RESEARCH ARTICLE

Impact of prone, supine and oblique patient positioning on CBCT image quality, contrast-to-noise ratio and figure of merit value in the maxillofacial region

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Objectives: To assess the impact of supine, prone and oblique patient imaging positions on the image quality, contrast-to-noise ratio (CNR) and figure of merit (FOM) value in the maxillofacial region using a CBCT scanner. Furthermore, the CBCT supine images were compared with supine multislice CT (MSCT) images.

Methods: One fresh frozen cadaver head was scanned in prone, supine and oblique imaging positions using a mobile CBCT scanner. MSCT images of the head were acquired in a supine position. Two radiologists graded the CBCT and MSCT images at ten different anatomical sites according to their image quality using a six-point scale. The CNR and FOM values were calculated at two different anatomical sites on the CBCT and MSCT images.

Results: The best image quality was achieved in the prone imaging position for sinus, mandible and maxilla, followed by the supine and oblique imaging positions. 12-mA prone images presented high delineation scores for all anatomical landmarks, except for the ear region (carotid canal), which presented adequate to poor delineation scores for all studied head positions and exposure parameters. The MSCT scanner offered similar image qualities to the 7.5-mA supine images acquired using the mobile CBCT scanner. The prone imaging position offered the best CNR and FOM values on the mobile CBCT scanner.

Conclusions: Head positioning has an impact on CBCT image quality. The best CBCT image quality can be achieved using the prone and supine imaging positions. The oblique imaging position offers inadequate image quality except in the sinus region.

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Keywords: CBCT; MSCT; image quality; CNR; FOM

Introduction

Mobile CBCT scanners were first introduced in the field of maxillofacial surgery in 2005.¹ Since then, mobile CBCT scanners^{2–8} have become increasingly popular as

they offer comparable images to those acquired on traditional multislice CT (MSCT) scanners.⁹ The major advantages of CBCT scanners are their lower cost, size, weight and effective dose.^{10–12} The lower effective dose is the result of the default exposure parameters and the partial gantry rotation used in CBCT scanners when compared with MSCT scanners.^{13,14} It has, however,

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been reported that the partial CBCT gantry rotation produces a non-uniform dose distribution¹⁵ that can in some cases affect the image quality. Nevertheless, the partial CBCT gantry rotation offers acceptable diagnostic image quality at a lower effective dose than MSCT scanners.¹⁶

A recent study by Koivisto *et al*¹⁷ reported the positive effect of head positioning on the effective dose in CBCT scanners. Furthermore, a study by Yan *et al*¹⁸ reported a close relationship between image quality and effective dose when using low-dose CBCT protocols. Taking the results of the previous studies into account, it can be hypothesized that CBCT images could be optimized by choosing the correct patient imaging position.

Currently, MSCT and CBCT image quality assessments are based on the visual grading of predefined anatomical landmarks,^{19–21} the quantitative analysis of physical properties such as the modulation transfer function²² and contrast-to-noise ratio (CNR).²³ The image contrast is affected by the X-ray mean photon energy that subsequently has an effect on the image quality.²⁴ Moreover, the relationship between the image quality and patient dose is commonly quantified using the traditional figure of merit (FOM) value that is defined as the CNR² divided by the incident patient exposure.^{24–27} The FOM value can provide useful information on the benefits and drawbacks of different imaging positions in CBCT and MSCT scanners. It also provides a means of comparing the ratio between the image quality and the resulting effective dose. Furthermore, the FOM offers the possibility of calculating a numerical value that can be used to compare two inherently different imaging modalities. Moreover, the FOM value can be used to select an appropriate protocol depending on the diagnostic task. The combination of CNR and FOM calculations with image quality assessments offers an adequate method for comparing and grading MSCT and CBCT images.

The objectives of this study were to assess the impact of three different patient imaging positions (supine, prone and oblique) on the CBCT image quality, CNR and FOM value in the maxillofacial region. The second objective was to compare the CBCT supine images with MSCT images acquired in the same position.

Methods and materials

This study was performed according to the Ethical Principles for Medical Research Involving Human Subjects as defined by the World Medical Association (Helsinki Declaration).²⁸ One fresh frozen human cadaver head was provided by the Department of Anatomy, Tampere University Hospital, Tampere, Finland, for image quality assessment.

Scanners

Cadaver images were obtained using a Planmed Verity® mobile CBCT scanner (Planmed Oy, Helsinki, Finland)

and a Philips Brilliance 64 MSCT scanner (64 slice; Philips Medical Systems, Eindhoven, Netherlands). The mobile CBCT scanner uses a partial 210° gantry scan and 3.0-mm aluminium and 0.5-mm copper filters. The Philips Brilliance 64 MSCT scanner uses a 360° rotation scan and combined filtration consisting of 2.5-mm aluminium and 1.2-mm titanium.

