Cone-Beam CT for Preoperative Implant Planning in the Posterior Mandible: Visibility of Anatomic Landmarks

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ABSTRACT

Background: The technical development has given a new type of modality, cone-beam computed tomography (CBCT). This technique has a high potential to solve different diagnostic problems among which is preoperative planning for implants in the posterior mandible.

Purpose: The aim of this retrospective study was to evaluate the visibility of the mandibular canal and the marginal bone crest and the agreement between observers in images from one CBCT technique.

Materials and Methods: Thirty consecutive patients were examined with 3D Accuitomo® (J. Morita Mfg. Corp., Kyoto, Japan) in one side of the mandible, where the second premolar and molars were lost. The examined volume was 30 by 40 mm. Seven observers evaluated the visibility and the location of the mandibular canal and the marginal crest by visually deciding if the structures were clearly visible, probably visible, or invisible in one cross-sectional image, approximately 1 cm posterior to the mental foramen. In a later session, the observers also marked the two anatomic structures. If the decision was not "clearly visible" or if the anatomic structures were difficult to identify, the observers had to use other cross-sectional, axial, and/or sagittal images in the volume.

Results: The confidence among the observers evaluating the marginal bone crest was high. Two observers never used any other images, and the rest took help in two to seven cases. When marking the mandibular canal, the observers, in general, used more images. In five cases (17%), all the observers only used the single cross-sectional image. The agreement on the position of the canal was also high.

Conclusion: With this CBCT modality (3D Accuitomo), the visibility of the mandibular canal and the marginal crest, as well as the observer agreement of the location of these structures, was high. Hence, the 3D Accuitomo can be recommended for implant planning in the posterior mandible.

KEY WORDS: anatomic landmarks, cone-beam computed tomography, dental implant planning, mandible, observers

INTRODUCTION

Today, there are more radiographic techniques available than ever before to guide the clinicians in implant treatment planning. Panoramic radiography can be considered for a primary evaluation in order to obtain information about the bone height and, to some extent, also information of horizontal distances.[1] When horizontal distances are critical for the treatment decision, supplementary intraoral radiographs can be obtained.[1] Intraoral and panoramic radiographies give, however, only information in two dimensions. The assessment of the location of the mandibular canal, the maxillary sinuses, and the nasal cavity, as well as the angulation of the alveolar crest and, in particular, the bone volume, is often a prerequisite for an appropriate planning. Hence, the radiographic examination has to, in some patients, include cross-sectional tomography.

Regarding what tomographic technique to choose, there are many different opinions. According to, for example, Clark and colleagues,[2] Ekestubbe and

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Gröndahl,[3] and Frederiksen and colleagues,[4] conventional tomography is to be preferred in the partial dentate patient not least because computed tomography (CT) delivers considerably larger radiation doses. One disadvantage with conventional tomography can be the degradation of the image quality as a result of disturbing ghost shadows from surrounding structures.[5] Among the disadvantages of the CT technique, its high cost, both monetary but more importantly in radiation dose, has been reported. Lower doses can be achieved by lowering the X-ray tube current.[6]

Guidelines for the preoperative radiographic planning of implants were published in 2000 and 2002 by the American Academy of Oral and Maxillofacial Radiology and the European Association for Osseointegration, respectively.[7,8] Unfortunately, the guidelines do not include cone-beam computed tomography (CBCT), as this technique by then was fairly new and not widely spread on the dental market. Today, several CBCT devices, also called digital volume tomography, are available, and of which 3D Accuitomo® (J. Morita Mfg. Corp., Kyoto, Japan) is specially made to display small parts of the jawbone with an image field size similar to that of ordinary dental films.[9–11] Generally, a lower radiation dose has been reported with the CBCT[12] compared with conventional CT, and in particular the 3D Accuitomo.[13,14] Consequently, this technique can be useful as a diagnostic tool in the treatment planning for implants in the partial dentate patient.

When evaluating different tomographic techniques for preimplant examinations, the posterior mandible has often been selected as a test region as an accurate localization of the mandibular canal is of vital importance for the treatment outcome.[3,6,15–21]

The aim of this retrospective study was to evaluate the visibility of the mandibular canal and the marginal bone crest in images performed by the 3D Accuitomo technique for implant planning in the posterior mandible.

