A comparison of a new limited cone beam computed tomography machine for dental use with a multidetector row helical CT machine

Koji Hashimoto, DDS, PhD,[a] Yoshinori Arai, DDS, PhD,[b] Kazuo Iwai, DDS, PhD,[c] Masao Araki, DDS, PhD,[d] Shoji Kawashima, DDS, PhD,[e] and Masaaki Terakado, DDS, PhD,[f] Tokyo and Matsumoto Nagano, Japan
NIHON UNIVERSITY AND MATSUMOTO DENTAL COLLEGE

Objective. We sought to compare a new limited cone beam computed tomography (CT) machine for dental use (3DX) with the multidetector CT machine for image quality and skin doses.
Study design. Images of the right maxillary central incisor and the left mandibular first molar of an anthropomorphic phantom were taken by both the 3DX and the multidetector CT. A 5-point method was used to evaluate the depiction of cortical and cancellous bone, enamel, dentin, pulp cavity, periodontal ligament space, lamina dura, and overall impressions. Furthermore, the skin doses for both modalities were compared.
Results. The image quality of the 3DX was better than the multidetector CT for all items ($P < .01$). Moreover, the mean skin doses with the multidetector CT were 458 mSv per examination, whereas the doses with the 3DX were 1.19 mSv per examination.
Conclusions. These results clearly indicate the superiority of the 3DX in the display of hard tissues in the dental area while substantially decreasing the dose to the patient.
(Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2003;95:371-7)

The development of computed tomography (CT) in 1972, which was reported in 1973,[1] enabled conditions to be diagnosed with 3-dimensional images. Although CT devices are becoming more compact, they continue to be relatively large and expensive and expose the patient to relatively high doses of radiation. In the field of dentistry, these devices are used in the diagnosis of tumors, traumatic injuries, maxillary and mandibular joint problems, and other diagnoses, but they have not proved ideal for the diagnosis of diseases particular to dentistry, such as impacted teeth or apical lesions. Arai et al[2,3] set out to develop a compact CT apparatus specifically for use in dentistry; in 1997, they created a prototype limited cone beam CT device for dental use that was dubbed *Ortho-CT*. In the roughly 2 years after that achievement, the device was used in approximately 2000 cases to evaluate conditions such as impacted teeth, apical lesions, and mandibular and maxillary diseases both before and after surgery in the Department of Radiology at the Nihon University School of Dentistry Dental Hospital, proving highly successful.[4] This prototype apparatus, the Ortho-CT, was an improved version of the Scanora (Soredex Corporation, Helsinki, Finland), a multifunctional pantomographic imaging apparatus. In the Ortho-CT, the section where the film cassette was installed was replaced with an image intensifier, resulting in improved operability and resolution and reduced radiation doses.[2,3] In 2000, this technology was transferred to Morita Co Ltd through the Nihon University Business Incubation Center. The 3DX multi-image micro-CT (3DX) was developed as a limited cone beam CT device for practical use, enabling 3-dimensional imaging of the hard tissues (ie, bone, tooth) of the maxillofacial and ear and nose regions.[5] This article provides an overview of the apparatus and reports the results of a comparison of the image quality and skin doses obtained with the 3DX and the multidetector row helical CT (Multidetector CT), the newest CT unit.

[a]Associate Professor, Department of Radiology and Division of Advanced Dental Treatment, School of Dentistry and Dental Research Center, Nihon University, Tokyo, Japan.
[b]Associate Professor, Department of Oral Radiology, School of Dentistry, Matsumoto Dental College, Nagano, Japan.
[c]Assistant Professor, Department of Radiology and Division of Advanced Dental Treatment, School of Dentistry and Dental Research Center, Nihon University, Tokyo, Japan.
[d]Assistant Professor, Department of Radiology and Division of Advanced Dental Treatment, School of Dentistry and Dental Research Center, Nihon University, Tokyo, Japan.
[e]Instructor, Department of Radiology, School of Dentistry, Nihon University, Tokyo, Japan.
[f]Associate Professor, Department of Oral and Maxillofacial Surgery and Division of Systemic Biology and Oncology, School of Dentistry and Dental Research Center, Nihon University, Tokyo, Japan.
Received for publication May 20, 2002; returned for revision Sep 17, 2002; accepted for publication Nov 8, 2002.

