DIMENSIONAL ACCURACY OF A BINDER JET MODEL PRODUCED FROM COMPUTERIZED TOMOGRAPHY DATA FOR DENTAL IMPLANTS

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KEY WORDS

Multislice helical CT
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A full-scale model produced by multislice helical computerized tomography (CT) was made by using the binder jet method and applied for presurgical diagnosis, surgical simulation, and the production of surgical templates for dental implant treatment. In this study, accuracy of the full-scale model with plaster powder was assessed by shifting the binary threshold values. A step phantom was made from bone-equivalent material. When it was placed in water, the CT imaging was performed with a multislice helical CT unit. Three-dimensional (3-D) images were reconstructed by 3-D visualization software. Using 4 different threshold values, full-scale models were produced by a binder jet method with plaster powder. All sides of the full-scale models were directly measured, and their values were compared with that of the step phantom. The mean difference was approximately 0.1 mm in the axial plane when the setting was 0.75 for the threshold. In total, the mean difference was approximately 0.2 mm when the setting was 0.50 for the threshold. It is suggested this full-scale model could be applied for presurgical diagnosis, surgical simulation, and the production of surgical templates in dental implant treatment.

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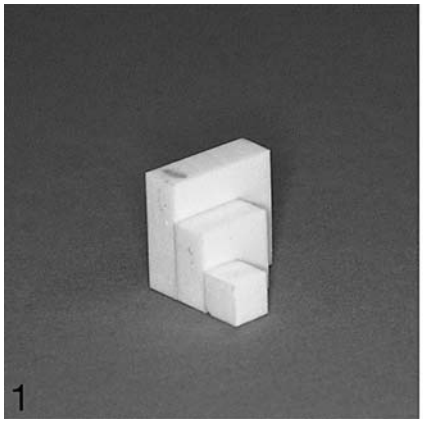
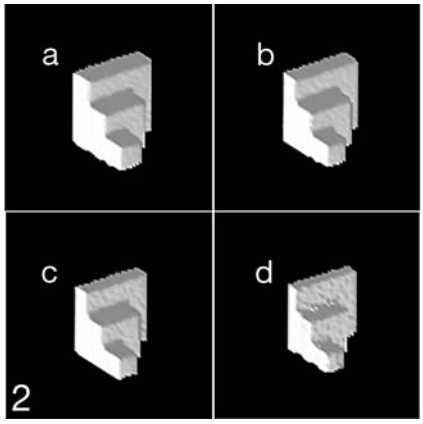
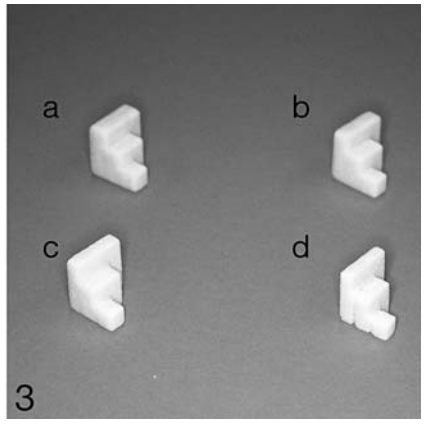
INTRODUCTION

Cross-sectional tomographic images in the buccolingual direction, which can be produced by conventional tomography,[1,2] computerized tomography (CT),[3,4] or compact computerized tomography for dental use,[5] have been used for treatment planning in implant dentistry. It is reported that the accuracy of images by multislice helical CT is high.[6,7] On the other hand, in the oral and maxillofacial region, a full-scale model produced with CT data has been applied for morphological diagnosis and surgical simulation, and its usefulness has been reported.[8–11] Formerly, a full-scale model was produced with CT slice image data and a laser lithography simulation device.[8–11] Previously, we have used a full-scale model produced with three-dimensional (3-D) data obtained by CT and a binder jet method with powder materials.[12] Measurement accuracy of the