The mobile scanner was initially developed for extremity imaging and has recently been approved by the American Food and Drug Administration for maxillofacial imaging. The scanner is equipped with a head positioning tray and a detachable forehead support. During oblique imaging, the cadaver head was placed on the default tray and attached to the forehead support. To acquire prone and supine images, the forehead support was removed and the gantry was tilted accordingly.

Imaging positions

A total of nine CBCT images were acquired in supine (Figure 1b), prone (Figure 1c) and oblique (Figure 1d) imaging positions. Furthermore, one MSCT image was acquired using the default supine imaging position (Figure 1a).

Exposure protocols

CBCT images were obtained using a constant 96 kV tube voltage. Three different tube currents: (1) 4.8 mA, (2) 7.5 mA and (3) 12 mA were used to encompass the full dynamic range of the mobile CBCT scanner. All CBCT exposures were performed using the smallest possible voxel size (0.2 mm). The MSCT exposures were performed using a default standard high-resolution imaging protocol (120 kV, 93 mA).

All effective doses required to calculate the FOM value were scaled proportionally using the exposure values (mAs) attained in a previous study by Koivisto *et al*¹⁷ using an anthropomorphic phantom. All exposure protocols, parameters and calculated effective doses are presented in Table 1.

Standard axial, coronal and sagittal reconstructions were performed on a Philips Brilliance Extended Workstation v. 4.5.2.40007 (Philips Medical Systems, Eindhoven, Netherlands). The reconstructed image data consisting of 474 MSCT and 652 CBCT digital imaging and communications in medicine files were subsequently exported to an Agfa Impax picture archiving and communication system (Agfa Healthcare, Mortsel, Belgium) and randomly visually graded by two experienced radiologists using the same viewing conditions. All evaluations were repeated after 4 weeks to assess the intraobserver reliability.

Image quality assessment

All image quality assessments were performed on 10 different anatomical landmarks in four different anatomical regions: sinus, ear, maxilla and mandible (Figure 2). The image quality was graded by two radiologists using the following scale: Level 5, excellent delineation of structures and excellent image quality; Level 4, clear delineation of structures and excellent image quality; Level 3, anatomical

Figure 1 A schematic presentation of the multislice CT (MSCT) (a) and mobile CBCT (b–d) scanner used in this study with different head positions: supine (a, b), prone (c), and oblique (d). FOV, field of view.

structures still fully assessable in all parts and good image quality; Level 2, structures identified and results in adequate image quality; Level 1, anatomical structures not identifiable due to poor image quality; and Level 0, no diagnostic value.

Statistical analysis of the image quality

The interrater agreement was evaluated by calculating the percentage of absolute agreement and two-way random effects intraclass correlation coefficients (interclass correlation coefficient) with absolute agreement corresponding to the 95% confidence interval.²⁹ The interclass correlation coefficient (two-way mixed) model (2,2) was used to determine interrater reliability.³⁰

The intrarater reliability was calculated for four selected protocols [oblique position (4.8 mA), supine position (12 mA) and prone position (7.5 mA)] using ICC (two-way mixed) model (3,1).³⁰ ICCs range from 0 with no agreement to +1 with perfect agreement in the interpretation of the ICC. Landis and Koch³¹ have characterized the values of reliability coefficients as follows: <0.4, poor; 0.4–0.75, fair to good; and >0.75, excellent. Although arbitrary, these divisions provide useful benchmarks.²⁹

Contrast-to-noise ratio

The CNR evaluation was performed in the fossa olfactorius (anatomical landmark no. 6) and the apical

Table 1 Exposure parameters of the CBCT and multislice CT (MSCT) exposures

Parameter	Planmed Verity® (Planmed Oy, Helsinki, Finland)			Philips Brilliance (Philips Medical Systems, Eindhoven, Netherlands)
	CBCT			64 MSCT
Imaging position	Supine/ prone/ oblique	Supine/ prone/ oblique	Supine/ prone/ oblique	Supine – –
Imaging protocol	Protocol 4.8 mA	Protocol 7.5 mA	Protocol 12 mA	Protocol High resolution
Tube voltage (kVp)	96	96	96	120
Tube current (mA)	4.8	7.5	12	93
Exposure time (s)	6	6	6	0.912
Q (mAs)	28.8	45	72	85
Slice thickness (mm)	0.2	0.2	0.2	0.67
Slice increment (mm)	0.2	0.2	0.2	0.33
Pitch (mm)	NA	NA	NA	0.55
CTDIvol (mGy)	–	–	–	11
Voxel size (mm)	0.2 × 0.2 × 0.2	0.2 × 0.2 × 0.2	0.2 × 0.2 × 0.2	0.33 × 0.352 × 0.352
Scan angle	210°	210°	210°	360°
Frame number	300	300	300	–
Radiation source	Pulsed	Pulsed	Pulsed	Continuous
Field of view (cm)	13 × 16	13 × 16	13 × 16	16 × 18
Eff. dose, supine (μSv) ^a	125	195	312	781
Eff. dose, prone (μSv) ^a	97	151	242	–
Eff. dose, oblique (μSv) ^a	29	45	72	–

CTDIvol, volume computed tomography index; Eff, effective; NA, not applicable.