1079-2104/2003/$30.00 + 0
doi:10.1067/moe.2003.120

Fig 1. Overall view of the 3DX apparatus (while taking images of the phantom).

MATERIAL AND METHODS

Apparatus

The 3DX uses a cone beam, in which the radiation field is limited to a height of 29 mm and a width of 38 mm at the center of rotation. A chair for positioning the patient stands in the center of the apparatus, and the rotating section is supported by 2 columns (Fig 1). The X-ray tube and a 4-inch image intensifier are positioned diagonally to each other on the rotating section. A direct-drive motor is used to rotate the apparatus. Imaging is performed with the center of the subject aligned with the rotation center of the apparatus by light beams along the *x*-, *y*-, and *z*-axes. Standard imaging conditions are set at a tube voltage of 80 kV and a tube current of 2 mA, and exposure time is set at 17 seconds. The apparatus rotates once around the subject and compiles data from each degree in a 360° rotation. Image data are quantized on a 2-dimensional screen measuring 240 pixels in the vertical direction by 320 pixels in the horizontal direction, with each pixel quantified at 8 bits, and then stored in a computer (Pentium III, 600 MHz, 256 MB RAM; Dell Computer Corp, Austin, Tex). This computer, used to reconstruct images, requires approximately 10 minutes to form an image. The image reconstruction area is 29 mm (240 voxels) in height and 38 mm (320 voxels) in diameter, with a voxel comprising a square of sides, each of which is 0.119 mm long. Because images are normally reconstructed in continuous tomographic layers 1 mm is width and in a 1-mm interval, 30 layers can be obtained from 1 image in each of the 3 directions. Unlike the prototype Ortho-CT machine, the 3DX uses independently developed proprietary dedicated software to display images on the CRT monitor, with images parallel (parallel section) and perpendicular to the dental arch (cross section) and perpendicular to the body axis (horizontal section) all displayed on 1 screen. With this software, the user can scroll from a point on any given layer of the parallel section to observe the corresponding position on a cross section or horizontal section (Fig 2). The image quality and radiation exposure obtained with the 3DX have already been compared through visual evaluations with the quality and exposure obtained with the Ortho-CT (Arai et al[5]) and with the helical CT (Honda et al[6]). These authors reported that the image quality obtained with the 3DX far surpassed that of the other 2 devices and that skin doses were reduced.[5,6] In addition, Iwai et al[7] reported that the effective dose per exposure was less than that generated with intraoral or rotational panoramic radiography.

This study involved subjective visual evaluations of image quality and skin dose in a comparison of the 3DX with the multidetector CT, which is the newest CT apparatus available. The specific multidetector CT used for comparison was the Aquilion Multi Slice CT (Toshiba Medical Co Ltd, Tokyo, Japan) located in Tokyo, Japan, at the Juntendo University Hospital Department of Radiology (Fig 3). This apparatus obtains 0.5-mm slices in 4 rows, doubling the resolution along the *z*-axis in comparison with earlier devices, and enabling coronal scans and sagittal scans with exactly the same spatial resolution as axial scans. In addition, scanning is performed at 0.5-second rotations, reducing artifacts and further decreasing skin doses.[8]

Study method

Evaluation of image quality. Using an anthropomorphic phantom with cervical vertebrae (SE-1; Miwa Pharmaceuticals, Osaka, Japan) as a subject, we took images of the right maxillary central incisor and left mandibular first molar, with both the 3DX and the multidetector CT (Aquilion Multi Slice CT). The 3DX images were taken under the following conditions: tube voltage was 80 kV and tube current was 2 mA; the filtration was 3.1 mmAl equivalent, and the exposure