FIGURES 1–3. FIGURE 1. A step phantom made from bone-equivalent materials. FIGURE 2. Three-dimensional image of the step phantom on display reconstructed by using rendering software. (a) R = 0.25, (b) R = 0.50, (c) R = 0.75, (d) R = 0.95. FIGURE 3. Full-scale models of the step phantom by shifting the binary threshold values. (a) R = 0.25. (b) R = 0.50. (c) R = 0.75. (d) R = 0.95.

full-scale model may be affected by the binary threshold value.[13]

In the future, a detailed full-scale model produced by the binder jet method will be applied for presurgical diagnosis, surgical simulation, and the production of surgical templates in dental implant treatment.[14,15]

In this study, the accuracy of a full-scale model produced with multislice helical CT data and by a binder jet method with plaster powder was assessed by shifting the binary threshold values.

MATERIALS AND METHODS

Object

A step phantom was made from bone-equivalent material (Tough Bone Phantom, BE-T, Kyoto Kagaku Co, Kyoto, Japan). The steps were made from cubes with sizes of $5 \times 5 \times 5$ mm^3, $10 \times 10 \times 5$ mm^3, and $15 \times 15 \times 5$ mm^3 (Figure 1).

CT scan

The step phantom was placed in water, and CT stacks were performed with a multislice helical CT unit (HiSpeed NX/i Pro, GE Yokogawa Medical Systems, Tokyo, Japan). Exposure procedures were set to 120 kV, 200 mA, and 1.0-mm-thick axial slices with 1.5-mm table pitch and a field of view of 200 mm in diameter.

Measurements of CT values

Computerized tomography values of all these portions of the phantom cubes were measured 5 times by using software supplied with the CT unit.

Production of the full-scale model

The data from all axial slices were saved on a magnetic optical (MO) disk as 16-bit DICOM files with 512×512 matrix data (the size of 1 pixel = 0.39 mm) through the medical display software (VOXBASE, J-MAC SYSTEM, Sapporo, Japan). The 3-D image reconstructions were performed as follows. First, on a personal computer (Macintosh G4, Apple Computer Inc, Cupertino, Calif) 3-D images were reconstructed by using rendering software (VoxBlast version 2.2, Vay Tec Inc, Fairfield, Iowa) and the data were saved on an MO disk. Next, the 3-D data formatted with the rendering software were transferred to a personal computer (Windows 2000 Professional Deskpro Workstation 300, Hewlett-Packard Japan, Tokyo, Japan), and binary threshold values were established by using 3-D visualization and measurement software (Forge version 1.5, LEXI Co, Tokyo, Japan). The threshold value was calculated as

$$(\text{CT value of a } 10 \times 10 \times 5\text{-mm}^3 \text{ cube} - \text{CT value of water}) \times R + \text{the CT value of water},$$

where R is set at 4 levels: 0.25, 0.50, 0.75, and 0.95 (Figure 2). The data were converted to Standard Triangulated Language formatted data to produce a 3-D model.

After these steps, full-scale models were produced by a binder jet method with plaster powder with a trader commission (Z402System, Naka Tec Co, Tokyo, Japan) (Figure 3).

Accuracy of full-scale models

All sides of the full-scale models and the step phantom were directly measured 5 times with a digital caliper (CD-S15, Mitsutoyo, Tokyo, Japan). The measurement

values were compared using the following calculations:

Difference = the measurement value from the full-scale model − the measurement value from the step phantom.

Results

CT values of the bone step phantom

The mean CT values (in Hounsfield Units [HU]) were 1475 HU (SD 9) for $5 \times 5 \times 5$ mm^3, 1415 HU (SD 6) for $10 \times 10 \times 5$ mm^3, and 1384 HU (SD 3) for $15 \times 15 \times 5$ mm^3.

Accuracy of full-scale models

The differences between the full-scale models and the step phantom are shown in the Table. In the axial plane, the mean difference was small (approximately 0.1 mm) when the setting was 0.75 for the threshold. In total, the mean difference was small (approximately 0.2 mm) when the setting was 0.50 for the threshold.

