

# Evaluation of marginal and internal gaps of all-ceramic crowns using X-ray micro-computed tomography

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Many dental ceramics are commercially available for the fabrication of dental fixed prostheses. The variation in processing and composition of these ceramics could affect the marginal discrepancy of all-ceramic dental prostheses. The objective of this study was to evaluate the marginal and internal adaptation of lithia-disilicate-based all-ceramic posterior crowns fabricated by heat-pressing and computer-aided designed and manufacturing (CAD-CAM) techniques.

**Materials and methods:** Three lithia-disilicate-based dental ceramics were used in this study (VINTAGE LD Press, IPS e.max Press and IPS e.max CAD). A complete coverage preparation on a posterior upper first molar crown was made on an Ivorine dentoform tooth. Forty type IV gypsum plaster dies were fabricated for use in four experimental groups. For Group 1 and 2, the die plaster models and a wax-up were used to make ten posterior crowns for VINTAGE LD Press and IPS e.max Press as monolithic crowns using a heat-pressing technique. Ten posterior crowns were made for IPS e.max CAD using a CAD-CAM technique for Group 3. For Group 4, ten posterior molar substructures were also made using IPS e.max CAD and veneered with IPS e.max Ceram using a conventional condensation and sintering technique. All ceramic crowns were affixed to their corresponding dies using a silicone material. Micro-computed tomography (Micro-CT) was used to analyze marginal and internal fit of each ceramic crown. The differences between the mean gap widths of all experimental groups were analyzed using the Kruskal-Wallis nonparametric test at a significance level of .05.

**Results:** The median marginal gap widths of all groups were not significantly different and these values were within an acceptable limit at 120  $\mu\text{m}$ . For internal gap widths, IPS e.max<sup>®</sup> Press crowns had a significant lower internal gap width than those of the other three remaining groups. IPS e.max<sup>®</sup> CAD veneered with IPS e.max<sup>®</sup> Ceram had marginal and internal gap widths comparable to those of IPS e.max<sup>®</sup> CAD monolithic crowns.

**Conclusions:** The marginal and internal adaptation of lithia-disilicate-based all-ceramic posterior crowns fabricated by a heat-pressing procedure was as good as those fabricated from the CAD-CAM technique. The micro-CT analysis was a useful analytical technique for internal and interfacial studies of dental prostheses and materials.

**Key words:** all-ceramic crown, heat-pressing, CAD-CAM, marginal gap, internal gap, micro-CT

**How to cite:** Thongpun N, Thongbai-on N, Sithiamnuai P, Suputtamongkol K. Evaluation of marginal and internal gaps of all-ceramic crowns using X-ray micro-computed tomography. M Dent J 2017; 37: 55-61.

## Introduction

Marginal discrepancy of all-ceramic restorations is an important factor in determining the longevity of dental restorations. An excessive marginal gap width will lead to cement leakage, secondary caries which can compromise the survival of a restoration or an abutment tooth

[1]. Periodontal and endodontic complications can also be a cause of failure resulting from an accumulation of plaque and food debris at the crown margin [2]. McLean and von Fraunhofer proposed that the clinically acceptable marginal gap after cementation should be less than 120  $\mu\text{m}$  [3].

There are many research studies that compared marginal and internal fit of dental all-ceramic restorations [4-8]. The marginal and internal gap widths obtained from these studies were varied, sometimes with high standard deviations [9,10]. Direct measurement and replica technique are widely used in those studies [10]. Direct measurement techniques provide an accurate result without any additional procedure. However, it was difficult to locate the consistent reference points for the measurement and it might have projection errors caused by the variations in cervical preparation line and shoulder angles [11]. If a cemented specimen was sectioned to directly measure the internal gaps, only limited numbers of sections would be available for a measurement. For the silicone replica technique, it is supposed to be a simple and convenient technique. However, dealing with extremely thin silicone sheets that represent the cement spaces between an abutment tooth and a fixed restoration is not straightforward. Tearing or separation of a thin silicone sheet from a restoration or abutment tooth is frequently happened even when preparing with extra care. Sectioning of the silicone replica in the wrong direction or point would also give incorrect results. Other measurement techniques are profile projector, digimatic micrometer and micro-computed tomography (micro-CT) [10].

