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Clinical performance and wear characteristics of veneered lithia-disilicate-based ceramic crowns

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Abstract

Objectives—The objectives of this study were to characterize the clinical performance and wear characteristics of lithia-disilicate-based ceramic crowns.

Methods—Thirty posterior crowns were made using the heat-pressing technique and lithia-disilicate-based core ceramic. Subjects were recalled annually. The quality of crowns and adjacent gingival tissues were examined using nine criteria for acceptability. All crowns were examined and ranked from 4 (Excellent) to 1 (Unacceptable) for each criterion. Impressions were made for replica models at each appointment. Wear characteristics of dental ceramic and enamel were obtained by comparing the surface of the original model with the follow-up model using a laser scanner.

Results—Twenty nine subjects returned for the one-year recall examination. The maximum clenching force for the 30 subjects ranged from 125 to 815 N. All clinical criteria were ranked good to excellent at the one-year recall exam and no fractures were observed. The mean occlusal wear volumes for the ceramic crowns after one year were 0.19 (0.065) mm³ for premolar sites and 0.34 (0.08) mm³ for molar sites. The mean occlusal wear volumes of opposing enamel after one year were 0.21 (0.06) mm³ for premolar teeth and 0.50 (0.22) mm³ for molar teeth. The mean occlusal wear volume of ceramic molar crowns was significantly lower than the volume of enamel wear of the opposing teeth ($p \leq 0.05$).

Conclusions—The quality of the overall prostheses and the gingival tissues were acceptable after one year. The mean occlusal wear volume of ceramic molar crowns was significantly lower than the enamel wear volume of the opposing teeth.

Keywords

clinical performance; ceramic crown; wear volume

Introduction

Dental ceramics have been widely used for construction of fixed dental prostheses for decades because they have several advantages such as their aesthetic quality and excellent biocompatibility. Clinical performance in posterior areas of metal-ceramic systems has been

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satisfactory from aesthetic and fracture resistance viewpoints. However, when used in anterior teeth, metal-ceramic prostheses are not as aesthetic as all-ceramic prostheses, which generally exhibit greater translucency and potentially have no visible metal substructure. These aesthetic advantages of all-ceramic systems combined with their excellent fracture resistance when used in anterior tooth sites have increased the demand for all-ceramic restorations.

The major disadvantages of ceramic materials are their low tensile strength, relatively low fracture toughness, and abrasiveness to opposing enamel [1–3]. These shortcomings limit their use in dental applications where high chewing and clenching forces are involved. The fracture resistance of dental ceramics and the wear characteristics of some dental porcelain and ceramics for all-ceramic systems have been reported in several studies [2–6]. Most of these reports represent *in vitro* studies that used some clinically relevant parameters as the test variables. The test results for ceramics and enamel have been presented as height loss, area loss, or volume loss. Also, several clinical studies have been performed to evaluate the clinical survival and performance of all-ceramic crowns [7–11]. Clinical performance of all-ceramic crowns is generally excellent in the anterior region and failure percentages range from 0 to 4% after 2 to 11 years, respectively [7–9]. Failure percentages of posterior all-ceramic crowns ranged from 1 to 14% after 4 to 11 years, respectively. These failure values are greater than those for metal-ceramic restorations, which ranged from 2.3 to 11% after 7.5 to 10 years, respectively [7–13]. The compositions of ceramics used in dentistry vary from a weak material with fracture toughness of $1 \text{ MPa}\cdot\text{m}^{1/2}$ to tougher materials having fracture toughness of $5\text{--}9 \text{ MPa}\cdot\text{m}^{1/2}$ [14–15]. Clinical performance of a ceramic crown is related to its mechanical properties. Tough materials are assumed to perform well and data from clinical studies appear to correlate roughly with the fracture toughness and strength of the core ceramics [7–12].

