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Stability of pixel density in cone-beam computed tomographic images

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Cone-beam computed tomography (CBCT) is not well equipped to provide readouts in CT number (CTN). We examined the correlation between the pixel density of CBCT images from two machines and CTN of multi-detector row computed tomography (MDCT) from one machine. A quality assurance phantom was used to evaluate the stability of the images. The contrast medium *Iopamidol* (Iopamiron 300® ; Bayer Health, Osaka, Japan) at 6 different concentrations (0, 1, 2.5, 5, 10 and 20%) were placed in 5 mL syringes. Test objects were positioned in several patterns and both CBCT and MDCT images were obtained. The pixel density was measured and analyzed with an image workstation. We found that the CBCT image became less dense closer to the edge of the imaging area, while the density of the MDCT image was stable throughout. A strong correlation was observed between the pixel density of CBCT and the CTN of MDCT in the same materials. Placing materials around the object resulted in smaller values. We concluded that the density near the center of the field of view (FOV) is accurate in CBCT images. A high correlation and linear relationship between the CTN and pixel density were observed for each parameter. (J Osaka Dent Univ 2014 ; 48 : 97–102)

Key words : Dental cone-beam CT ; CT number ; Density

INTRODUCTION

The use of cone-beam computed tomography (CBCT) is well accepted for dental diagnosis. However, there has not been adequate evaluation of the image quality that takes into consideration pixel density and dimensional integrity. As a result, some manufacturers claim without substantiation that their CBCT adequately displays CT numbers (CTN). Several authors have claimed that the same volume data can be obtained with CBCT as with multi-detector row computed tomography (MDCT). The density of CBCT images are not displayed as actual CTN because of structural limitations that include radiating condition, scatter radiation, dynamic range limitation of the detector, beam hardening, imaging parameters and object positioning.[1] Another author has reported that the pixel density of CBCT can be used like CTN because there is linearity between pixel density in CBCT and the concentration of the materials.[2–4]

We also found a correlation between pixel density of CBCT and MDCT images. We took into consideration differences in the exposure condition and position of the object in the exposure field for the two image types. Our first goal was to check the stability of the density for the two image types. Then we clarified the correlation of the pixel density between the CBCT and MDCT images by exposing various materials and analyzing the results.

MATERIALS AND MATHODS

We examined MDCT images taken with the 16 Row Bright Speed Elite (GE Healthcare, Milwaukee, WI, USA) and CBCT images obtained with the AUGE X (Asahi Roentgen, Kyoto, Japan) and a White Fox machine (Satelec Acteon Group, Mérignac Cedex, France). The AUGE X has three exposure modes of the field of view (FOV) (Table 1). The White Fox has five exposure modes for the FOV, although we used only two of them in this experiment. The data is shown in Table 2. The CT images were transferred to a personal computer and an image workstation in DICOM

Table 1 Detailed AUGE image acquisition parameters

Acquisition mode	FOV (mm)	Voxel size (mm)	Rotation time (sec)
A	104×80	0.203	17
I	79×80	0.155	17
D	51×55	0.1	17

Table 2 Detailed White Fox image acquisition parameters

Acquisition mode	FOV (mm)	Voxel size (mm)	Rotation time (sec)
Cephalometric	200×170	0.3	18
Half arch	60×60	0.1	18

Fig. 1 QA phantom.

format. An Advantage Workstation (AW ; GE Healthcare) and a zio Term 2009 (ZIO ; Ziosoft, Tokyo, Japan) were used for analysis and measurements. The study was designed in consideration of the rights and interests of the subjects and approved by Medical Ethics Committee of Osaka Dental University (approval number : 110736 and 110737).

Experiment 1

In experimental series 1 we compared the stability of the flat panel detectors (FPD) used in CBCT with the detector of MDCT. We assumed that the amount of density would decrease in the peripheral region of the FOV, which is a character of the FPD used in CBCT. We used a quality assurance calibration phantom (QA phantom ; 215 mm in diameter and 60 mm in height ; GE Healthcare, Milwaukee, WI, USA) (Fig. 1). We took the images with MDCT and with CBCT in the wide mode of FOV to cover the entire phantom. The exposure conditions are shown in Table 3. Multi-planar reconstruction (MPR) images from CT data were constructed to obtain measurements. The cylindrical MPR images were divided into upper, middle and lower regions. Lines were drawn through the center of each region at 45 degrees. Density measurement points were placed every 5 mm on each line. Line graphs were drawn using the average of five measurements at each point to avoid errors.

