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Full Length Article

Influence of patient position and other inherent factors on image quality in two different cone beam computed tomography (CBCT) devices

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ABSTRACT

Objectives: The aim of this *in vitro* study was to evaluate how a deviation from the horizontal plane, affects the image quality in two different CBCT-devices.
Methods: A phantom head SK150 (RANDO, The Phantom Laboratory, Salem, NY, USA) was examined in two CBCT-units: Accuitomo 80 and Veraviewepocs 3D R100 (J. Morita Mfg. Corp. Kyoto, Japan). The phantom head was placed with the hard palate parallel to the horizontal plane and tilted 20 ° backwards. Exposures were performed with different field of views (FOVs), voxel sizes, slice thicknesses and exposure settings. Effective dose was calculated using PCXMC 2.0 (STUK, Helsinki, Finland). Image quality was assessed using contrast-to-noise-ratio (CNR). Region of interest (ROI) was set at three different levels of the mandibular bone and soft tissue, uni- and bilaterally in small and large FOVs, respectively. CNR values were calculated by CT-value and standard deviation for each ROI. Factor analysis was used to analyze the material.
Results: Tilting the phantom head backwards rendered significantly higher mean CNR values regardless of FOV. The effective dose was lower in small than in large FOVs and varied to a larger extent between CBCT-devices in large FOVs.
Conclusions: Head position can affect the image quality. Tilting the head backward improved image quality in the mandibular region. However, if influenced by other variables *e.g.* motion artifacts in a clinical situation, remains to be further investigated.
Advances in knowledge: Image quality assessed using CNR values to investigate the influence of different patient positions and FOVs.

1. Introduction

Cone beam computed tomography (CBCT) is an imaging modality that since its introduction into the field of diagnostic radiology in the late 1990s [1] has gained a widespread use in various disciplines: endodontics [2], orthodontics [3], implantology [4], pediatric dentistry [5] and periodontology [6]. Due to its relatively high availability, low cost and small footprint the technique is often used to enhance the diagnostic capability of different pathological conditions in the dento-maxillofacial area, as well as an aid in digital treatment planning.

The number of CBCT devices has increased substantially since the introduction, and today there are a large number of CBCT devices from different manufacturers on the market [7]. However, even if the term CBCT often is addressed as a generic name for the technique, the devices may vary in several aspects such as patient positioning (sitting or lying down, standing up), X-ray spectrum (voltage peak, filtration), X-ray exposure (mA-value, number of projections, rotation angle), volume of the exposed field and voxel size [8]. Further, a majority of the devices today is equipped with different imaging protocols and thus, varying voxel sizes and acquisition/exposure time to adapt the image resolution to the specific diagnostic task and the cooperation of the patient. Due to these differences between CBCT devices the radiation dose to the patient reveals a large variation, 27–674 μSv [9] depending on region of interest (ROI) and different exposure settings used [10].

There are several publications including guideline statements on the use of CBCT in the head and neck region [11]. However, there is still a lack of specific instructions of how to optimize the radiographic examination on basis of the individual patient and region of interest. This may be due to the large number of different CBCT devices with their inherent differences.

A possibility to overcome these shortcomings, and investigate how different CBCT devices perform under certain conditions, is to use the

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Fig. 1. Illustrates the difference in the phantom head position.

