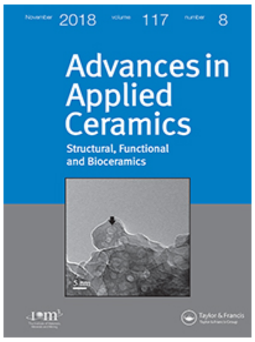

Advances in Applied Ceramics
Structural, Functional and Bioceramics

ISSN: 1743-6753 (Print) 1743-6761 (Online) Journal homepage: http://www.tandfonline.com/loi/yaac20

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ADVANCES IN APPLIED CERAMICS
2018, VOL. 117, NO. 8, 445–451
https://doi.org/10.1080/17436753.2018.1477567

Wear performance of self-glazed zirconia crowns with different amount of occlusal adjustment after 6 months of clinical use

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ABSTRACT
The amount of enamel wear on the antagonist occlusal surfaces caused by self-glazed zirconia crowns was compared with that caused by contralateral natural teeth. Thirteen self-glazed zirconia crowns were placed *in situ*. The impressions of self-glazed zirconia crowns, their antagonists and the control teeth were taken and scanned at baseline and 6-month follow-up. The patients were divided into two groups, the self-glazed crowns in one group were subjected to a large amount of grinding with well polishing (LaP group, $n = 7$), while the other group required a little amount of grinding with well polishing (LiP group, $n = 6$). Statistics were analysed by two-sided paired Student's t-tests to a significance level of $p < .05$. The results revealed that the maximum and mean enamel wear significantly different between the antagonists of self-glazed crowns and the control teeth ($p < .05$). Increased amount of enamel wear was found in LaP group ($p < .05$). The self-glazed zirconia crowns caused more enamel wear of antagonists than natural teeth after 6 months. Occlusal adjustment and polishing were considered as possible confounders which affected wear behaviour.

ARTICLE HISTORY
Received 3 January 2018
Accepted 13 May 2018

KEYWORDS
Self-glazed zirconia; enamel wear; polishing; grinding

Introduction

Development of ceramic materials has contributed to the extensive use of ceramic prostheses in dentistry. The high strength of zirconia ceramics enables its application as crowns in the molar area. However, many studies have highlighted the high clinical chipping incidence between the ceramic core and the glassy veneer. As a consequence, the availability of monolithic zirconia restorations without any veneer successfully avoided the clinical failure of chipping. However, concerns were raised towards the increased wear behaviour and surface roughness on the antagonists of the zirconia restorations.

Recent *in vitro* studies have shown that well-polished monolithic zirconia revealed no detectable signs of wear, while the veneering porcelains demonstrated the most amount of wear [1,2]. These studies pointed that the exposure of the rough surface of glazed and veneering zirconia after long time use led to the increased wear of antagonists. In addition, not enough polishing after occlusal adjustment thereby increased surface roughness and wear damage. Our previous study showed that the surface of self-glazed zirconia was very smooth on micrometer scale, similar friction and wear performance were found between self-glazed zirconia and well-polished zirconia *in vitro* [3].

However, a series of clinical studies of full-contour zirconia have shown significant difference of enamel wear between the antagonists of natural teeth and zirconia restorations. One study found that the mean and maximum enamel were significantly difference between the enamel opposed to the monolithic zirconia and natural tooth after 6 months of clinical use [4]. Another study showed that the wear of tooth against monolithic polished zirconia was more than natural enamel after 1 year [5]. Nevertheless, Lohbauer and Reich [6] reported less enamel wear of the antagonist of zirconia (LAVA plus) compared to that of natural teeth after 2 years of clinical service. Clinical practice necessitates the correction of occlusal contact areas (OCA) to achieve a proper occlusal discrepancy. Study has revealed that different material structure and component produce distinctive finishing surface after polishing [7]. Since the self-glazed zirconia is of gradient structure with fine-grained nanoparticles on the external surface and larger granules in the internal layer of a crown. Quantitative assessment of the wear behaviour of self-glazed zirconia with different amount of grinding assists the fabrication of better dentistry materials and the improvement of polishing procedure as well.

