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# Evaluation of marginal gap of lithium disilicate glass ceramic crowns with optical coherence tomography

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**Abstract.** Marginal gap (MG) was the most important factor to evaluate the success of crowns. The study was to assess the MG of lithium disilicate glass ceramic crowns with spectral domain optical coherence tomography (OCT) and stereomicroscopy *in vitro*, and to provide evidence to measure the MG with OCT. Consistency was observed between OCT and stereomicroscopy to measure the MG after cementation. There was no significant difference between the MG of lithium disilicate glass ceramic crowns using OCT and stereomicroscopy (OCT  $59.55 \pm 7.22 \mu\text{m}$ , stereomicroscope  $59.48 \pm 6.53 \mu\text{m}$ ,  $P = 0.736$ ) after cementation. OCT was a noninvasive diagnostic technique to measure the MG of lithium disilicate glass ceramic crowns. © 2018 Society of Photo-Optical Instrumentation Engineers (SPIE) [DOI: 10.1117/1.JBO.23.3.036001]

Keywords: optical coherence tomography; stereomicroscopy; marginal gap.

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## 1 Introduction

Marginal gap (MG) was the most important factor to evaluate the success of crowns.<sup>1,2</sup> Holmes et al.<sup>3</sup> described MG as the horizontal discrepancy from the crown surface and the tooth (Fig. 1). Previous studies had described various methods to measure the MG including direct-view technique, cross-sectioning technique, replica technique, profile projector, digital impression, and microcomputed tomography ( $\mu$ -CT). Due to the limitations, those techniques could have a significant impact on the results.<sup>4-8</sup> It was difficult to identify reference points to measure<sup>9</sup> and thus led to projection errors,<sup>10</sup> when direct-view technique was applied. While only partial sections of the specimen could be obtained, and might not represent the complete gap of the crown for long-term analysis and comparison of the MG when cross-sectioning technique was applied.<sup>11,12</sup> It was difficult to detect micron-scale gaps due to the radio-opacity similarity between the adhesive and the air when  $\mu$ -CT was used.<sup>13</sup> The silicone replication was the only MG measurement method used *in vivo*, but the results were not as accurate as those yielded *in vitro*.<sup>14</sup>

Optical coherence tomography (OCT) was a noninvasive diagnostic imaging technique based on the light backscattering of the interior biologic microstructure and material. OCT had been applied in clinic and prospective studies in terms of cardiology, orthopedics, and ophthalmology. OCT used safe light sources to produce time-domain, high-resolution cross-sectional images. Tooth hard tissues and lithium disilicate glass ceramic were good scattering media, so they were suitable substrates for OCT.<sup>15,16</sup> Tooth restoration interface under direct and indirect resin restorations had been investigated using this technique;<sup>17-21</sup> however, few data were recorded on evaluation of the MG of a lithium disilicate glass ceramic crown with OCT. This study was to measure the MG of lithium disilicate glass ceramic crowns with OCT and stereomicroscopy technique,

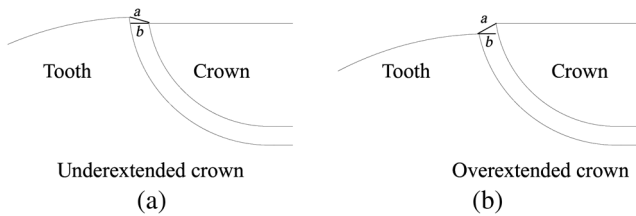
and to provide evidence to measure the MG of lithium disilicate glass ceramic crowns with OCT for clinical requirement.

