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Original

Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT

Koji Hashimoto[1,3], Shoji Kawashima[1,3], Masao Araki[1,3],
Kazuo Iwai[1,3], Kunihiko Sawada[1,3] and Yutaka Akiyama[2]

Departments of [1]Oral and Maxillofacial Radiology and [2]Oral and Maxillofacial Surgery,
Nihon University School of Dentistry, Tokyo, Japan
[3]Division of Advanced Dental Treatment, Dental Research Center,
Nihon University School of Dentistry, Tokyo, Japan

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Abstract: The authors evaluated the imaging performance of cone-beam computed tomography (CBCT) for dental use using 3DX multi-image micro-CT (Morita Co., Kyoto, Japan) and four-row multidetector helical computed tomography (MDCT) using an Asteion (Toshiba, Tokyo, Japan). A dried right maxillary bone was cut into eight slices 2 mm thick toward the zygomatico-palate and used as a phantom. Images of the phantom were then taken using 3DX and MDCT. The images of two bone slices were evaluated by five dentists for image quality and reproducibility of cancellous bone, as well as enamel, dentin, pulp cavity, periodontal ligament space, lamina dura and the overall image. Using the MDCT images as the standard, the 3DX images were evaluated with a subjective 5-level scale: 3 for an image equal to the MDCT image, 4 or greater for better, and 2 or lower for worse. The scores for all parameters exceeded 4 points. Maximum mean score was 4.8 for the lamina dura. Statistically significant differences were found for all items ($P < 0.01$). Our subjective evaluation of imaging performance clarified that 3DX was superior to MDCT. The results of this study suggest that 3DX is useful for imaging in the dental field. (J. Oral Sci. 48, 27-34, 2006)

Correspondence to: Dr. Koji Hashimoto, Department of Oral and Maxillofacial Radiology, Nihon University School of Dentistry, 1-8-13 Kanda Surugadai, Chiyoda-ku, Tokyo 101-8310, Japan
Tel: +81-3-3219-8104
Fax: +81-3-3219-8354
E-mail: hashimoto-k@dent.nihon-u.ac.jp

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Introduction

A medical CT system known as multidetector row helical CT has recently been developed and is now being applied for the diagnosis of malignant tumors (1), external injuries (2) and also in the dental field for clarifying the relationship between the lower third molar and inferior canal (3). In comparison with conventional CT systems, multidetector row helical CT allows rapid imaging with a smaller burden on the patient, and yields higher image quality while requiring a smaller exposure dose (4,5). In 1997, Arai et al. developed another system, cone-beam computed tomography (CBCT) for dental use, and named it Ortho-CT (6,7). As we have described previously (8,9), this system also yields high image quality with a low radiation dose. In 2000, a revised version of this system was marketed by Morita Co. (Kyoto, Japan) under the name 3DX multi-image micro-CT ("3DX"). We have investigated this system in various situations and reported its effectiveness for the diagnosis of various dental diseases (10-14). In Europe and the United States, this system is marketed as "3D Accuitomo" and is considered to be more effective and economical than medical CT systems for diagnosis in the maxillofacial region (15).

In the present study, we evaluated and compared the medical four-row multidetector CT (MDCT) system and CBCT for dental use system (3DX) in terms of performance for imaging of the maxillary bone. The specifications of the 3DX system have been described previously (13). This X-ray CT system uses a cone beam. An X-ray tube and image intensifier (sensor) rotate 360 degrees around the patient's head to collect raw digital data for image reconstruction. Imaging time is about 17 seconds for a single scan. The irradiation field at the center of rotation is limited to an area 29 mm high and 38 mm wide. Since voxels are regular 0.119-mm cubes, this imaging method used to be called Ortho cubic super high-resolution CT (Ortho-CT). As tomographic images 1 mm wide and 1 mm thick are continuously reconstructed, one imaging produces 30 tomographic images in each of the three directions. We previously compared 3DX and MDCT images of a maxillary central incisor and mandibular first molar in a human equivalent phantom and subjectively evaluated the image quality of these two systems (13). In the present study, to evaluate the image quality of 3DX, we compared 3DX images with MDCT images in order to determine how well bone and tooth conditions can actually be reproduced.