The data from several wear tests indicate that ceramic prostheses cause more wear to opposing enamel than do dental alloys, even though the failure mechanisms responsible for excessive wear of enamel caused by ceramic prostheses have not been conclusively identified [4–6]. It is uncertain whether data obtained from the *in vitro* studies are clinically relevant [16,17]. Wear is a progressive phenomenon associated with several factors [18]. Wear of enamel caused by ceramic prosthesis is a major concern because it is associated with the clinical success of the restoration.

The objectives of this study were to characterize the clinical performance and wear characteristics of all-ceramic posterior crowns. The wear rates of all-ceramic crowns and opposing enamel in selected patients were quantified. The relationship of each subject's maximum clenching force to wear volume was also analyzed.

Materials and methods

Thirty adult subjects, of good to excellent overall dental health, were recruited from the pool of subjects on the waiting list of the Faculty of Dentistry, Mahidol University. These subjects were screened to exclude individuals with poor medical health. All selected subjects had healthy periodontal tissues, were free of active periodontal disease and caries, and showed no evidence of bruxing. For these 30 adult subjects, five were men and 25 were women with ages ranging between 20 to 56 years. Eligible subjects had at least one posterior endodontically treated tooth opposed by natural dentition in the maxillary or mandibular arch. This endodontically treated tooth was used as an abutment for an all-ceramic crown. After obtaining informed consent, a maximum of two crowns were placed per patient.

Prior to the preparation of the abutment tooth, the maximum clenching force capability of each subject was determined using a bite force gauge. The abutment tooth was prepared for a cast post and core as a foundation for the glass-ceramic crown. After the final preparation, an

impression was made of the prepared tooth using a double impression technique with a polyvinyl siloxane impression material. A temporary acrylic resin crown was cemented on the prepared tooth using temporary cement (non-eugenol cement). The following minimal guidelines for the final tooth preparation were followed; axial tooth reduction of 1 mm, shoulder or deep chamfer design, occlusal reduction of 1.5–2 mm, and rounded inner angles/edges/transitions. The treatment and evaluation procedures were performed by three prosthodontists. Calibration between examiners was made using thorough discussion for the details ranking of each criterion to obtain agreement between examiners. Cross-examination between two examiners was performed randomly to obtain consistent evaluation.

The ceramic material used in this study was a lithia-disilicate-based all-ceramic system (Ivoclar Vivadent, Schaan, Liechtenstein). Thirty crowns were made using a layering technique according to the manufacturer's instructions. Ceramic crowns were cemented using either temporary cement or resin cement. The crowns were divided into three groups as follows.

Group 1: Ten crowns were cemented with Variolink II resin cement (Ivoclar Vivadent).

Group 2: Ten crowns were cemented with temporary cement. These ten crowns were retrieved after one year of insertion. Ten new all-ceramic crowns were made for this group and cemented with Variolink II resin cement.

Group 3: Ten crowns were cemented with temporary cement. These ten crowns will be retrieved after two years of service. Ten new all-ceramic crowns will be made and cemented with Variolink II resin cement.

After try-in and occlusal adjustment, each crown was glazed before insertion. Patients were informed that the temporarily cemented crowns would function as effectively as “permanently” cemented crowns. After cementation, impressions were made using polyvinyl siloxane for the upper and lower arches. The models were poured using synthetic stone (Fujirock, GC, Japan). These models were marked as baseline models. The patients were recalled after one year and two years. At the recall appointments, impressions were made for replica models. The occlusal contacts were observed and photographically recorded.

Examinations of the overall prosthesis, the marginal area, the adjacent gingival tissues, and the occlusion were evaluated at baseline, one year and two years. The following data were recorded: 1) gingival health; 2) occlusion; 3) secondary caries; 4) integrity of the restoration; 5) sensitivity to mastication; 6) facial and lingual marginal adaptation; 7) facial or lingual marginal discoloration; 8) contour and proximal contact of the restoration; and 9) patient satisfaction with the prosthesis or prostheses. One or two standard radiographs were taken of the abutment tooth at each recall. The resulting X-ray films were used for diagnostic purposes to determine periodontal health and the presence or absence of secondary caries and resin overhangs. The quality of crowns and tissues were examined at baseline and at each recall appointment for acceptability. Rankings of each criterion were made from 1 to 4; 4 = excellent, 3 = good, 2 = unacceptable, needs replacement in the near future, 1 = unacceptable, needs immediate replacement.