MATERIALS AND METHODS

Thirty consecutive patients, referred to The Clinic of Oral and Maxillofacial Radiology at the Public Dental Health, Göteborg, Sweden, for radiographic implant planning, were selected for tomography with the CBCT technique. Selection criterion was implant planning in one side of the posterior mandible with loss of second premolar and molars on the actual side. Among the patients were 22 women and 8 men with a mean age of 69 years (range 48–88 years).

The CBCT technique used was the 3D Accuitomo. During the examination and exposure, the patient is in a sitting position using a headband to position the head against the headrest. The 3D Accuitomo is equipped with an image intensifier, and a single 360° scan collects the projection data for image reconstruction. The X-ray field size is 30 × 40 mm, and the reproduced volume is a cylinder with a height of 30 mm and a diameter of 40 mm. The images are displayed in three perpendicular planes on the screen. The reconstructed volume was placed parallel with the horizontal axis of the alveolar process, and the inferior border of the mandibular canal or the mandibular base if the canal was not depicted clearly in the sagittal plane. Depending on the angle between the base of the mandible and the horizontal plane during the X-ray exposure, the software displays the images with different magnification. In this study, the magnification in the images of the 30 cases varied between 3.0 and 4.7. The mental foramen had to be included in the imaged volume. Operating parameters were 2, 2.5, 4, 5, or 6 mA, 75 or 80 kV, and exposure time 17.5 seconds. Cross-sectional, sagittal, and axial slices (1-mm thick) were transferred to a PACS system (Sectra-Imtec AB, Linköping, Sweden).

The images were presented to the observers as in ordinary clinical work on a 21-inch monochrome monitor (RadiForce G21 2MP, Eizo Nanao Corp., Ishikawa, Japan) with a resolution of 1,600 × 1,200 pixels. The screen was divided in four equal parts to enable a presentation of cross-sectional, sagittal, and axial tomographic images in separate stacks. At the viewing sessions each case was presented with a predetermined cross-sectional image in the region of interest, approximately 1 cm posterior to the mental foramen, while the axial and sagittal stacks showed the position of the mental foramen (Figure 1). No image enhancement was allowed. Seven observers, all oral radiologists, evaluated the visibility of the mandibular canal and the marginal bone crest in two sessions (a and b). When performing the first session (a) the observers were not informed of the task in the second session (b). The evaluation was made in the following way.

(a) Visibility

In the predetermined image for each case, the observer had to decide whether the mandibular canal and the

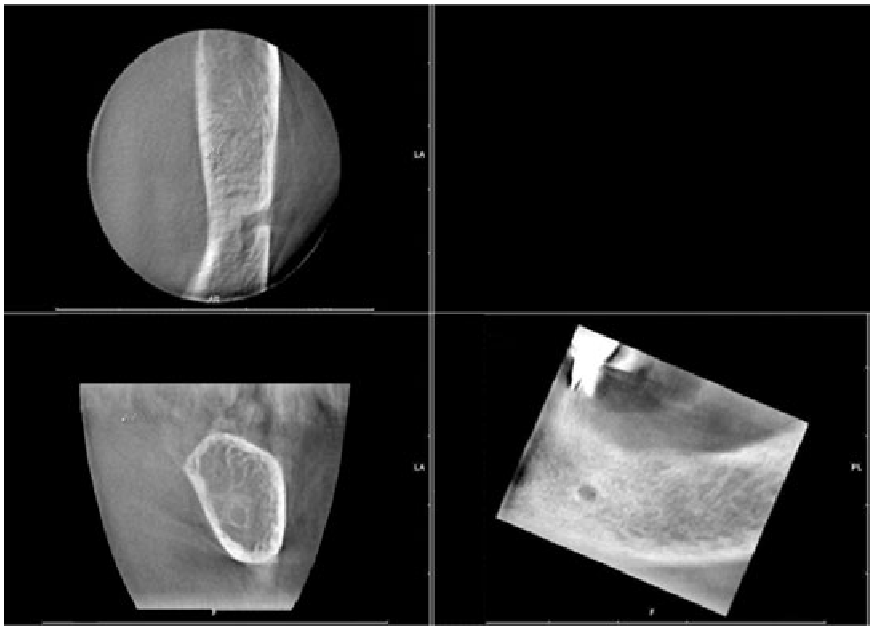

Figure 1 The three-dimensional Accuitomo images displayed on the monitor when starting the two viewing sessions (*case 29 in Figure 2*).

