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Reliability of distance measurements in dental CBCT images

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We evaluated the accuracy of linear measurements in dental CBCT-based images for various sites in the field of view (FOV). We used a phantom of 30 stacked commercially available CD-R disks. The phantom was scanned with two cone-beam computed tomography (CBCT) units, a Kyocera Prevista Uni-3D MultiOS and a Morita 3D Accuitomo F 17, and linear measurements were obtained with a digital caliper. The error characteristics were different for each device. There were similar errors on the edges of the FOV at 90 kV. Measurement errors in the upper and lower regions of the FOV tended to be slightly larger than in the middle. It is important to understand that the accuracy of linear measurements in CBCT images varies depending on their location in the FOV. (J Osaka Dent Univ 2016 ; 50 : 111-116)

Key words : CBCT ; Accuracy ; Measurements

INTRODUCTION

Dental cone-beam computed tomography (CBCT) has been widely used in Japan, because lesions can easily be examined in the three-dimensional image display.[1] An increasing number of dentists are using CBCT images in the field of implantology for preoperative surgical simulation and for constructing surgical guides, as has been recommended in implant guidelines for the use of CT images during the pre-surgical examination.[2] Recently, more CBCTs are being sold with a wide field of view (FOV) as they make it possible to decrease the exposure time. However, there is a possibility that the accuracy of linear measurements is compromised in CBCT with a wide FOV because of the greater angulation of the exposure beam. The accuracy of the linear measurements in the CBCT images has been reported in various articles.[3-6] A few articles have described the effect of the location in the FOV position on dimensional accuracy.[4, 6] No reports have examined the accuracy of horizontal and vertical linear measurements on the edges of the FOV. We attempted to analyze the accuracy in this location in the CBCT images by comparing actual linear dimensions with measurements obtained in the CBCT images.

MATERIAL AND METHODS

Evaluation methods

Measurement locations in the exposed object

We constructed a phantom by stacking 30 commercially available compact discs (CD). A gap equivalent to the thickness of the one CD was created between each disk. Exposure by the CBCT equipment of the phantom was done with its center line at the center of the FOV (Fig. 1). CDs were used for the phantom because they are standardized by JIS code (X 6281 ; 120 mm in diameter and 1.2 mm in thickness), and because they are inexpensive, making it possible to verify the experiments.

Measured items at each location were based on the thickness of 10 CDs (Fig. 2). Figure 3 shows that the measurement locations were set at the center and on the edges of the FOV in the images and the actual object. The areas examined were divided into three regions (the upper, middle and lower) that were measured in the images and on the real object. Thus, six vertical distances were measured in this experiment in the images and the

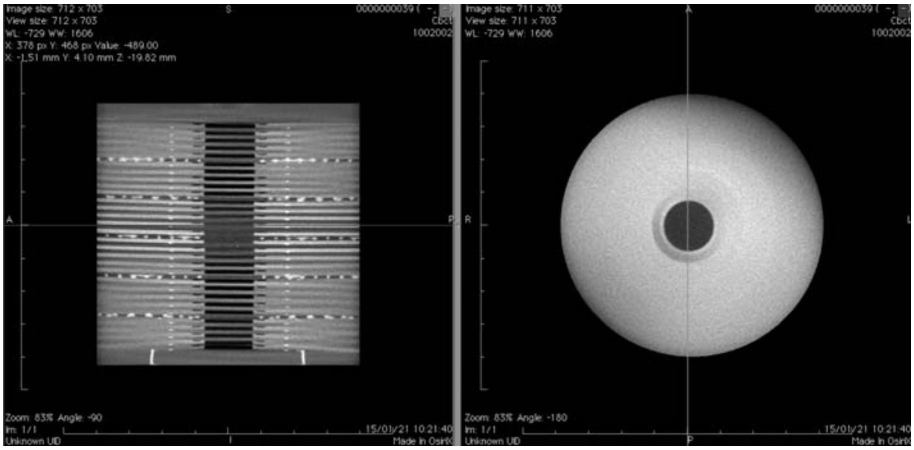

Fig. 1 Photograph of scanned phantom.