## 2 Material and methods

### 2.1 Specimen Preparation

In this study, 32 extracted human maxillary third molars without cracks, caries, and restorations were selected after obtaining informed consents of the patients. The ceramic crown preparation was free of undercuts, the occlusal surface was reduced 2 mm, the angles were rounded, and the walls were tapered 6 deg to the occlusal surface. The margins were 1-mm wide with chamfer finish line design above the 1.5-mm cemento-enamel junction. A thin layer of titanium dioxide powder was applied to the prepared surface with an aerosol (Cerec powder, Vita Zahnfabrik, Germany). Optical impressions of the prepared teeth were made using the scanner (MD-ID 200, Segma, Korea). The crowns were designed by HyperDent CAD software with luting space and adhesive gap set to 0  $\mu\text{m}$ .<sup>5</sup> A milling unit (ARUM 5X-200, Segma, Korea) was used for CAM processing of the designed crowns. The lithium disilicate glass ceramic materials (IPS e.max CAD Ivoclar-Vivadent, Liechtenstein) were used to fabricate the crowns. After the completion of the milling process, all the crowns were crystallized in a porcelain furnace (Programat EP 3010, Ivoclar-Vivadent, Liechtenstein). The total etching technique was performed and the crowns were bonded to the teeth with luting (Variolink N, Ivoclar-Vivadent, Liechtenstein) according to the manufacturer's instructions. After one hour of cementation, all specimens were embedded under 2-mm cemento-enamel junction by epoxy resin and stored in deionized water at 37°C for one week. This study was approved by ethics committee at Beijing Tong Ren Hospital, Capital Medical University (Clinical Trials. 2014BJSZR-10).

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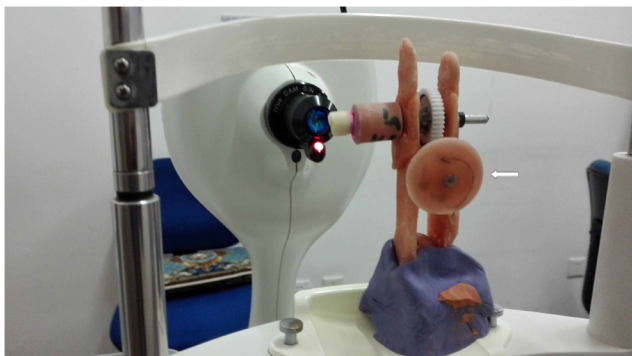


**Fig. 1** Crown misfit terminology (a) absolute marginal discrepancy and (b) MG.

## 2.2 Optical Coherence Tomography

A spectral domain OCT system (iVue-100, Optovue) was used in this study. The scan beam wavelength was  $840 \pm 10$  nm with a 26-kHz sweep rate. The axial and lateral resolution of the system was 5 and 15  $\mu\text{m}$ , respectively. A series of A-scans from the crowns to the teeth produced a raw data file (B-scan) with information of backscattered light as well as X, Z coordinates of each point in the scanned area. Backscattered light carrying microstructure information of the specimens was received by the system, and then digitized into time-series data that can be analyzed to reveal the depth information of the subject. The system was capable of creating real-time high-resolution 2-D images by analyzing the frequency components of backscattered light from the specimens.

To ensure the repeatability of the OCT scans for the same specimen, thin lines were drawn on the surface of each crown to assure that specimens were accurately placed at the exact same angle. Before the measurement, the object lens center, marked line on the crown and the tooth long axis were on the same geometric plane, and the object lens center and marked line of restoration were perpendicular to the axis with a special device (Fig. 2). To capture the OCT image, the specimen was positioned along the tooth long axis and rotated 7.5 deg each time. In this manner, 48 serial 2-D sections for each tooth were obtained with gray-scale images. For the data analysis, each of the 48 2-D sections was digitally analyzed using Image J (ver. 1.50i, National Institutes of Health). A customized program was plugged into the ImageJ to facilitate the analysis procedure and identify pixel clusters with higher brightness indicating the MG. The picture was turned to 8-bit. We used the line profile tool to detect the gray value between ceramic and tooth, and used the line selection tool in ImageJ to draw a line along the length of the scale bar in the right side of



**Fig. 2** OCT equipment and special device to fix a tooth: we used a special device to locate and turn the teeth and to ensure the repeatability of the OCT scans for the same specimen (left arrow).

the figure as a calibration, draw a horizontal line between enamel and ceramic, and calculate the MG of the crowns using the equation as below.

The equation used to calculate as follows:

The marginal gap of the crowns =  $a * b/c$ ,

where  $a$  the distance of the scale bar,  $b$  is the horizontal length between enamel and ceramic, and  $c$  is the length of the scale bar.

