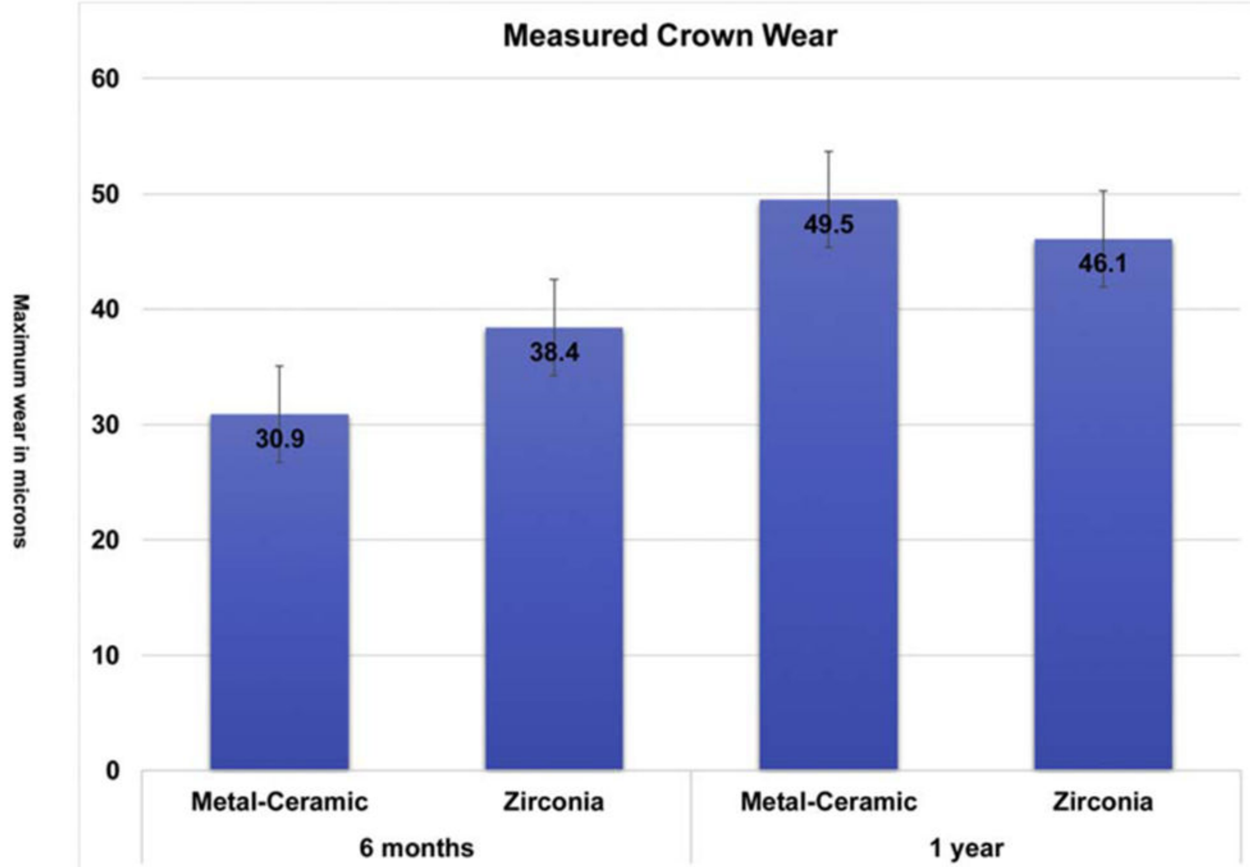

Fig. 2.
Comparison of wear between metal-ceramic (PFM) and monolithic zirconia crowns at 6 months and one year.

