



## Research article

# Optimization of image quality and radiation dose using different cone-beam CT exposure parameters



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## ABSTRACT

**Purpose:** To investigate and optimize the impact of different exposure parameters on image quality and radiation dose for a latest generation orthopedic cone-beam CT system.

**Materials and methods:** 110 consecutive scans of the same cadaver forearm were performed before and after the insertion of a distal radius plate on the palmar radius to achieve highest intra-individual comparability. All scans were conducted on a latest generation cone-beam CT scanner (Carestream OnSight 3D Extremity System, Carestream Health, Rochester, NY, USA). Extremity imaging was performed using different combinations of tube voltage (kV) and tube current – exposure time product (mAs). Radiation dose (DLP and CTDI<sub>VOL</sub>) was recorded to widely varying combinations. Subjective and objective image quality analysis included a blinded evaluation by five different readers independently using 5-point-Likert scales.

**Results:** Highest radiation dose was achieved using the manufacturers' suggested standard protocol (90-kV and 5.0 mAs with DLP of 111.91 mGy\*cm and CTDI<sub>VOL</sub> of 4.49 mGy), while 70-kV and 2.0 mAs provided the most dose reduction with DLP of 20.34 mGy\*cm and CTDI<sub>VOL</sub> of 0.79 mGy.

Regarding subjective image quality, higher tube voltage improved depiction of cortical bone ( $p \leq 0.038$ ) and cancellous bone ( $p \leq 0.001$ ) as well as overall image quality ( $p \leq 0.027$ ). Changes of the tube current – exposure time product did not show significant alterations of image quality ( $p \geq 0.063$ ). After plate insertion, only the subjective overall image quality showed reduced subjective perception ( $p < 0.001$ ).

Between the different scan protocols, no relevant changes were observed in the objective image quality analysis (SNR:  $p \geq 0.125$ ; CNR:  $p \geq 0.086$ ). However, presence of osteosynthesis significantly lowered the mean SNR and CNR ( $p < 0.001$ ).

**Conclusion:** Even with lowest exposure settings, orthopedic extremity CBCT revealed good overall image quality. The best result regarding subjective image quality was achieved with 85-kV / 4.7 mAs with a dose reduction of 18,9% compared to the manufacturer's recommended protocol (90-kV and 5.0 mAs).

## 1. Introduction

During the last decade, cone-beam computerized tomography (CBCT) has become a well-established, common diagnostic tool in many dental and medical examinations of the head and neck region. Thanks to several advantages compared to multi-detector computed tomography (MDCT), including superior spatial resolution, easy

accessibility, simple handling, low cost and the possibility for reduced radiation exposure, CBCT has been widely implemented in radiological practice [1–3].

Following this trend, several orthopedic CBCT systems designed for extremity imaging have been introduced [4]. Detection of trauma and neoplasms, preoperative planning as well as postoperative assessment are the main application purposes of this skeletal imaging technique.

**Abbreviations:** CBCT, cone-beam computerized tomography; CTDI<sub>VOL</sub>, volume CT dose index; DLP, dose-length product; FOV, field-of-view; HU, hounsfield unit; ROI, region-of-interest; SD, standart deviation; SNR, signal-to-noise ratio

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High-resolution three-dimensional images of a patient's upper or lower extremity can be acquired in a single rotation of the detector and x-ray source. Additionally, CBCT provides the ability to obtain images of the lower extremities in a natural weight-bearing setup, providing further functional information about joint biomechanics [4].

Considering that CBCT is increasingly used by healthcare professionals other than radiologists, the adjustment and investigation of most dose-efficient scan protocols is essential to ensure comprehensive radiation protection for patients [2]. Since there is limited clinical experience with the newest CBCT systems and the potential to reduce X-ray exposure has not been assessed yet, we aimed to explore the effect of varying scan parameters on radiation dose and image quality. Therefore, the overall aim of this study was to evaluate and optimize the influence of different exposure parameters on image quality and radiation dose for a latest generation extremity CBCT system.

## 2. Materials and methods

### 2.1. Cadaver phantom

To obtain direct comparability and to avoid patient radiation in an experimental setting, a fresh cadaver forearm from an anonymous body donor was used for this prospective study.

### 2.2. CBCT-Examinations

All examinations were performed on the latest generation orthopedic CBCT scanner (Carestream OnSight 3D Extremity System, Carestream Health, Rochester, NY, USA).

The device provides manual selection of scan parameters for every scan. After positioning the forearm inside the gantry and choosing the scan parameters, images were acquired during a 215.5°-degree rotation of the detector and the x-ray source.

The fresh cadaver arm was placed inside the scan area and was not moved between scan-sets (Fig. 1).