marginal bone crest were *clearly visible*, *probably visible*, or *invisibl*e. If the decision for each of the anatomic structure was *probably visible* or *invisible*, the observer had to go further to the axial, sagittal, and/or cross-sectional images in the stacks. The observers noted if they used axial, sagittal, and/or cross-sectional images and made a new decision on the visibility of the mandibular canal and/or the marginal bone crest in the predetermined cross-sectional image.

(b) Marking

After an interval of more than 2 weeks for each observer, a new evaluation was performed. In the predetermined cross-sectional images, the observers had to mark the center of the mandibular canal and the marginal bone crest with a cross (an x). If the observer found the structures difficult to identify, they were allowed to look at the separate stacks of axial, sagittal, and/or cross-sectional images. One of the authors recorded if and which stack/s was/were used. If the marking in the predetermined cross-sectional image was done without any help of other images, the evaluated structures were considered as *clearly visible*. The marked cross-sectional image with finally identified structures was saved as a "print-screen" picture.

RESULTS

(a) Visibility

For each of the seven observers, the visibility of the marginal bone crest was better than the visibility of the mandibular canal when interpreting the cross-sectional image obtained from the predetermined region of interest (Table 1). In 22 of the 30 images, all observers agreed on the decision that the marginal bone crest was *clearly visible*. The corresponding number for the mandibular canal was 10.

Tables 2 and 3 show the shift to a higher visibility score when getting access to more images within the cross-sectional stack or images from the other two. Out of the total 19 decisions by all observers as a *probably visible* marginal bone crest, eight decisions were changed to *clearly visible*. For the mandibular canal, the pattern was more complex. In 33 decisions out of 59, the decision was changed from *probably visible* to *clearly visible*, while two to *invisible*. Of those 22 decided as *invisible*, the decision was changed for nine to *clearly visible* and seven to *probably visible*.

When the two anatomic structures were decided as not *clearly visible*, the choice of which additional images to use varied among the observers. When deciding upon the marginal bone crest, the preference was to use more

TABLE 1 The Number of Each Visibility Decision in Session a (Visibility) for the Two Anatomic Structures Presented for Each Observer (A–G)

	Marginal Bone Crest			Mandibular Canal		
Observer	Clearly	Probably	Invisible	Clearly	Probably	Invisible
A	26	4	—	15	12	3
B	26	4	—	17	11	2
C	29	1	—	19	5	6
D	26	4	—	24	6	—
E	27	3	—	20	8	2
F	26	3	1	18	6	6
G	30	—	—	16	11	3

cross-sectional images, while one observer never used any extra images. Also, for the visibility of the mandibular canal, more cross-sectional images were used in a higher number of cases (range 6–16 cases) by all observers, while the axial images were seldom used (range zero to five cases). In seven cases (cases 8, 13, 18, 19, 22, 27, and 29), none of the observers asked for more images than the selected cross-sectional image (Figure 2).

(b) Marking

When the 30 predetermined cross-sectional images were reexamined, the observers reached a higher score of *clearly visible* for the marginal bone crest, while the opposite was noticed for the mandibular canal (Table 4). Figure 2 shows the variation between the marks in each cross-sectional image for the marginal bone crest and center of the mandibular canal among the seven observers.

When marking the marginal bone crest, two observers based their decisions on just the predetermined cross-sectional images, while two observers asked for more cross-sectional images in two cases, and another two observers in seven cases. The remaining observer asked for sagittal and/or axial images in three cases.