Experiment 2

In experimental series 2 we examined the density of the CBCT and MDCT images, taking test samples with different concentrations. Six test samples were made with solutions of the contrast medium *Iopamidol* (Iopamiron 300® ; Bayer HealthCare, Osaka, Japan) at concentrations of 0, 1, 2.5, 5, 10 and 20%. The solutions were sealed into 5-mL syringes (Terumo, Tokyo, Japan). The samples were surrounded by air. The exposure conditions of CBCT are shown in Table 4. The exposure conditions for MDCT were deter-

Table 3 Imaging parameters

MDCT	Tube voltage (kV)	Tube current (mA)	Thickness (mm)	FOV (mm)	Matrix size
Bright Speed Elite	100	100	0.625	240×240	512×512

CBCT	Tube voltage (kV)	Tube current (mA)	Voxel size (mm)	FOV (mm)	Matrix size
AUGE (A mode)	85	6	0.2	104×80	512×512
White Fox (Cephalometric)	105	9	0.3	200×170	

Table 4 Imaging parameters

MDCT	Tube Voltage (kV)	Tube Current (mA)	Thickness (mm)	FOV (mm)	Matrix size
Bright Speed Elite	100	100	0.625	240×240	512×512

CBCT	Tube Voltage (kV)	Tube Current (mA)	Voxel size (mm)	FOV (mm)	Matrix size
AUGE (I mode)	85	4	0.155	80×80	512×512
White Fox (Half arch)	105	9	0.1	60×60	

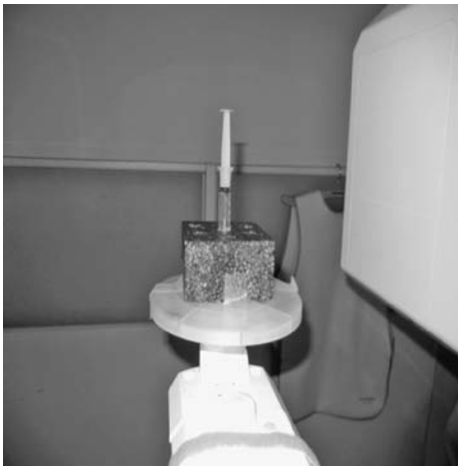

Fig. 2 Placement of a test sample in the center of the FOV for CBCT.

Fig. 3 Placing a test sample and surrounding syringes for CBCT.

mined as closely as possible to those for CBCT.

Experiment 2–1

We exposed CBCT and MDCT images for each test sample placed in the center of the FOV (Fig. 2). The density of the images was measured with the region of interest (ROI) measurement in AW or ZIO. We measured the density in the center of the solution images, set with a ROI size of 5 mm^2. Line graphs were drawn based on the average of five measurements for each point.

Experiment 2–2

Subsequently, in order to simulate conditions of the oral cavity, five solution syringes were placed around each of the phantoms used in Experimental 2–1. The five solution syringes surrounding the Experiment 2–1 test samples contained 5 or 2.5% solutions (Fig. 3). We exposed CBCT and MDCT images to measure the density in the center of the test samples, in the same way as for Experiment 2–1, and line graphs were drawn in the same way.

RESULTS

We compared the ROI data for CBCT and that of MDCT. The graphs show the final data for CBCT and CTN of MDCT.

Experiment 1

The results of Experiment 1 are shown in Figs. 4 A, B and C. The data for MDCT were stable throughout, with the results of the measurements always close to the zero level. The average and standard deviation of the middle region were 5.3 HU and 18.3 HU (Hounsfield units). On the other hand, the pixel density for the CBCT images decreased in the outer peripheral area of the FOV in all regions. However, we found that the density data for CBCT was essentially stable in the central regions of the FOV. In these regions, the data for CBCT were similar to those for MDCT. We found