^aCalculated from the effective doses reported by Koivisto *et al*.¹⁷

Organ nr.	Region	Anatomical landmarks
1	Sinus	Fossa olfactorius
2	Sinus	Lamina papyracea
3	Sinus	Hiatus maxillaris
4	Sinus	Middle turbinate
5	Sinus	Ostium of the osteomeatal c.
6	Ear	Carotid canal
7	Maxilla	Foramen infraorbitale
8	Maxilla	Tooth 16 apex
9	Mandible	Tooth 43 apex
10	Mandible	Foramen mentale

Figure 2 Anatomical landmarks assessed on the reconstructed MSCT and CBCT images.

aspect of Tooth 43 (D43, anatomical landmark no. 2). These anatomical sites were chosen since they represent commonly diagnosed regions in the head area. The locations of regions of interest (ROIs) were verified by superimposing CBCT and MSCT images. During superimposition, all CBCT and corresponding MSCT images were manually aligned into a coordinate system using control points chosen by the experienced radiologist.^{32–34}

The CNR was calculated using the following equation:

$$\text{CNR} = \frac{S_{\text{ROI}} - S_{\text{BGR}}}{\sigma_{\text{mean}}} \quad (1)$$

where, S_{ROI} is the mean signal at the anatomical landmark in gray value unit, S_{BGR} is the mean signal in the background (Hounsfield unit) and σ_{mean} is the average standard deviation in the anatomical landmark and background ROIs (Figure 3). Furthermore, the correlation between the CNR and subjective image quality was calculated to assess the association between the two image quality indicators.

Figure of merit

In this study, the FOM value was used to assess the diagnostic efficacy of the image quality vs the effective dose obtained using different imaging protocols. The

FOM value was calculated using the following equation described by Ogden *et al.*²⁶

$$\text{FOM} = \frac{\text{CNR}^2}{E} \quad (2)$$

where E is the effective dose. In the present study, the FOM value was calculated for two anatomical landmarks: the fossa olfactorius and the apex of Tooth 43.

Results

Image quality assessment

The average image quality results of nine different CBCT imaging protocols acquired in different imaging positions and one MSCT protocol acquired in one position are presented in Figure 4.

Statistical analysis of image quality

Statistical analysis was performed on all CBCT and MSCT image quality results. The absolute agreement percentages, interrater intraclass correlation coefficients (ICCs) and 95% confidence intervals of all examination protocols are presented in Table 2. The intrarater reliability results of the two observers are presented in Table 3.

Contrast-to-noise ratio

The mean CBCT contrast-to-noise values calculated in different imaging positions were as follows: 3.6 in the prone imaging position, 1.8 in the supine imaging position and 1.5 in the oblique imaging position. The Philips Brilliance 64 MSCT scanner mean CNR was 2.6. Furthermore, the correlation between the CNR and subjective image quality was 0.8217 for Tooth 43 and 0.3581 for the fossa olfactorius. The CNR values and the subjective image qualities of the apex of Tooth 43 and the fossa olfactorius are presented in Figure 5a,b, respectively.

Figure of merit

The mean FOM values of the Planmed Verity CBCT scanner in different imaging positions were as follows: 96.1 in the prone imaging position, 24.3 in the supine

Figure 3 Axial view of Tooth 43 (apex, D43) and background locations used for contrast-to-noise ratio calculation for multislice CT supine position (a) and for CBCT using supine (b), prone (c) and oblique (d) positions.

nr.	Region	Anatomical landmark											
1	Sinus	Fossa olfact.	2.0	1.0	2.0	1.5	1.5	2.0	3.0	3.0	3.0	2.0	
2	Sinus	Lamina papyr.	2.5	2.0	2.0	2.5	2.5	3.0	3.5	2.5	3.0	2.5	
3	Sinus	Hiatus max.	2.0	2.0	2.0	3.0	2.0	2.5	4.0	3.0	3.0	2.0	
4	Sinus	Middle turb.	2.0	2.0	2.0	3.0	2.5	3.0	4.0	3.0	3.0	2.0	
5	Sinus	Ostium	2.0	2.0	2.0	3.0	2.0	2.5	4.0	3.0	3.0	2.0	
6	Ear	Carotid canal	1.0	1.0	1.0	2.0	2.0	1.0	2.0	2.0	1.5	2.0	
7	Maxilla	Foramen inf.	3.0	2.5	2.5	3.0	3.0	2.5	4.0	3.0	3.0	3.0	
8	Maxilla	D 16 apex	2.0	2.5	1.0	3.0	3.0	1.0	4.0	3.0	2.0	2.0	
9	Mandible	D 43 apex	3.0	3.0	1.0	4.0	3.0	1.0	4.0	3.0	3.0	2.0	
10	Mandible	Foramen ment.	3.0	3.0	1.0	3.0	3.0	2.0	4.0	3.0	3.0	3.0	
Average quality			2.3	2.1	1.7	2.8	2.5	2.1	3.7	2.9	2.8	2.3	
			Prone 4.8 mA	Supine 4.8 mA	Oblique 4.8 mA	Prone 7.5 mA	Supine 7.5 mA	Oblique 7.5 mA	Prone 12 mA	Supine 12 mA	Oblique 12 mA	MSCT 93 mA	

