New Evaluation Method by Microfocus Radiograph CT for 3D Assessment of Internal Adaptation of All-Ceramic Crowns

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The aim of this study was to evaluate the effectiveness of the microfocus radiograph CT system in examining the adaptation of all-ceramic crowns three-dimensionally and non-destructively. The computed tomograms of the crown and abutment model were filmed by microfocus radiograph CT. Using a volumetric rendering software, images of gaps were extracted and reconstructed three-dimensionally, and their volume data analyzed. In order to compare this method with the conventional method, fitness test silicone paste was sandwiched between the abutment and all-ceramic crown. Adaptation of the crown on the abutment model was then observed non-destructively and three-dimensionally. Furthermore, the gaps could be analyzed in any arbitrary position. Concerning mean gap thickness, there was significant differences between the two measurement methods. However, it was very slight. We therefore concluded that the microfocus radiograph CT system is well positioned to be an extremely effective method in examining the adaptation of all-ceramic crowns.

Key words: Microfocus radiograph CT, All-ceramic crown, Internal adaptation

INTRODUCTION

Recently, metal-free crowns using ceramics and particulate filler composites have been put into clinical use. Excellent adaptation is an important factor with these crowns in preventing fracture.

Until now, crown adaptation has been examined by measuring the thickness of marginal gaps, by cutting an epoxy-embedded sample and then measuring the thickness of the gap between the abutment surface and the inside of the crown, and by obtaining mean gap thickness from the weight-to-volume ratio of silicone paste loaded between a crown and abutment.

However, these conventional techniques are two-dimensional methods that determine the thickness of marginal gaps along the thickness of gap in a single section — they do not examine 3D adaptation. In addition, cutting an epoxy-embedded sample is destructive and makes it impossible to examine the same sample again.

Radiograph CT (computed tomography) is used in medicine to reconstruct 3D images of organs, collect 3D images of a particular organ, and analyze its volumetric image data. Medical radiograph CT cannot be used for analyzing crown restorations due to its poor resolution. Nevertheless, the use of microfocus radiograph CT should allow a 3D image reconstruction of crowns, the volumetric analysis of each area, and the examination of their interiors in a non-destructive manner.

The purpose of this study is to evaluate the adaptation of crown restorations in a 3D and non-destructive manner by filming all-ceramic crowns and abutment models using a microfocus radiograph CT system.

MATERIALS AND METHODS

In this experiment, a clinical abutment model of the maxillary left first molar was used. These were epoxy abutment teeth (HP24S, Nissin, Kyoto, Japan) duplicated from an artificial tooth prepared with a taper of 6° and a marginal configuration of a round shoulder shape with an entire circumference of 0.8 mm (Fig. 1). Working dies were made by making an

Fig. 1 Abutment model, plaster model, and all-ceramic crown used in experiment.
impression of the epoxy abutment with a silicone impression material and by casting modified dental stone. Ceramic crowns (IPS Empress, Ivoclar AG, Liechtenstein) were fabricated on the dies by a heat-pressed method according to the manufacturer’s instructions, and five experimental crowns with the same shape were prepared. The thickness of each crown sample was about 1.5 mm at the central groove and about 2.0 mm at the cusp tips.

The crowns were seated on the abutment models without applying any special pressure, and computed tomograms were taken by the microfocus radiograph CT system (SMX-225CT, Shimadzu, Kyoto, Japan). Each die was secured onto a turntable with the occlusal surface pointing upward (Z-axis direction), and measurements were taken in a 31 µm pitch in the Z-axis direction and in 31 µm pitch on the X-Y plane (horizontal plane).

Adaptation of the crowns was analyzed by extracting the images of internal gaps between the crown and abutment using an image editing software (Photoshop 7.0J, Adobe, CA, USA). Then, using a volumetric rendering software (VGStudio MAX 1.1, Volume Graphics, Heidelberg, Germany), the 3D volume of the internal gaps was calculated (Fig. 4). At the same time, the 3D shape of the abutment teeth was measured using a non-contact 3D shape measurement device(3), and the surface area of each abutment was calculated using a 3D shape measurement program (3D-Rugle-3, Medic, Kyoto, Japan). Mean thickness of internal gap was calculated by dividing the volume by the area of the entire abutment surface.

In addition, as a control measurement, the conventional method was also carried out. Fitness test silicone paste (Fitchecker2, GC, Tokyo, Japan) was applied to the internal surface of the crowns. The crown specimen was then seated on the abutment, and a load of 20 N — simulating finger pressure — was applied on the occlusal surface of the crown using a compact material tester (EZTest, Shimadzu, Kyoto, Japan). After polymerization of the paste, excess paste was removed from around the crown using a knife, and the silicone paste remaining between the crown and abutment was weighed using an electronic scale (ER-60A, A&D, Tokyo, Japan). Gap volume was derived from the density of Fitchecker2, which was 1.15 g/mm³. Density of Fitchecker2 was calculated based on manufacturer’s published specifications: base 1.00 g/mm³ and catalyst 1.30 g/mm³. Mean gap thickness was then calculated by dividing the volume by the surface area.

Results of the two measurement methods for the five crowns were statistically compared using a paired t-test.