## 2.3 Stereomicroscopy

Stereomicroscopy was widely used to detect the MG of crowns due to its convenience and brevity. The specimens were positioned along the tooth long axis and rotated 7.5 deg for each image. The object lens center, marked line of restoration, and axis of the tooth were on the same geometric plane, and the object lens center and marked line of restoration were perpendicular to the axis. In this manner, 48 serial 2-D planes were obtained at a magnification level of 60 $\times$  by stereomicroscopy. For the data analysis, the midline of 2-D planes in the series was digitally analyzed using Image J (ver. 1.50i, National Institutes of Health).

## 2.4 Statistical Analysis

The horizontal discrepancies between the ceramic surface and the tooth in the series of 48 images of each specimen were recorded as MG (Fig. 1). Descriptive statistics were computed for each group with SPSS v19.0. Bland-Altman analysis and paired  $t$  test were used to test consistency of MG between stereomicroscopy and OCT. In all evaluations, the  $p$  value  $<0.05$  was considered statistically significant.

## 3 Results

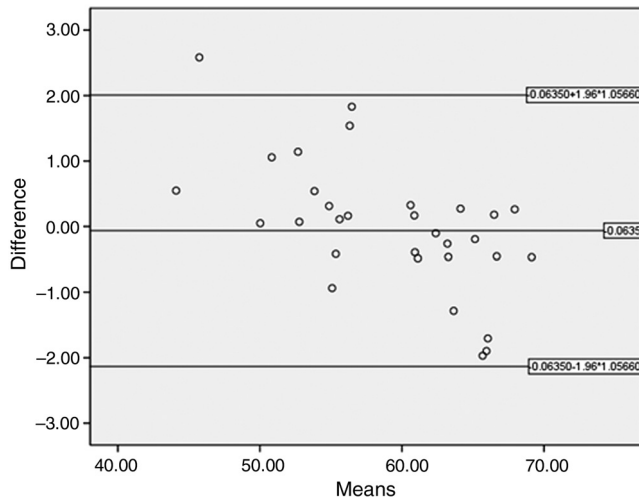
The results showed no significant difference in the MG between OCT and stereomicroscopy (OCT  $59.55 \pm 7.22$   $\mu\text{m}$ , stereomicroscope  $59.48 \pm 6.53$   $\mu\text{m}$ ,  $p = 0.74$ ) (Table 1). Bland-Altman methods were used to analyze the correlation between the distribution of the scattered distance of the MG measured by OCT and stereomicroscopy, the degree of variation of the measurement method, and the consistency based on the observed difference between the two measurement methods (Figs. 3 and 4). All the indicators of the results mentioned above were found to be comparable between OCT and stereoscopic microscopy.

## 4 Discussion

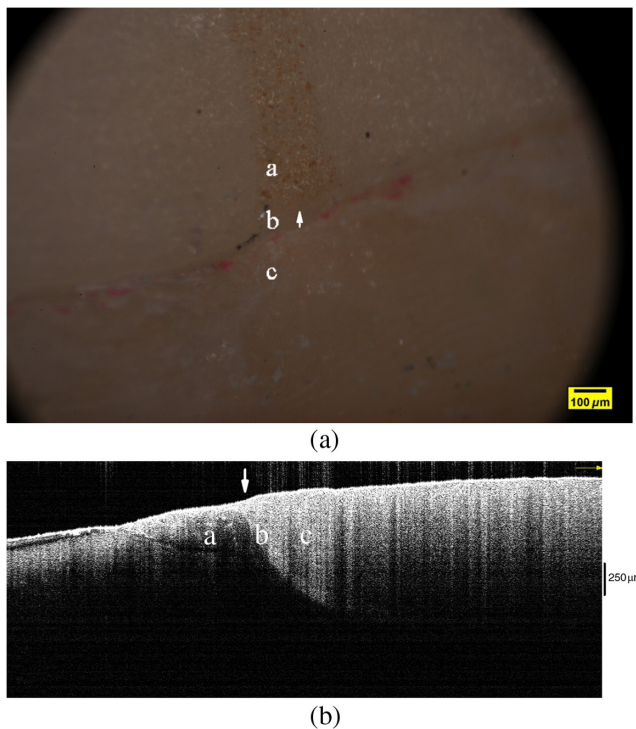
This study evaluated the MG of lithium disilicate glass ceramic crowns using OCT and stereomicroscopy. OCT was identified as