When marking the mandibular canal, none of the observers asked for more images than the predetermined cross-sectional image in five cases (cases 22, 24, 26, 27, and 29). The choice of supporting images varied among the observers: three observers preferred more cross-sectional images; three preferred sagittal images; and the remaining observer used all three types of images. One of the observers radically changed the choice of images in this second session, from preferring more cross-sectional images (16 cases) in the visibility

TABLE 2 The *Change* of the Visibility Score *Probably Visible* and *Invisible* (Session a) for the Marginal Bone Crest Based on More Images per Observer (A–G)

	Marginal Bone Crest		
Observer	Clearly	← Probably	← Invisible
A	*3* ←	4	
B	*1* ←	4	
C		1	
D	*1* ←	4	
E	*2* ←	3	
F	*1* ←	3	*1* ← 1
G		—	

TABLE 3 The *Change* of the Visibility Score *Probably Visible* and *Invisible* (Session a) for the Mandibular Canal Based on More Images per Observer (A–G)

	Mandibular Canal		
Observer	Clearly	← Probably →	← Invisible
A	*1* ←		
	8 ←	12	*1* ← 3
B	*1* ←		
	2 ←	11 →	*1* 2
C	*5* ←		
	4 ←	5	6
D	*4* ←	6	—
E	*1* ←		
	7 ←	8	*1* ← 2
F	*1* ←		
	3 ←	6 →	*1* 6
			3 ←
G	*5* ←	11	*2* ← 3

