Accuracy in Measurement of Distance Using Limited Cone-Beam Computerized Tomography

Kaoru Kobayashi, DDS, PhD[1]/Shinji Shimoda, DDS, PhD[2]/Yoichi Nakagawa, DDS, PhD[3]/
Akira Yamamoto, DDS, PhD[4]

Purpose: *The purpose of this study was to evaluate the accuracy of measurement of distance on the images produced by limited cone-beam computerized tomography (CT).* ***Materials and Methods:*** *Five cadaver mandibles were examined by spiral computerized tomography (SCT) and limited cone-beam computerized tomography (LCBCT). The vertical distance from a reference point to the alveolar ridge was measured by caliper on the sliced mandible, and measurement error on the CT images was calculated in percentages based on the actual values and the measurement values obtained from the CT images.* ***Results:*** *Measurement error was determined to range from 0 to 1.11 mm (0% to 6.9%) on SCT and from 0.01 to 0.65 mm (0.1% to 5.2%) on LCBCT, with measurement errors of 2.2% and 1.4%, respectively (*$P < .0001$*).* ***Discussion:*** *This study suggests that distance can be measured accurately using LCBCT. The size of the rectangular solid images obtained using LCBCT (30 mm wide and 42.7 mm long) is thought to be adequate for observation of mandibular bony structure and for preoperative assessment before dental implant placement.* ***Conclusion:*** *In this experiment on cadaver mandibles, LCBCT was shown to be a useful tool for preoperative evaluation in dental surgery because the relatively small field size of its images limits the patient's exposure to radiation.* INT J ORAL MAXILLOFAC IMPLANTS 2004;19:228–231

Key words: *cone-beam computerized tomography, dental implants, mandibular surgery, spiral computerized tomography*

The goal of presurgical dental implant treatment planning is to determine the optimum number and size of implants for the best restorative results.[1] This has been done by primarily by radiographic examination. Radiographic imaging can reveal information about the presence of disease, bone morphology and density, and the location of anatomic features that should be avoided when placing the implant. Panoramic radiographs provide a wide view of both jaws and a medial and distal view of the region in which the implant is to be placed, while cross-sectional images offer buccolingual information. Both conventional tomography and computerized tomography (CT) can provide panoramic and cross-sectional images, but the advantages of CT include uniform magnification, multiplanar views, 3-dimensional (3D) reconstruction, simultaneous study of multiple implant sites, and shorter acquisition time.[1] Furthermore, CT is generally considered more accurate than conventional tomography.[2,3] However, CT exposes the patient to higher doses of radiation than conventional radiography techniques.[1,4]

The recently developed limited cone-beam x-ray CT (LCBCT),[5] which makes use of a cone beam and a 2-dimensional x-ray sensor, has been reported to be useful in preoperative treatment planning for dental implant placement.[6] LCBCT produces high-resolution images and does not require the administration of high doses of radiation. The integral

[1]Associate Professor, Department of Oral Radiology, Tsurumi University School of Dental Medicine, Yokohama, Japan.
[2]Assistant Professor, First Department of Oral Anatomy, Tsurumi University School of Dental Medicine, Yokohama, Japan.
[3]Assistant Professor, Second Department of Oral and Maxillofacial Surgery, Tsurumi University School of Dental Medicine, Yokohama, Japan.
[4]Professor and Chair, Department of Oral Radiology, Tsurumi University School of Dental Medicine, Yokohama, Japan.

Correspondence to: Dr Yoichi Nakagawa, Second Department of Oral and Maxillofacial Surgery, Tsurumi University School of Dental Medicine, 2-1-3 Tsurumi, Tsurumi-ku, Yokohama, 230-8501 Japan. Fax: +81 45 573 9599. E-mail: nakagawa-y@tsurumi-u.ac.jp

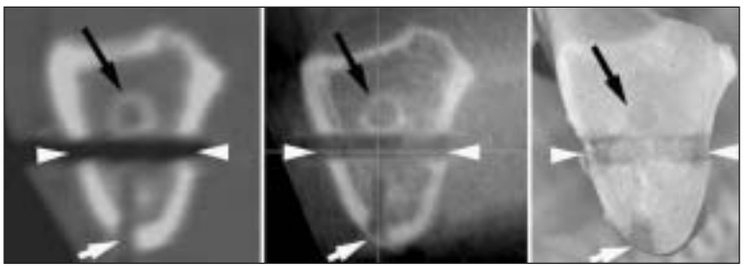

Fig 1 *(Left)* Cross-sectional image of the mandible produced by SCT. *(Center)* Cross-sectional image of the mandible produced by LCBCT. *(Right)* The sliced mandible. Reference holes were made by a 2-mm dental bur in 7 regions on a cadaver mandible. One reference hole *(white arrowheads)* ran through the buccal and lingual cortices and another was made on the inferior border of the mandible *(white arrow)*. The images were reconstructed along the holes and the same plane was observed on the sliced mandible. The vertical distance from the reference hole on the cortical surface to the alveolar ridge was measured to evaluate the accuracy of measurement on the CT images. The long black arrow indicates the mandibular canal.

absorbed dose of radiation using LCBCT was approximately 1/15 that of spiral CT (SCT) when the exposure condition of the latter was optimized.[7,8]

The purpose of this study was to investigate the accuracy of LCBCT in the measurement of distance in the bony structure of the jaw. The measurement error on both SCT and LCBCT images was analyzed, and the clinical usefulness of LCBCT as a preoperative examination tool for dental implants was considered.