Micro-CT has some advantages such as good resolution images obtained from small and complex shaped materials, no specimen preparation, and noninvasive technique. In dentistry, micro-CT is used to characterize bone and implant interfaces, internal tooth structures and restorations [12-14]. This technique can also be used to examine internal and marginal gaps of dental restorations [15,16]. Many sections can be obtained using micro-CT images and direct measurement could be performed from these 2-dimension sections without any additional preparation. The micro-CT technology appears to be a reliable tool to evaluate the fit of dental restorations and this method may

be recommended as a useful tool for the evaluation of dental restorations [9,15].

The sources of marginal discrepancy for fixed dental prostheses are the processing techniques, abutment preparation, type of dental ceramics, cementation techniques, etc. [9,10]. For all-ceramic materials, several processing techniques are available for different ceramic systems such as slip-casting, heat-pressing, conventional condensation and sintering technique. Currently, computer-aided design and computer-aided milling systems (CAD-CAM) are generally available for processing of all-ceramic prostheses. Different ceramic systems can be used in the CAD-CAM processing techniques such as leucite-based, lithia-silicate-based, lithia-disilicate-based, alumina-based and zirconia-based dental ceramics. There processing and composition difference factors could affect the marginal discrepancy of all-ceramic dental prostheses. The objective of this study was to evaluate the marginal and internal adaptation of lithia-disilicate-based all-ceramic posterior crowns fabricated by heat-pressing, and the CAD-CAM techniques using X-ray micro-computed tomography.

## Materials and methods

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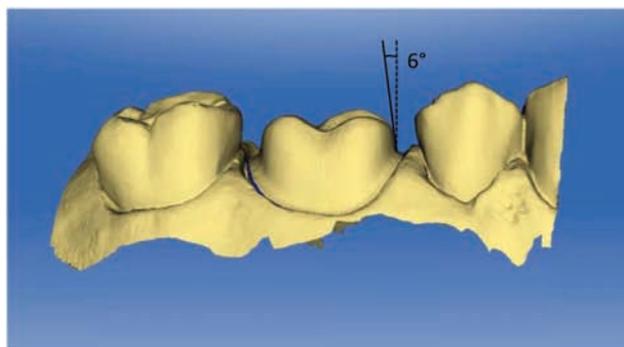
Materials used in this study are shown in Table 1. Three lithia-disilicate-based dental ceramics were used in this study.

### 1. Crown preparation

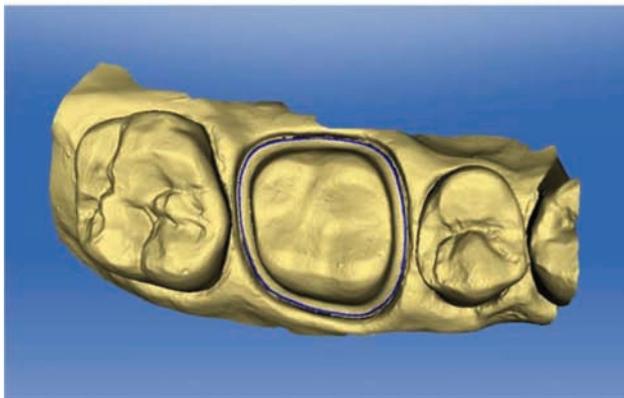
A complete coverage preparation on a posterior upper first molar crown was made on an Ivorine dentoform tooth with a convergence angle of 12 degree, occlusal reduction of 2 mm and chamfer finishing line width of 1 mm with rounded internal angle as shown in Figure 1. Forty type IV gypsum plaster dies (Kromotypo4, Lascod, Florence, Italy) were fabricated by duplicating the prepared tooth with a silicone material.