Wear analysis

Wear characteristics of ceramic crowns and enamel were obtained by comparing the surface of the original model with the follow-up model. The volume loss was determined using a 3-D laser scanner (Etkon, Willytec GmbH, Gräfelfing, Germany). The precision of this device is $\pm 20 \mu\text{m}$. The wear patterns of dental ceramic surfaces were characterized using a scanning electron microscope (SEM).

Statistical analysis

All data were analyzed using Student's t-test to determine the differences between mean wear volumes for the crowns and opposing teeth observed at baseline and those at each recall time.

Results

The quality of crowns and tissues were examined at baseline and one-year recall appointments and the results are summarized in Table 1. Twenty nine subjects returned for one-year recall examination. There were sixteen molar crowns and thirteen premolars. The overall clinical performance of ceramic crowns was rated good to excellent after one year. No fractures were observed. Representative photographs of the ceramic crowns are shown in Figure 1–2.

The maximum clenching force for the 30 subjects ranged between 125 and 815 N. These values are within normal limits reported from a previous review [19]. The mean maximum clenching force was 394 ± 193 N. The relationship of each subject's maximum clenching force to wear volume was analyzed using linear regression analysis (Fig. 3). The results showed that there was no significant relationship between maximum clenching force and the wear rate of enamel ($R^2 = 0.08$) or ceramic crowns ($R^2 = 0.02$).

Wear analysis

After one year the mean occlusal wear volumes of enamel were 0.21 ± 0.06 mm³ for premolar teeth and 0.50 ± 0.22 mm³ for molar teeth, respectively. This was not significantly higher ($p > 0.05$) than the volume of enamel wear for the contralateral teeth (0.20 ± 0.09 mm³ for premolars and 0.4 ± 0.16 mm³ for molars). The mean occlusal wear volumes of ceramic crowns after 1 year were 0.19 ± 0.06 mm³ for premolars and 0.34 ± 0.08 mm³ for molars, respectively (Table 2). The mean occlusal wear volume of ceramic molar crowns was significantly lower than the enamel wear of the opposing natural tooth ($p \leq 0.05$). The representative laser-scan images of ceramic crowns and opposing teeth are shown in Figures 4 to 6. The vertical height loss of opposing enamel for both premolar and molar teeth was higher than those of ceramic crowns.

Discussion

The overall clinical performance of hot-pressed ceramic crowns was rated good to excellent after one year. One subject was missing from the study and these data were not used for analyzing the results. No fracture or evidence of secondary caries was observed in this study. The success rate of hot-pressed ceramic crowns was 100% after one year and this result was in agreement with the results from a previous study [20]. Fracture of dental ceramics is the most common type of failure for ceramic prostheses because of their low tensile strength and their generally low fracture toughness of the ceramic layers. The fracture rates of 2.7 to 30% after 1.5–14 years have been reported for all-ceramic crowns [7,9,21–22]. A high failure rate of all-ceramics limits their use in dentistry even though their aesthetic quality is superior to that of metal-ceramic restorations. For metal-ceramic prostheses, the failure rate is lower and the fracture of ceramic veneers is not as significant as that observed in other studies. Follow-up of the crowns in this study is necessary for further conclusions to be made.

Enamel wear is a progressive phenomenon associated with several factors, including the physical, microstructural and surface characteristics of ceramic restorations [18]. For all-ceramic restorations, excessive wear of opposing enamel is another concern for the dental practitioner, in addition to its low fracture resistance. Loss of anatomic form caused by wear can alter functions of the masticatory system. Other investigators used wear machines to simulate the chewing movements in the oral environment [6,23–25]. However, there is no

evidence to show that *in vitro* wear testing can predict the amount or pattern of clinical wear of enamel caused by ceramic prostheses.