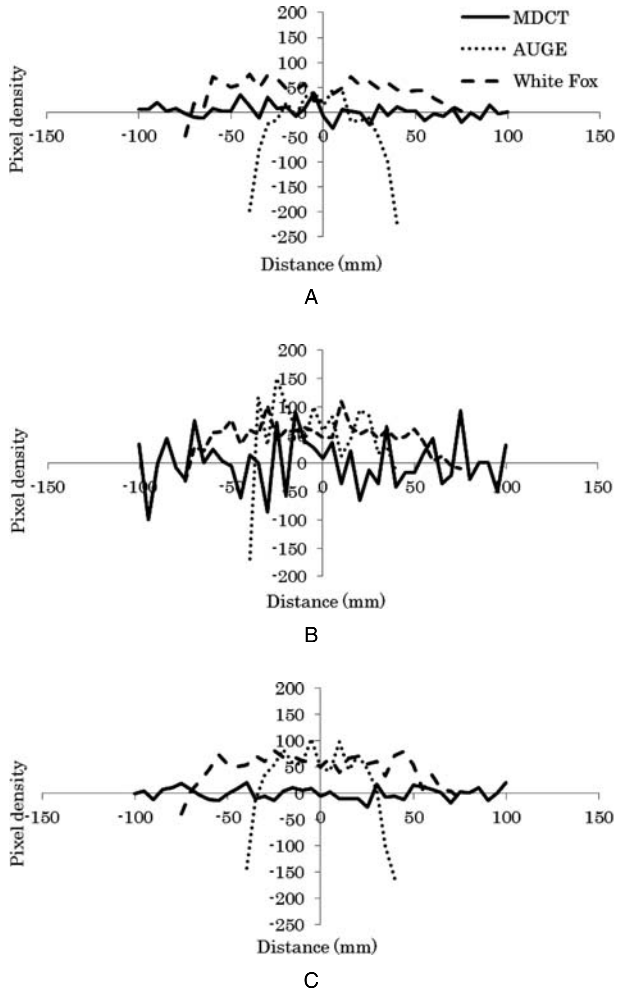

Fig. 4 Results for Experiment 1. The efficiency was measured of FPD for CBCT and the detectors for MDCT for the upper (A), middle (B) and lower (C) regions.

that the pixel density of CBCT was reliable in the central region of the FOV.

Experiment 2

Experiment 2–1

Comparing the X-ray tube currency, we confirmed that the CTN of MDCT is stable and the pixel density of White Fox was comparable to the CTN of MDCT. In Fig. 5 A, the line of the pixel density for the AUGE X was parallel to the line of the CTN for MDCT, although it always had a slightly higher density.

Experiment 2–2

When a test sample was surrounded by solution syringes with a higher concentration of solution, we observed that the pixel density of CBCT decreased more than that for the previous experiment. These trends were observed more clearly in the AUGE X images than in the others. Although we were able to observe a good linear relationship in the lower density range, the relationship was not maintained in the high density range (Figs. 5 B, C, D, E, F and G).

DISCUSSION

We undertook this study to clarify the correlation between the density of CBCT and the CTN for MDCT under simulated clinical conditions of CT exposure after checking the performance of the equipment. Although a number of studies have already been carried out, few have been done where the evaluation of density in the acquired image was performed in conjunction with the evaluation of the equipment. Given the variations in performance of CBCT, it was necessary to continue research in this area.[5–7] In Experiment 1, we evaluated the stability in the image from the equipment used in this study. In Experiment 2, we evaluated the possibility of finding a correlation between the density of CBCT and the CTN of MDCT.

Experiment 1 was designed with reference to the study by Nackaerts *et al.*[1] We compared the imaging volume in three regions (upper, middle and lower). We evaluated the performance on the FPD, the problem of image construction, and differences in X-ray exposure angulation. We found that there was a tendency for the density to decrease around the periphery of the FOV. This tendency, which had previously been reported by Nackaerts[1], appeared in all modes of CBCT used in this experiment. We found that pixel density with CBCT is reliable in the vicinity of the center of the FOV. Subsequently, test syringes were placed in the central area of the FOV for the CBCT.

Furthermore, in Experiment 2, we investigated changes in the image density for CBCT and MDCT. To evaluate differences in intensity for scans with several objects, it is important to compare the pixel intensity for the same conditions on each scan. From these results, we confirmed that the intensity obtained for MDCT images is stable and can even be used as a reference for this analysis.