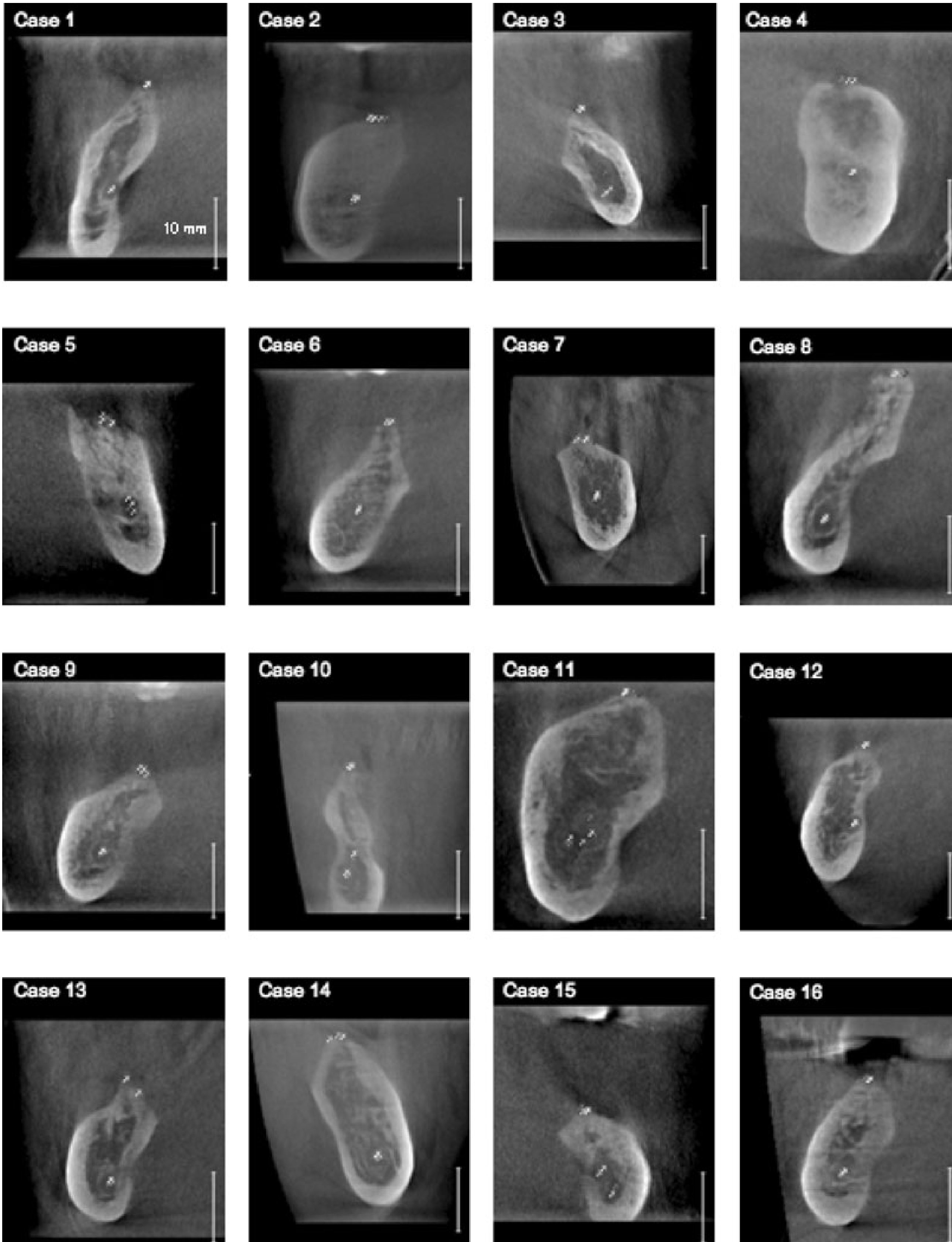

Figure 2 Location of the marginal bone crest and mandibular canal as marked with an x by each of the seven observers in all 30 selected cross-sectional images. The white vertical bar (in the lower right corner) in each image corresponds to 10 mm.