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The objectives of this clinical study were: to quantify enamel wear caused by self-glazed zirconia crowns and the wear of the self-glazed zirconia crowns by opposing natural tooth respectively. The teeth without crowns or fillings in the contralateral sides were served as controls. The null hypothesis was that the amount of wear caused by the self-glazed zirconia crowns was comparable with that of the natural teeth under clinical conditions.

Methods

Participants

The Ethics Committee of the affiliated hospital of Guangzhou Medical University independently reviewed and approved the study (KY201702). Thirteen patients requiring full crowns on either molars or premolars were included in the study. Patients were informed of the purpose and the procedure of the test. Contents were given to patients.

Inclusion/exclusion criteria

To meet the inclusion criteria, the patients needed natural opposing antagonists and contralateral antagonists without any fillings on the OCA. Subjects with the following symptoms were excluded, clinical sign of bruxism, grinding, clenching and mental disorders, obvious attrition (attrition score > 2 according to Smith and Knight index). The age of 13 participants ranged from 18 to 56 years, 8 participants were male.

Clinical procedures and fabrication of the crowns

The clinical procedures for each patient were performed strictly with a standardised protocol. Teeth were prepared by the removal of 1.0–1.5 mm (occlusal) and 0.8–1.0 mm (circular) with a rectangular shoulder. All the tooth preparation met the standard of 4°convergence angle. The crowns were designed on the basis of conventional impression or digital scanner (CS3500, Carestream, USA). Self-glazed zirconia crowns (Self-glazed zirconia®, Lot 2016030101A, Erran Tech Ltd, Co.) were produced by the wet-chemistry technology in which nano-sized grains were packed to form the dental restorations [3]. 40 μm articulating paper (BK 61, Bausch, Germany) was used to identify and adjust the premature contact points until all the paper mark areas were even in shade. At least four contact points were detected on the occlusal surface of each crown. In order to maintain a smooth surface, the crowns were carefully polished with diamond impregnated polishers (HP321, EVE, Germany) once the occlusal sides were adjusted for at least 30 s and were cleaned with 75% ethanol. The crowns were fitted to the suitably prepared abutment teeth and cemented using self-adhesive universal resin cement (RelyX Unicem Aplicap, 3M, USA) with light cured for 20 s each surface.

The participants were divided into two groups: crowns suffered from a little amount of grinding after occlusal adjustment with well polish (LiP group), crowns suffered from a large amount of grinding after occlusal adjustment with well polish (LaP group). The crowns of LiP group required moderate to no occlusal grinding until at least four uniform contact points were obtained. The crowns of LaP group were of larger adjustment areas and deeper occlusal vertical grinding. The surface of the self-glazed zirconia was scanned by SEM.

Wear evaluation

At baseline and follow-up recall after 6 months (±2 week), high precision polyvinyl siloxane impressions were taken from the self-glazed zirconia crowns, the antagonist natural teeth and the reference teeth. All the impressions followed the same procedure: (i) clean the surface of the teeth with brush and water; (ii) made the polyvinyl siloxane impressions using stock trays when the surface of teeth was dried. The occlusal contact points were marked intra-orally and photographed as reference. Wear was determined indirectly by manufacturing the replica with epoxy resin (Schütz Dental, Rosbach, Germany). Wear of the occlusal contact area of the self-glazed zirconia crowns, of the antagonists and the reference natural teeth was determined by the use of a 3-D white light non-contact profilometer (VR-3200, Keyence, Japan) with a precision of ± 2 μm in accordance with the method described by Mehl et al. [8]. A threshold value of −30 μm was defined to exclude the artefacts. This meant that all area of the recall replica which differed from the baseline replica by more than 30 μm in the negative direction were not included in the matching process. Matching was accepted when the standard deviations between the image points of the two occlusal surfaces were <20 μm.

An electric XY multidirectional platform (VR-S200, Keyence, Japan) was used. A software (VR-H2P, Keyence, Japan) served as a tool for surface topography superimposing.