Table 1. Details of materials used in this study

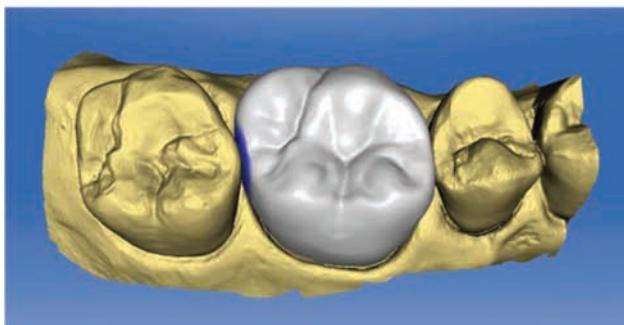
Materials	Manufacturers	Compositions
VINTAGE LD PRESS	SHOFU INC. Address: 11 Kamitakamatsu-cho, Fukuine, Higashiyama-ku, Kyoto 605-0983, JAPAN	Lithium-disilicate-based glass ceramic for heat-pressed technique
IPS e.max <sup>®</sup> Press	Ivoclar Vivadent AG Bendererstrasse 2 9494 Schaan Liechtenstein	Lithium-disilicate-based glass ceramic for heat-pressed technique
IPS e.max <sup>®</sup> CAD	Ivoclar Vivadent AG Bendererstrasse 2 9494 Schaan Liechtenstein	Lithium-disilicate-based glass ceramic for CAD-CAM technique
IPS e.max <sup>®</sup> Ceram	Ivoclar Vivadent AG Bendererstrasse 2 9494 Schaan Liechtenstein	Nano-fluorapatite glass ceramic veneering material



(a) Side view



(b) Top view



(c) Ceramic crown model

Figure 1. Preparation of an abutment tooth (a,b) and a ceramic crown model (c) designed by a CAD software.

For specimen preparation in Group 1 and 2, a wax-up of a posterior upper first molar crown was made on a prepared tooth. A die plaster model and a wax-up were scanned using a laboratory scanner (inEos Blue, Sirona dental systems GmbH, Bensheim, Germany) to attain 3-dimensional images and used to construct a 3-D full-contour crown model with a cement space of 40  $\mu\text{m}$  (Figure 1). Twenty crowns were milled from a milling machine (inLab MC XL, Sirona dental systems GmbH, Bensheim, Germany) using investable acrylate polymer blocks (IPS AcryCAD blocks, Ivoclar Vivadent AG, Schaan Liechtenstein). After investing of twenty acrylate crowns and pressing according to the manufacturers' instruction, twenty ceramic crowns were fabricated, ten crowns for VINTAGE LD Press (Group 1) and ten crowns for IPS e.max Press crowns (Group 2). These ceramic crowns were cleaned, finished and glazed with a glazing material to obtain the final restorations.

For posterior single crown fabricated from a CAD-CAM technique in Group 3, ten crowns were milled from a 3-D full-contour crown model, identical to that used for pressing technique, using IPS e.max CAD blocks. After crystallization in a furnace, all ceramic crowns were glazed with a glazing material to obtain the final restorations. In Group 4, ten crowns were milled from a cut-back crown model using IPS e.max CAD blocks to obtain ceramic substructure for veneering. After crystallization, these substructures were veneered

with IPS e.max Ceram veneering material using a silicone index in order to obtain all-ceramic crowns that were closely resemble to the monolithic crowns. These veneered crowns were glazed to obtain the final restorations.

For an x-ray analysis, all ceramic crowns were affixed to their corresponding dies made from gypsum plaster type IV using a silicone material (Fit Checker, GC DENTAL PRODUCTS CORP., Aichi, Japan) and placed under 5 kg-load using a loading device. After polymerization of a silicone material, the die-ceramic crown assembly was directly examined by an experienced dental technician to ensure an optimal seating of these crowns.

## 2. Micro-computed tomography (Micro-CT)

The micro-CT measurements of marginal and internal fit were performed using a SkyScan 1173 micro-CT scanner (Bruker, Kontich, Belgium). Images were acquired using 80 kV voltage, 100 uA current, and a 1mm Al filter with a pixel size of 9.16  $\mu$ m. A detector size of 2240×2240 pixels was chosen. The specimens were scanned for 180 degrees (1 complete rotation) at 3 frames per rotation step of 0.4 degree. After scanning, the images were reconstructed in a software (SkyScan NRecon 1.6.8.0, Kontich, Belgium). The reconstruction settings used were level 20 ring artifact correction, 60% beam hardening artifact correction. The SkyScan DataViewer software (Kontich, Belgium) was used to generate 3 image views: coronal (x-z plane), sagittal (y-z plane), and transaxial (x-y plane). These views were used to locate the mesiodistal and buccolingual positions of an all-ceramic crown.