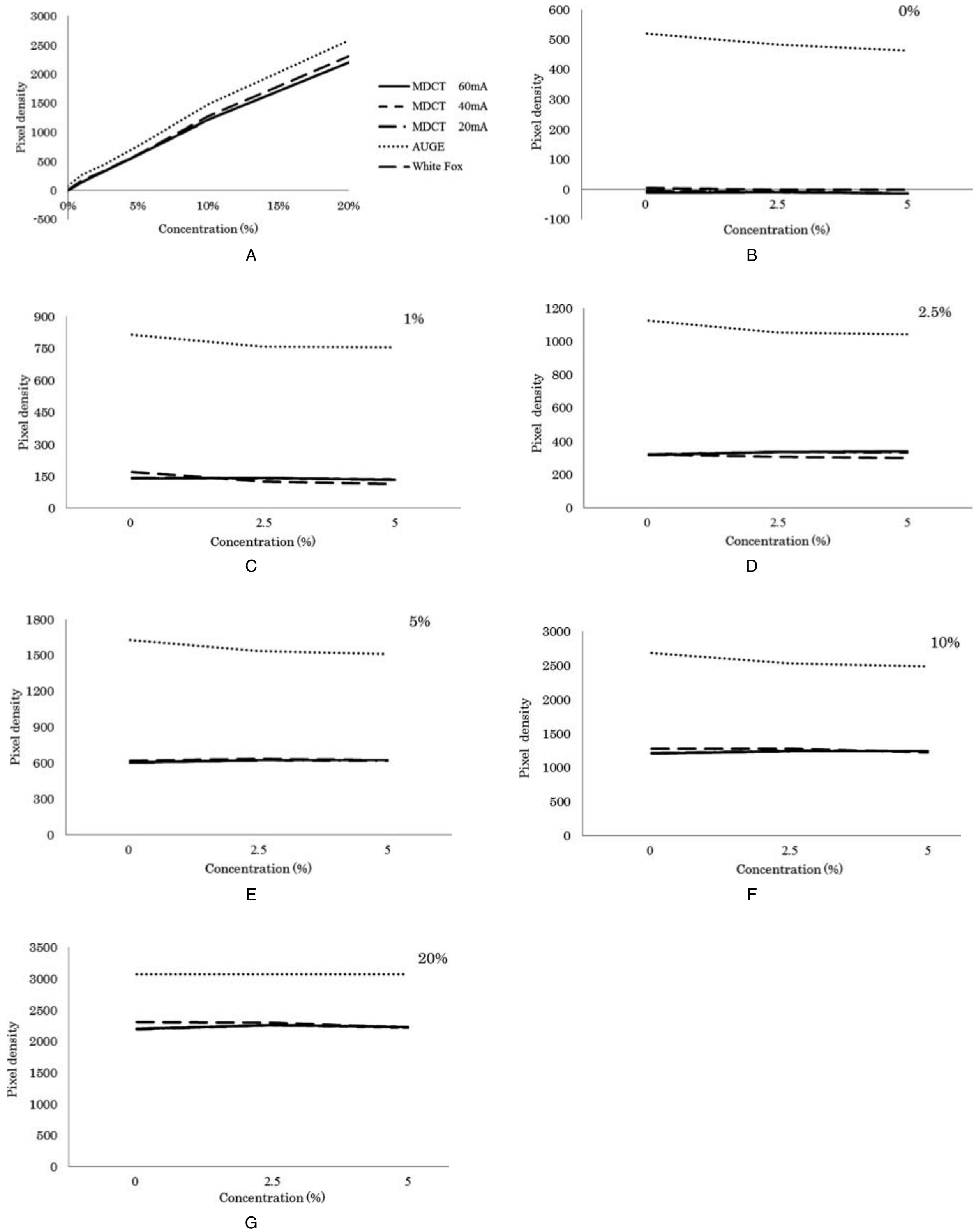

Fig. 5 Results for Experiment 2. (A) Experiment 2–1 compares pixel density/CTN and concentration. (B–G) Results for Experiment 2–2 where the test piece is surrounded by syringes with a solution of 0, 1, 2.5, 5, 10 and 20%, respectively.

We carried out Experiment 2–2 in order to investigate changes in the density of CBCT images when test syringes were surrounded by highly concentrated materials. This experiment was designed with reference to the study of Chindasombatjaroen *et al.*[2, 8–10] We attempted to predict changes in the density of the CBCT images when teeth were present. Experiment 2 confirmed that the pixel density of the test syringes showed good correlation with the concentration of the test syringes. However, the density with CBCT was not equivalent to CTN with MDCT. It is obvious that the pixel density with CBCT is not consistent with CTN of MDCT because of such factors as the low X-ray tube current. However, we confirmed that there were correlations between them. Chindasombatjaroen *et al.*[2] described the high correlation and linear relationship between CTN and the pixel value of CBCT. Valiiyaparambil *et al.* and Nomura *et al.* noted that bone mineral density might correlate with CBCT density.[8, 9] We found a correlation between the density of CBCT, the CTN of MDCT, and the sample concentration.