MATERIALS AND METHODS

Study Design

Five cadavers with edentulous mandibles were used to examine the accuracy of measurements of CT images. The deceased had agreed to provide the cadavers for anatomic courses for dental students and for research, and the families of the deceased gave their permission for the cadavers to be used in this study. The cadaver heads were scanned using SCT and LCBCT. The distances between 2 reference points created on the removed mandible were measured by digital caliper, and the values were compared with those found on the CT images.

SCT Imaging System

RADIX-Prima (Hitachi Medical, Tokyo, Japan) was used. Helical scans were reformatted to obtain 3D views by volume rendering using a personal computer (PCV-LX70/BPK; Sony, Tokyo, Japan) with Express Vision image software (Zio Software, Tokyo, Japan).

LCBCT Imaging System

The LCBCT apparatus used was the Dental 3D-CT (PSR 9000 [prototype]; Asahi Roentgen, Kyoto, Japan), which consisted of a cone-beam–type CT scanner and a small radiographic image intensifier.[7] The exposure is completed by rotation of an x-ray beam and the image intensifier around the mandible under examination. The Dental 3D-CT, an independently developed LCBCT apparatus, has shown itself to be a useful assessment tool for preoperative examination prior to minor oral surgery.[7] The Dent 3D-CT has 2 functions: block CT imaging and panoramic CT imaging. Block CT imaging produces rectangular solid reconstructed images 42.7 mm high and 30 mm wide. A single scan provides 365 slices of axial projection data, with a slice thickness of 0.117 mm. Images are reconstructed in any plane from the projection data. In the panoramic CT imaging mode, the entire mandibular image can be obtained from 5 consecutive scans. Block CT imaging was used in the present study. The same computer and graphics software used for SCT were used for LCBCT.

Measurement of Distance in the Mandibular Bone

Reference holes 2 mm in diameter were made in 7 regions on each cadaver mandible (right molar, right premolar, right canine, midline, left canine, left premolar, and left molar) using a 1.8-mm-wide dental bur (Shofu, Tokyo, Japan). After CT scanning was completed, the mandibles were removed from the cadavers and were sliced along the reference holes. One reference hole ran through the buccal and lingual cortices, and another was made on the inferior border of the mandible so that the holes formed a plane (Fig 1). Using these holes as indices, the same planes could be measured on both CT images and on the sliced mandible. The vertical distance from the top of the reference hole on the cortical surface to the alveolar ridge was measured using a digital caliper (Mitsutoyo, Kawasaki, Japan) to evaluate the accuracy of measurement on the CT images (Fig 1).

Table 1 Measurement Error (in mm) on SCT and LCBCT Images

	Mean ± SD (n = 66)	Minimum	Maximum
SCT	0.36 ± 0.24	0.00	1.11
LCBCT	0.22 ± 0.15*	0.01	0.65

*Significant differences between SCT and LCBCT images, $P < .0001$.

Table 2 Measurement Error on SCT and LCBCT Images by Region

	Right molar (n = 10)	Right premolar (n = 10)	Right canine (n = 10)	Median (n = 10)	Left canine (n = 10)	Left premolar (n = 8)	Left molar (n = 8)
SCT	2.39 ± 1.69	2.73 ± 1.36	2.62 ± 1.94	2.51 ± 2.02	1.61 ± 1.35	1.06 ± 1.39	1.97 ± 1.56
LCBCT	1.61 ± 1.44	1.29 ± 0.73*	1.84 ± 1.44	0.71 ± 0.71*	1.25 ± 0.61	1.25 ± 1.37	1.07 ± 0.70*

All values expressed in percentages (mean ± SD), which are calculated as described in the Materials and Methods section. Measurements included both buccal and lingual vertical distance from the reference hole to the alveolar ridge in each region.
*Significant differences between SCT and LCBCT images, $P < .05$.

The values obtained by anatomic and radiographic measurement were compared. Measurement error was calculated by subtracting the value obtained on the MPR images of the CT (A) from the value obtained by direct measurement of the cadaver using a digital caliper (B) and was then expressed as an absolute percentage value:

$$\text{Error (\%)} = \frac{|(A-B)|}{B} \times 100$$

The SCT and LCBCT values for measurement error were compared.

Statistical Analysis

All values are expressed as means ± standard deviation. The paired *t* test was used for statistical analysis. Results were considered to be statistically significant at $P < .05$.

RESULTS

Measurement error was found to range from 0 to 1.11 mm (0% to 6.9%) on the images produced by SCT and from 0.01 to 0.65 mm (0.1% to 5.2%) on LCBCT (Table 1). Although the errors were not large in either type of CT image, and only 1 value exceeded 1 mm, a significant difference was recognized between the 2 methods. The average measurement error was 2.2% with SCT and 1.4% with LCBCT ($P < .0001$).