Table

Differences between a step phantom and powder plaster models (units in millimeters)

	Threshold			
	0.25	0.50	0.75	0.95
Horizontal direction of axial image				
5-mm portion	0.49	0.07	−0.28	−0.34
10-mm portion	0.72	0.29	−0.10	−0.68
15-mm portion	0.81	0.36	0.06	−0.98
Subtotal	0.67	0.24	−0.11	−0.66
Vertical direction of axial image				
5-mm portion	0.72	0.23	−0.10	−0.36
10-mm portion	0.95	0.28	0.04	−0.59
15-mm portion	1.10	0.66	0.27	−0.78
Subtotal	0.92	0.39	0.07	−0.58
Direction of table moving				
5-mm portion	0.70	−0.27	−1.05	−2.20
10-mm portion	0.99	0.00	−0.98	−1.80
15-mm portion	1.09	0.03	−0.81	−1.59
Subtotal	0.93	−0.08	−0.95	−1.86
Total	0.84	0.18	−0.33	−1.03

Discussion

In the oral and maxillofacial region, a full-scale model was produced with CT data applied for morphological diagnosis, surgical simulation, and the production of surgical templates. Its usefulness has been reported in several papers.[8–11]

Recently, multislice helical CT images from which thinner slices and more detailed two-dimensional and 3-D reconstructed images were obtained have been used in the imaging diagnosis of dental implant treatment.[6,7]

In this study the accuracy of a system combining multislice helical CT images and full-scale models constructed by the binder jet method with powder materials was evaluated.

The material of the step phantom was selected based on mandibular cortical bone, and the CT level was approximately 1400 HU. However, the CT values of the bone plate differed according to the size of the bone plate, despite being made of the same material. This result was considered related to a beam hardening effect.

Although 3-D images obtained from thinner slice thicknesses and smaller intervals were more accurate, the exposure and reconstructing values were selected with consideration of the clinical usefulness and the amount of data available from the 3-D model.

The binder jet method permits the use of either plaster or starch as the powder material. Plaster powder was the material used in this study because plaster is the more suitable fixation material when emphasis is placed on the reproducibility of a detailed structure.[16]

The threshold binary value needed to be set to produce a full-scale model by the binder jet method, and the accuracy of the full-scale model was influenced by the binary threshold value.[13] The differences between the full-scale models and the step phantom were small in the axial plan when the setting was 0.75 for the threshold and were small in total when the setting was 0.50 for the threshold. The CT values were approximately 700 HU for the 0.50 threshold and approximately 1000 HU for the 0.75 threshold.

Iwashita[17] reported that the optimal threshold for extraction of mandibular cortical bone was 90% of the peak. Ono and coworkers[16] reported that the threshold value for 3-D images on display was 200 HU in a comparison with full-scale models. Schneider and coworkers[13] proposed one would have to choose a threshold of 350 HU to 400 HU to get a model with the same dimensions as a phantom. However, they suggested a threshold of 200 HU had to be chosen to have all structures reproduced, and more of the fine structures failed to be produced with higher

thresholds. The CT value of the jaw with the special phantom, which was made by Schneider et al,[13] was about 540 HU, and the CT value of soft tissue was about 40 HU.[13] The R value used in this study was calculated as 0.62 to 0.72 for the threshold in an accurate model. Computerized tomography values for the threshold differed between this study and the study of Schneider et al;[13] however, the R value of the accurate full-scale model for the step phantom was close to that in the study of Schneider et al.[13] In this study, the step phantom was made of material with a CT value equal to mandibular cortical bone. We considered that the CT value for the threshold would be influenced by the outer portion of the reconstructed structure when a full-scale model was produced.

Our results showed the differences were very small, suggesting full-scale models could be applied for presurgical diagnosis, surgical simulation, and the production of surgical templates in dental implant treatment.

For maxillae that have a thinner cortical bone, further studies are needed to evaluate their threshold values.

CONCLUSION

The accuracy of a full-scale model made with plaster powder and by the binder jet method with multislice helical CT data was assessed and compared with a real phantom.