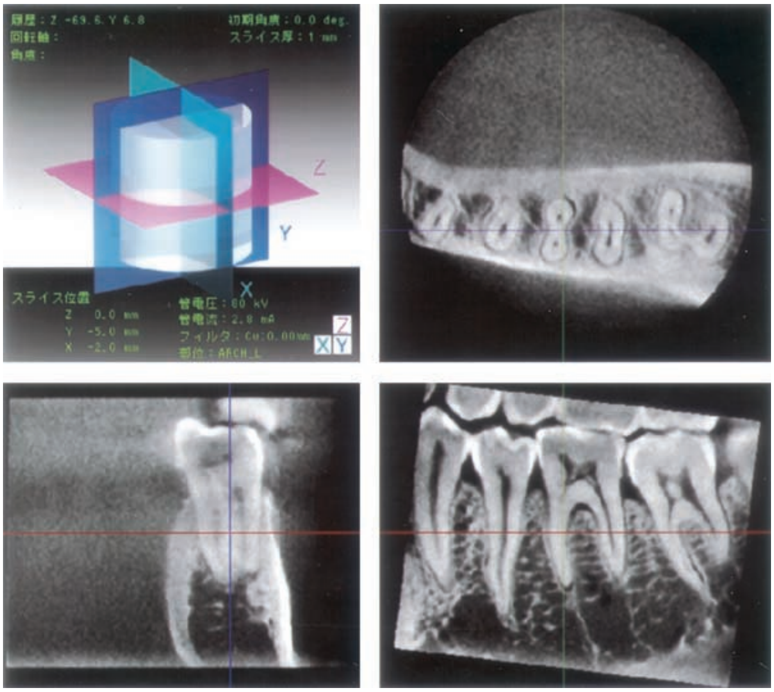

Fig 2. Image taken with the 3DX machine, displayed on the CRT.

time was 17 seconds. With the multidetector CT, the following settings were used: tube voltage 135 kV; tube current, 190 mA, 0.75 second, 0.5 mm, and helical pitch 2.5. The reconstruction interval was 0.2 mm, central field of view: small, and reconstruction function was FC 80, 81, and 10. To evaluate image quality, parallel images taken with the multidetector CT and 3DX were used. Images were printed at the same magnification with an Olympus P-330 printer in 300-dpi full-color mode. An image was then constructed to show both images of the right maxillary incisor placed side by side (image 1: Fig 3). Another was constructed showing both images of the left mandibular first molar (image 2: Fig 4). Images 1 and 2 were shown separately to 5 observers, 3 of whom are authors of this study (M.A., M.T., S.K.). Observers evaluated (1) how well cortical and cancellous bone was portrayed in images and (2) how well the enamel, dentin, pulp cavity, periodontal ligament space, and lamina dura were portrayed. Observers then rated their overall impressions of images. Eight items were observed and evaluated. The image from the multidetector CT was used as a standard, and the quality of 3DX images 1 and 2 was evaluated in terms of the following scores:

- Score 1: The 3DX image was clearly inferior to the multidetector CT image.
- Score 2: The 3DX image was slightly inferior to the multidetector CT image.
- Score 3: The 3DX image quality was the same as the multidetector CT image.
- Score 4: The 3DX image was slightly superior to the multidetector CT image.
- Score 5: The 3DX image was clearly superior to the multidetector CT image.

Evaluations were conducted by 2 dental radiologists with 23 and 9 years of clinical experience, 2 oral surgeons with 30 and 5 years of clinical experience, and 1 general practitioner with 10 years of clinical experience. Each person evaluated the images 2 times at 10-day intervals. Data analysis was performed with statistical software (SPSS 7.5 for Windows; SPSS, Chicago, Ill). Because a similar test of single mean (vs $\mu = 3.00$, $\sigma = 0.00$) is equivalent to a paired Student t test, the latter was used to analyze image quality. A weighed kappa (κ) statistic was used to evaluate the intrarater and interrater agreement.