A defined colour scheme was applied onto the differential scans, referring yellow and green colour as the neutral level, orange and red for positive volume and bluish colours for negative volume. Figures 1 and 2 show examples of antagonistic tooth when cemented initially, 6 months later and the differential image.

The amount of maximum vertical loss of the OCA was measured. The maximum vertical loss represents an average value of three maximum values in the

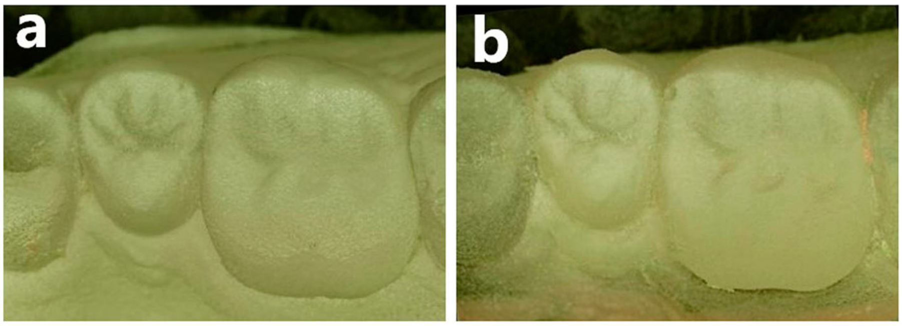

Figure 1. Replica models of antagonist teeth made from epoxy resin at baseline (a) and 6-month follow-up (b).

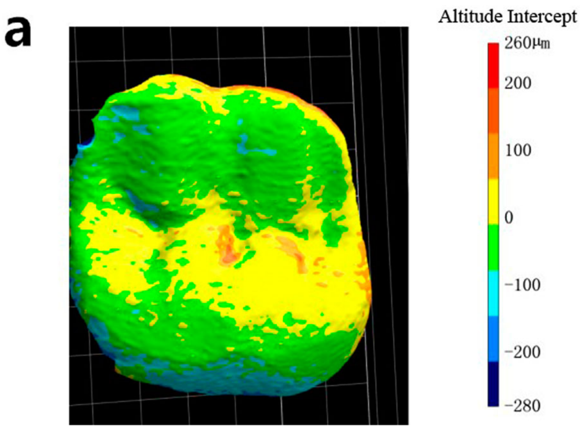

Figure 2. Altitude differential image from baseline and 6-month recall replica indicates the worn areas in red or orange (a).

depth peaks from each scan area on an investigated tooth. The mean maximum vertical loss value was calculated often maximum depth peaks in OCAs on a single tooth. The positive volume was defined as the area above the neutral level.

Statistical analysis

Two-sided paired Student's t-tests were used to analyse the wear of the self-glazed zirconia crowns, antagonists of self-glazed zirconia crowns and antagonists of contralateral natural teeth as controls. Type 1 error was fixed at 0.05. SPSS 20.0 (SPSS Inc., Chicago, IL, USA) was used for statistical analysis.

Results

The null hypothesis of this study was rejected that the enamel wear caused by the self-glazed zirconia crowns with a large amount of occlusal adjustment followed well polishing was more than that of the natural teeth.

The results revealed that Mean ± SD maximum vertical occlusal wear (mean vertical occlusal loss in parentheses) in LiP group of the antagonistic enamel 6 months after the cementation of self-glazed zirconia crowns was 77.11 ± 17.61 µm (51.00 ± 18.63 µm), 59.18 ± 12.3 µm (30.82 ± 7.22 µm) for self-glazed crowns, 63.01 ± 25.42 µm (36.09 ± 16.57 µm) for the contralateral antagonists (Figure 3).

The results revealed that Mean ± SD maximum vertical occlusal wear (mean vertical occlusal loss in parentheses) in LaP group of the antagonistic enamel 6 months after the cementation of self-glazed zirconia crowns was 172.34 ± 62.65 µm (82.88 ± 26.59 µm), 76.79 ± 41.04 µm (39.09 ± 16.93 µm) for self-glazed crowns, 98.75 ± 28.99 µm (44.38 ± 20.20 µm) for the contralateral antagonists (Figure 4, Table 1).