A 3D Laser-scanner (Willytec GmbH, Gräfelfing, Germany) was used in this study. It can be used to measure wear on replicas to an accuracy of $\pm 20 \mu\text{m}$. Generally, the scanner [26–28] uses a laser beam that is projected through a special optic system onto the surface being studied. For the instrument used in this study, the reflection of the beam is observed at an angle of 25° by a high resolution CCD camera based on the principle of the light-slit microscope. After scanning, it allows 3-D superimposition of images using at least three reference points or areas and quantifies the spatial differences between the two images. This machine also allows measurement of wear in three dimensions, thereby giving a more realistic view of the clinical characteristics of wear and the potential mechanisms involved.

The mean volumes of enamel wear obtained from this study were $0.21 \pm 0.06 \text{ mm}^3$ for premolar teeth and $0.50 \pm 0.22 \text{ mm}^3$ for molar teeth after one year. These values were not significantly higher than the enamel wear of the contralateral teeth ($p > 0.05$). This indicates a comparable wear rate between opposing enamel and the controls after one year. Although the results from this study indicate that these ceramic crowns did not cause significant wear of the opposing enamel after one year, these data must be verified with the results obtained from the two-year recall examination.

The mean occlusal wear volume of ceramic crowns was lower than that of the tooth enamel, especially for the molar site. Hot-pressed ceramic core material used in this study was based on the lithia-disilicate composition. The veneering material that opposed the enamel was glass-based with fracture toughness of $0.7 \pm 0.1 \text{ MPa m}^{1/2}$ and hardness of 5.3 GPa [29]. The fracture toughness of tooth enamel is $0.77 \text{ MPa m}^{1/2}$ and the hardness is 3.23 GPa [12]. The fracture toughness values of veneering material and tooth enamel were comparable, but surface hardness of the veneering material was higher. Higher hardness suggests a greater resistance to surface scratching or damage caused by other restorative materials. However, hardness is not the only factor that can affect wear characteristics. It is known that wear of dental materials is associated with several factors, and its mechanisms are not well identified. Therefore, more information regarding results from the long-term clinical study and the material's properties are required for identifying the relationship between wear volume and associated parameters.

The amount of dental porcelain, castable ceramic and enamel wear obtained from previous *in vitro* studies varied from 0.03 to 0.6 mm^3 after 150,000–300,000 loading cycles [30–32]. In these studies, the authors assumed that 250,000 cycles simulated one year of clinical wear under normal intraoral conditions [31–32]. Applied loads of 13.4 to 30 N at frequency of 4 Hz were used as clinically-relevant parameters. Vertical wear depth and area loss were also used to determine the amount of wear for restorative materials [23,33–35]. The mean area increase of enamel varied from 0.16 to 0.82 mm^2 after 25,000 loading cycles at a load of 40 N [33]. The mean wear depth of enamel ranged from 0.23 to 1.19 mm after 10,000–100,000 loading cycles at a load of 4–40 N [23,34–35]. The mean wear depths of porcelain varied from 3.7 to $74 \mu\text{m}$.

Most of the previous *in vitro* methods used for wear measurement were performed in two dimensions. The change in height of the tooth structure was measured and the amount of wear was calculated. Those results were quite variable depending on the testing conditions. Also, the loss of vertical height and area reduction cannot be adjusted to determine the three-dimensional wear volume. The anatomy of tooth structure exhibits contours with cusps and grooves. Variations in the shape and size of natural teeth are substantial. Large areas may be associated with a small loss of height or vice versa. This makes comparison between the wear

values from these *in vitro* studies and the values obtained from this study very difficult because of the variability of wear conditions.