Evaluation of radiation exposure. A Rando phantom (Alderson Research Laboratories, Stanford, Conn) was used as the subject. Skin doses in the maxillofacial region when the multidetector CT and the 3DX were used were measured with a thermoluminescence dosimeter (TLD) (Panasonic UD-170A; Panasonic, Osaka, Japan). A UD-170A was used, and calibration was performed under imaging conditions identical to those used with the CT, with a KXO-15

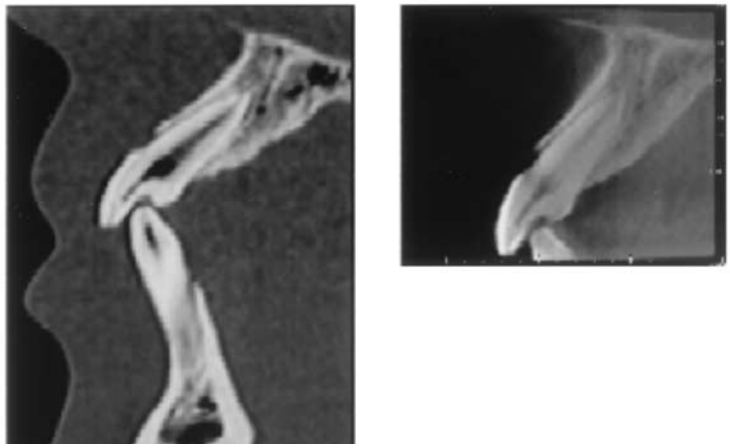

Fig 3. Images taken with the multidetector CT machine (*left*) and the 3DX machine (*right*) of the right maxillary incisor (images taken at magnification equivalent to that of image 1).

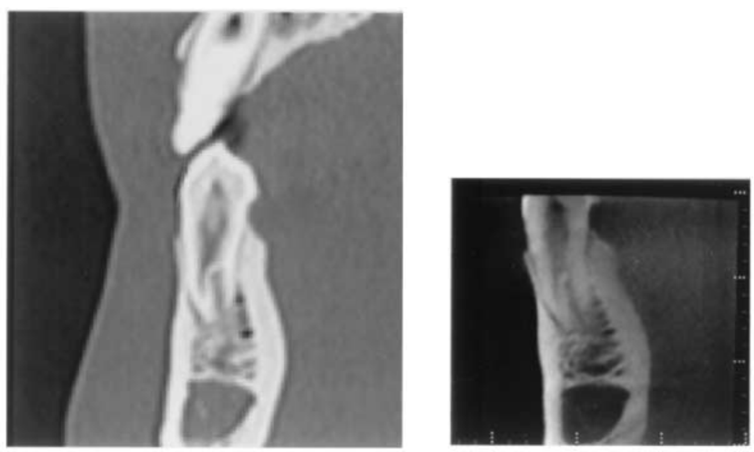

Fig 4. Images taken with the multidetector CT machine (*left*) and the 3DX machine (*right*) of the left mandibular first molar (images taken at magnification equivalent to that of image 2).

single-plate full-wave rectification generator (Toshiba, Tokyo, Japan) of the same tube voltage and current. The effective energy was 60 kV, and calibration was performed according to the standard procedures of the National Institute of Radiological Sciences. For the multidetector CT, the portion imaged was the maxillary occlusal plane; the image was taken at the level of the third cervical vertebra, at a scanogram of 120 kV and 150 mA. Scanning was performed at 135 kV, 190 mA, 0.75 second, 0.5 mm, and HP 2.5, with an image range of 82.5 mm. Ten TLD elements were affixed at each of 8 locations on the skin surface, at the height of the occlusal plane in the center of the imaging range of the phantom. With the 3DX, the tube voltage was 80 kV, tube current was 2 mA, filtration was 2.1 mmAl, and the exposure time was 17 seconds. When images were taken, the position was the maxillary first molar on the left, and 17 TLDs were affixed at 3-cm intervals along an imaginary line on which the rotation plane of the main X-ray beam intersected with the skin plane of the phantom. The aforementioned tests were performed 3 times, and mean values were calculated for each TLD.