Significant difference of maximum ($P = .026$) and mean ($P = .018$) vertical wear of OCA between enamel wear of zirconia-opposed teeth and control teeth was found in LaP group. Whereas there is no difference in maximum ($P = .251$) and mean ($P = .140$) vertical wear of OCA between enamel wear of zirconia-opposed teeth and control teeth in LiP group. This confirmed that the self-glazed zirconia crowns cause more amount of wear compared with natural teeth after 6 months.

SEM images of self-glazed zirconia surface of LiP group, LaP group and original one are demonstrated in Figures 5–7.

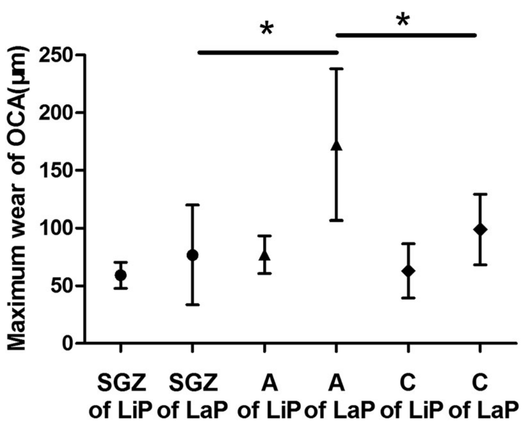

Figure 3. Maximum wear (mean values, µm) of OCA of self-glazed zirconia (SGZ) crowns and their enamel antagonists, and of control teeth in groups of little amount of grinding (LiP) and large amount of grinding (LaP) after 6 months. Error bars represent the 95% CI. The difference between antagonists of LaP and SGZ crowns of LaP, the control teeth of LaP was statistically significant ($P < .05$).

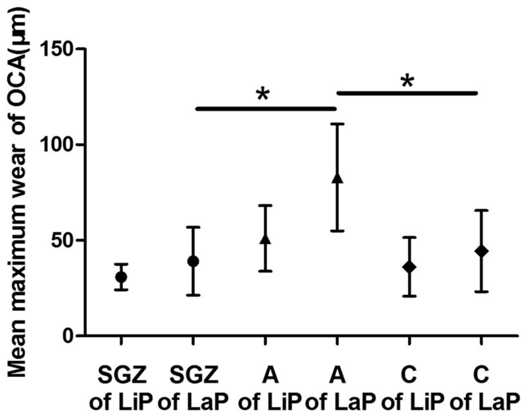

Figure 4. Mean maximum wear (mean values, μm) of OCA of self-glazed zirconia (SGZ) crowns and their enamel antagonists, and of control teeth in groups of little amount of grinding (LiP) and large amount of grinding (LaP) after 6 months. Error bars represent the 95% CI. The difference between antagonists of LaP and SGZ crowns of LaP, the control teeth of LaP was statistically significant ($P < .05$).

Table 1. Results of the quantitative wear analysis of the antagonist teeth after 6 months.

Case ID	Group	Teeth	Tooth	Maximum vertical loss (μm)	Mean vertical loss (μm)
1	LaP	Zirconia	17	67.33	34.59
		Antagonist	47	146.13	63.78
		Control	37	65.00	30.13
2	LaP	Zirconia	35	26.27	20.77
		Antagonist	25	125.61	72.01
		Control	15	63.61	21.47
3	LiP	Zirconia	36	67.91	32.57
		Antagonist	26	81.37	72.23
		Control	16	56.20	27.62
4	LaP	Zirconia	36	125.93	63.26
		Antagonist	26	218.31	121.03
		Control	16	117.01	70.99
5	LiP	Zirconia	36	57.17	28.85
		Antagonist	26	83.27	46.33
		Control	16	75.35	49.69
6	LiP	Zirconia	36	59.85	36.85
		Antagonist	26	81.00	71.43
		Control	16	110.51	67.06
7	LiP	Zirconia	26	55.85	26.98
		Antagonist	36	86.22	24.27
		Control	16	54.10	30.86
8	LiP	Zirconia	24	55.67	25.77
		Antagonist	34	80.33	44.67
		Control	14	69.74	25.85
9	LiP	Zirconia	27	78.96	42.98
		Antagonist	37	89.74	63.75
		Control	17	39.34	32.46
10	LaP	Zirconia	16	122.73	56.28
		Antagonist	46	273.02	108.70
		Control	26	106.10	66.43
11	LaP	Zirconia	25	41.33	26.21
		Antagonist	35	105.58	52.58
		Control	15	104.51	33.49
12	LaP	Zirconia	14	77.17	33.44
		Antagonist	44	165.42	79.21
		Control	24	136.27	43.78
13	LaP	Zirconia	35	38.85	21.80
		Antagonist	25	37.89	34.35
		Control	15	35.83	19.12