To date, there is limited information about enamel or ceramic wear. Few clinical studies for wear determination have been conducted because it is a time-consuming process. However, the data obtained from such clinical trials are extremely useful and readily applicable to the design and development of dental ceramic materials, especially when results from *in vitro* studies vary depending on the testing conditions. As previously mentioned, wear is a destructive phenomenon associated with patient-related and dentist-related factors. This makes the wear process a very difficult task to simulate or to identify the basis of wear mechanisms. Wear data from the present study can be used for initial analysis but preliminary records and more information are required from future wear studies as a foundation for design and development of well-performing dental ceramics.

Conclusions

1. The overall clinical performance of hot-pressed ceramic crowns was rated good to excellent after one year. No fracture or secondary carious lesions were observed in this study. Even though fracture was not observed in this study, follow-up of these crowns is necessary for long-term conclusions to be made.
2. The mean occlusal wear volumes of enamel opposing ceramic were 0.21 ± 0.06 mm³ for premolar teeth and 0.50 ± 0.22 mm³ for molar teeth after 1 year. The mean occlusal wear volumes of ceramic crowns were 0.19 ± 0.06 mm³ for premolar sites and 0.34 ± 0.08 mm³ for molar sites after 1 year. The mean occlusal wear volume of ceramic molar crowns was significantly lower than the enamel wear of the opposing tooth but the mean occlusal wear volume of ceramic premolar crowns was not significantly different from that of opposing enamel.
3. Statistical analysis showed that there was no significant relationship between the maximum clenching force and the amount of occlusal wear or the mean wear rate of enamel or ceramic assuming a linear model.

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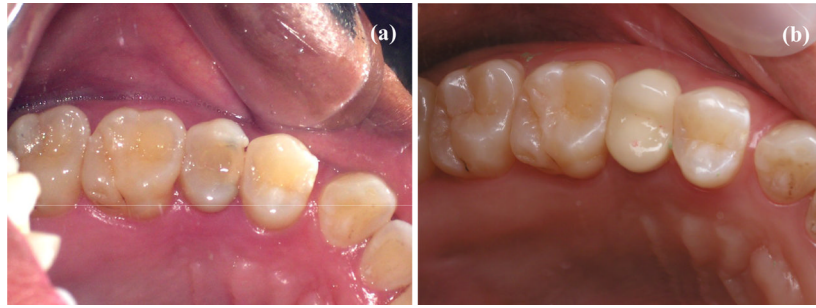


Figure 1. Representative photographs of an abutment second premolar tooth (a) before treatment, (b) at the one-year recall exam.

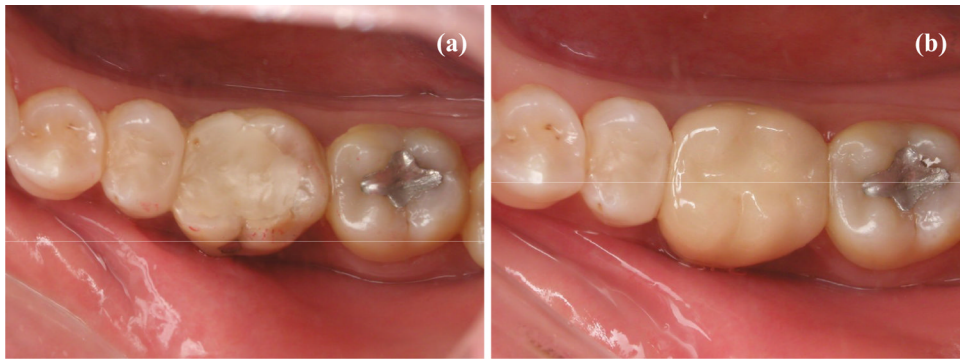


Figure 2. Representative photographs of an abutment molar tooth (a) before treatment, (b) at the one-year recall.