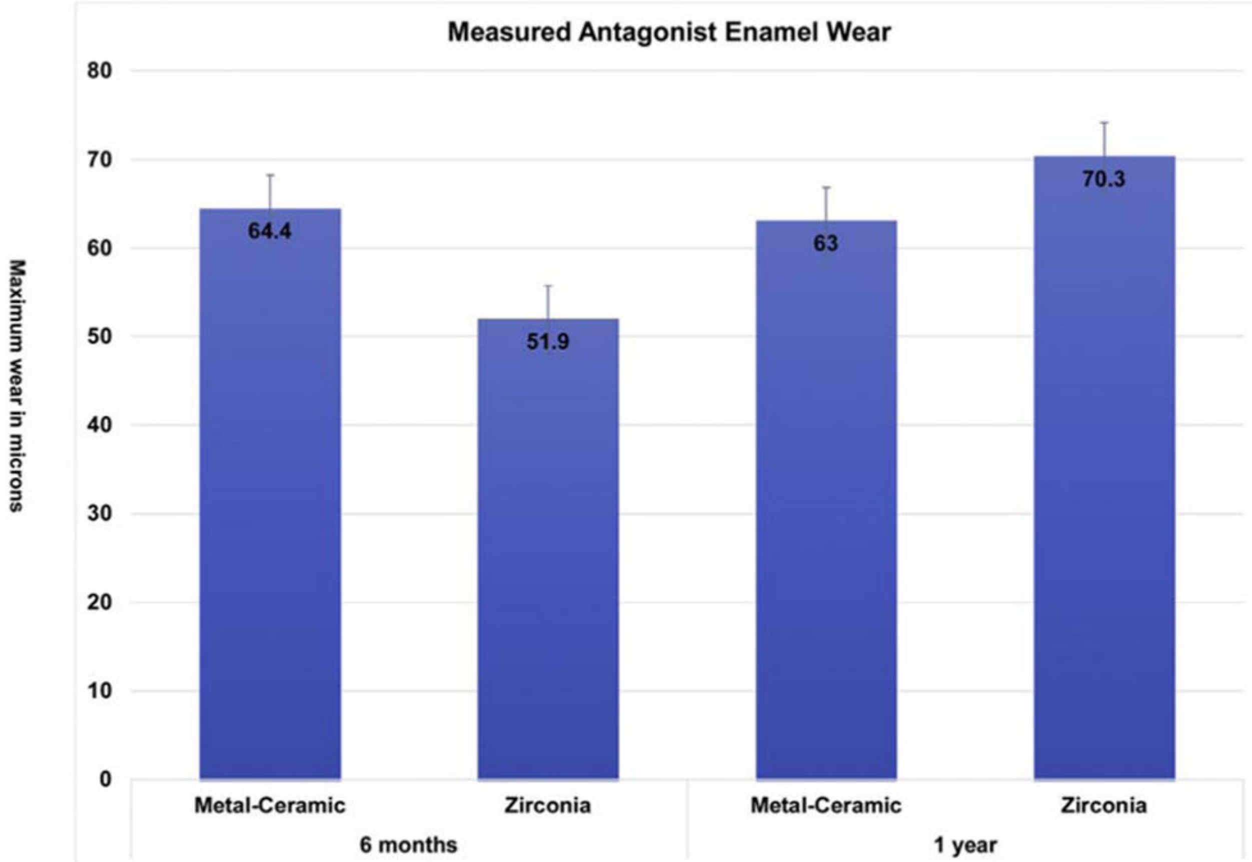

Fig. 3.
Comparison of antagonist enamel wear between metal ceramic and monolithic zirconia crowns at 6 months and one year.