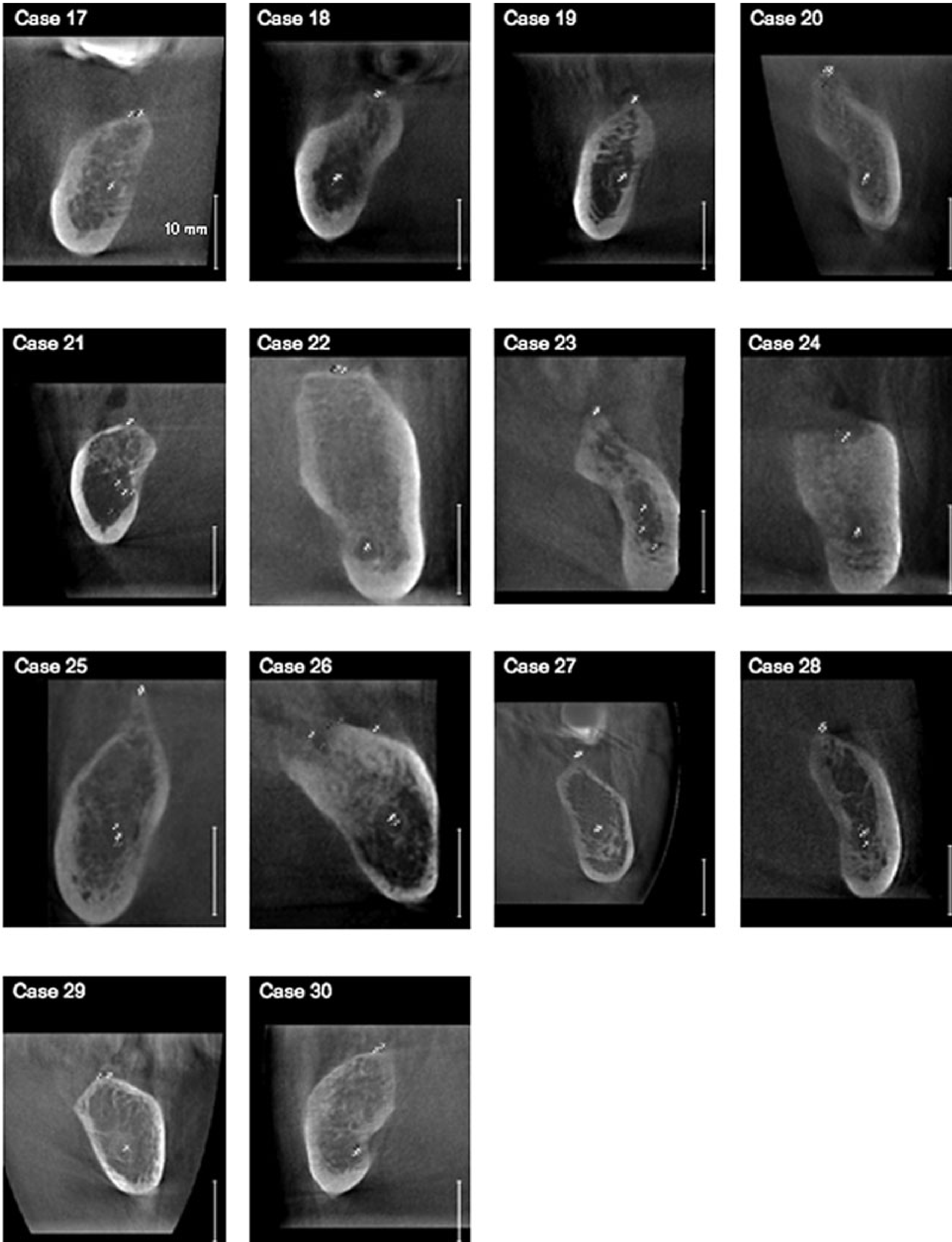

Figure 2 *Continued*

TABLE 4 Agreement in Visibility Score *Clearly Visible* Between the Two Sessions, Visibility (a) and Marking (b), for Each Observer and Anatomic Structure

	Marginal Bone Crest			Mandibular Canal		
Observer	a + b	a	b	a + b	a	b
A	26	—	1	11	1	3
B	23	3	—	12	5	2
C	29	—	1	16	3	3
D	26	—	3	19	3	2
E	27	—	3	17	2	2
F	26	—	3	14	4	2
G	23	7	—	5	9	—

test to using both sagittal and axial images in 25 cases, and more cross-sectional images in only four cases. All observers took help of other images in cases 15, 23, and 30 in both sessions.

DISCUSSION

Variability was found between the seven observers reading the same cross-sectional Accuitomo (3D Accuitomo) image of the posterior mandible. The variability was less when identifying the marginal bone crest than the mandibular canal. When getting access to more images, within the cross-sectional stack or images from the other two stacks, the number of decisions with a higher score of visibility was achieved. A large agreement among the observers was observed when marking the marginal bone crest with a disagreement in only two of the 30 cases, while there was a disagreement of >1 mm in nine cases for the mandibular canal. There was a preference to use more cross-sectional images for both anatomic structures and for both evaluations, visibility and marking tests. The observers might have been unwilling to make a decision on a single image knowing that more radiographic information was present. Furthermore, there might be a difference because of the different experiences in the interpretation of tomographic images among the observers, regardless of the kind of technique.

According to Lou and colleagues,[22] the reliability of the identification of different landmarks depends on numerous factors such as the clarity of the definition used to describe the landmark to the observers, the quality of the image, and the image contrast between adjacent objects. When studying conventional spiral tomography (Scanora® technique) in a clinical study, Ekestubbe and Gröndahl[3] found that the variation between observers measuring the distance between the highest point of the marginal bone crest to the upper border of the mandibular canal may be mainly because of the discrepancies in identifying the marginal bone crest. They pointed out that it must be of greater importance to correctly identify the mandibular canal than the marginal bone crest, as this often has to be lowered at implant surgery. The difference between the observers in the present study to identify the marginal bone crest might be because of a misunderstanding in the instruction to the observers. They were asked to identify the marginal bone crest, but some observers might have interpreted that the purpose was to identify the highest point, while some marked what they thought might be the starting point for drilling of an implant site.

Regarding the mandibular canal, a misunderstanding of the instruction cannot be expected as the observers were asked to mark the center of the canal. A supplementary panoramic radiograph or rather a consistent use of the sagittal images might have lowered the disagreement among the observers when locating the canal. Figure 3 shows how the mandibular canal (case 6 in Figure 2) can, besides the cross-sectional view, be seen in axial and sagittal planes. The observers did not always use the sagittal images in nine cases (cases 3, 6, 10, 11, 15, 21, 23, 25, and 28) where the marked location of the mandibular canal showed a discrepancy of >1 mm (see Figure 2). In cases 10, 15, and 21, sagittal images were used by six of the observers. Among the observers, there was no outlier. One observer differs in two cases, and two observers in one, but a different case, from the majority when marking the mandibular canal.