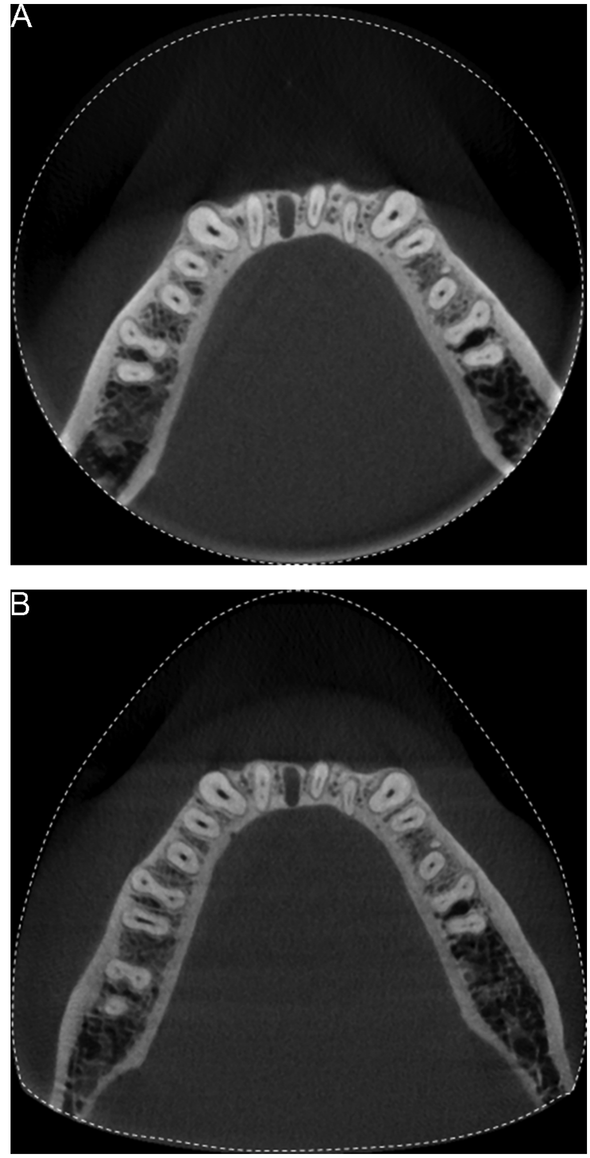

Fig. 2. Illustrates the difference between the areas of the large FOV in (A) Accuitomo and (B) Veraviewepocs. The Veraview has a rouleaux shape that is more adjusted the shape of the jaws.

contrast-to-noise-ratio (CNR) as an objective measure of image quality. In science and engineering, the signal-to-noise ratio (SNR) is a measure that compares the level of a desired signal to the level of background noise, CNR measure of image quality is based on image contrast rather than the raw signal. Using CNR instead of observers in image quality assessments may reduce the possibility of observer influence due to individual preferences. The difference in CNR values has been used in several articles to assess and compare image quality and optimization using different device settings [12–17].

However, until today there is, to our knowledge, no study that has investigated the influence of patient position on CNR value and thus, its effect on image quality in CBCTs for dental applications.

The head position of the patient may influence the amount of tissue volume that the cone shaped radiation field has to pass to get to the detector. Since the radiation field is rotating around the patient head during exposure this may influence the amount of photons that reach the detector and hence the image building process.

Therefore the aim of this *in vitro* study was to evaluate how a deviation of the hard palate from the horizontal plane, affects the image quality, using two different CBCT devices. Further, to investigate the influence of different exposure parameter settings and field of views (FOVs).

2. Materials and methods

2.1. Test object

The Sectional Head Phantom, SK150 (RANDO, The Phantom Laboratory, Salem, NY, USA) a human skull embedded in acrylic material (*i.e.* polyurethane) to simulate soft tissue, was used. The phantom

Table 1
Specifications for the different image parameter settings for the different CBCT-devices.

Device	Voxel size (mm)	Slice thickness (mm)	No of axial slices in each scan	No of projections during scan	Exposure time (s)
Accuitomo[a] 40 mm × 40 mm	0.125	0.375	107	586	17.5
Veraview[b] 40 mm × 40 mm	0.125	0.375	115	342	9.4
Accuitomo[a] 80 mm × 80 mm	0.160	0.480	167	586	17.5
Veraview[b] 100 mm × 80 mm[c]	0.160	0.480	167	342	9.4

[a] Accuitomo F80.
[b] Veraviewepocs 3D R100.
[c] Reuleaux Full Arch is an area shaped like a convex triangle. By more closely matching the natural dental arch form, this FOV allows a more complete scan of the maxilla and mandible.

was placed with the hard palate parallel to the horizontal plane and in a 20 ° backward tilted position (Fig. 1).

2.2. CBCT imaging

Two different CBCT devices were used: Accuitomo ® F 80 and Veraviewepocs® 3D R 100 (J. Morita Mfg. Corp. Kyto, Japan). The phantom head was examined with different FOVs, voxel sizes and slice thicknesses (Table 1). The small FOVs (40 mm × 40 mm) were identical but the area of the large FOVs (80 mm × 80 mm and 100 mm × 80 mm) differed between the CBCT devices (Fig. 2A and B) due to the reuleaux shape of the large FOV in Veraviewepocs [18]. The exposure parameters used in the first set of scans were 75, 80, 85, and 90 kV with a constant tube current of 5 mA. Then the mA value was varied at 2 and 8 together with different kV settings 80, 85 and 90. In total 80 examinations were performed.

All the axial slices (data sets) were sent to Picture Archiving and Communication System (PACS) (IMPAX 6.5.3 AGFA Healthcare, Belgium). The software of this program was used to display the ROI in different locations in the axial slices. The images were presented on two equal 21″ medical monitors, (MDCC-2121 Barco, Kortrijk, Belgium) with a special graphic card MXRT5200.