Figure 4 Results of subjective image quality assessments undertaken by two radiologists using different CBCT and MSCT imaging protocols. Fossa olfactorius, Lamina papyracea, Hiatus maxillaris, Middle turbinate, Ostium of the osteomeatal complex, Carotid canal, Foramen infraorbitale, Tooth 16 apex, Tooth 43 apex, Foramen mentale.

imaging position and 22.3 in the oblique imaging position. The mean FOM value of the Philips Brilliance 64 MSCT scanner was 10.6. The FOM values of the apex of Tooth 43 and the fossa olfactorius obtained using one MSCT modality and multiple CBCT imaging modalities are presented in Figure 6a,b, respectively.

Discussion

In this study, the impact of supine, prone and oblique imaging positioning on image quality in four different skull regions was assessed. Furthermore, the CNR and FOM value were calculated and compared. Finally, the image quality of CBCT images acquired in the supine imaging position was compared with that of MSCT images acquired in the same imaging position.

The combined mobile extremity/maxillofacial CBCT scanner used in this study is unique in that it uses an adjustable gantry instead of a fixed gantry.³⁵ The adjustable gantry, which moves in an enclosed housing, offers the possibility of acquiring patient images in the seated and standing positions. Furthermore, supine, prone and oblique imaging positions are possible. The position of the head with respect to the X-ray beam and reciprocal sensor in the mobile CBCT scanner is almost identical to other dental CBCT scanners on the market

in the supine (Figure 2b) and prone (Figure 2c) imaging positions. Therefore, there are no major image quality differences between mobile CBCT scanners and other dental CBCT scanners. However, the results found in this study concerning the oblique imaging position are unique to the mobile CBCT scanner and therefore do not apply to other dental CBCT scanners.

CBCT image quality

Sinus: In the sinus region, the differences between the image qualities acquired using the supine and oblique imaging positions were negligible. However, the best CBCT mean image quality was observed in the prone imaging position. When compared with the prone and oblique imaging positions, the supine imaging position offered only poor image quality in the fossa olfactorius using 4.8 mA tube current. Furthermore, inadequate image quality was observed in the fossa olfactorius using the prone and supine imaging positions and 7.5 mA tube current. In the sinus region, only minor variations in the image quality were observed when using 4.8 and 7.5 mA. However, when using the highest 12 mA tube current, a significantly better image quality was observed in the sinus area. This phenomenon could be caused by the better signal-to-noise ratio attained using 12 mA tube current. Moreover, the better image quality

Table 2 Interrater absolute agreement (%), intraclass correlation (ICC) and confidence interval (CI) at 95% confidence level

Protocol	Absolute agreement (%)	ICC	95% Confidence interval (CI)
MSCT (supine)	90	0.942	0.836, 0.984
Oblique (12 mA)	90	0.967	0.908, 0.991
Oblique (7.5 mA)	70	0.955	0.868, 0.988
Oblique (4.8 mA)	90	0.964	0.897, 0.991
Supine (12 mA)	80	0.893	0.696, 0.971
Supine (7.5 mA)	70	0.880	0.659, 0.967
Supine (4.8 mA)	70	0.887	0.675, 0.969
Prone (12 mA)	70	0.889	0.687, 0.970
Prone (7.5 mA)	70	0.898	0.710, 0.972
Prone (4.8 mA)	80	0.940	0.827, 0.984

MSCT, multislice CT.

Table 3 Intrarater reliability of selected protocols

Observers	Philips Brilliance 64 MSCT (Philips Medical Systems, Eindhoven, Netherlands)	Planmed Verity® CBCT (Planmed Oy, Helsinki, Finland)		
	Supine 93 mA	Oblique 4.8 mA	Supine 12 mA	Prone 7.5 mA
Observer 1	0.780	0.873	0.571	0.856
Observer 2	1.000	0.877	0.667	0.816

MSCT, multislice CT.

observed in the prone imaging position could be due to the closer proximity of the cadaver head to the scanner sensor.