RESULTS

A 3D image of the crown and abutment was reconstructed using the microfocus radiograph CT, such that crown adaptation could be analyzed in a 3D manner without destroying any sample (Figs. 2 and 3). Concerning the adaptation of the crown samples, internal gap thickness at cross-section (c) in Fig. 3 was 66 µm on the buccal side, 64 µm on the lingual side, 65 µm on the mesial side, and 37 µm on the distal side. At cross-section (d), the measurements were 73 µm, 60 µm, 74 µm, and 55 µm respectively. As seen from the above results, gap thickness at cross-sections (c) and (d) was not uniform.

A screenshot for analyzing an extracted gap by volumetric rendering software is shown in Fig. 4. The upper left-hand image represents the three-dimensional reconstruction of the gap and the analyzing position is indicated by the red point. Gap thickness is indicated in yellow. This manner of gap analysis is possible in any arbitrary position.

The three-dimensional images of the gap reconstructed are shown from three angles in Fig. 5. The upper figures are opaque images that visualize gap, and the lower figures are translucent images that visualize gap thickness. When gap thickness decreased, the translucency increased as shown by the five red measuring points (Fig. 5(a)). From the mesial side view, gap size was estimated to be smaller at the lower part of the mesio-axial surface and at the margins (Fig. 5(b)). On the buccal surface from abutment viewpoint, gap size at the buccal-axial surface was estimated to be uniform (Fig. 5(c)).

The mean gap thicknesses of the five samples measured by microfocus radiograph CT and fitness test silicone paste are shown in Fig. 6. For comparison purpose, this figure also shows the average thickness values obtained by these two methods. With microfocus radiograph CT, average thickness was 119 ± 7 µm — slightly larger than 113 ± 9 µm by the fitness silicone paste method. Using the paired t-test, significant difference was observed between them (P=0.018).

DISCUSSION

Microfocus radiograph CT has been used for the analysis of bone structures,14 anatomical study of tooth morphology,16,17 and construction of models for the 3D finite element method in the medical and dental fields.18,19 In this study, the use of microfocus radiograph CT was extended to examining crown adaptations — leveraging on the advantages that microfocus radiograph CT is capable of measuring the inner structure of an object accurately and without the need for sectioning.

To examine crown adaptation in a non-
Fig. 2 Cross-section images of crown and abutment measured by microfocus radiograph CT shown in upper stand and extracted gap images shown in lower stand.

Fig. 3 Tomographic images of all-ceramic crown and abutment model measured by microfocus X-ray CT and 3D reconstruction image.

a) 3D reconstruction image;
b) Bucco-lingual tomographic image;
c) Horizontal tomographic image of line (c) in Fig. 3(b);
d) Horizontal tomographic image of line (d) in Fig. 3(b).
Fig. 4 A screenshot for analyzing the extracted gap by volumetric rendering software.

Fig. 5 3D images of the gap reconstructed. The upper figures are opaque images, and the lower figures are translucent images.

a) View from occlusal side;  
b) View from mesial side;  
c) View to buccal surface from abutment side.
3D ASSESSMENT OF INTERNAL ADAPTATION

If crown adaptation can be analyzed non-destructively, then it is possible to repeat the experiment with a set of changed conditions such as exerting different pressure on the crown when it is returned to the abutment. In addition, it is an unarguably great advantage to be able to check crown adaptation before loading the crown.

With respect to adaptation of all-ceramic crowns, Grey et al.\(^8\) reported that the mean gap thickness between an all-ceramic crown and the abutment was 123 \(\mu m\) for the In-Ceram system. For the Empress system, Henn et al.\(^6\) reported that gap widths at the lingual and buccal margins were 41.2 \(\mu m\) and 45.2 \(\mu m\) respectively, and a part of the incisal edge was more than 250 \(\mu m\) after being heat-pressed and fired once. In this experiment, the mean gap thickness was 119 \(\mu m\) — which was within the range of other reported studies. Significant differences were observed between the thickness measured by microfocus radiograph CT and by fitness test silicone paste. All crowns had a slightly larger mean gap thickness when measured by the microfocus radiograph CT system than when measured by the fitness test silicone paste method. Sohmura et al.\(^22\) reported that the size and morphology of a 3D object reconstructed by CT data were influenced by the CT values. In this study, it was thought that gap thickness was influenced by the image processing threshold value — hence suggesting that calibration was necessary. However, the difference between the two measuring methods was very small and the accuracy of iterative measurement was stable, indicating that the microfocus radiograph CT system has sufficient accuracy in evaluating crown adaptation.

At present, the microfocus radiograph CT system is expensive. However, this equipment is easy to use and the measurement time is less than 15 minutes per crown. Other advantages of this system include its ability to perform non-destructive, three-dimensional, quantitative and visual measurements for several types of material (such as metal, ceramic, and resin), including biohistological materials. Based on the evaluation results of this study and coupled with the advantageous features of this system, microfocus radiograph CT is well positioned to be an extremely effective method in examining the adaptation of all-ceramic crowns.

CONCLUSIONS

1. Adaptation of all-ceramic crowns can be analyzed quantitatively, visually, non-destructively, and three-dimensionally using a microfocus X-ray CT system.
2. Mean gap thickness of the five samples analyzed by microfocus X-ray CT was higher than that by fitness test silicone paste. There was significant
differences in gap size between the two measurement methods, but the difference was very slight.

3. This system makes it possible to examine internal defects in crown restorations in a non-destructive manner.

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