2.3. Calculation of CNR

In the small FOVs, ROIs were set at three different levels on one side of the mandibular bone and bilaterally in the large FOVs. The ROIs had a diameter of 2.2 mm and 2.0 mm, in small and large FOVs, respectively. The vertical distance between the axial scans holding the ROIs was 4.5 mm (10 and 12 slices for large and small FOVs, respectively). Soft tissue and cortical bone were selected separately in each ROI and at each level in all the selected images.

For each ROI the mean CT-value and the standard deviation (SD) were obtained, provided by the PACS software (Fig. 3A and B). At every level CNR values were calculated using the formula:

$$\mathrm{CNR} = \frac{\text{Mean CT value}_{(\text{cortical bone})} - \text{Mean CT value}_{(\text{soft tissue equivalent material})}}{\sqrt{(\mathrm{SD}_{(\text{cortical bone})})^2 + (\mathrm{SD}_{(\text{soft tissue equivalent material})})^2}}$$

2.4. Calculation of radiation dose

To determine effective dose Monte Carlo (MC) simulations were used applying PCXMC 2.0 (STUK). This program calculates absorbed organ and effective doses in x-ray examinations based on measurable quantities, *e.g.* dose area product (DAP) or incident air kerma. The program uses a modified anatomic phantom based on a mathematical model described by Cristy and Eckerman [19]. When calculating the effective dose, the tissue weighting factors of both International Commission on Radiological Protection (ICRP) publications 60, 1991 and Publication 103, 2007 can be used. The technical specifications used in the PCXMC simulation program are presented in Table 2. This software has been used for CBCT examinations and compared to metal-oxide semiconductor field-effect transistor (MOSFET) dosimeter devices in effective dose calculation [20].

DAP values (Table 3) were measured using equipment Doseguard nr. 481 (RTI Electronics AB, www.rtigroup.com) and KAP-meter VA-cuDAP2002 nr 1590001 (VacuTec Meßtechnik GmbH). The calculated effective dose for each scanning protocol is presented in Table 4.

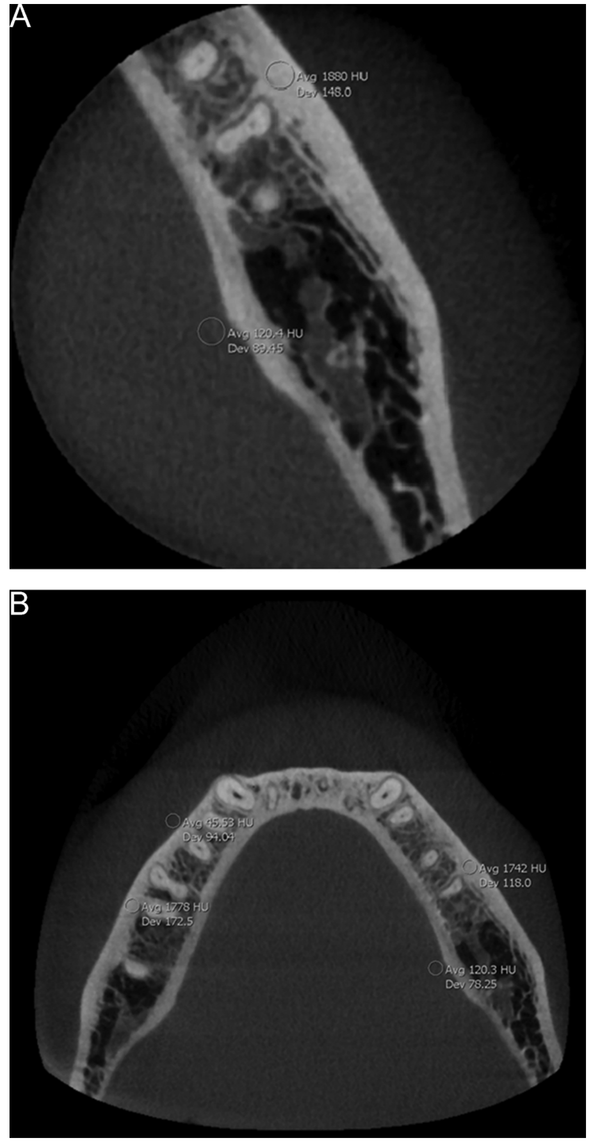

Fig. 3. The setting of different regions of interest (ROIs). Hounsfield value (HU) represent the CT value used to calculate the CNR and deviation (DEV) represent the standard deviation (SD) value also used in the same formula. Unilateral settings in the small FOV (A) and bilaterally in the large FOV (B).

Table 2
Technical specifications used in the PCXMC simulation program (version 2.0).