Previous authors had mixed opinion about the correlation between MDCT and CBCT.[3–12] When we compared the graphs for MDCT and CBCT we found that the correlation was not as good when the test syringes were surrounded by a solution of high concentration liquid. This is because the high concentration produces artifacts on the CT/CBCT images, resulting in inaccurate pixel density. A recent study reported that pixel density is influenced by the device, imaging parameters and positioning. Therefore, we used only the center position and chose clinical exposure modes.

We concluded the CBCT density is a reliable parameter. However, we only studied the AUGE X and White Fox, using established exposure modes. The results for the two machines were not the same. At the center of the FOV there was a correlation between CTN with the MDCT and pixel density with CBCT. Our research confirmed that there are differences among machines.

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REFERENCES

1. Nackaerts O, Maes F, Yan H, Couto Souza P, Pauwels R, Jacobs R. Analysis of intensity variability in multislice and cone beam computed tomography. *Clin Oral Impl Res* 2011 ; **22** : 873–879.
2. Chindasombatjaroen J, Kakimoto N, Shimamoto H, Murakami S, Furukawa S. Correlation between pixel values in a cone-beam computed tomographic scanner and the computed tomographic values in a multidetector row computed tomographic scanner. *J Comput Assist Tomogr* 2011 ; **35** : 662–665.
3. Hashimoto K, Kawashima S, Araki M, Iwai K, Sawada K, Akiyama Y. Comparison of image performance between cone-beam computed tomography for dental use and four-row multidetector helical CT. *J Oral Sci* 2006 ; **48** : 27–34.
4. Naitoh M, Katsumata A, Kubota Y, Ariji E. Assessment of three-dimensional X-ray images : reconstruction from conventional tomograms, compact computerized tomography images, and multislice helical computerized tomography images. *J Oral Implantol* 2005 ; **31** : 234–241.
5. Elstrøm UV, Muren LP, Petersen JB, Grau C. Evaluation of image quality for different kV cone-beam CT acquisition and reconstruction methods in the head and neck region. *Acta Oncol* 2011 ; **50** : 908–917.
6. Hofmann E, Schmid M, Sedlmair M, Banckwitz R, Hirschfelder U, Lell M. Comparative study of image quality and radiation dose of cone beam and low-dose multislice computed tomography – an in-vitro investigation. *Clin Oral Invest* 2014 ; **18** : 301–311.
7. Chikui T, Yoshida Y, Okamura K, Inadomi D, Yuasa K, Yoshiura K. Fundamental matters required for comprehending the performance of cone-beam CT. *J Kyushu Dental Society* 2012 ; **66** : 134–141. (Japanese)
8. Valiyaparambil JV, Yamany I, Ortiz D, Shafer DM, Pendrys D, Freilich M, Mallya SM. Bone quality evaluation : comparison of cone beam computed tomography and subjective surgical assessment. *Int J Oral Maxillofac Implants* 2012 ; **27** : 1271–1277.
9. Nomura Y, Watanabe H, Shirotsu K, Honda E, Sumi Y, Kurabayshi T. Stability of voxel values from cone-beam computed tomography for dental use in evaluating bone mineral content. *Clin Oral Implants Res* 2013 ; **24** : 543–548.
10. Katsumata A, Hirukawa A, Okumura S, Naitoh M, Fujishita M, Ariji E, Langlais RP. Effects of image artifacts on gray-value density in limited-volume cone-beam computerized tomography. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod* 2007 ; **104** : 829–836.
11. Araki K, Okano T. The effect of surrounding conditions on pixel value of cone beam computed tomography. *Clin Oral Implants Res* 2013 ; **24** : 862–865.
12. Yamashina A, Tanimoto K, Sutthiprapaporn P, Hayakawa Y. The reliability of computed tomography (CT) values and dimensional measurements of the oropharyngeal region using cone beam CT : comparison with multidetector CT. *Dentomaxillofac Radiol* 2008 ; **37** : 245–251.