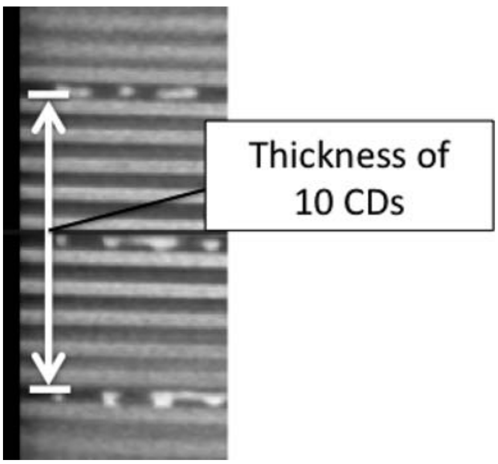

Fig. 2 Measured items at each location were based on the thickness of 10 CDs.

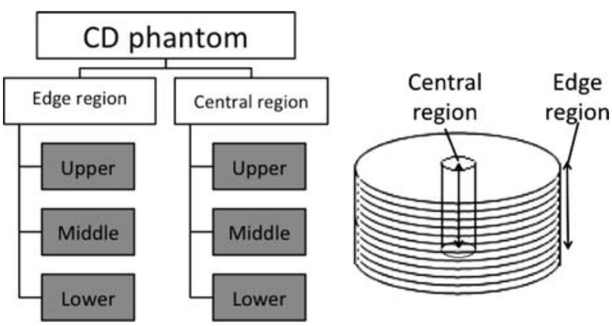

Fig. 3 Measurement points.

actual object. The measurement of the images was performed with one computer under identical conditions.

By comparing the acquired CBCT dimension measured on the image with the actual measured dimension, we could calculate the distortion and errors in the CBCT images for each item. The errors were calculated from the difference between the actual distance and the distance acquired from the CBCT image, all determined in 0.1 mm increments. The distortion was calculated from the quotient of the calculated error and the actual dimension. In this way we were able to evaluate the dimensional accuracy of each region in the FOV. We calculated the distortion for each measured distance with the tube voltage set at 70 kV, 80 kV and 90 kV on each CBCT, and calculated the distortion for each measured item. To evaluate the effect of the measured position in the FOV on dimensional stability, we calculated the distortion and errors in the upper, middle and lower regions on the edge of the phantom and in the central region.

Equipment and exposure conditions

The CBCTs used in this experiment were the Pre-Vista Uni-3D Multi OS (Uni ; Kyocera Medical, Osaka, Japan) and the 3D Accuitomo F 17 (3DX ; Morita, Kyoto, Japan) (Fig. 4). The FOV was set at the maximum for the equipment. With the Uni, that was a diameter of 120 mm and a height of 85 mm. The respective dimensions for the 3DX were 80 mm each. We set the pixel size to 0.2 mm × 0.2 mm × 0.2 mm. The exposure time was determined

Fig. 4 Phantom mounted on the 3D Accuitomo F17.

by the CBCT machine. Measurements on the images were done by Osirix ver 5.8.1 (Pixmeo, Geneva, Switzerland). Measurements on the phantoms were done with a Digimatic Caliper (Mitutoyo, Kawasaki, Japan).