**Table 1** The MG with OCT and stereomicroscopy paired  $t$  test.

Pair of differentials		Mean standard error		Differential 95% confidence interval		Sig. (two sides)	
Mean	standard deviation	standard error	Lower	Higher	t	df	
-0.064	1.06	0.19	-0.44	0.32	-0.34	31	0.736



**Fig. 3** Consistency analysis of MG with OCT and stereomicroscopy: Bland-Altman analysis.



**Fig. 4** Measure the MG with different methods (a) stereomicroscope and (b) OCT [MG shown (up arrow)]; (a) enamel, (b) luting, and (c) lithium disilicate glass ceramic. (a) MG with stereomicroscope was  $66.38 \mu\text{m}$  and (b) MG with OCT was  $66.40 \mu\text{m}$ .

a good method to evaluate MG in this study. This study showed consistency between OCT and stereomicroscopy to measure the MG of lithium disilicate glass ceramic crowns after cementation.

Different measurement methods were used to evaluate the MG among the previous studies. Measurements including direct-view technique, cross-sectioning technique, replica technique, profile projector, digital impression, and  $\mu$ -CT were used to evaluate the MG and led to the results with significant various methods.<sup>4-8</sup> Those measurement methods had advantages and disadvantages (Table 2). For technical reasons, silicone replication was the only MG measurement method used in the clinic.

It was difficult to identify reference points measured and results of silicone replication were not as accurate as those methods described above *in vitro*.

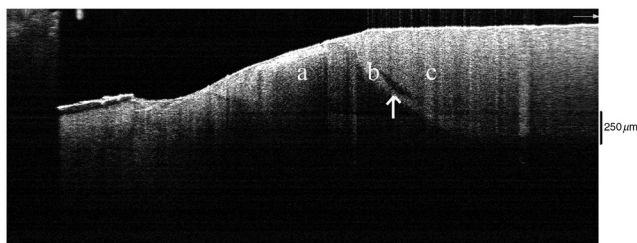
Compared with measurement methods described above, OCT was a noninvasive diagnostic imaging technique based on different light backscattering of biological microstructures and materials, which could produce real-time, high-resolution images with a safe light source. To date, OCT has been applied to the fields of ophthalmology, pathology, and vascular biology. Previous studies have found that dental materials and dental tissue can backscatter light very suitable for OCT.<sup>15,21</sup> Without cutting the specimen or using radioactive material, the OCT can detect the adhesive interface of the tooth directly repaired.<sup>17-21</sup> Turkistani et al.<sup>21</sup> found that OCT could distinguish between multilayer interfaces between resin inlays and dental tissue, assess internal adaptation, and observe and compare the same site at different times in a long-term study. OCT could measure the MG between the teeth and the crowns and thus could be used to detect internal adhesion defects (Fig. 5). The MG of the lithium disilicate glass ceramic crown measured with stereomicroscope and OCT was evaluated. There was no significant difference between the two methods ( $p = 0.736$ ), which indicated that the OCT method could be applied to evaluate the MG of the lithium disilicate glass ceramic crowns.

In this study, the signal intensities (small peak) at the interface between luting and tooth, and that between luting and ceramic were stronger than other areas, causing brighter areas in the images, which could be used to indicate the boundaries of different materials. The refractive index of air is  $n = 1.0$ , whereas the lithium disilicate glass ceramic had a refractive index of  $1.55$ <sup>28</sup> and that of both the tooth and the resin composites are in the range of  $n = (1.5, 1.6)$ .<sup>29</sup> When light traverses the interface through two different medium, it generates refraction as well as partial reflection. The Fresnel phenomenon is the reflection of a fraction of light at an interface between two media with different refractive indices, which depends on the incidence angle and refractive index ( $n$ ) contrast.<sup>19</sup> A higher OCT signal value at the boundary was seen depending on the optical properties of the substances involved. Interpretation of the OCT signal requires knowledge of the optical properties of the media involved, and that of the interactions of light within the specimens. The range of enamel crystal caused the attenuation of the light, with weaker signal intensity at the deeper regions in the teeth. In comparison, attenuation of the light through the ceramic was less due to good optical properties of the ceramic. The Fresnel reflection can be clearly observed at the interfacial areas of teeth and luting, and that of ceramic and luting. The surface reflection was significant in the ceramic. In contrast, the surface reflection was difficult to observe well at the tooth and luting due to rough surface. As the interface between the ceramic and the luting, and that between the luting and the tooth could be easily distinguished, the MG was then measurable.