The low image quality achieved in the supine imaging position can be explained by the stronger attenuation and scattering resulting from the thick and complex bony structures in the anterior part of the skull.^{32,33} Furthermore, the low image quality observed in the oblique imaging position is likely to be caused by the longer radiation path length and subsequent attenuation caused by the parietal bones at the top of the cranium.^{22,34} These findings suggest that it could be advantageous to use the oblique imaging position instead of the supine imaging position in the sinus region. This hypothesis is in good agreement with a previous study by Heiland et al¹ who reported on the advantage of using the oblique imaging position to image the sinuses on a Siremobil Iso-C^{3D} CBCT scanner (Siemens Medical Solutions, Erlangen, Germany). However, it must be noted that an oblique imaging position is not attainable using a standard upright CBCT scanner.

Ear: In the ear region, the oblique imaging position resulted in poor image quality of the carotid canal. Furthermore, the supine and prone imaging positions offered only adequate image quality of the carotid canal. The low image quality observed in the oblique position could have been caused by the attenuation of the parietal bones situated on the top of the cranium.

The difficulty of acquiring adequate image quality in the carotid canal regardless of the tube current (4.8–12 mA) could be due to the attenuation caused by the dense bony structures of the temporal bone. These findings are in good agreement with a previous study by Pereira et al³⁹ who reported on the difficulty of obtaining adequate images in the temporomandibular joint

region due to the dense bony structures in the petrous part of the temporal bone. These findings are further supported by the results of Kwong et al⁴⁰ and Sohaib et al⁴¹ who concluded that no significant image quality difference occurred when tube currents were changed.

Maxilla: Using the mobile CBCT scanner, the prone and supine imaging positions offered better image quality in the maxilla than the oblique imaging position. The prone imaging position offered the best image quality of Tooth 16 and the foramen infraorbitale using 12 mA. The impact of different tube currents on image quality in all imaging positions was moderate.

Mandible: In the mandible, the prone and supine imaging positions resulted in good image quality for all three investigated tube currents. Furthermore, the oblique imaging position demonstrated an adequate image quality of the apex of Tooth 43 and poor image quality of the foramen mentale using 7.5 mA tube current. However, only poor image qualities were attainable in the mandible using the oblique imaging position and 4.8 mA tube current. The impact of different tube currents on the image quality in the prone imaging position was negligible and moderate in the oblique imaging position. However, the tube current did not have any effect on image quality in the supine imaging position.

In general, the low image quality observed in this study using the oblique imaging position is likely due to the anatomy of the head. Moreover, in the oblique position, the X-ray beam enters the head on the back side of the cranium, and therefore the radiation path length through the head becomes longer than in the prone position. This phenomenon subsequently causes

Figure 5 The image quality and contrast-to-noise ratio (CNR) values of Tooth 43 (a) and the fossa olfactorius (b) using different imaging positions and protocols. MSCT, multislice CT.

Figure 6 The figure of merit (FOM) values of Tooth 43 (a) and fossa olfactorius (b) using different imaging positions and protocols. MSCT, multislice CT.

stronger attenuation, which has a negative effect on the overall image quality.¹⁷

Comparison between multislice CT and CBCT images acquired in the supine position

The MSCT and CBCT interrater and intrarater reliabilities were assessed according to the characterization method described by Landis *et al.*³¹ The MSCT intrarater reliability was excellent. On the other hand, the CBCT intrarater reliability was excellent in the oblique and prone imaging positions and only good in the supine position.

In the supine position, the mobile CBCT scanner offered similar image quality to that of the MSCT scanner when using 7.5 mA tube current (Table 4). However, the mobile CBCT scanner resulted in lower image quality and higher local variations in image quality when 4.8 mA tube current was used. Furthermore, when using 12 mA tube current, the mobile CBCT scanner offered a good delineation of most anatomical structures and better image quality than those acquired on the MSCT scanner.

Contrast-to-noise ratio

In this study, the best CNR value was observed in the apex of Tooth 43 in the prone imaging position. The lower CNR values observed in the oblique imaging position could have been caused by the longer radiation

path length and the parietal bones on the top of the cranium. Interestingly, in the oblique imaging position, the delineation of the fossa olfactorius resulted in a higher CNR value than in the supine imaging position. The lower CNR value observed in the fossa olfactorius using the supine imaging position can be explained by the stronger attenuation and scattering from the thick and complex bony structures in the anterior nasofrontal area of the skull.^{36–38} Furthermore, the correlation between the CNR value and subjective image quality results was excellent in the apex of Tooth 43. However, only a fair correlation between the CNR value and image quality was achieved in the fossa olfactorius. These results are in good agreement with a recent study by Choi *et al.*²² who described a strong association between subjective image quality and CNR values.

Figure of merit

The prone imaging position offered the best FOM value in the fossa olfactorius and the apex of Tooth 43. The differences between the oblique and supine imaging positions were negligible. However, in the fossa olfactorius, the differences in the FOM values attained in the oblique and supine imaging positions were significant. This could have been caused by the highest CNR value attained at a moderate effective dose.