RESULTS

Effects of voltage changes on the dimensional accuracy

Figure 5 shows the distortions on the edge of the FOV. Distortion of the images exposed with the Uni at 70 kV was 0.5% in the upper and middle regions, and 0.9% in the lower region. Distortion at 80 kV was 0.6%, 0.3% and 0.8%, respectively. Distortion at 90 kV was 0.4%, 0.1% and 1.1%, respectively. Except in the lower region, images exposed at 90 kV had less distortion than those exposed at 70 kV or 80 kV. Distortion in the images exposed with the 3DX at 70 kV was 2.5% in the upper re-

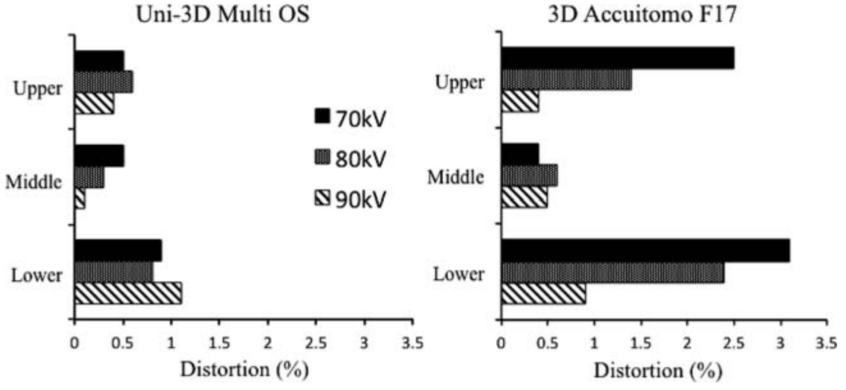

Fig. 5 Distortion at the edge as a function of tube voltage.

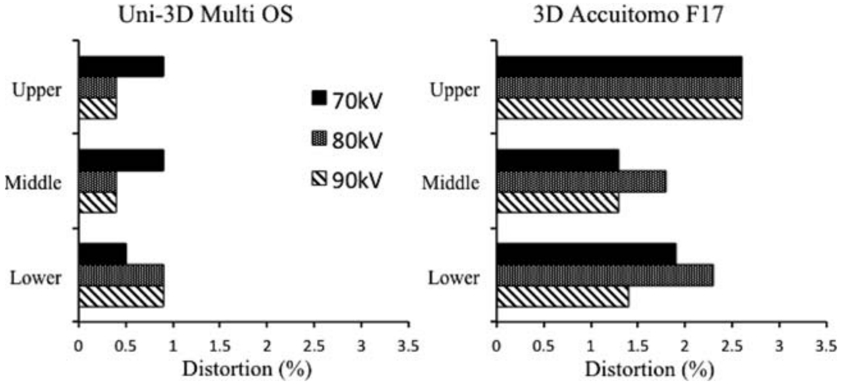

Fig. 6 Distortion in the central region as a function of tube voltage.

gion, 0.4% in the middle region and 3.1% in the lower region. At 80 kV, these values were 1.4%, 0.6% and 2.4%, respectively. At 90 kV, they were 0.4%, 0.5% and 0.9%, respectively. Similar to the results for the Uni, the distortion of images exposed at 90 kV was less than for those exposed at 70 kV and 80 kV.

Figure 6 shows the distortions in the central region in the FOV. Distortion in the images exposed at 70 kV with the Uni was 0.9% in the upper and the middle region, and 0.5% in the lower region. At 80 kV the distortion was 0.4%, 0.4% and 0.9%, respectively. At 90 kV it was the same as that exposed at 80 kV in all regions. Compared with images exposed at 70 kV, the images at 90 kV had less distortion in the upper and the middle regions. Distortion in the images exposed with the 3DX at 70 kV was 2.6%, 1.3% and 1.9% in the upper, middle and lower regions, respectively. At 80 kV the distortion was 2.6%, 1.8% and 2.3%, respectively. At 90 kV, it was 2.6%, 1.3% and 1.4%, respectively. When compared with images exposed at 70 kV, the images exposed at 90 kV had the same distortion in the upper and the middle regions, and less in the lower region. Compared with images exposed at 80 kV, images exposed at 90 kV had the same amount of distortion in the upper region and less in the middle and the lower regions.

