CT Study of Radiopaque Implant Template for Gingival Form

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Abstract
The purpose of this study was to determine the optimal concentration of contrast medium incorporated in a radiopaque implant template for gingival form using computed tomography (CT). Trays were prepared with vacuum acrylic shells using casts of the gingival region of porcine mandible. Barium sulfate was then mixed with silicone impression material as a radiopaque material. The concentrations of barium sulfate were 0, 5, 10, 15, 20, 25 vol%. The CT template was replaced the porcine mandible and was fixed by immersion in a water vessel using a phantom before cone beam CT examination. Cross-sectional images evaluated at different barium sulfate concentrations were obtained from the same part. During assessment, the images were visually evaluated using the two-alternative forced-choice (2AFC) method, during which, each of 6 radiologists made an individual assessment. Statistical analysis of the results recorded by the 6 radiologists was performed. Their assessment involved allocating a score to each barium sulfate concentration image; the 5 vol% and 10 vol% concentration images subsequently recorded the highest scores. In particular, cross-sectional images of 5 vol% barium sulfate scored higher than those of all other concentrations. CT templates comprising silicone impression materials containing 5 vol% barium sulfate were easy to use with regard to precise visualization of gingival form. The present study suggests that CT templates comprising silicone impression material containing 5 vol% barium sulfate provide useful information in the assessment of soft tissue structures such as the gingiva prior to implant treatment.

Keywords:
diagnostic CT template, barium sulfate, implant, gingival form, two-alternative forced-choice (2AFC)

Introduction
Accurate assessment before implant surgery requires precise radiographic visualization of anatomical structures and pathological conditions (1–4). The 2001 recommendations of the American Academy of Oral and Maxillofacial Radiology (AAOMR) state that adequate presurgical examination using CT is required in implant dentistry. This recommendation emphasizes accurate determination of pathological conditions and anatomical structures using precise computed tomography (CT) imaging prior to implant placement in the maxilla or mandible (3, 4). Diagnosis of soft tissue structure, including the gingiva, should also be incorporated in the presurgical planning of implant dentistry (5, 6). However, cone beam CT (CBCT) examination dedicated to maxillofacial imaging does not provide sufficient resolution to discriminate soft tissue structures such as the gingiva (6, 7). Therefore, various CT templates have been developed for the precise examination of soft tissue structures, although only a few radiological studies have been conducted in this field (8–12).

The purpose of this study was to evaluate the optimal concentration of radiopaque contrast medium incorporated in implant templates for investigation of gingival form during CT examinations.

Materials and Methods
Experimental CT templates in the present study were prepared as follows:
1. The porcine mandibular bone including the gingival region was used. Impressions were taken...
using alginate impression material (Aromaloid; GC Corp., Tokyo, Japan) in a standard powder–liquid ratio (Aroma fine plus; GC Corp.), and plaster (New Fujirock; GC Corp.) casts were prepared.

2. A paraffin wax sheet (approximately 1.5 mm thickness) was applied to the plaster casts, and then, vacuum acrylic shells were applied to the plaster cast and then using a vacuum former. The vacuum acrylic shells were removed from the casts after curing.

3. Radiopaque barium sulfate materials were added to a base paste of hydrophilic vinyl silicone impression material (Exahiflex Tube Type; GC Corp.) of intermediate viscosity (regular type) and were mixed homogeneously. Thereafter, the catalyst paste was added and mixed.

4. Impression materials prepared contained radiopaque barium sulfate at 6 levels of concentration (0, 5, 10, 15, 20, and 25 vol%) with tray were used as an experimental CT template.

5. CT templates were replaced to the porcine mandible, and CT examination was performed through a phantom study. The porcine mandible with experimental CT templates were then fixed in a 15 cm cubic water vessel and immersed in water (Fig. 1). For CT imaging, the phantom was set in the center of the gantry so that the X-ray rotation axis was in the same direction as the mandibular bone.

**CBCT imaging**

The NewTom QR–DVT 9000R CBCT system (Verona, Italy) was used (tube voltage 110 kV; tube current 2.9 mA; field of view diameter 160 mm × 150 mm; slice thickness 1.0 mm; scan time 70 s; voxel size 0.25 × 0.25 × 0.30 mm).

**Evaluation of CT images**

Observation conditions during assessment were computationally set using optimal values. Conditions such as monitor brightness, contrast, and gamma values were maintained constant, and images were displayed on the monitor. The cross-sectional image evaluated at each barium sulfate concentration was taken from the same portion.

During the assessment, 6 radiologists visually evaluated the cross-sectional images in a dark room using the two-alternative forced-choice (2AFC) method (13–16) as follows: the 6 images (1 for each barium sulfate concentration) were paired and presented sequentially without identification (1 pair at a time). The observer was asked to choose the image with “better quality,” even if they perceived no difference between the images. To prevent disclosure of the barium sulfate concentrations, viewing time was limited to approximately 30 s at a viewing distance of approximately 40 cm. Each of the radiologists made an individual assessment, and statistical analysis of the results was performed using Stat View–J 5.0 (Abacus Concepts) statistical software and the Kruskal–Wallis test.