The MSCT scanner resulted in a higher FOM value than the mobile CBCT scanner in the supine imaging

Table 4 A comparison between the multislice CT (MSCT) and CBCT image qualities acquired in supine imaging positions

Region	Anatomical landmark	Planmed Verity® CBCT (Planmed Oy, Helsinki, Finland)			Philips Brilliance 64 MSCT (Philips Medical Systems, Eindhoven, Netherlands)
		4.8 mA	7.5 mA	12 mA	High resolution
Sinus	Fossa olfact.	Poor	Poor	Good	Adequate
	Lamina papyr.	Adequate	Adequate	Adequate	Adequate
	Hiatus max.	Adequate	Adequate	Good	Adequate
	Middle turb.	Adequate	Adequate	Good	Adequate
	Ostium	Adequate	Adequate	Good	Adequate
Ear	Carotid canal	Poor	Adequate	Adequate	Adequate
Maxilla	Foramen inf.	Adequate	Good	Good	Good
	D 16 apex	Adequate	Good	Good	Adequate
Mandible	D 43 apex	Good	Good	Good	Adequate
	Foramen ment.	Good	Good	Good	Good

inf., infraorbitale; max., maxillaris; ment., mentale; olfact., olfactorius; papyr., papyracea; turb., turbinate.

position. However, the FOM value obtained using the MSCT was lower than those acquired using the mobile CBCT scanner in the prone and oblique imaging positions.

The lower FOM value obtained on the MSCT scanner can be explained by the manufacturer-recommended high-resolution imaging parameters that subsequently resulted in a higher effective dose than in the mobile CBCT scanner. Nevertheless, the effective dose can be significantly reduced by using a lower mAs value that subsequently does not markedly affect the diagnostic image quality in the sinus region.⁴¹

One weakness of this study is the use of a frozen cadaver head for image quality assessment. During freezing, residual water in the cadaver expands and subsequently causes anatomical alterations especially in the fine bony structures of the sinonasal region. Furthermore, frozen fatty acids in the brain⁴² decrease in volume and consequently increase the attenuation resulting in an increase of the Hounsfield or the gray values.^{42,43} The aforementioned factors subsequently reduce the image quality and contrast resolution.⁴⁴ Moreover, the FOM value was assessed based on the CNR value from a cadaver head, whereas the effective dose used for calculating the FOM value was obtained using an anthropomorphic phantom. Another drawback of this study is that the image quality was assessed for only one

anatomical landmark in the ear region while there is a growing interest for diagnostic imaging of temporal bones due to the cochlear implants.⁴⁵ Furthermore, an interpretation with the results obtained using the MSCT scanner should be carried out with care since the images were acquired using standard exposure parameters without image quality optimization.

Conclusions

Head imaging positioning has an impact on the overall CBCT image quality. The best mean CBCT image quality, CNR value and FOM value were observed using the prone imaging position for all diagnostic regions. The oblique imaging position offers inadequate image quality except in the sinus region. The MSCT scanner offered similar mean image quality in the supine position to that acquired on the mobile CBCT scanner using 7.5 mA tube current.

Conflicts of interest

Juha Koivisto is an employee of Planmeca Oy, Helsinki, Finland.