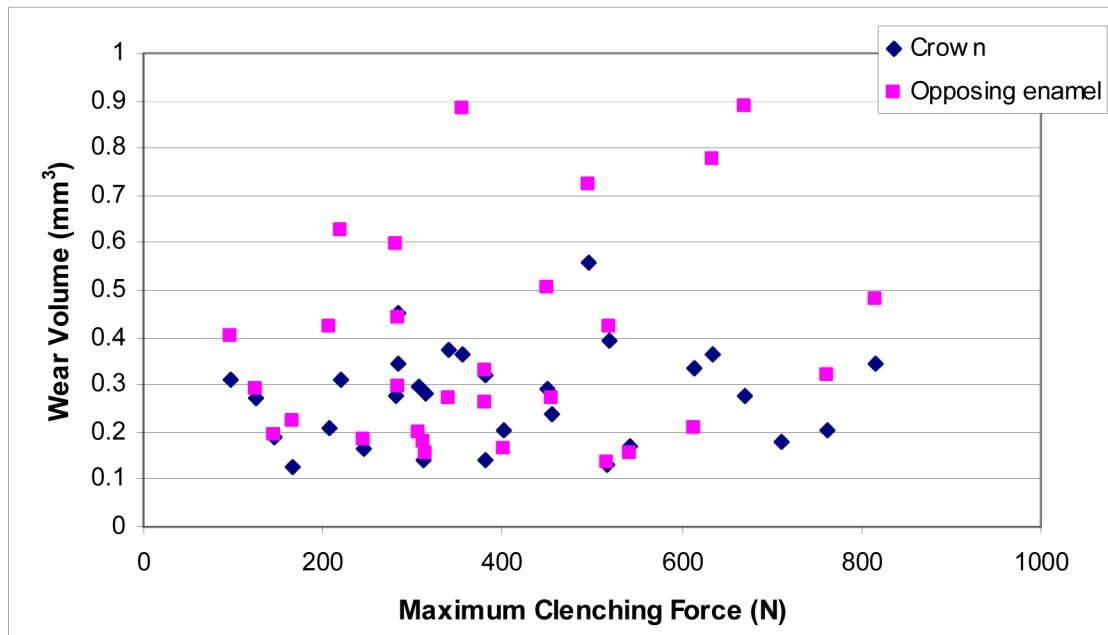


Figure 3.
Wear volume of ceramic crowns and opposing enamel.

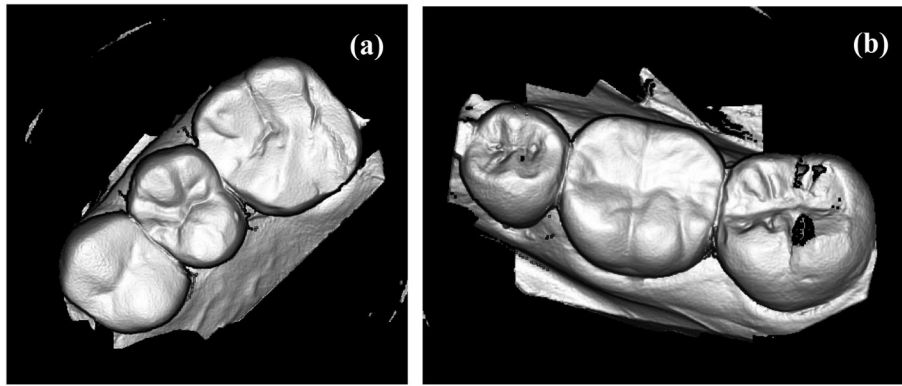


Figure 4.
Laser-scan images of a first premolar ceramic crown (a) and a molar ceramic crown (b)