The mean difference in the axial plane was approximately 0.1 mm when the setting was 0.75 for the threshold, whereas in total the mean difference was approximately 0.2 mm when the setting was 0.50 for the threshold.

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REFERENCES

1. Almog DM, Sanchez R. Correlation between planned prosthetic and residual bone trajectories in dental implants. *J Prosthet Dent.* 1999;81:562–567.

2. Naitoh M, Kawamata A, Iida H, et al. Cross-sectional imaging of the jaws for dental implant treatment: accuracy of linear tomography using a panoramic machine in comparison with reformatted computed tomography. *Int J Oral Maxillofac Implants.* 2002;17:107–112.

3. Mecall RA, Rosenfeld AL. The influence of residual ridge resorption patterns on fixture placement and tooth position, part 3: presurgical assessment of ridge augmentation requirements. *Int J Periodontics Restorative Dent.* 1996;16: 33–51.

4. Naitoh M, Ariji E, Okumura S, et al. Can implants be correctly angulated based on surgical templates used for osseointegrated dental implants? *Clin Oral Implants Res.* 2000;11:409–414.

5. Ito K, Gomi Y, Sato S, et al. Clinical application of a new compact CT system to assess 3-D images for the preoperative treatment planning of implants in the posterior mandible: a case report. *Clin Oral Implants Res.* 2001;12:539–542.

6. Naitoh M, Katsumata A, Nohara E, et al. Measurement accuracy of reconstructed 2-D images obtained by multislice helical computed tomography. *Clin Oral Implants Res.* 2004;15:570–574.

7. Naitoh M, Katsumata A, Kubota Y, et al. Assessment of three-dimensional X-ray images: reconstruction from conventional tomograms, compact computerized tomography images, and multislice helical computerized tomography images. *J Oral Implantol.* 2005;31: 234–241.

8. Kishi K, Hasegawa I, Shigehara H, et al. Clinical application of 3-D CT and 3-D plastic model in the maxillaofacial region. *Oral Radiol.* 1997;13: 83–92.

9. D'Urso PS, Barker TM, Earwarker WJ, et al. Stereolithographic biomodelling in cranio-maxillofacial surgery: a prospective trial. *J Craniomaxillofac Surg.* 1999;27:30–37.

10. Ozawa Y, Shibahara T, Takagi T, et al. Surgical simulation of class III edentulous patient using a 3D craniofacial model: report of a case. *Bull Tokyo Dent Coll.* 2000;41:73–77.

11. Watson RM, Coward TJ, Clark RKF, et al. The contribution of imaging and digitized data to mandibular reconstruction and implant stabilized occulusal rehabilitation: a case report. *Br Dent J.* 2001;190:296–300.

12. Kasahara K, Okada M, Takashima H, et al. Clinical applications of full-scale model from CT image data with the rapid prototyping technique using binder jet method. *J Jpn Soc Oral Implant.* 2005; 18:315–323.

13. Schneider J, Decker R, Kalender WA. Accuracy in medical modeling. *Phidias Newsletters.* 2002;8:5–14.

14. Sarment DP, Sukovic P, Clinthorne N. Accuracy of implant placement with a stereolithographic surgical guide. *Int J Oral Maxillofac Implants.* 2003;18: 571–577.

15. Van Steenberghe D, Malevez C, Van Cleynenbreugel J, et al. Accuracy of drilling guides for transfer from three-dimensional CT-based planning to placement of zygoma implants in human cadavers. *Clin Oral Implants Res.* 2003;14:131–136.

16. Ono I, Abe K, Shiotani S, et al. Producing a full-scale model from computed tomographic data with rapid prototyping technique using the binder jet method: a comparison with the laser lithography method using a dry skull. *J Craniofac Surg.* 2000;11: 527–537.

17. Iwashita Y. Basic study of the measurement of bone mineral content of cortical and cancellous bone of the mandible by computed tomography. *Dentomaxillofac Radiol.* 2000;29:209–215.