RESULTS

Image quality

Table I shows the results of the judgments made by the 5 observers who evaluated image quality. Because only 1 of all 80 judgments had 2 or fewer judgment points, a similar test of the single mean was performed by means of a 1-sided test. In all items evaluated, 3DX

Table I. Results of image quality evaluation for images 1 and 2 (categorized by observer)

Observers	*A*				*B*				*C*				*D*				*E*						
Evaluation image	*1*		*2*		*1*		*2*		*1*		*2*		*1*		*2*		*1*		*2*				
Evaluation time	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*	*1*	*2*			
Observation items																					*Mean*	*SD*	P *value of similar test of single mean*
Cortical bone	5	5	5	5	5	5	5	5	4	5	4	4	5	4	4	5	4	5	5	5	4.70	0.47	9.91E–09
Cancellous bone	5	5	4	5	5	5	5	5	4	4	4	4	4	4	4	5	3	3	5	5	4.40	0.68	7.29E–13
Enamel	5	5	3	4	5	5	4	5	4	4	4	4	4	4	4	5	4	4	3	3	4.15	0.67	1.57E–07
Dentin	4	5	4	5	4	5	4	5	4	4	3	4	4	5	4	5	4	3	3	4	4.15	0.67	1.57E–07
Pulp cavity	5	4	5	5	4	3	4	5	4	4	2	3	3	5	3	5	3	5	3	4	3.95	0.94	1.23E–04
Lamina dura	4	5	4	5	5	4	5	4	5	4	3	3	5	5	4	4	3	5	4	5	4.30	0.73	9.46E–08
Periodontal ligament space	4	5	4	5	5	4	5	4	5	5	4	4	5	5	5	4	4	3	4	4	4.40	0.60	1.26E–09
Overall impression	4	5	4	5	5	5	5	5	4	4	4	4	4	5	4	5	4	4	4	4	4.40	0.50	6.88E–11

images were significantly superior to multidetector CT images ($P < .01$). The evaluation of intrarater and interrater agreement by weighed κ are summarized in Table II. The results reveal poor agreement in all tests. Table III represents similar test of single mean of each observer. All observers judged the 3DX to be significantly superior in terms of image quality to the multidetector CT ($P < .01$).

Measurement of the skin dose

The mean skin dose when the multidetector CT was used for imaging was 458 mSv per examination, whereas that for the 3DX was 1.19 mSv per examination.

DISCUSSION

Terakado et al[4] reported the clinical efficacy of the Ortho-CT, the prototype of the limited cone beam CT for dental use developed by Arai et al[2,3] in 1997. This limited cone beam CT for dental use became available on the market in 2000 under the name *3DX MultiImage Micro-CT*. Whereas the tube current of the Ortho-CT was 10 mA, that parameter has been further reduced to 2 mA in the 3DX.