Discussion

The physical properties and composition of the dental materials affect the wear behaviour in clinical use. Increased friction and roughness coefficient will limit the clinical use of a dental material.

This study showed that the self-glazed zirconia crowns that were grinded heavily increased wear to the natural enamel even if they were polished. The working hypothesis is therefore rejected. Maximum vertical loss of the antagonists of LaP group was 172.34 ± 62.65 μm which was twice as much as that of the LiP group. It is reported that after 6 months clinical application, the maximum vertical loss of zirconia crowns was about 43 μm, while the antagonists of the monolithic zirconia and the natural tooth was about 112 and 58 μm [4]. The maximum wear was significantly different between the antagonists of the zirconia crowns and the control teeth which were in accordance to this study. Nevertheless, the maximum and mean maximum vertical loss of antagonists in LiP group are respectively, 77.11 ± 17.61 μm, 51.00 ± 18.63 μm which were not statistically different from the enamel wear caused by natural teeth. A clinical study, over a period of 2 years, has presented that the mean of maximum vertical loss of enamel in OCA caused by zirconia (0.145 μm) was approximately twice less than that caused by natural teeth (0.204 μm) [9]. Even though our study only records the statistic after 6 months, it reveals that the well-polished self-glazed zirconia with little amount of grinding caused a similar amount of enamel wear compared with natural teeth which is in agreement with this study.

Based on the results reported so far it can be concluded that the wear of the opposing natural teeth is determined by the hardness of zirconia as well as the surface microstructure and roughness [10]. A series of clinical researches have confirmed that polished zirconia leads to significantly less wear of natural antagonists than did other ceramic materials [11,12]. It was revealed *in vitro* that self-glazed zirconia surface was inherently as smooth as enamel on micrometer scale. The friction and wear performance of well-polished and self-glazed zirconia ceramic agonists natural enamel was very similar [3]. The mean maximum vertical loss of enamel in LiP group was 51.100 ± 18.63 μm which was less than that of the Procera (130.96 ± 16.80 μm) within 6 months [13]. The original smooth surface of the self-glazed zirconia crowns was responsible for the superior wear behaviour in the LiP group.

Figures 5–7 show the SEM microstructure of the self-glazed zirconia surface of little grinding with well polish, large grinding with well polish and with no grinding or polish. It appears that surface of little grinding (Figure 5) with well polish was the smoothest one with little shallow ditches and scratches on it. In addition, most areas of the surface of large grinding with well polish crowns (Figure 6 (A)) revealed no obvious granule but with wide