Table 1 Distortion in measurements on the edges

Uni-3D Multi OS					
Region of FOV	Average	SD	Distortion	Min	Max
Upper	0.2	0.14	0.4%	0	0.5
Medium	0.1	0.06	0.1%	0	0.3
Lower	0.3	0.23	1.1%	0	0.8

(mm)

3D Accuitomo F 17					
Region of FOV	Average	SD	Distortion	Min	Max
Upper	0.1	0.11	0.4%	0	0.3
Middle	0.2	0.12	0.5%	0	0.4
Lower	0.2	0.12	0.9%	0	0.4

(mm)

Table 2 Distortion in the central region

Uni-3D Multi OS					
Region of FOV	Average	SD	Distortion	Min	Max
Upper	0.2	0.08	0.4%	0	0.4
Middle	0.1	0.09	0.4%	0	0.2
Lower	0.1	0.14	0.9%	0.1	0.3

(mm)

3D Accuitomo F 17					
Region of FOV	Average	SD	Distortion	Min	Max
Upper	0.6	0.05	2.6%	0.6	0.7
Middle	0.3	0.11	1.3%	0.2	0.4
Lower	0.3	0.01	1.4%	0.3	0.4

(mm)

Effect of location in the FOV on the dimensional stability

Table 1 shows the error and the distortion of images exposed at 90 kV on the edge of the FOV. Images exposed at 90 kV had higher dimensional accuracy than those at lower voltages; therefore, we set the tube voltage to 90 kV. Distortion in the lower region with the Uni was 1.1% and the maximum error was 0.8 mm, indicating that the lower region had more distortion than the upper or middle regions. Also, with the 3DX, the distortion in the lower region was more than that in the upper or middle regions. With both the Uni and the 3DX, the average errors were 0.2 mm or less in most measured items.

The error and distortion in the central region of the FOV are shown in Table 2. With the Uni, the greatest maximum error was found in the upper region (0.4 mm), while the greatest distortion was found in the lower region (0.9%). With the 3DX, the lower region had the greatest distortion (2.6%) and the greatest maximum error (0.7 mm), compared with the upper and middle regions. Although the average errors with the Uni were 0.2 mm or less, with the 3DX they were greater than 0.2 mm in all regions. The distortion in the upper and lower regions was about twice that of the middle. Figure 7 shows that the upper and lower regions of the images were more indistinct than the middle region.

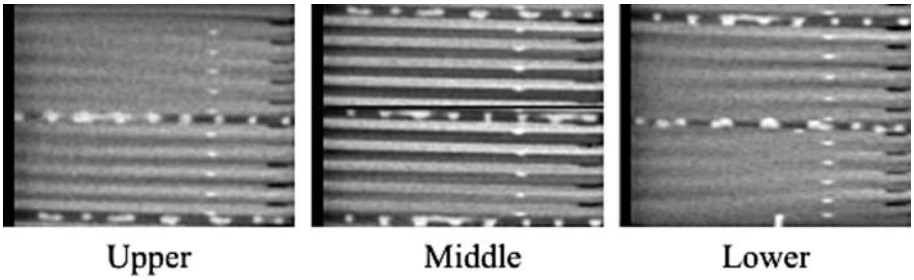

Fig. 7 Scanned measurement points on the edge.

DISCUSSION

The CBCT has come to be utilized by many dental clinicians with the spread of dental implant treatment. The acquired CT images are used for simulation of treatment and for making surgical guides prior to surgery.[2] However, no standards for evaluating the performance of the CBCT have not been established. There are not even standards for evaluating the stability of CBCT linear measurements.[7] Unlike computed tomography for medical use, the dental CBCT uses a conical X-ray beam to expose a sufficient area at one time to obtain the 3D image. In contrast, the multi detector CT (MDCT) uses fan beams that expose a strip-shaped area. Because of this difference, the CBCT can obtain images without sliding the patient on a table, in a shorter time and with a lower radiation dose, compared with the MDCT. Recently, sales are increasing of CBCT devices that have a large FOV, which makes it possible to reduce the exposure time. On the other hand, the large FOV increases the risk of noise resulting from scattered radiation. In addition, the vertical angulation of the exposure leads to an increase in distortion and artifacts in the images. This is especially true in the upper and lower regions of the FOV, and is caused by the image engineering factor.