In this study, the 3DX apparatus was compared with the multidetector CT, which is the newest CT apparatus to evaluate image quality and skin doses during imaging. The apparatus used for comparison was the Aquilion Multi-Slice CT manufactured by Toshiba, which uses 4 rows of sensors as the 4 multidetector CT machines. These devices yield a slice thickness of 0.5 mm, which is half the maximum slice thickness of 1 mm, and enable wide-range scanning. In addition, the number of artifacts is reduced by using a 0.5-second scan, the resolution in the body axis direction is improved, and the skin dose is reduced.[8-14] Therefore, the use of this device enables better examination of the cranial bones, the base of the skull, the paranasal sinuses, and other structures. Not only can the small bones of the ear be examined, but the scope extends to include the ligaments, muscles, and other small soft tissues in the area of the ears and nose,[15] so that fractures can be effectively diagnosed. In terms of cancer diagnosis, Johnson[16] discovered that a greater volume of data could be obtained than was possible from conventional helical CT. At the same time, however, no reports have yet described the use of the apparatus in dental radiology. In this study, the multidetector CT and 3DX were compared for image quality and skin doses. In subjective evaluations of image quality with the 3DX, the results were basically the same for images of the maxillary incisor and mandibular first molar, regardless of the position at which the image was taken, indicating that the 3DX offered superior performance. In the subjective 5-point evaluation of 3DX image quality, with the multidetector CT as the standard, the lowest score was for the pulp cavity and the highest was for cortical bone, at 4.70. Similar scores were assigned to the maxillary central incisor and the mandibular first molar. For all areas observed, statistically significant improvements over the standard were observed ($P < .01$). Therefore, the 3DX far surpassed the multidetector CT in terms of the subjective evaluation of image quality ($P < .01$). The poor agreement of the intrarater and interrater test results may be because of wavering decisions in judgment between point 4 and point 5. According to a report in which Honda et al[6] compared the resolution of the 3DX with that of a helical CT, the resolution of the 3DX was 1.1 line-pair per millimeter in the horizontal direction at moduration transfer function 0.5, 3.1 line-pairs per millimeter in the horizontal direction at moduration transfer function 0, and 4.2 line-pairs per millimeter in the vertical direction. These values were significantly higher than those of the helical CT, which measured 0.9 line-pair per millimeter, 2.0 line-pairs per millimeter, and 2.3 line-pairs per millimeter. We believe this is because 1 side of the voxel of the square is 0.136 mm, which is a small value

Table II. Evaluation of intrarater and interrater agreement by weighted kappa (κ)

	Intrarater					*Interrater*							
	A	*B*	*C*	*D*	*E*	*A*B*	*A*C*	*A*D*	*A*E*	*B*C*	*B*D*	*B*E*	*C*D*
Weighted κ coefficients	0.03	–0.05	0.61	0.17	0.26	0.10	–0.04	0.04	0.11	0.05	0.19	–0.01	0.24
P value	0.89	1.12	0.09	1.48	0.29	0.66	1.15	0.84	0.52	0.76	0.34	1.06	0.26

Table III. Similar test of single mean of each observer

Observer	*A*	*B*	*C*	*D*	*E*
Mean	4.59	4.66	3.94	4.41	3.94
SD	0.56	0.55	0.62	0.62	0.76
P value of similar test of single mean	6.57E–16	1.07E–17	5.59E–10	2.46E–14	3.87E–08

5. With the prototype Ortho-CT apparatus, a pulley-type belt drive is used as the rotation mechanism, resulting in uneven rotation, whereas the 3DX uses a direct-drive motor developed for machine tooling, which offers the highest level of precision of all the motors currently available. This significantly boosts the rotation precision, enabling a high resolution to be obtained, and is thought to be connected to the high-quality images. The 3DX was given a high score with respect to the periodontal ligament space and the lamina dura, which require a particularly high resolution in to capture the most minute changes. This result is thought to be indicative of the efficacy of the apparatus in dental applications. With respect to skin dose, our results reveal a value for the 3DX of approximately 1/400 that of the multidetector CT. Honda et al[6] reported that when images were taken with the helical CT, the mean skin dose was 160 mSv per examination, which indicates that the skin dose of the multidetector CT is approximately 3 times that of the helical CT. The comparison between the 3DX and the multidetector CT revealed skin doses with the 3DX to be approximately 400-fold less than those of the multidetector CT. This is an extremely strong advantage in clinical applications. Because X-ray energies differ for the 2 units, however, actual skin doses must be determined separately for each organ and compared to obtain an accurate comparison. This is currently being investigated. As indicated earlier, the 3DX for dental use that has recently appeared on the market offers outstanding performance in the areas of high image quality and low skin dose. It is likely to prove extremely effective in a broad spectrum of applications in such general clinical fields as endodontics, periodontics, and oral surgery, in addition to evaluations before and after dental implant surgery.