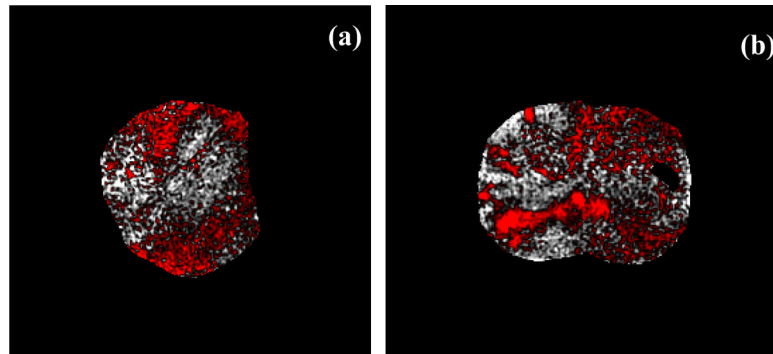


Figure 5. Laser-scan images of ceramic crowns after matching the baseline model with the one-year model of a premolar crown (a) and a molar crown (b). The red area indicates the negative volume or wear volume.

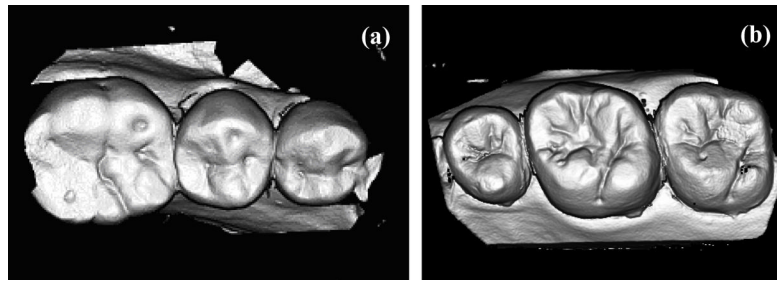


Figure 6. Laser-scan images of (a) a premolar tooth and (b) a molar tooth that have been worn by a ceramic crown after one year.

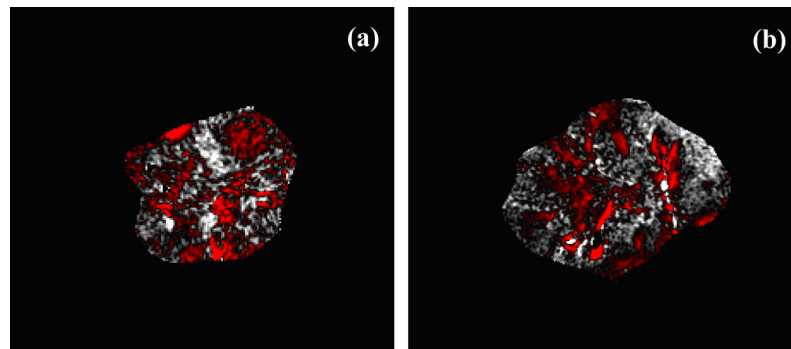


Figure 7. Laser-scan images of opposing teeth after matching between the baseline and one- year models for (a) a premolar tooth and (b) a molar tooth. The red area indicates the negative volume or wear volume.

Table 1

The quality of crowns and tissues examined after one year.

Parameters	Number of subjects			
	4	3	2	1
1. gingival health	21	8	-	-
2. occlusion	29	-	-	-
3. integrity of restoration	29	-	-	-
4. secondary caries	29	-	-	-
5. facial and lingual marginal adaptation	29	-	-	-
6. facial or lingual marginal discoloration	29	-	-	-
7. sensitivity to temperature and mastication	29	-	-	-
8. contour and proximal contact of the restoration	29	-	-	-
9. patient satisfaction	15	14	-	-

4 = Excellent, 3 = good, 2 = need replacement in the future, 1 = need immediate replacement

Table 2
Mean occlusal wear of ceramic crowns and opposing enamel.

Group	Wear volume (mm ³)	Wear height (µm)
Premolar (crown)	0.19 (0.06)	29 (12)
Molar (crown)	0.34 (0.08)	36 (34)
Premolar (enamel)	0.21 (0.06)	46 (13)
Molar (enamel)	0.50 (0.22)	65 (29)