	Accuitomo F80	Veraviewepocs 3D R100
Source-to-detector distance (mm)	710	519
Source-to-isocenter distance (mm)	500	346
Anod angle (°)	5	5
Rotation angle (°)	360	180
Detector field (WxH, mm)	67 × 67 (400 × 400) 117 × 123 (800 × 800)	62 × 71 (400 × 400) 125 × 130 (100 × 80)
Exposure time (s)	17.5	9.4
Total filtration	3.9 mm Al	2.5 mm Al + 0.2 mm Cu
Frames/basal images	586	343

Table 3
Exposure parameters and DAP values ($mGycm^2$).

	75 kV 5 mA	80 kV 5 mA	85 kV 5 mA	90 kV 5 mA	80 kV 2 mA	80 kV 8 mA	85 kV 2 mA	85 kV 8 mA	90 kV 2 mA	90 kV 8 mA
Accuitomo[b] 40 mm × 40 mm	288[a]	329	367	410	137	519	153	581	164[a]	656[a]
Veraview[c] 40 mm × 40 mm	166	201	236	276	84	318	98	377	110[a]	441[a]
Accuitomo[b] 80 mm × 80 mm	1046[a]	1212	1351	1531	504	1913	562	2139	612[a]	2450[a]
Veraview[c] 100 mm × 80 mm	546	657	764	890	274	1040	319	1209	356[a]	1424[a]

[a] *Calculated values* (extrapolated from measured values).
[b] Accuitomo F80.
[c] Veraviewepocs 3D R100.

Table 4
Calculated effective dose ($E = DAP \times E_{DLP}$) values (in mSv), based on weighting factors of ICRP Publication 103 (2007).

	E_{DLP} [a]	75 kV 5 mA	80 kV 5 mA	85 kV 5 mA	90 kV 5 mA	80 kV 2 mA	80 kV 8 mA	85 kV 2 mA	85 kV 8 mA	90 kV 2 mA	90 kV 8 mA
Accuitomo[b] 40 mm × 40 mm	0.156	0.045	0.051	0.057	0.064	0.021	0.081	0.024	0.091	0.026	0.102
Veraview[c] 40 mm × 40 mm	0.212	0.035	0.043	0.050	0.059	0.018	0.067	0.021	0.080	0.023	0.093
Accuitomo[b] 80 mm × 80 mm	0.139	0.145	0.168	0.188	0.213	0.070	0.266	0.078	0.297	0.085	0.340
Veraview[c] 100 mm × 80 mm	0.166	0.091	0.109	0.127	0.148	0.045	0.173	0.053	0.201	0.059	0.236

[a] Conversion factor. Calculated with PCXMC 2.0 program ($mSv/Gycm^2$).
[b] Accuitomo F 80.
[c] Veraviewepocs 3D R100.

2.5. Statistics

Factor analysis was used to study the variability among the observed variables. Using the program SAS 9.3 (®SAS Institute Inc., Cary, NC, USA) and the procedure Proc. mixed.

3. Results

The effects of co-variation of different variables tested were analyzed and are presented in Table 5.

Regardless of FOV or CBCT device, the tilted head position rendered the highest CNR mean values (Tables 6 and 7) indicating better image quality. Further analysis of the other variables CBCT device and FOV and then mA and FOV, showed that the large FOV of the Accuitomo and the small FOV in the Veraviewepocs rendered the highest CNR mean values. Analyzing mA and FOV, high CNR mean values were found in small FOVs at high mA settings and in large FOVs at low mA (Table 8).

In the large FOVs the effective dose varied to a larger extent between CBCT devices than in small FOVs where they were almost equal.

Table 5
Analysis of variance.

Effect	p-value
CBCT-device and kV	0.9709
CBCT-device and mA	0.9001
CBCT-device and FOV	0.0016*
CBCT-device and patient position	0.0215*
kV and mA	0.6936
kV and FOV	0.9851
kV and patient position	0.7487
mA and FOV	0.0424*
mA and patient position	0.0829
FOV and patient position	0.0014*

* Significant covariance.

Table 6
Mean CNR value analysing CBCT device and patient position.