**Results**

As per the radiologist assessment by the 2AFC method, each barium sulfate concentration image had a different score, with the 5 vol% and 10 vol%
Fig. 2. Cross-sectional CT images at different barium sulfate concentrations
A: In a cross-sectional CT image at 0 vol% barium sulfate concentration, visual evaluation of the radiopaque implant template is poor.
B: At 5 vol% barium sulfate concentration, density of the radiopaque implant template is similar to that of mandibular cortical bone. The template is uniform, and no artifacts noted at this concentration.
C: Improved evaluation of gingival form at 10 vol% barium sulfate concentration; however, the internal barium particles are not homogeneous.
D: At 15 vol% barium sulfate concentration, a minor artifact is found around the template.
E: At 20 vol% barium sulfate concentration, because the density of the template is greater than mandibular cortical bone, a beam-hardening artifact is found around the template.
F: At 25 vol% barium sulfate concentration, a beam-hardening artifact is found around the template.
concentration images having the highest scores. In particular, the cross-sectional image of 5 vol% barium sulfate concentration scored higher than the images of all other concentrations (p<0.0001). In the cross-sectional CT images of 0 vol% barium sulfate concentrations, the density of the silicone rubber impression material was slightly detectable and visual evaluation was poor. In the 5 vol% images, the density of the radiopaque implant template was similar to that of the mandibular cortical bone. The barium sulfate template was uniform, and no artifact developed at this concentration. Cross-sectional CT imaging of gingival form was superior with the 10 vol% concentration, although a small artifact was found around the template. At concentrations of 15 vol%−25 vol%, confirmation on CT imaging was satisfactory, although a beam-hardening artifact was found around the radiopaque implant template (Figs. 2 and 3).

Discussion

Placement of dental implants requires meticulous planning and careful surgical procedures because the position of the implant cannot be easily changed after implant osseointegration (1). Therefore, preoperative assessment of the anatomical structure of the jaw, including the gingiva, may allow better prediction of a successful outcome following implant placement. Furthermore, prosthodontic expectations encourage the clinician to gain precision in the planning and positioning of implants.

In the present study, the author examined radiopaque implant templates for determining gingival form before CT. This method is a useful tool in implant patients, especially in situations with anatomical limitations, insufficient bone dimensions, and poor bone density. The radiopaque implant template is a combination of a currently used CT template and a mechanical system designed to transfer a preoperatively defined implant position onto the surgical site. The radiopaque implant template can be used not only in critical anatomical situations including soft tissue such as the gingiva but also in placing the implant in an ideal position on the bone, because this eliminates possible manual placement errors and matches planning to prosthetic requirements. Therefore, the present study developed a radiopaque CT template using vinyl polysiloxane silicone impression material containing contrast media. This material is currently the most popular type of impression material, especially for crowns and bridges (17). The precise impression features of silicone enables the precise delineation of soft tissues without any resulting deformity because it has appropriate flexibility and can be firmly and stably returned to diagnostic casts and the oral cavity (17−20).

The results obtained in the present study indicate that the optimal concentration of barium sulfate is 5 vol%, because template density was the same as that of cortical bone and because a portion where the gingival surface was particularly conspicuous on the plate was appropriately indicated. However, fine images could be obtained at concentrations up to 15 vol%, suggesting that suitable CT templates can be obtained with low risk of failure because of variation in the mixing ratio. Barium sulfate artifacts occur because of the beam-hardening, partial−volume effect (12).

In the present study, high−percentage (>15 vol%) templates produced artifacts on CT images (Fig. 2).
The major types of CT artifacts commonly found in clinical practice can be classified as streaking, ring and band, partial-volume, photon starvation, and patient-induced artifacts (21–23). In the present study, the high-percentage templates did not precisely delineate soft tissue because of the presence of artifacts (Fig. 2), most likely beam-hardening and partial-volume artifacts. Beam-hardening artifacts, including metal artifacts, appear as cupping, streaks, or dark zones between highly attenuated objects (23). Beam hardening refers to increase in the mean energy of the X-ray beam as it passes through the object. Clinically, metal artifacts are caused by the presence of metal objects either within the patient’s body, such as metal prostheses, or outside the patient, such as jewelry or metal belts (23). In vivo metal objects such as dental prostheses cause streaking artifacts as a result of beam hardening.

In contrast, partial-volume artifacts occur when a dense object lying off center partially protrudes into the path of the X-ray beam in certain projections. Image obtained with dense objects intruded partially shows partial volume artifacts and objects intruded completely shows no partial volume artifacts. Partial-volume artifacts also occur when an object partially projects into the scanning plane. Scanning of objects of uniform density with partial intrusion from a high-density object results in inconsistencies between different views, causing appearance of shading artifacts in the image (6). These artifacts are best avoided by thin slice acquisition, which is a normal practice with CBCT and is one of the reasons for fewer partial-volume artifacts.

These results also provide useful information in preparing computer guide systems and in selecting superstructures. However, further research needs on this point.

In conclusion, CT templates composed of radiopaque silicone impression material used for the determining gingival form demonstrated the highest score at 5 vol% barium sulfate concentration. These findings suggest that CT templates comprising silicone impression material containing 5 vol% barium sulfate provide useful information for assessing soft tissue anatomical structures such as gingival form before implant treatment.

Acknowledgments
The author is grateful to Professor Takashi Kaneda (Department of Radiology, Nihon University School of Dentistry at Matsudo) for his direction and helpful advice and to Assistant Professor Shintaro Mori (Department of Radiology, Nihon University School of Dentistry at Matsudo) for helpful discussions and reviews of the manuscript. The author also wishes to thank his colleagues at the Department of Radiology and the staff of Tsutsumi Dental Clinic for their excellent support. Furthermore, he wishes to thank his wife for her support.

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