Since the introduction of the NewTom 9000 (Quantitative Radiology, Verona, Italy) in 1998, several systems have been commercialized, including 3D Accuitomo introduced in the European market in 2002. Marmulla and colleagues[23] found the digital volume tomograms of NewTom 9000 to be geometrically correct, and from a geometric point of view, suitable for three-dimensional implant planning when testing a geometric measuring object with air-filled cylinder bores. When testing the accuracy of measurements of mandibular anatomy in dry skulls, also using NewTom 9000, Ludlow and colleagues[24] found, based on the measurements by two observers, the horizontal wire length to be slightly overestimated whereas vertical wire length to be underestimated. Further, Lascala and colleagues[25] performed

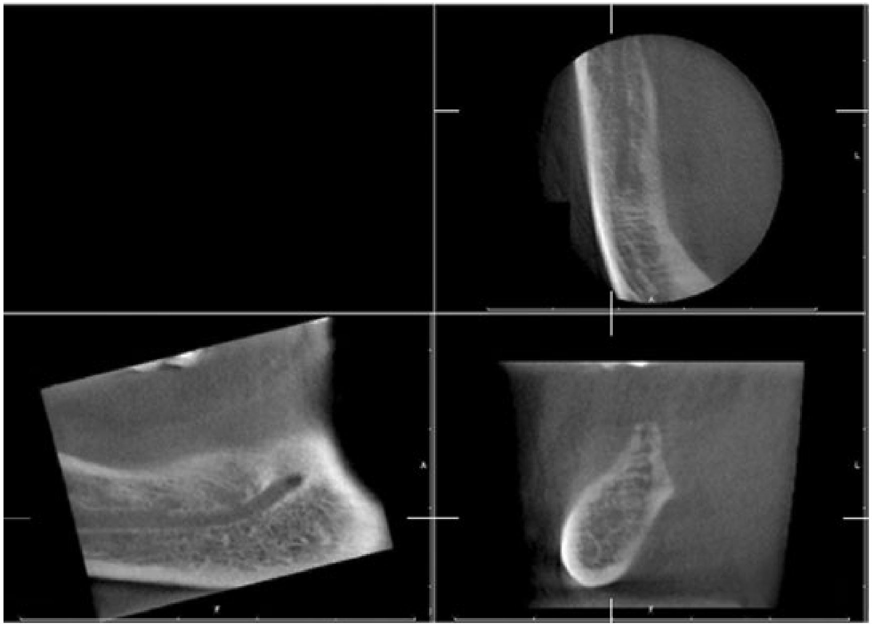

Figure 3 The mandibular canal (*case 6 in Figure 2*) shown in an optimal view in all three planes.

linear measurements between anatomic landmarks in dry human skulls scanned with the NewTom 9000 device and found real distances always larger than those obtained from the CBCT images. In assessing linear measurement accuracy, the first step is to identify the landmarks, anatomic or constructed, that make up the measurement. As dry skulls, used in most studies,[24–28] are devoid of soft tissue, which can obscure the visualization and identification of landmarks, the results ought to be interpreted with caution. Kobayashi and colleagues[10] measured cross-sectional distances on cadaver mandibles and compared them with the measurements obtained from spiral CT scans and scans obtained with a prototype of a cone-beam device (Asahi Roentgen, Kyoto, Japan). They determined a mean error of 0.22 mm (1.4%) for CBCT scans and of 0.36 mm (2.2%) for spiral CT scans. A similar result was found by Suomalainen and colleagues[29] when two observers measured four linear distances in cross-sectional images obtained from the 3D Accuitomo and multislice CT (MSCT) in three regions of a human cadaver mandible. The measurement error for 3D Accuitomo was 4.7% for dry mandible and 2.3% for the mandible immersed in sucrose solution. For the MSCT, the corresponding results were 8.8 and 6.6%, respectively.

Lou and colleagues[22] pointed to the need of further evaluations of the CBCT on identifying and testing landmarks, and that the studies have to represent real-life conditions.