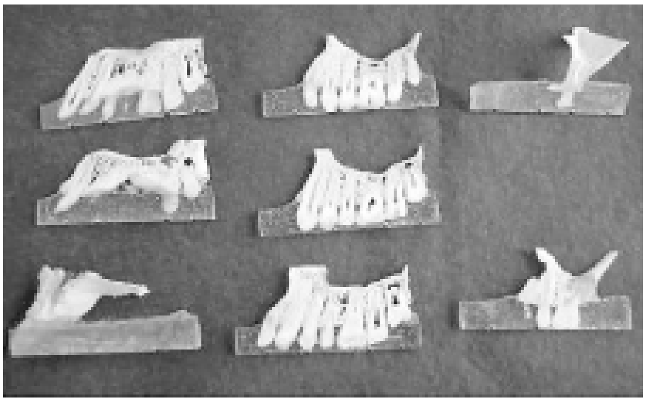

Fig. 1 Eight bone sections of maxillary bone.

Materials and Methods

The MDCT system used for the experiment was an Asteion Super 4 edition (Toshiba, Tokyo, Japan) that has been installed in the Dental Radiology Department of Nihon University School of Dentistry Dental Hospital since April 2004. This is a four-row multidetector CT machine. A phantom created from a dried specimen of the right maxillary bone was used as the object for evaluation. This maxillary bone was cut into eight slices 2 mm thick toward the zygomatico-palate in parallel with the midline plane (Fig. 1). For imaging, it was considered most straightforward to restore each slice at its pre-cutting position. The crowns of the maxillary teeth were secured by embedding them in dental acrylic resin. The bottom of the resin was then grooved with a dental cutting bar, and dental plaster was poured into the groove to obtain a counterdie so that bone slices could be restored to their pre-cutting positions by returning them to the locations where the plaster and resin groove matched. Note that cutting caused a loss of about 1 mm from each bone slice. This phantom was imaged as an object by both 3DX and MDCT. For comparison with MDCT images, 3DX images were obtained not from the section parallel to the dental arch but from that directly parallel with the median sagittal plane corresponding to the direction in which the maxillary bone had been cut. In an ordinary clinical situation, MDCT images from this section are obtained as reformatted

Table 1 Exposure conditions

1. Cone-beam CT for dental use (3DX)

Tube voltage: 80 kv Tube current: 2 mA

Exposure time: 17 sec Filtration: 3.1 mm Al equivalent

2. Multidetector CT (Asteion)

Tube voltage: 120 kv Tube current: 200 mA

Exposure time: 0.75 sec/slice (total 5.5 sec) Helical pitch: 4.5

Reconstruction interval: 0.3 mm FOV: 58.8 mm (SS) images; so-called multiplanar reconstruction (MPR) images. In the present study, however, direct high-quality images called direct sagittal images were taken and compared with the 3DX images. Table 1 gives the exposure conditions for both systems. For MDCT, the exposure time was 0.75 sec/slice, and total scan time was 5.5 sec. The helical pitch employed in this experiment was 4.5. The FOV employed was 58.8 mm. These exposure conditions for MDCT and 3DX were decided on the basis of the conditions we usually used clinically. Regarding the reconstruction function for MDCT images, images were obtained with bone function FC30, which is usually used clinically. With MDCT imaging, the window level (wl) and window width (ww) suitable for observation of bone structure differ from those suitable for observation of tooth enamel and dentin. To observe both bone and tooth structure on the same image for comparison with the 3DX image, we selected a suitable wl and ww while observing MDCT images on the monitor. These were 450 for wl and 2500 for ww. From the tomographic images obtained, these two matching bone slices were visually selected for evaluation. In other words, two 3DX images and two MDCT images were evaluated. Prints at the same enlargement level were output from an Olympus P-330 printer in 300 dpi full-color mode. Fig. 2 shows the third bone slice from the zygomatic side and images of this bone slice obtained with both imaging systems (Image 1). The MDCT image was evaluated first to see how well the conditions of the bone slice were reproduced. With this imaging quality as the standard, the 3DX image was evaluated in the same way. Fig. 3 shows the fifth bone slice from the zygomatic side and images of this slice obtained with both imaging systems (Image 2). These images were also evaluated in the same way. The evaluators were blinded to the image source. For Image 1, the MDCT image was evaluated first as B, followed by the 3DX