Measurement of individual regions is summarized in Table 2. A significant difference between the measurements provided by the 2 CT methods was found in 3 regions.

Cancellous bone was sharply visualized by LCBCT in cross-sectional images compared with SCT (Fig 1).

DISCUSSION

The data presented here indicate that LCBCT can be used to measure the distance between 2 points in mandibular bone more accurately than SCT, although SCT provided satisfactory information about 3-dimensional distances. The average error measurement on LCBCT images was 1.4% when the vertical distance from a reference point to the alveolar ridge was estimated. Reported errors associated with measurement on CT scans can range from 0.5 to 2 mm, and measurement error is generally required to be less than 1 mm on images for implant treatment.[9] In the present study, the maximum error in measuring vertical distance was 0.65 mm using LCBCT, while the maximum error observed using SCT was 1.11 mm. LCBCT appears to be a reliable tool for preoperative evaluation before dental implant surgery because of its high resolution.

LCBCT images can be obtained in any plane by primary reconstruction of the raw data.[5] The spatial resolution is nearly the same in all directions in LCBCT images, whereas in SCT images there is a loss of resolution of the system in the direction of cross-sectional reformatting.[10] This may be a reason why LCBCT is superior to SCT in terms of spatial resolution on cross-sectional images.

A high dose of radiation is required for SCT. When the slice width is decreased to obtain more accurate data, even higher doses of radiation are needed. LCBCT has an advantage in this regard. The integral absorbed dose of LCBCT was less

than 1/15 that of SCT when the exposure condition of SCT was optimized.[7,8] In most minor oral surgery cases, only a small examining field is needed. Projection over only a limited area can reduce total radiation dose.

SCT is appropriate for examining large areas. LCBCT was developed specifically for the examination of dental lesions. Its field size is therefore limited, and it is difficult to examine lesions exceeding 30 mm without repeated scanning.[5] The Dental 3D-CT, however, produces rectangular solid images 42.7 mm in height, a size which is able to accommodate the height of the mandible with standing teeth. This CT method can depict lesions in the mandible and evaluate the relationship between the lesions and adjacent teeth. The size of the images obtained from LCBCT is thought to be adequate for observation of the mandibular bony structure and for preoperative assessment before dental implant surgery.

A drawback of LCBCT is that it is incapable of discriminating soft tissue because of its low contrast resolution.[5] However, LCBCT provides essential information about the osseous morphology for planning the placement of dental implants, including cortical integrity and thickness, enlarged bone marrow spaces, postextraction irregularities, and trabecular bone density. Cancellous bone in particular has been reported to be sharply visualized by LCBCT,[5,7] while SCT did not show cancellous bone clearly in cross-sectional images of the dental arch.

In summary, the LCBCT can be a useful tool in preoperative evaluation for dental implants because of its high resolution and the field size of its images.

ACKNOWLEDGMENTS

This study was supported in part by a grant-in-aid for High Technology Research Centers from the Ministry of Education, Culture, Sports, Science, and Technology.

REFERENCES

1. White SC, Heslop EW, Hollender LG, et al. Parameters of radiologic care: An official report of the American Academy of Oral and Maxillofacial Radiology. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001;91:498–511.
2. Klinge B, Petersson A, Maly P. Location of the mandibular canal: Comparison of macroscopic findings, conventional radiography, and computed tomography. Int J Oral Maxillofac Implants 1989;4:327–332.
3. Naitoh M, Kawamata A, Iida H, Ariji E. 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.
4. Lecomber AR, Yoneyama Y, Lovelock DJ, Hosoi T, Adams AM. Comparison of patient dose from imaging protocols for dental implant planning using conventional radiography and computed tomography. Dentomaxillofac Radiol 2001;30: 255–259.
5. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac Radiol 1999;28:245–248.
6. Ito K, Gomi Y, Sato S, Arai Y, Shinoda K. 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.
7. Nakagawa Y, Kobayashi K, Ishii H, et al. Preoperative application of limited cone beam computerized tomography as an assessment tool before minor oral surgery. Int J Oral Maxillofac Surg 2002;31:322–326.
8. Mishima A, Kobayashi K, Yamamoto A, Kimura Y, Tanaka M. Comparison of patient radiation dose from Dental CT and Spiral CT. Symposium of high technology research center in Tsurumi University School of Dental Medicine. Yokohama, Japan: Nagasue Shoten, 2001:171–172.
9. Wyatt CC, Pharoah MJ. Imaging techniques and image interpretation for dental implant treatment. Int J Prosthodont 1998;11:442–452.
10. Bianchi SD, Lojacono A. 2D and 3D images generated by cone beam computed tomography (CBCT) for dentomaxillofacial investigations. In: Lemke HU (ed). CAR '98: Computer Assisted Radiology and Surgery: Proceedings of the 12th International Symposium and Exhibition, Tokyo, 24–27 June 1998. Amsterdam: Elsevier, 1998:792–797.