References

- Heiland M, Schulze D, Blake F, Schmelzle R. Intraoperative imaging of zygomaticomaxillary complex fractures using a 3D C-arm system. *Int J Oral Maxillofac Surg* 2005; **34**: 369–75.
- Koskinen SK, Haapamäki VV, Salo J, Lindfors NC, Kortensniemi M, Seppälä L, et al. CT arthrography of the wrist using a novel, mobile, dedicated extremity cone-beam CT (CBCT). *Skeletal Radiol* 2013; **42**: 649–57. doi: <https://doi.org/10.1007/s00256-012-1516-0>
- Tuominen EK, Kankare J, Koskinen SK, Mattila KT. Weight-bearing CT imaging of the lower extremity. *AJR Am J Roentgenol* 2013; **200**: 146–8. doi: <https://doi.org/10.2214/AJR.12.8481>
- Zbijewski W, Stayman JW. Volumetric soft tissue brain imaging on xCAT, a mobile, flat-panel X-ray CT system. *Proc SPIE* 2009; **10**: 7258.
- Zhang J, Weir V, Fajardo L, Lin J, Hsiung H, Ritenour ER. Dosimetric characterization of a cone-beam O-arm imaging system. *J Xray Sci Technol* 2009; **17**: 305–17. doi: <https://doi.org/10.3233/XST-2009-0231>
- Siewerdsen JH, Daly MJ, Bachar G, Moseley DJ, Bootsma G, Brock KK, et al. Multimode C-arm fluoroscopy, tomosynthesis, and cone-beam CT for image-guided interventions: from proof of principle to patient protocols. *Proc SPIE* 2007; **6510**: 65101A-1–65101A-11.
- Siewerdsen JH, Daly MJ, Chan H, Nithiananthan S, Hamming N, Brock KK, et al. High-performance intraoperative cone-beam CT on a mobile C-arm: an integrated system for guidance of head and neck surgery. *Proc SPIE* 2009; **7261**: 72610J-1–72610J-8.
- Siewerdsen JH. Cone-beam CT with a flat-panel detector: from image science to image-guided surgery. *Nucl Instrum Methods Phys Res A* 2011; **648**: S241–50. doi: <https://doi.org/10.1016/j.nima.2010.11.088>
- Schafer S, Nithiananthan S, Mirota DJ, Uneri A, Stayman JW, Zbijewski W, et al. Mobile C-arm cone-beam CT for guidance of spine surgery: image quality, radiation dose, and integration with interventional guidance. *Med Phys* 2011; **38**: 4563–74. doi: <https://doi.org/10.1118/1.3597566>
- Siewerdsen JH, Chan Y, Rafferty MA, Moseley D, Jaffray DA, Irish JC. Cone-beam CT with a flat-panel detector on a mobile C-arm: pre-clinical investigation in image-guided surgery of the head and neck. *Proc SPIE* 2005; **5744**: 789–97.
- Loubele M, Bogaerts R, Van Dijk E, Pauwels R, Vanheusden S, Suetens P, et al. Comparison between effective radiation dose of CBCT and MSCT scanners for dentomaxillofacial applications. *Eur J Radiol* 2009; **71**: 461–8. doi: <https://doi.org/10.1016/j.ejrad.2008.06.002>
- Ludlow JB, Ivanovic M. Comparative dosimetry of dental CBCT devices and 64-slice CT for oral and maxillofacial radiology. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod*. 2008; **106**: 106–14. doi: <https://doi.org/10.1016/j.tripleo.2008.03.018>
- Nemtoi A, Czink C, Haba D, Gahleitner A. Cone beam CT: a current overview of devices. *Dentomaxillofac Radiol* 2013; **42**: 20120443. doi: <https://doi.org/10.1259/dmfr.20120443>
- Kim S, Yoo S, Yin FF, Samei E, Yoshizumi T. Kilovoltage cone-beam CT: comparative dose and image quality evaluations in partial and full-angle scan protocols. *Med Phys* 2010; **37**: 3648–59. doi: <https://doi.org/10.1118/1.3438478>
- Fahrig R, Dixon R, Payne T, Morin RL, Ganguly A, Strobel N. Dose and image quality for a cone-beam C-arm CT system. *Med Phys* 2006; **33**: 4541–50. doi: <https://doi.org/10.1118/1.2370508>
- Lofthag-Hansen S, Thilander-Klang A, Gröndahl K. Evaluation of subjective image quality in relation to diagnostic task for cone beam computed tomography with different fields of view. *Eur J Radiol* 2011; **80**: 483–8. doi: <https://doi.org/10.1016/j.ejrad.2010.09.018>
- Koivisto J, Wolff J, Järnstedt J, Dastidar P, Kortensniemi M. Assessment of the effective dose in supine, prone, and oblique positions in the maxillofacial region using a novel combined extremity and maxillofacial cone beam computed tomography