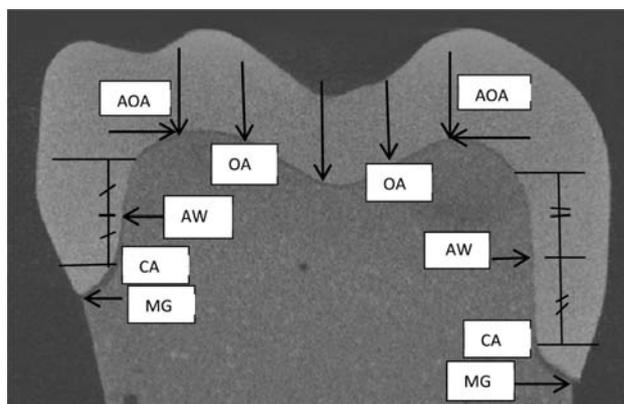
The DataViewer software was used to locate the desired measurement points. With the points identified in two sections, the marginal and internal gap values were determined at four reference planes (sagittal buccal, sagittal lingual, coronal mesial and coronal distal). All points for a gap measurement were located in Data Viewer as

shown in Figure 2, and the measurements were made at ×130 magnification. The marginal gap (MG) was measured at 4 points and internal adaptation at 8 points for each specimen. The sites of internal gap measurement were axial wall (AW) and occlusal area (OA).

The gap width at each point of measurement in each all-ceramic crown was used for a statistical analysis. Because of asymmetrical distribution of the gap width values as analyzed by Shapiro-Wilk test, the differences between the mean gap widths of all experimental groups were analyzed using the Kruskal-Wallis nonparametric test at a significance level of .05.

## Results

The median values of marginal and internal gaps of all experimental groups are summarized in Table 2. The median marginal gap widths of all groups were not significantly different and these values were within an acceptable limit at 120  $\mu$ m [3]. For internal gap widths, IPS e.max<sup>®</sup> Press crowns had a significant lower internal gap width than those of the other three remaining groups. IPS e.max<sup>®</sup> CAD veneered with IPS e.max<sup>®</sup> Ceram



**Figure 2.** Scanned crown and die by Skyscan 1173 Micro CT, showing sites of marginal gap (MG), chamfer area (CA), axial wall (AW), and occlusal area (OA), axio-occlusal angle (AOA) of mesiodistal and buccolingual positions of the crown.

had marginal and internal gap widths comparable to those of IPS e.max<sup>®</sup> CAD monolithic crowns. The veneering procedure appeared to have no effect on the marginal and internal adaptation of all-ceramic crowns.

## Discussion

There are several factors described as the causes for marginal discrepancy of all-ceramic dental prostheses such as finish line configuration, predefined cement space, veneering process, cementation procedure [9,10]. The measurement protocols also have an influence on the gap evaluation as reported by Nawafleh et al. [10]. For the effect of a ceramic processing process, few studies reported the comparable results for the marginal adaptation of lithia-disilicate-based dental prostheses processed by heat-pressing and CAD-CAM techniques with the gap width ranged from 30 to 88  $\mu\text{m}$  [8,17,18]. Two studies used micro-CT as a measurement tool and the results obtained from the micro-CT analysis appeared to be in good agreement with the results obtained from other techniques [8,17-19], including the marginal and internal gap results obtained from this study. The micro-CT analysis is a direct measurement of the internal space between the internal crown surface and the tooth abutment. It offers the opportunity to explore any point within the area or volume of

interest without cutting off the specimen. Because many sections or planes could be selected, many points of interest could be measure as desired without any cutting or making replicas of the internal spaces of dental prostheses. The image obtained from the micro-CT analysis had high resolution and the data acquisition process was not complicated. Therefore, there is no time to spend on the specimen dissection or preparation and reliable results could be obtained without the errors from the preparation steps. For these reasons, micro-CT is considered to be a useful analytical tool for internal and interfacial studies of dental specimens.