CONCLUSIONS

The 3DX Multi Image Micro CT recently developed for dental use as a result of a technology transfer from Nihon University to Morita Co Ltd was compared with a multidetector CT, which is the newest CT apparatus, in a subjective comparison of image quality and skin dose. Images taken with the 3DX received higher scores than those taken with the multidetector CT for all 8 of the items evaluated. These scores represented statistically significant improvements ($P < .01$) for all 8 items. Skin doses from the 3DX are extremely low, approximately 1/400 of those from the multidetector CT. The aforementioned results are believed to be indicative of the efficacy of the 3DX in the diagnosis and examination of hard tissues in the maxillofacial region.

We would like to thank Morita Co Ltd (Kyoto, Japan) and Toshiba Medical Systems Co Ltd (Tokyo, Japan) for the provision of 3DX and Multidetector CT machines.

REFERENCES

1. Hounsfield GN. Computerized transverse axial scanning (tomography). 1. Description of system. Br J Radiol 1973;46:1016-22.
2. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of Ortho Cubic Super High Resolution CT (Ortho-CT). Car '98 Computer Assisted Radiology and Surgery 1998;780-5.
3. Arai Y, Tammisalo E, Iwai K, Hashimoto K, Shinoda K. Development of a compact computed tomographic apparatus for dental use. Dentomaxillofac Radiol 1999;28:245-48.
4. Terakado M, Hashimoto K, Arai Y, Honda M, Sekiwa T, Sato H. Diagnostic imaging with newly developed ortho cubic super high resolution CT (Ortho-CT). Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2000;89:509-18.
5. Arai Y, Hashimoto K, Iwai K, Shinoda K. Fundamental efficiency of limited cone-beam X-ray CT (3DX multi image micro CT) for practical use. Dental Radiology 2000;40:145-54.
6. Honda K, Arai Y, Iwai K, Hashimoto K, Saitou T, Shinoda K. Fundamental efficiency of new-style limited-cone-beam CT

(3DX)—comparison with helical CT. Jpn J Tomogr 2000;27:193-8.
7. Iwai K, Arai Y, Hashimoto K, Nishizawa K. Estimation of effective dose from limited cone beam X-ray CT examination. Dental Radiology 2000;40:251-9.
8. Katada K. Role of multislice CT in neuroradiological diagnosis. Jpn J Diagnostic Imaging 2000;20:1326-31.
9. Taguchi K, Aradate H. Algorithm for image reconstruction in multi-slice helical CT. Med Phys 1998;25:550-61.
10. Berland LL, Smith JK. Multidetector-array CT: Once again, technology creates new opportunities. Radiology 1998;209:327-9.
11. Hu H, He HD, Foley WD, Fox SH. Four multidetector-row helical CT: Image quality and volume coverage speed. Radiology 2000;215:55-62.
12. Murakami T, Kim T, Takamura M, Hori M, Takahashi S, Federle MP, et al. Hypervascular hepatocellular carcinoma: detection with double arterial phase multi-detector row helical CT. Radiology 2001;218:763-7.
13. Hara A, Johnson CD, MacCarty RL, Welch TJ, McCollough CH, Harmsen WS. CT colonography: single- versus multi-detector row imaging. Radiology 2001;219:461-5.
14. Katada K. Recent development of computed tomography in neuroradiology—significance of multislice CT. Jpn J Tomogr 2001;28:203-9
15. Fukuda K, Nishioka M, Tozaki M, Fukuda Y. Clinical contribution to and suitability for musculoskeletal imaging. Jpn J Diagnostic Imaging 2000;20:1364-73.
16. Johnson CD. Pancreatic carcinoma: Developing a protocol for multi-detector row CT. Radiology 2001;220:3-4.

Reprint requests:

Koji Hashimoto, DDS, PhD
Department of Radiology
Nihon University School of Dentistry
1-8-13 Kanda Surugadai, Chiyoda-ku
Tokyo, 101-8310 Japan
hashimoto-k@dent.nihon-u.ac.jp