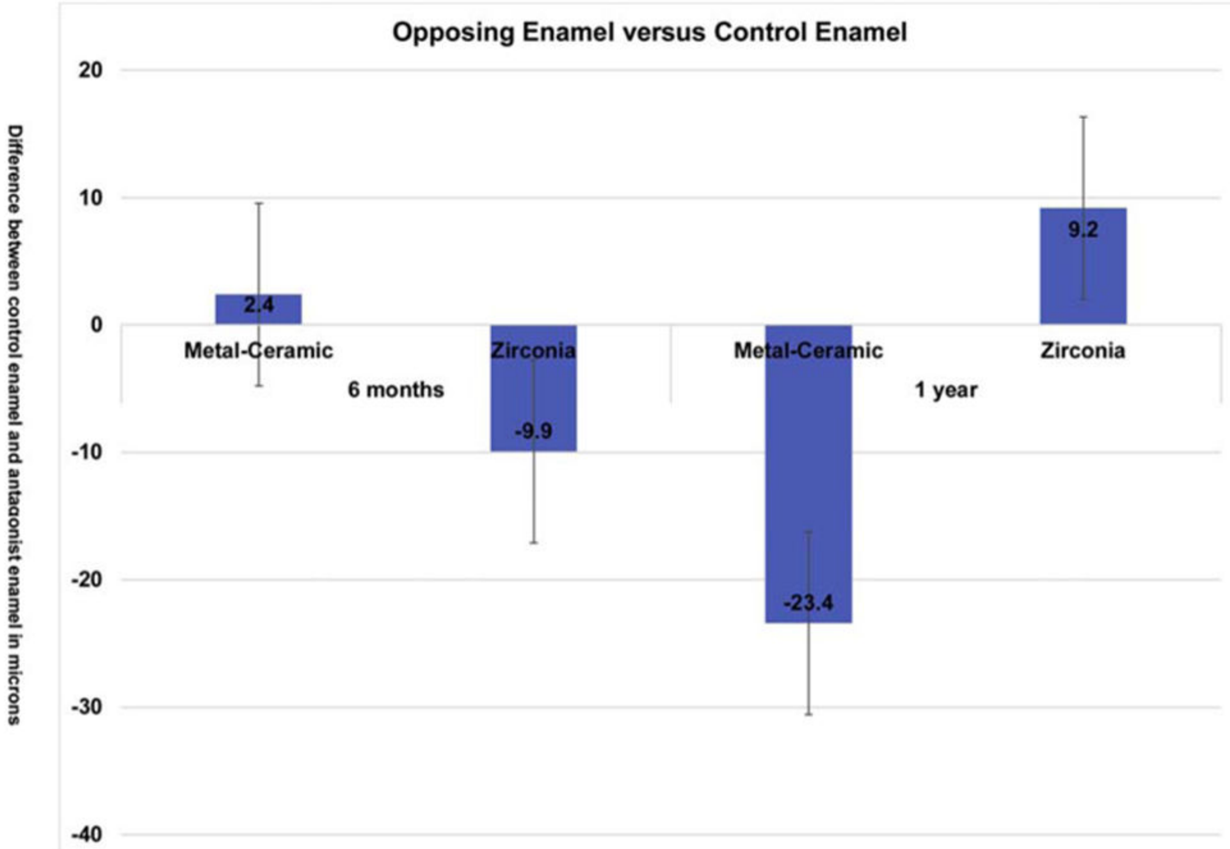

Fig. 4.

Comparison of enamel wear between crown antagonist enamel and control enamel. Negative values indicate greater control enamel wear while positive values indicate greater antagonist enamel wear.

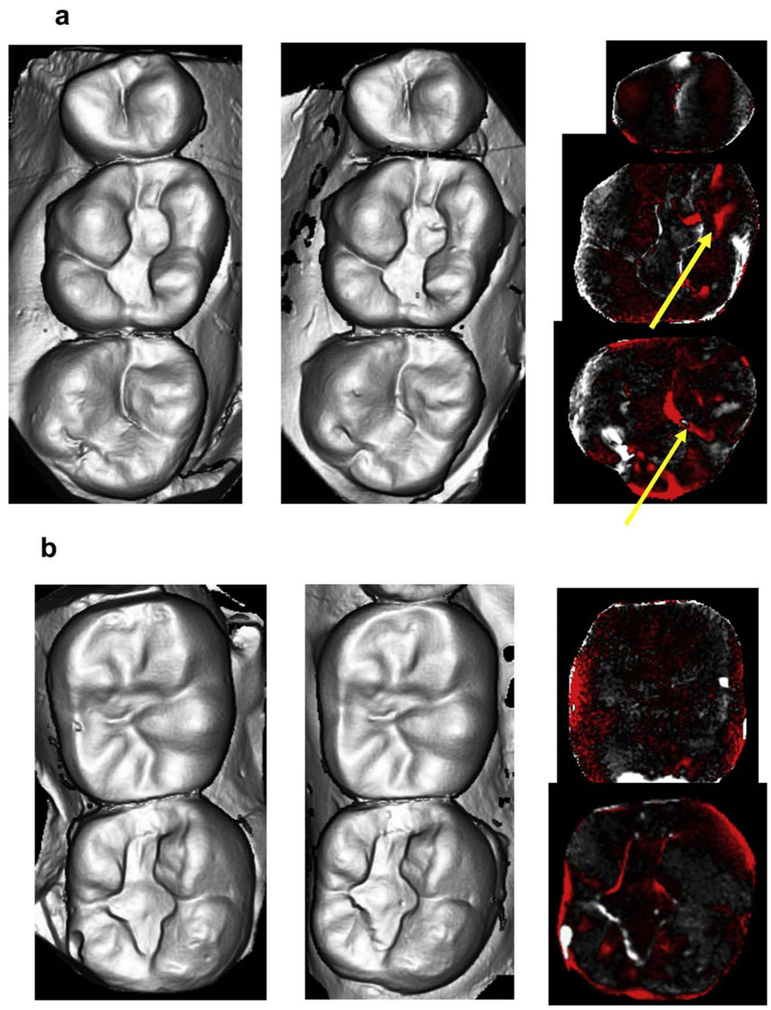

Fig. 5.