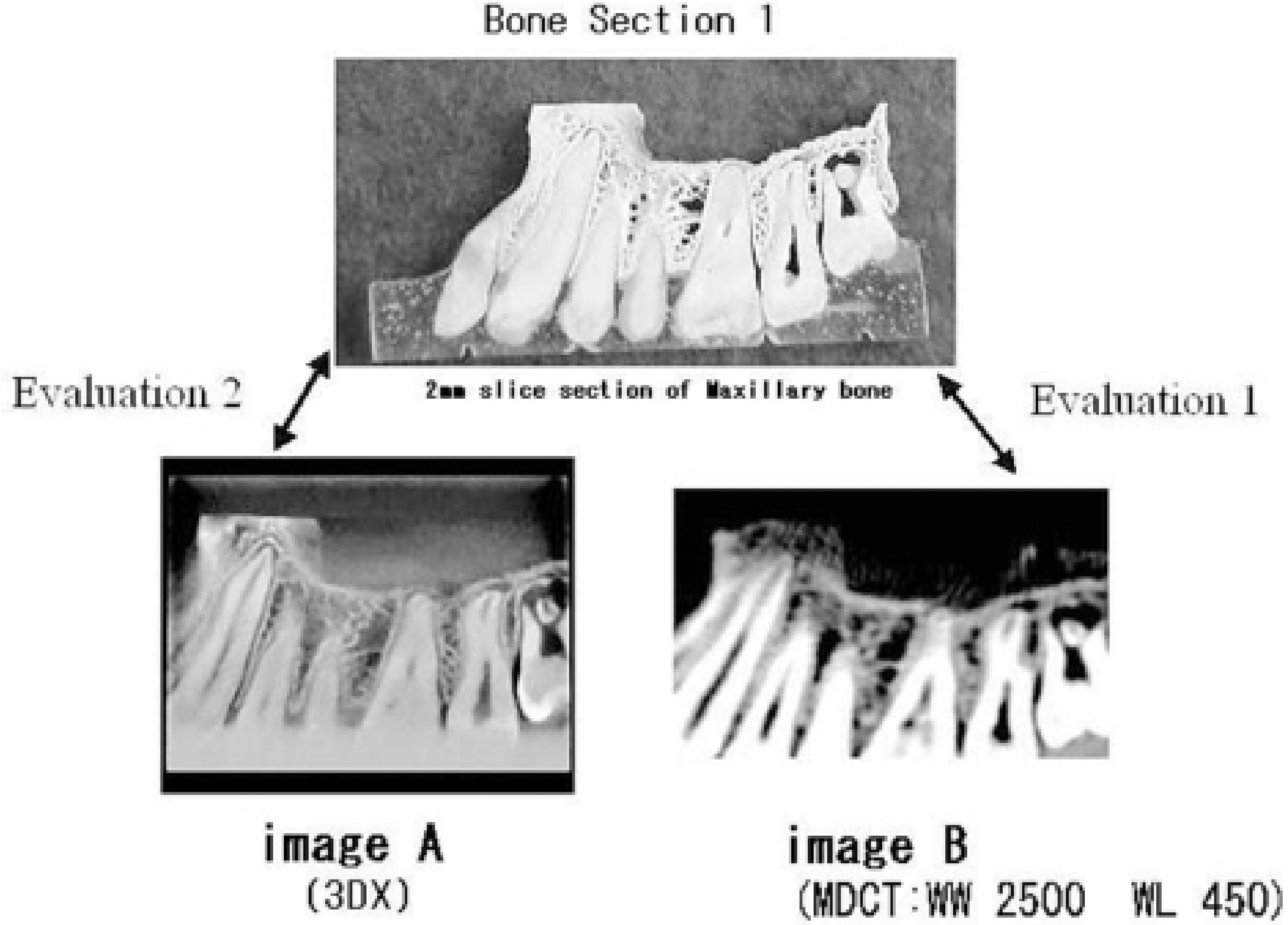

Fig. 2 Evaluation of 3DX and MDCT images (Image 1).

image as A (Fig. 2). For Image 2, the MDCT image was evaluated first as A, followed by the 3DX image as B (Fig. 3). Image 1 and Image 2 were presented to the evaluators separately. We used a total of five evaluators: three dental radiologists with 25, 29, and 9 years clinical experience, one oral surgeon with 7 years clinical experience, and one endodontist with 28 years clinical experience. Each evaluator assessed each image twice at an interval of one week. Average values for each image were obtained and Student's t test was then performed with a 95% confidence interval. The image evaluation items were the same as those reported previously (13) and the scores are shown below. The bone conditions selected for evaluation were bone trabeculae of cancellous bone. The tooth and surrounding tissue conditions selected for evaluation were enamel, dentin, pulp cavity, periodontal ligament space, and lamina dura. The overall image was then evaluated. Images were evaluated using the following scale:

Score 1: The 3DX image is obviously inferior in quality and reproducibility to the MDCT image.

Score 2: The 3DX image is slightly inferior in quality and reproducibility to the MDCT image.

Score 3: The 3DX image is equal in quality and reproducibility to the MDCT image.

Score 4: The 3DX image is slightly superior in quality and reproducibility to the MDCT image.

Score 5: The 3DX image is obviously superior in quality and reproducibility to the MDCT image.

The data obtained were processed using the statistical analysis software package SPSS 7.5 for Windows (SPSS, IL, USA). Since a similar test of a single mean (vs. $\mu = 3.00, \sigma = 0.00$) yielded the same results as paired Student's t test, the former was used for analysis in image evaluation. Weighted kappa (κ) was used to determine intra- and inter-observer variation.