MG was the most important factor used to evaluate the success of crowns. Fransson et al.<sup>30</sup> and McLean and von Fraunhofer<sup>31</sup> indicated that the clinically acceptable MG after cementation should be  $<150$  and  $120 \mu\text{m}$ , respectively. While others agreed that maximum clinically acceptable MG should be between  $100$  and  $150 \mu\text{m}$  with CAD/CAM ceramic blocks fabricated.<sup>32-34</sup> The mean value of the MG of ceramic restorations was  $56.1 \mu\text{m}$  *in vivo* studies.<sup>35</sup> Additionally, McLean and von Fraunhofer<sup>31</sup> examined the MG of 1000 fixed restorations

**Table 2** The methods to assess the MG.

Methods	Measurements	Advantages	Disadvantages
Direct-view technique	Stereomicroscopy	1. Convenient 2. Brief 3. Long-term analysis	1. Identified reference points to measure may prove difficult <sup>9</sup> 2. Large standard deviations <sup>22</sup> 3. Projection errors <sup>10</sup>
Cross-sectioning technique	Stereomicroscopy, scanning electron microscope	Accuracy	1. Partial sections 2. Not long-term analysis <sup>12</sup>
Replica technique	A light body silicone replica	1. <i>In vitro</i> and <i>vivo</i> 2. Convenient 3. Long-term analysis	1. Each specimen partial sections 2. Mistakes in the sectioning plane can lead to overestimated measurement. <sup>23</sup>
Digital impression	Laser scan crown, silicone replica	Measure internal gap <sup>24-26</sup>	Identified reference points to measure may prove difficult interpretation by profilometer <sup>27</sup>
Profile projector	Profilometer	1. Convenient 2. Brief 3. Long-term analysis	
$\mu$ -CT	$\mu$ -CT	1. Long-term analysis and comparison 2. Nondestructive 3. Provide very close sections. <sup>5</sup>	1. Spend much time 2. x-ray radiation 3. Radio-opacity, low resolution



**Fig. 5** Adhesion defect: there was some air (up arrow) between the enamel and the lithium disilicate glass ceramic. It was difficult to find from the surface of the crowns. (a) Enamel, (b) luting, and (c) lithium disilicate glass ceramic.

over a 5-year period and indicated that the MG  $<80 \mu\text{m}$  was difficult to detect under clinical conditions. Anadioti et al.<sup>36</sup> found that the MG of E.max CAD was  $74 \pm 26 \mu\text{m}$  with a laser coordinate measurement machine before cementation. Neves et al.<sup>5</sup> found that the MG of E.max CAD was  $39.2 \pm 8.7 \mu\text{m}$  with  $\mu$ -CT before cementation. In this study, the MG of E.max CAD was  $59.55 \pm 7.22 \mu\text{m}$  measured by OCT after cementation.

OCT technology was a good method to detect MG of lithium disilicate glass ceramic crowns. This technology was also potentially suitable to measure the MG with a noninvasive method in durability clinic studies. Because the crowns with chamfer had better adaptation than rounded shoulder before and after cement,<sup>37</sup> only the crowns with chamfer were used in our study. While imaging depth limitation for examination of deeper

interfaces and device miniaturization, OCT was an innovation technology for various lab and clinical applications in the dental field.

## 5 Conclusions

OCT was a noninvasive diagnostic imaging technique to measure the MG of lithium disilicate glass ceramic crowns. There was consistency between OCT and stereomicroscopy when measuring the MG of lithium disilicate glass ceramic crowns after cementation.

## Disclosures

The authors have no conflicts of interest to disclose.

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