- scanner. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2014; **118**: 355–62. doi: <https://doi.org/10.1016/j.oooo.2014.05.016>
18. Yan H, Cervino L, Jia X, Jiang SB. A comprehensive study on the relationship between the image quality and imaging dose in low-dose cone beam CT. *Phys Med Biol* 2012; **57**: 2063–80. doi: <https://doi.org/10.1088/0031-9155/57/7/2063>
19. Heiland M, Schulze D, Adam G, Schmelzle R. 3D-imaging of the facial skeleton with an isocentric mobile C-arm system (Siremobil Iso-C3D). *Dentomaxillofac Radiol* 2003; **32**: 21–5.
20. Schulze D, Heiland M, Blake F, Rother U, Schmelzle R. Evaluation of quality of reformatted images from two cone-beam computed tomographic systems. *J Craniomaxillofac Surg* 2005; **33**: 19–23.
21. Kamburoğlu K, Murat S, Kolsuz E, Kurt H, Yüksel S, Paksoy C. Comparative assessment of subjective image quality of cross-sectional cone-beam computed tomography scans. *J Oral Sci* 2011; **53**: 501–8.
22. Choi JW, Lee SS, Choi SC, Heo MS, Huh KH, Yi WJ, et al. Relationship between physical factors and subjective image quality of cone-beam computed tomography images according to diagnostic task. *Oral Surg Oral Med Oral Pathol Oral Radiol* 2015; **119**: 357–65. doi: <https://doi.org/10.1016/j.oooo.2014.11.010>
23. Yu L, Vrieze TJ, Bruesewitz MR, Kofler JM, DeLone DR, Pallanch JF, et al. Dose and image quality evaluation of a dedicated cone-beam CT system for high-contrast neurologic applications. *AJR Am J Roentgenol* 2010; **194**: W193–201. doi: <https://doi.org/10.2214/AJR.09.2951>
24. Martin C. The importance of radiation quality for optimisation in radiology. *Biomed Imaging Interv J* 2007; **3**: e38. doi: <https://doi.org/10.2349/biij.3.2.e38>
25. Zamenhof RG. The optimization of signal detectability in digital fluoroscopy. *Med Phys* 1982; **9**: 688–94. doi: <https://doi.org/10.1118/1.595130>
26. Ogden KM, Huda W, Khorasani MR, Scalzetti EM. A comparison of three CT voltage optimization strategies. *Proc SPIE* 2008; **6913**: 691351–1–691351-10.
27. Boone JM. Parametrized X-ray absorption in diagnostic radiology from Monte Carlo calculations: implications for x-ray detector design. *Med Phys* 1992; **19**: 1467–73.
28. World Medical Association. World Medical Association Declaration of Helsinki. Ethical principles for medical research involving human subjects. *JAMA* 2013; **310**: 2191–4. doi: <https://doi.org/10.1001/jama.2013.281053>
29. Prather H, Hunt D, Steger-May K, Hayes MH, Knaus E, Clohisey J. Inter-rater reliability of three musculoskeletal physical examination techniques used to assess motion in three planes while standing. *PM R* 2009; **1**: 629–35. doi: <https://doi.org/10.1016/j.pmrj.2009.05.003>
30. Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psychol Bull* 1979; **86**: 420–8.
31. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics* 1977; **33**: 159–74.
32. Gupta N, Garg NK. Review on different techniques of image registration. *Int J Eng Comput Sci* 2014; 2319–7242.
33. Wang CW, Chen HC. Improved image alignment method in application to X-ray images and biological images. *Bioinformatics* 2013; **29**: 1879–87. doi: <https://doi.org/10.1093/bioinformatics/btt309>
34. Korsager AS, Carl J, Østergaard LR. Comparison of manual and automatic MR-CT registration for radiotherapy of prostate cancer. *J Appl Clin Med Phys* 2016; **17**: 294–303.
35. Pauwels R, Araki K, Siewerdsen JH, Thongvigitmanee SS. Technical aspects of dental CBCT: state of the art. *Dentomaxillofac Radiol* 2015; **44**: 20140224. doi: <https://doi.org/10.1259/dmfr.20140224>
36. Timperley DG, Banks C, Robinson D, Roth J, Sacks R, Harvey RJ. Lateral frontal sinus access in endoscopic skull-base surgery. *Int Forum Allergy Rhinol* 2011; **1**: 290–5. doi: <https://doi.org/10.1002/alar.20042>
37. Rigolizzo MB, Camilli JA, Francischone CE, Padovani CR, Brånemark PI. Zygomatic bone: anatomic bases for osseointegrated implant anchorage. *Int J Oral Maxillofac Implants* 2005; **20**: 441–7.
38. Moreira-Gonzalez A, Papay FE, Zins JE. Calvarial thickness and its relation to cranial bone harvest. *Plast Reconstr Surg* 2006; **117**: 1964–71. doi: <https://doi.org/10.1097/01.prs.0000209933.78532.a7>
39. Pereira AM, Batigália F, Santos FS, Martins AT, Lyra AO. Clinical application of cone-beam tomography in disorders of the head of mandible. *J Morphol* 2012; **29**: 151–3.
40. Kwong JC, Palomo JM, Landers MA, Figueroa A, Hans MG. Image quality produced by different cone-beam computed tomography settings. *Am J Orthod Dentofacial Orthop* 2008; **133**: 317–27. doi: <https://doi.org/10.1016/j.ajodo.2007.02.053>
41. Sohaib SA, Peppercorn PD, Horrocks JA, Keene MH, Kenyon GS, Reznick RH. The effect of decreasing mAs on image quality and patient dose in sinus CT. *Br J Radiol* 2001; **74**: 157–61. doi: <https://doi.org/10.1259/bjr.74.878.740157>
42. Chang CY, Ke DS, Chen JY. Essential fatty acids and human brain. *Acta Neurol Taiwan* 2009; **18**: 231–41.
43. Pech P, Bergström K, Rauschnig W, Haughton VM. Attenuation values, volume changes and artifacts in tissue due to freezing. *Acta Radiol* 1987; **28**: 779–82.
44. Hemmingsson A, Johansson A, Rauschnig W. Attenuation in human muscle and fat tissue *in vivo* and *in vitro*. *Acta Radiol Diagn (Stockh)* 1982; **23**: 149–51.
45. Zou J, Koivisto J, Lähelmä J, Aarnisalo A, Wolff J, Pyykkö I. Imaging optimization of temporal bones with cochlear implant using a high-resolution cone beam CT and the corresponding effective dose. *Ann Otol Rhinol Laryngol* 2015; **124**: 466–73. doi: <https://doi.org/10.1177/0003489414565004>