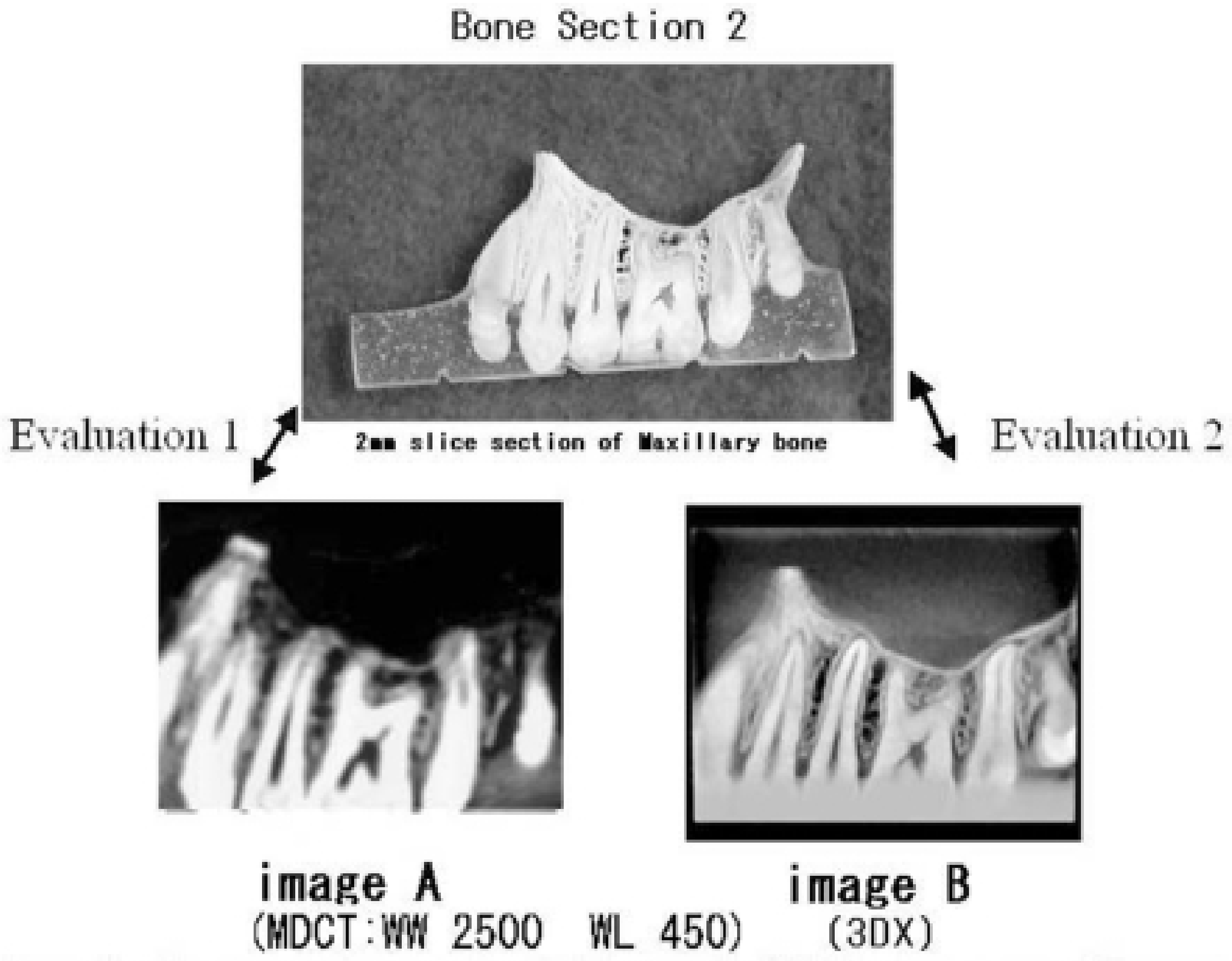

Fig. 3 Evaluatoin of 3DX and MDCT images (Image 2).

Results

Table 2 gives the results of image quality and reproducibility evaluation by the five evaluators. For all the evaluation items, 3DX images scored 4 or 5, indicating superiority to MDCT images. Maximum mean score was 4.8 for lamina dura, while minimum mean score was 4.3 for cancellous bone. We found that image quality and reproducibility of bone slice conditions for 3DX images were significantly superior to those for MDCT images (*P* < 0.01). Weighted κ showed no significant intra- or inter-observer differences (Table 3). Table 4 gives the results of similar tests of the single mean for each evaluator. All evaluators considered the 3DX images to be significantly superior, in terms of image quality and reproducibility, to MDCT images (*P* < 0.01).