Several articles have discussed CBCT dimensional stability. However, very few of them have described the effect in different locations in the FOV of the CBCT images.[4] In particular, no author has examined the dimensional accuracy on the horizontal and vertical edges of the FOV. In this study, we made phantoms that encompassed the entire FOV, making it possible to calculate the error on the edges and in the central region of the phantoms. Also, we examined the exposure conditions that might increase these distortions.

Effect of changes in voltage on dimensional stability

Normally, clinicians who use the CBCT must set optimal exposure conditions that reduce the radiation dose while maintaining image quality.[8] Although the tube voltage does not affect the diagnosis, the tube current does.[9] However, no reports have examined the effect of changes in tube voltage on the dimensional stability. In this study, we set the tube voltage at 70 kV, 80 kV and 90 kV on each of the CBCT machines and evaluated the dimensional stability in several regions. We found that close to the edge of the FOV, the images exposed at 70 kV and 80 kV had greater distortion than those exposed at 90 kV. Distortion in the upper edge of the image exposed at 70 kV was up to six times that in the image exposed at 90 kV. On the edge of the FOV the diagnostic capacity decreases with decreases in the tube voltage. However, in the central region of the FOV, the difference in the image quality between 90 kV and the lower voltages (70 kV and 80 kV) was much smaller. As a result, lowering of the tube voltage may lower the dimensional stability accordingly, and create artifacts on the edges. Dimensional stability on the long axis of the head is important when an operation is simulated using CBCT images. For this reason images should be taken with a lowered tube voltage to reduce radiation dose.

Effect of location in the FOV on dimensional stability

In clinical practice, dental implantologists would like to examine the patient from the lower boarder of the mandible to the infraorbital region. Therefore, they tend to use the CBCT with a wide FOV setting. However, they may not notice the differences in the dimensional accuracy in the various regions of the FOV that may occur during construction of the CBCT image. An article on the dimensional accuracy of regions in the FOV describes the head axis direction in the central regions.[4] In this study, we measured all regions in the FOV and studied the vertical and horizontal dimensional distortions. When we compared the horizontal distortion on the edge and in the central region, with the Uni the error was within 0.2 mm, which is equivalent to one pixel. With the 3DX, the error in the central region was between 0.3 mm and 0.6 mm. On the edge, the error was between 0.1 mm and 0.3 mm. Our results were similar to those reported by Tsutsumi et al., where the distortion on the edge portion was larger than in the central region.

When compared to the effect in the vertical direction on the edge and in the central region, there tended to be more distortion in the lower and upper regions than in the middle. In the case of the Uni, the distortion on the edge was 0.1% in the middle region and 1.1% in the lower region. In the central region, it was 0.4% in the middle region and 0.9% in the lower region. In the case of the 3DX, the distortion in the central region was 1.3% in the middle region and 2.6% in the upper region.

Our results indicated that the upper and the lower region had twice the distortion of the middle region. When considering treatment of multiple sites in the oral cavity, dentists tend to choose a large FOV when using the CBCT. This is especially true when planning a surgical procedure, such as a sinus lift. When a large FOV is selected when exposing a CBCT, structures such as the sinus and the lower boarder of the mandible are located near the edges. Therefore, they should take note of distortions and consider not accepting accuracies of less than 1 mm. If a high accuracy image is important, the site of interest should be in the middle of the FOV. One report noted that the CBCT radiation dose with a large FOV is almost the same as that of an MDCT when examining facial bones.[10] We found that the dimensional accuracy of the CBCT was affected by the tube voltage and the location of the measurement in the FOV. In addition, a lower tube voltage decreases accuracy, and measurements in the upper and lower edges of the FOV are less accurate. Before exposing the CBCT it is necessary to set the optimum exposure conditions and size of the FOV.

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