CBCT-device	Patient position	No of observations	Mean CNR	Std Error
Accuitomo F80	Horisontally	78	7.21	0.253
Accuitomo F80	Tilted	78	9.01	0.253
Veraviewepocs 3D R100	Horisontally	78	7.87	0.253
Veraviewepocs 3D R100	Tilted	78	8.50	0.253

4. Discussion

To approach a more objective evaluation of image quality CNR value can be calculated. Different scull and jaw models have been used *in vitro* to test this. In some studies the SEDENTEXCT (Safety and efficacy of a new and emerging dental X-ray modality) IQ (image quality) or polymethyl methacrylate phantoms were used [12,15,21], others have used a maxillary or mandibular bone embedded in resin as a test object [13] or just a dry mandible together with an epoxy resin bone tissue substitute block [14]. Choi et al., [17] used SEDENTEXCT IQ phantom and a scull phantom with soft tissue replica for comparison of technical and diagnostic image quality and came to the conclusion that the CNR value has a significant association with subjective image quality. Pauwels et al. [22] reported on technical versus diagnostic image quality in dental CBCT imaging, where CNR values and observer scores for different anatomical landmarks were found to have a specific correlation for each CBCT device tested.

This study showed that the only significant variable with unanimous outcome was head position. The backward tilted position always rendered higher mean CNR values despite FOV or CBCT device. Findings by Bryant et al., [23], showed that exo-mass *i.e.* the irradiated mass

Table 7
Mean CNR value analysing FOV and patient position.

FOV	Patient position	Number of observations	Mean CNR	Std Error
Small[a]	Horisontal	78	7.33	0.253
Small[a]	Tilted	78	9.35	0.253
Large[b]	Horisontal	78	7.75	0.253
Large[b]	Tilted	78	8.15	0.253

[a] 40 mm × 40 mm Accuitomo F80 and Veraviewepocs 3D R100.
[b] 80 mm × 80 mm Accuitomo F80 and 100 mm × 80 mm Veraviewepocs 3D R100.

Table 8
Mean CNR value analysing mA and FOV.

mA	FOV	No of observations	Mean CNR	Std Error
2.00	small[a]	36	6.44	0.373
	large[b]	36	7.22	0.373
5.00	small[a]	84	8.57	0.244
	large[b]	84	7.91	0.244
8.00	small[a]	36	9.71	0.373
	large[b]	36	8.79	0.373

[a] 40 mm × 40 mm Accuitomo F80 and Veraviewepocs 3D R100.
[b] 80 mm × 80 mm Accuitomo F80 and 100 mm × 80 mm Veraviewepocs 3D R100.

outside the actual FOV, could influence the CT value depending on its location in relation to the FOV. In small FOVs the exo-mass is larger. However, the total mass in a slice affects the uniformity of the density values. This could explain our findings that the tilted head position rendered higher CNR values.

Another finding was that the CNR values between the devices did not differ more despite the difference in number of basis images. The Accuitomo uses 586 compared to the Veraviewepocs 342. Bechara et al. [14] showed in a study that increasing the number of basis images increased the CNR value in small FOVs. But increasing the number of basis images not necessarily have a positive effect on the CNR value in large FOVs.

A recent study by Koivisto et al. [24] demonstrated that the image quality varies between different anatomical landmarks in the scull, except for the mandible were the image quality always was evaluated as good. Hence, the mandible may not be affected by surrounding structures to the same extent as other regions in the maxillofacial complex due to its location more apart from the scull base.

FOV and voxel size are other variables influencing image quality [13,24–27]. In this study we choose the mandible and a FOV not exceeding 100 mm × 80 mm and small voxel sizes. Excluding the variable head tilting from the statistical analysis, we obtained diverting findings regarding mean CNR values.

The phantom used did not have any fillings or metal components incorporated nor did it move during examinations. Thus, artifacts like beam hardening, exponential edge-gradient effect and motion [28] were not present and have no implications on the image quality in this study. The scan time is 9.4 s for Veraviewepocs and 17.5 s for Accuitomo. In a clinical situation a long exposure time could deteriorate the image quality if the patient cannot be fixated properly. A recent review by Spin-Neto 2016[29] concluded that investigations monitoring patients during CBCT reported a movement prevalence of 20% and artefact recognition, without knowledge of movement in the range of 4.5%–41.5%.

In a clinical situation it is of great importance to choose a FOV and an image resolution due to the clinical task. It is also important that the patient is positioned in a way that allows him or her not to move, even if it means tilting the head backward or positioning the head horizontally.

All other factors constant, the radiation dose is dependent on the FOV[30]. In our study the effective dose differed more in the large than in the small FOVs between CBCT devices, in favor of Veraviewepocs despite a larger FOV than Accuitomo. This may be an effect of the posteriorly directed projection, 180 ° rotation and the reuleaux shape.

5. Conclusions

Head position can affect the image quality. Tilting the head backward rendered higher mean CNR values in the mandibular region regardless of CBCT device or FOV used indication an improved image quality. Other variables such as motion artefacts may have more influence on image quality in a clinical setting than the patient head position. This remains to be further investigated.

Conflict of interest

None.

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