Discussion

Cone-beam CT (CBCT) systems for dental use have been developed by several manufacturers and are now providing preoperative diagnostic information valuable for dental implant procedures and other clinical applications (15). As the CBCT for dental use, we employed the multi-Image micro-CT (3DX), marketed in 2000. In this system, the tube current can be set as low as 2 mA, lower than that achievable with the prototype Ortho-CT (13). For medical CT, a system with multi-row detectors capable of quickly acquiring projection data has been developed and marketed (15,16). The authors previously compared images of a maxillary central incisor and mandibular first molar in an anthromorphic phantom and evaluated them subjectively (13). In that study, 3DX images of cortical bone, cancellous bone, enamel, dentin, pulp cavity, periodontal ligament space, lamina dura and overall image impression were all evaluated as significantly higher quality than corresponding MDCT images. With these results in mind, the present study investigated 3DX and MDCT images to determine the accuracy of reproduction. The MDCT used in this study was an Asteion, which is the sister model of the Aquilion (Toshiba, Tokyo, Japan) used in the previous study (13) and has almost the same performance. As a four-row detector CT system, the model can scan slices of 0.5 mm, half the minimum slice of 1 mm, in a wide range with four rows of detectors. In addition, the system can produce 0.5-mm slice images because it can obtain four slices simultaneously by a single rotation of 0.5 seconds. Both high-speed and high-resolution scans are available. The minimum slice width is 0.5 mm and the slice thickness can be selected from 0.5, 1, 2, 3, 4, or 5 mm. Since the minimum scanning time is as short as 0.5 seconds, production of artifacts is minimal, the axial direction is improved, and the exposure dose is reduced. In the present study, the exposure conditions adopted for MDCT and 3DX were

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

Observation Items	Mean	S.D.	*P* value of Similar test of Single mean
Cancellous bone	4.30	0.57	1.98E−09※
Enamel	4.75	0.44	1.58E−13※
Dentin	4.60	0.60	1.37E−10※
Pulp cavity	4.55	0.60	2.80E−10※
Lamina dura	4.80	0.41	2.27E−14※
Periodontal ligament space	4.55	0.51	1.56E−11※
Overall impression	4.60	0.50	3.13E−16※

※ : Significant at the 5% level

based on those we usually employed clinically. Exposure time was 0.75 s/slice and total scan time was 5.5 s for MDCT and 17 s for 3DX. The exposure times for both machines differed depending on the tube voltage and tube current. Although these exposure conditions were used daily in a clinical situation, they would not have been optimal for the machine. For example, if the tube current of the 3DX machine were 3 mA or more, the image quality would have been better than that which we actually experienced. Deciding the specific exposure conditions was difficult. Therefore, the conditions employed were based on those we were accustomed to using. Similarly, a helical pitch of 4.5 was employed in this experiment because it is usually used clinically. Generally, the helical pitch is thought to influence MDCT image quality due to noise (4). A smaller helical pitch is thought to yield a better image without any influence of noise. However, the problem of patient radiation exposure cannot be ignored. In selecting the helical pitch, we were not aiming specifically for optimal machine performance, but rather used a pitch with which we were familiar clinically. The cone-angle problem in multi-detector row CT generally creates cone-beam artifacts at high-contrast objects such as bones. However, some authors have reported that cone-beam artifacts can be tolerated if the maximum number of simultaneously acquired sections does not markedly exceed four (4,17). Four-row CT systems can neglect the cone angle of the measurement rays. Hu et al. investigated the image quality and volume coverage speed of the four-row detector CT system. Compared with the one-row detector CT system, the four-row system was reported to have more than twice the volume coverage speed, as well as reduced artifact and noise production, resulting in improved image quality (18). The reconstruction function used was FC30, which is usually used clinically. In our previous study (13), both image systems were evaluated subjectively for image quality of a maxillary central incisor and mandibular first molar in an anthromorphic phantom. In the present study, using actual slices of the maxillary bone as the gold standard, imaging quality was compared to see how well the conditions of the bone slices were reproduced. Particularly for MDCT imaging, images suitable for bone

Table 3 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	C*E	D*E
Weighted κ Coefficients	0.00	0.41	−0.13	0.29	−0.35	0.06	0.01	0.09	−0.01	0.16	0.28	0.10	−0.32	0.11	−0.20
P value	1.00	0.16	1.36	0.29	1.81	0.83	0.98	0.65	1.06	0.50	0.18	0.63	1.90	0.57	1.68