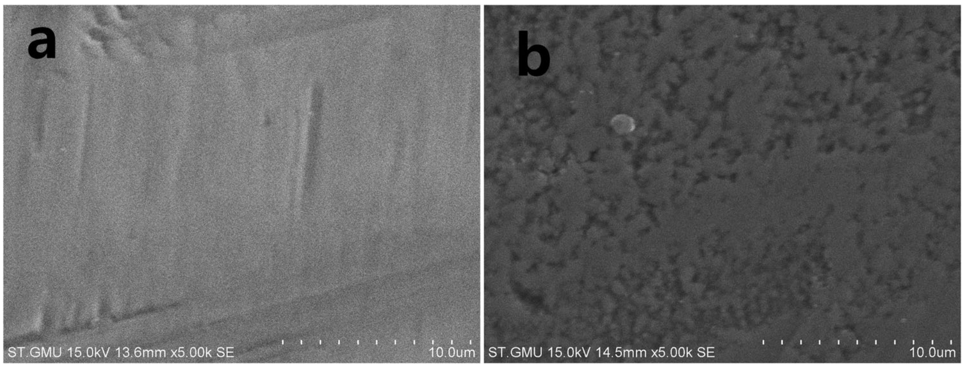

Figure 5. SEM images taken on the relative smooth surface of the crown in LiP group (a,b).

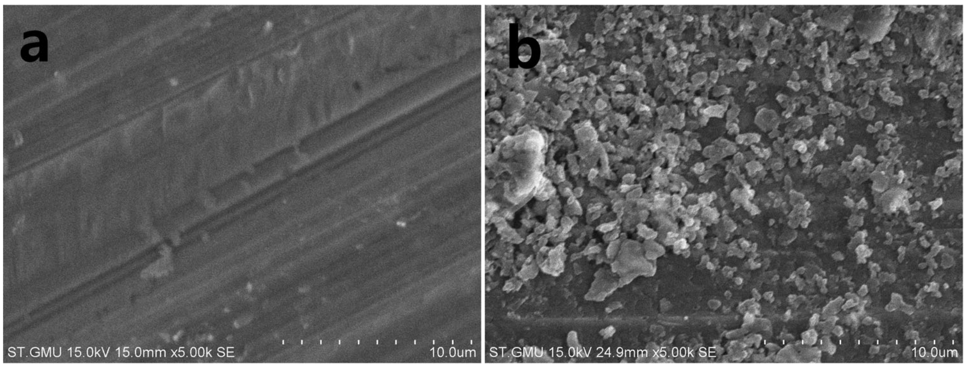

Figure 6. SEM images taken on the surface of the crown in LaP group with no obvious granule (a) and with noticeable increasing coarse particles (b).

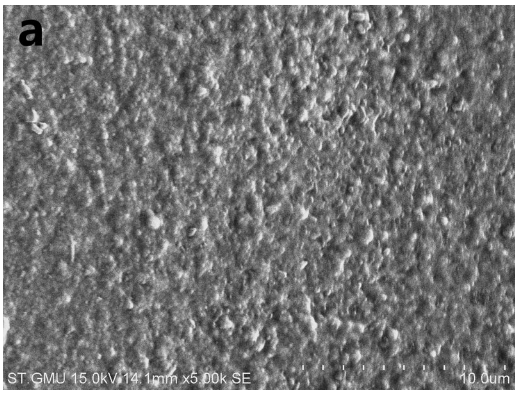

Figure 7. SEM images taken on the surface of self-glazed zirconia crown without grinding and polishing (a).

shallow ditches. However, noticeable increases of coarse particles (Figure 6(B)), with an average diameter in the range of 1–4 μm, peeling off the surface of large grinding with well polish were found in local areas especially in the middle region. There was a large area of depression or pit when the zirconia crown was grinded heavily. In this case, the grinding instrument, such as the disc bur, can hardly contact the middle concave areas. Besides, the particles of self-glazed zirconia crown that compose the core are of large diameter could not be polished as smooth as the surface which is formed by nanoscale particles.