So far, most evaluations have been performed on NewTom 9000, probably because it has been on the market for a longer period of time. The reproduced volume, exposure parameters, radiation dose, and design differ among the many CBCT brands. The 3D Accuitomo has a smaller image field than most CBCT units, and is therefore a valuable technique for a number of applications in oral and maxillofacial radiology, in particular when smaller regions are of interest.

In the present study, based on a retrospective patient material examined with the 3D Accuitomo, the image quality might not be optimal in all cases, but it will simulate an everyday use. Further, the observers were not allowed to use any kind of image enhancement. In addition, 73% of the patients were females, and the mean age of the entire group was 69 years (range 48–88 years).

All observers were well aware of the importance of accurate localization of the canal in implant treatment planning as unintentional penetration of the mandibular canal during the surgical drilling for implant as a result of lack of knowledge of its position might cause permanent neurologic complications. When comparing the results from marking the mandibular canal to the experienced visibility of the mandibular canal, the observers were found to be more unsure or maybe more unwilling to mark the canal with only one single cross-sectional image as support when knowing that more radiographic information was present. The observers asked for more images, although the choice of complementary images differed between them. Accurate radiographic data make implant surgery more precise and predictable and allow the surgeon to accurately plan the treatment and evaluate the surgical outcome. The acceptable degree of error depends on the type and complexity of the surgical procedure planned. As pointed out by Lou and colleagues,[22] the clinical significance of the magnitude of landmark identification error will depend on the level of accuracy required.

It is well known from studies in medical and dental radiology that various observers may arrive at different results when examining the same radiographs, and that one and the same observer can contradict his or her own findings at reexamination.[30] Difference in level of education and experience among the observers may result in the use of different criteria among the observers. The observers' influence on the measurements of distances between the marginal bone crest and the mandibular canal on conventional hypocycloidal tomograms has been described by Gröndahl and colleagues[15] who suggested that an increased reliability of the measurements might best be attained by repeated independent interpretations by the same observer. They also found a better agreement between oral radiologists than between oral surgeons. All observers taking part in this study had long experience in oral radiology, although, for obvious reasons, of shorter time for this particular technique. Multimodal units, like Cranex Tome®[19] and Scanora,[17] both performing conventional, spiral tomography, have been evaluated for assessing the localization of the mandibular canal and have been found to provide accurate information and sufficient details for preoperative planning of implant placement in the posterior mandible. The two observers evaluating the Cranex Tome tomograms on fresh cadavers both under- and overestimated the distance by as a mean absolute difference of 0.66 mm (SD 0.4).[19] In the study by Ekestubbe and colleagues,[17] conventional spiral tomograms were subjectively preferred over conventional CT images. When testing the reliability of spiral tomography with the Scanora technique, Ekestubbe and Gröndahl[3] found that in no case out of tomograms from 40 patients did all six observers agree on the measured distance of the marginal bone crest – mandibular canal, and the mean range between the observers was 3.3 mm (SD 2.3).

In the present study, all seven observers interpreted the marginal bone crests *clearly visible* in 22 of the 30 cases when only evaluating the predetermined cross-sectional image. Higher visibility scores (25 cases) were achieved when getting access to more images. For the mandibular canal, all observers decided the canal to be *clearly visible* for 10 cases. By getting more images, all observers agreed upon the highest visibility score in 16 cases. When marking the bone crest, all observers placed the mark within <1 mm in 28 of the 30 cases. For the mandibular canal, the corresponding number was 21 of the total 30 cases. So, if the distance between the marked mandibular canal and marginal bone crest in each case had been measured for each observer, the agreement between observers had been high in approximately 20 out of the 30 cases (see Figure 2).

Hence, it seems possible to conclude that the CBCT technique tested in the present study, the Accuitomo technique, is superior to conventional spiral tomography to localize both the marginal bone crest and the mandible canal and, consequently, can be recommended instead of the motion tomography in the prementioned guidelines.[7,8] Still, the goal is to achieve even higher agreement among observers. A more unanimous result might have been achieved if the observers had been allowed to use image enhancement. Other possibilities exist, too. It might be worthwhile to study if thicker scans, thicker than the 1-mm thick scans used in this study, will increase the image clarity of the mandibular canal. Even more interesting is to find out if it is possible to optimize the exposure parameters and hence, the image quality.

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