Table 4 Similar test of single mean of each observer

Observer	A	B	C	D	E
Mean	4.88	4.63	4.63	4.63	4.21
S.D	0.34	0.58	0.49	0.49	0.59.
P value of similar test of Single mean	3.04E−16	5.50E−11	3.95E−12	3.95E−12	1.01E−08

structure observation and for tooth structure observation depend on the window level (wl) and window width (ww). However, in the present study, for comparison with 3DX images, we selected the suitable ww and wl conditions that seemed to reproduce the images captured on the monitor for comparison, and observed the same image for both structures. Since bone changes are often seen in clinical applications, it is important to investigate 3DX and MDCT images with respect to bone structure image quality. In the present investigation, the evaluators who were blinded to the type of imaging were instructed to first compare a MDCT image with the source bone slice and then to compare a 3DX image with the source bone slice, and to assign a score reflecting which image they considered superior. 3DX images were considered to be of better quality and reproducibility than MDCT images with respect to all evaluation items. This tendency did not change even when observations were performed in duplicate. Among the items observed, 3DX images scored highly for the periodontal ligament space and lamina dura, suggesting good ability to differentiate between different disease processes in bone. As mentioned above, isotropic voxel size is 0.119 mm for 3DX and 0.4 mm for MDCT (15). This difference might be responsible for the difference in structural resolution. Regarding image quality, Arai et al. (10) compared 3DX with the prototype Ortho-CT system, while Honda et al. (11) compared it with the helical CT system by means of MTF. Both studies found that 3DX image quality was superior. The resolution of this system is approximately 2 lines/mm, about four times that of medical CT (15). The 3DX system is predominantly useful for observing hard tissues, but it is not satisfactory for observing soft tissues. Among the images obtained in the present study, those of MDCT appeared to reflect the influence of scattered radiation to a greater degree, especially the image quality of tooth enamel. In the present study, to compare image quality for bone, we eliminated soft tissue elements. In order to extend the ww and wl ranges of the MDCT system, simultaneous observation of tooth and bone is preferable. However, since it was difficult to observe both under favorable conditions, we confirmed images on the monitor while actually varying the ww and wl to select the best possible images reproducing both bone and tooth. As basic items for image observation, we evaluated trabeculae, other bone structures and enamel and dentin. Although the 3DX evaluation scores for tooth enamel and dentin were high, MDCT images were thought to be insufficient in terms of actual detail. As mentioned above, this might have been due to scattering of radiation, especially by enamel. MDCT was introduced by several companies in 1998, as a system offering improved scanning speed and Z-axis resolution (15). Since then, its use has been reported for imaging of the colon (189, brain (20) , liver (21), and also in angiography (22). In this situation, MDCT has been used for clinical soft tissue diagnosis, comparing a single-detector row helical system, offering excellent enhancement, scanning speed, and Z-axis resolution. All reports have emphasized the usefulness of the MDCT system. However, few authors have discussed the evaluation of bone images. Only Jager et al. (23) compared MDCT and single-detector row CT with respect to transverse images and reformatted coronal images of normal temporal bones from 100 patients and reported MDCT to be superior for anatomical landmark imaging. The present study is the first to evaluate MDCT images of the maxillary bone. With regard to exposure dose during imaging, we measured the skin dose per examination and found that it was 1.19 mSv for 3DX and 458 mSv for four-row MDCT. In other words, the exposure dose for MDCT was 400 times greater than that for 3DX. Similarly, Iwai et al. (12) reported that the effective dose per 3DX examination was less than that for intra-oral or rotational panoramic radiography. The 3DX system, yielding high image quality with a low radiation dose, is therefore likely to be used more often in a clinical situation in the future. In conclusion, using slices of the maxillary bone as a phantom, the authors compared images obtained by 3DX with those obtained using the four-row MDCT system in terms of image reproducibility and image quality. For both tooth and bone structure, 3DX was considered to yield higher image quality and reproducibility than four-row MDCT. Considering that the skin dose we reported is as low as about 1/400 that of four-row MDCT, which is currently used in the dental radiology field, the 3DX system was demonstrated to be useful in the maxillofacial region.

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