(a) Scanned image of casts of antagonist enamel and control enamel at baseline (left), one year (middle) and superimposed image showing wear areas in red (right); (b) Scanned image of casts from the same patient of crowned tooth and antagonist enamel at baseline (left), one year (middle) and superimposed image showing wear areas in red (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1

Comparison of published clinical studies documenting the wear of enamel against monolithic zirconia.

Author	surface treatment	replica	device	material	antanogist	Wear (a. mean volume loss, b. mean wear, c. mean maximum vertical loss)	control	duration (time)	Is zirconia acceptable after duration of observa-tion?
Lohbauer U. and Reich S.	polished	epoxy resin AlphaDie	3D-non contact profilometer (CT-100, Cybertechnologies, Ingolstadt, Germany). Samples were scanned with lateral step size of 5 µm.	monolithic zirconia premolar and molar crown (LAVA Plus, 3 M ESPE) (n = 14)	enamel (n = 7) ceramic (n = 10) ceramic/enamel (n = 2)	enamel [a]3.61E8 µm^3, [c]204 µm ceramic [a]3.33E8 µm^3, [c]145 µm ceramic/enamel [a]115 µm^3, [c]163 µm	none	2 years	monolithic zirconia crowns were acceptable after 2 years
Mundhe K. et. al	polished-zirconia glazed-metal ceramic	gypsum	3D white light scanner (SmartSCAN^{3D} HE scanner; Breukmann), precision: ± 9 µm	enamel monolithic yttrium-stabilized zirconium oxide crown (Y-TZP; LAVA; 3 M ESPE) (n = 10) metal ceramic (65.2% Ni, 22.5% Cr, and 9.5% Mo (Bellabond Plus; BEGO) (n = 10)	enamel	enamel [b]17.30 µm –premolar region enamel [b]35.10 µm-molar region enamel [b]42.10 µm for premolar teeth enamel [b]127.00 µm for molar teeth enamel [b]69.2 µm – premolar teeth enamel [b]179.70 µm – molar teeth	enamel vs. enamel; enamel vs. metal-ceramic	1 year	Wear of enamel caused by metal ceramic crown > zirconia crown > natural enamel
Stober T. et al.	polished	stone	Laserscan 3D and Match 3D, version 1.6; Willytec, Gräfelfing, Germany), resolution: 20 µm	yttrium-stabilised zirconia crown (Zenostar Zr Translucent; Wieland Dental) (n = 12) contralateral teeth (n = 24)	enamel	zirconia [b]14 µm, maximum vertical loss 60 µm enamel [b]46 µm, maximum vertical loss 151 µm enamel [b]19 ± 9 µm, [b]26 ± 13 µm, maximum vertical loss 75 µm, maximum vertical loss 115 µm	enamel vs. enamel	2 year	The wear of enamel antagonist caused by monolithic zirconia crowns was more than natural teeth
Cardelli P. et al.	glazed	polyurethane resin	3D scanner (Echo2 Scanner; Sweden & Martina, Due Carrare, Italy), accuracy: 10 µm	yttria-stabilized zirconia (Y-TZP; NexxZr; Sagemax, Federal Way, WA) (n = 47)	enamel nanohybrid composite	zirconia [b]63 µm, enamel [b]76 µm zirconia [b]19 µm, composite [b]70 µm	none	1 year	Wear of enamel or composite antagonists caused by zirconia was acceptable after 1 year.
Esquivel-Upshaw et al.	polished	stone	3D Laserscanner (CS2, Straumann, Germany), accuracy: 20 µm	monolithic zirconia (LavaTM Plus, 3 M ESPE, PZ) (n = 16) metal-ceramic (GC InitialTM, GC America; Argedent 62, Argen, USA, PV) (n = 14) contralateral enamel	enamel	Zirconia [c]38.4 µm (6 months), [c]46.1 µm (1 year) enamel [c]51.9 µm (6 months), [c]70.3 µm (1 year) metal-ceramic [c]30.9 µm (6 months), [c]49.5 µm (1 year) Enamel [c]64.4 µm (6 months), [c]63 µm (1 year)	enamel vs. enamel	6 months, 1 year	Wear of enamel caused by monolithic zirconia was comparable with metal-ceramic.

Author	surface treatment	replica	device	material	antanogist	Wear (a. mean volume loss, b. mean wear, c. mean maximum vertical loss)	control	duration (time)	Is zirconia acceptable after duration of observa-tion?
						contralateral enamel (zirconia vs. enamel) [c]61.8 µm (6 months), [c]61.1 µm (1 year) contralateral enamel (metal-ceramic vs. enamel) [c]62 µm (6 months), [c]86.4 µm (1 year)			