Zirconia led to less wear which contributes to its high strength (HV 1200–1500) and obtained superior wear-resistant properties than feldspathic dental porcelain *in vitro* [14]. The increased fracture resistance may be interpreted by phase transformation from tetragonal to monoclinic phase which results in 3–5% increase in volume, preventing crack propagation [15]. The ideal physical characteristic of zirconia keeps the shape of the crowns during the long period of mastication and preserves the smooth surface. The hardness and breaking strength of the feldspathic which constructs the glazed layer on the surface was inferior to that of the zirconia. The glaze layer (VH~500) with a thickness about 35–40 μm was removed by wear due to poor mechanical properties [16]. Besides, the propagation of flaws in the glass-ceramic veneer might chip during mastication. Therefore, the wear of antagonist natural enamel increased once the rough and damaged surface of the zirconia core was exposed. Therefore, the study reported that glazed zirconia caused more serious wear than the polished one [16]. With an average bending strength of 1120 ± 70 MPa, *Weibull* modulus of 18, fracture toughness of 5.2 ± 0.2 MPa $m^{1/2}$, hardness of 12.9 ± 0.1 GPa and Young's modulus of 234 GPa, the clinical application reliability of the self-glazed zirconia is warranted by its balanced mechanical properties that are superior to that of the conventional monolithic zirconia [17].

In addition, some studies suggested that mechanical fatigue of the materials may play a vital rule in wear performance. Lawson et al. [18] reported that polymer-ceramic, containing materials may not possessed high initial strength, caused less enamel wear than e.max CAD although whose hardness (452.9HV) was higher than previous groups. A recent study reported the initial crown fracture strength of Lava Ultimate (213 N) and Enamic (215 N) were less than zirconia (832.90N), however, the polymer crowns showed a 16% reduction in strength following 3.7m chewing cycles, whereas the strength of veneer zirconia dropped by 34.03% [19]. Although none of the tested veneered zirconia restorations were fractured during testing, chipping of the veneer ceramics was observed. Shembish et al. [20] pointed that Monolithic CAD/CAM resin composite crowns endured fatigue loads 3–4 times higher than glass-ceramic CAD crowns.

Zhang et al. [21] has pointed that both self-glazed zirconia and conventional zirconia slightly increased fracture force after fatigue test owing to the transformation to the tetragonal phase by fatigue stress. But significantly higher fracture force was observed on the self-glazed zirconia over the conventional zirconia which could be attributed to the fine-grained microstructure with no visible microscopic void.

The influencing factors to the wear behaviour also include the type of food, environment situation (pH, moisture and temperature) as well as the chewing force [22,23]. Occlusal situation also affects the wear behaviour. It is acceptable to maintain the interocclusal distance contact of the intercuspation within 50 μm to avoid the premature areas and high occlusal points [24]. An *in vivo* study [25] has pointed that very plastic T-Scan sensor and very thick articulating paper both affected SEMG activity which in term influenced the occlusal behaviour. However, the occlusal adjustment could hardly be accurate even by simply applied 40 μm articulating paper [26]. A study revealed that the antagonistic contacts of restorations were missed or less than the contralateral antagonists of natural teeth [27].

Large grinding is inevitable when premature contact occurs and the interocclusal space is less than 50 μm. As a result, the core layer of the self-glazed zirconia may be exposed and irregular interspace creates after manual occlusal adjustment with articulating paper which is not accurate enough [28]. The increasing bite force which attributes to the smaller gap width of interocclusal space is responsible for the excessive enamel wear [29]. Therefore, the clinical occlusal adjustment method with articulating paper was inaccurate and may cause excessive enamel wear.

To overcome deformation of outline and the inconformity of interocclusal space, it is necessary to develop a novel kind of restoration with less occlusal adjustment. A resin provisional crown which is fabricated before manufacturing the definite restoration is believed to be the ideal substitution to check the morphology and occlusal contact situation. In this case, definite restoration with zero occlusal adjustment could be obtained by scanning and imitating the outline of the provisional crowns which are of satisfied OCA and distance after clinical adjustment. Another study needs to be conducted to determine the effect of enamel wear by self-zirconia without clinical adjustment.

Conclusions

With regard to clinical conditions, significant difference was found between natural enamel antagonists and antagonists of self-glazed crowns with large amount of occlusal adjustment even if crowns were well polished. The self-glazed zirconia crowns did cause more enamel wear of antagonists than natural teeth after 6 months if they were grinded heavily which contributed to the gradient microstructure with a larger size of particles in the basic layer of the crown.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Guangzhou Medical University [grant number 2016A27]; Guangdong Provincial Department of Science and Technology [grant number 2017B3016413].

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