In this study, the effect of processing technique was not significant when compared the marginal gap widths between all-ceramic crowns fabricated from the heat-pressing and CAD-CAM techniques. Because the cement space setting was similar for all groups and the wax-up process was eliminated from the heat-pressed technique, the effect of the heat-pressing and the CAD-CAM procedure could be clearly evaluated and the results showed that these two techniques were comparable in terms of marginal and internal adaptation. Lithia-disilicated-based materials used in this study were acquired from two manufacturers. They have almost identical heat-pressed procedures but their compositions could not be compared because of limited information provided from the company. However,

**Table 2.** The median values of marginal and internal gaps of all experimental groups

Groups	Marginal gap ( $\mu\text{m}$ )		Axial gap ( $\mu\text{m}$ )		Occlusal gap ( $\mu\text{m}$ )	
	Median	Minimum-maximum	Median	Minimum-maximum	Median	Minimum-maximum
Vintage LD Press	73.25 <sup>a</sup>	9.16-146.50	91.56 <sup>A, B</sup>	9.16-311.32	106.76 <sup>A, C</sup>	36.63-316.13
IPS e.max <sup>®</sup> Press	54.94 <sup>a</sup>	18.31-129.49	75.51 <sup>A</sup>	9.16-202.27	75.51 <sup>B</sup>	18.31-220.52
IPS e.max <sup>®</sup> CAD	54.94 <sup>a</sup>	9.16-109.88	109.88 <sup>B</sup>	36.63-293.58	137.42 <sup>C</sup>	36.63-329.91
IPS e.max <sup>®</sup> CAD veneered with IPS e.max <sup>®</sup> Ceram	54.94 <sup>a</sup>	36.63-219.78	128.19 <sup>B</sup>	54.94-403.30	128.19 <sup>C</sup>	36.63-293.00

Different superscript letters in each column indicate statistically significant difference between those median values.

slight difference in the marginal gap widths was observed for Vintage LD Press and IPS e.max<sup>®</sup> Press. The composition differences might be the reason for this discrepancy. The veneering procedure is also a subject of interest when it has been considered as a cause of marginal discrepancy for a dental fixed prosthesis. For metal-ceramic restorations, it has been reported that the large marginal discrepancies developed during grinding and abrasive blasting procedures and the incompatibility stress induced by a contraction mismatch between veneering and metal substructure was not a primary cause of marginal distortion of metal-ceramic crowns [20]. For all-ceramic systems, there is limited information regarding this topic and the results from few studies indicated the possibility of marginal distortion during porcelain firing of zirconia-based dental prostheses and other dental ceramics, [21-24] while another study reported that the porcelain firing cycles did not affect the marginal fit of zirconia-based dental prostheses and In Ceram crowns [25,26]. For leucite-based and lithia-disilicate-based dental ceramics, there was a report indicated that the marginal gap increased during veneer application and decreased during the characterization and glazing firing cycle [27]. There was no clear explanation for these changes. In this study, the porcelain firing cycles did not affect the marginal and internal adaptation of lithia-disilicate-based posterior crown and substructure produced from a CAD-CAM technique.

Presently, the CAD-CAM system becomes a routine fabrication process of dental fixed prostheses. Comparing with the conventional heat-pressing or condensation and sintering techniques, it provides an alternative choice for a dental professional with some advantages such as less processing time, several materials for use with the CAD-CAM system, fewer errors caused from an inexperienced dental technician etc. The main disadvantage is its high cost for equipment and materials. Because the results from this study indicated the comparable marginal

and internal adaptation of all-ceramic crowns fabricated from heat-pressing and CAD-CAM techniques, these two techniques could be effectively used depending on the preference of dental practitioners and the availability of the equipment. The micro-CT analysis used in this study also provided reasonable results with some controlled machine-related difficulties. This technique could be a useful analytical tool for internal structure or interface characterization of many dental structures and dental restorative materials.

## Conclusion

In conclusion, within the limitation of this study, the following conclusions could be drawn;

1. The marginal and internal adaptation of lithia-disilicate-based all-ceramic posterior crowns fabricated by heat-pressing and CAD-CAM techniques were comparable.
2. The micro-CT analysis was considered to be a useful analytical tool for internal and interfacial studies of dental prostheses and materials.

**Acknowledgement:** None

**Funding:** VINTAGE LD PRESS ingots and investment materials were supported by SHOFU INC., JAPAN.

**Competing interests:** None

**Ethical approval:** None

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