Using the manufacturers' suggested protocol (90-kV and 5.0 mAs), the cadaver arm was scanned using different lower combinations of X-ray tube voltage (90-kV, 85-kV, 80-kV, 75-kV and 70-kV) and varying tube current-exposure time products (5.0 mAs, 4.7 mAs, 4.4 mAs, 4.1 mAs, 3.8 mAs, 3.5 mAs, 3.2 mAs, 2.9 mAs, 2.6 mAs, 2.3 mAs and 2.0 mAs). A total of 55 imaging protocols were selected and all examinations were performed without moving the cadaver arm between scans. The acquisition time for every scan was 25 s. The cylindrical field-of-view (FOV) was kept constant at  $22.3 \times 22.3 \times 22.3 \text{ cm}^3$  (standard FOV setting for adults) (Table 1). Emitted X-ray beams were filtered by means of a 0.5 mm aluminum and a 0.1 mm copper layer.

In order to evaluate the influence of metal artefacts on image



Fig. 1. Scan setup with cadaver arm placed inside the CBCT and left in the same position for the scans.

Table 1

Carestream Health OnSight Extremity CBCT operator settings.

Parameters	Values				
kV	90	85	80	75	70
mAs	5.0 4.7	4.4 4.1 3.8	3.5 3.2 2.9	2.6 2.3	2.0
FOV	$22.3 \times 22.3 \times 22.3 \text{ cm}^3$				
Scan time	25 sec*				

\* Constant for all scans.



Fig. 2. Placing a distal radius plate inside the cadaver arm.

quality, an experienced trauma surgeon (> 30 years of surgical practice) inserted a distal radius plate inside the cadaver's arm, simulating a postoperative status with osteosynthesis material being displayed (Fig. 2).

All scans were then repeated in the exact same setup and by using the earlier selected scan protocols and another set of 55 images was acquired.

An iterative reconstruction technique provided by the manufacturer was used for image reconstruction including axial, coronal and sagittal slices with a slice thickness and increment of 1 mm each.

### 2.3. Radiation dose

For each modulation of scan parameters, the volume CT dose index ( $\text{CTDI}_{\text{vol}}$ ) and dose-length product (DLP) were provided by the device. Their values were different and specific for each examination depending on the combination of kV / mAs and were documented for every scan.

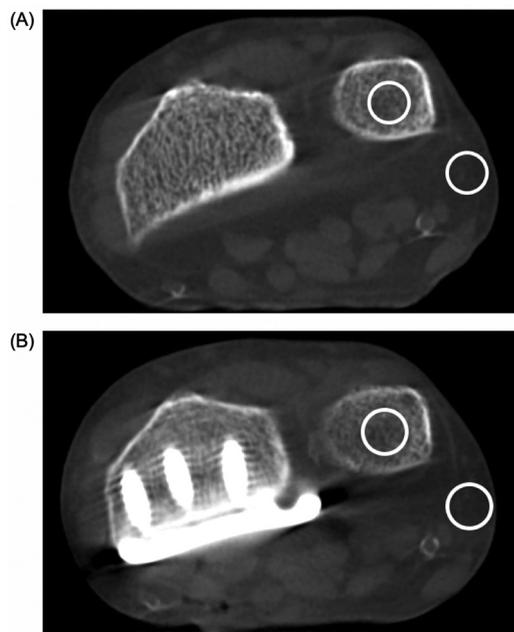
### 2.4. Subjective image quality

Datasets were individually, separately and blindly evaluated by five radiologists with different experience in musculoskeletal imaging (1, 3, 4, 6 and 15 years of experience).

Image analysis was performed under standardized conditions on certified diagnostic monitors (RadiForce RX240; Eizo, Ishikawa, Japan).

A standardized short verbal introduction about the device and the data acquisition was given individually before the beginning of a scoring session. Images showed no evidence of device settings and had a randomized order. Observations were performed with no time restriction. The observers were free to scroll through the three orthogonal reconstructions (axial, coronal and sagittal). Initial contrast was set to 2700/700 HU for all scans; however, observers were free to adjust the contrast and brightness as personally required.

Depiction of cortical and cancellous bone and overall image quality were assessed on all 110 datasets, while metal artefacts were present for cases with osteosynthesis. A 5-point Likert scale was used (5 = excellent/ no artefacts, 4 = good/ almost absence of artefacts, 3 = moderate/ mild artefacts, 2 = fair/ moderate artefacts, 1 = non-diagnostic/ severe artefacts).



**Fig. 3.** Axial CBCT images demonstrating regions-of-interest (ROI) measurements in the trabecular bone of the distal ulna and subcutaneous fat A) without osteosynthesis material; B) in presence of osteosynthesis material.

**2.5. Objective image quality**

Objective image analysis was performed by a radiologist with 3 years of experience in skeletal imaging. Signal attenuation in mean Hounsfield units (HU) was measured by placing circular regions-of-interest (ROI) in the trabecular bone of the distal ulna and subcutaneous fat before and after implantation of the radius plate. Image noise was defined as the standard deviation within subcutaneous fat, since fat-tissue provided a more homogenous texture. ROIs were carefully placed in consistent locations and in the region with the most amount of metal (Fig. 3). Extensive artefacts were avoided, and measurements were performed twice and averaged to ensure data consistency and high measurement accuracy.

The following formula was then used to calculate signal-to-noise ratio (SNR) and contrast-to-noise ratio (CNR) values:

$$SNR = \frac{HU (ulna)}{SD (fat)}$$

$$CNR = \frac{HU (ulna) - HU (fat)}{SD (fat)}$$

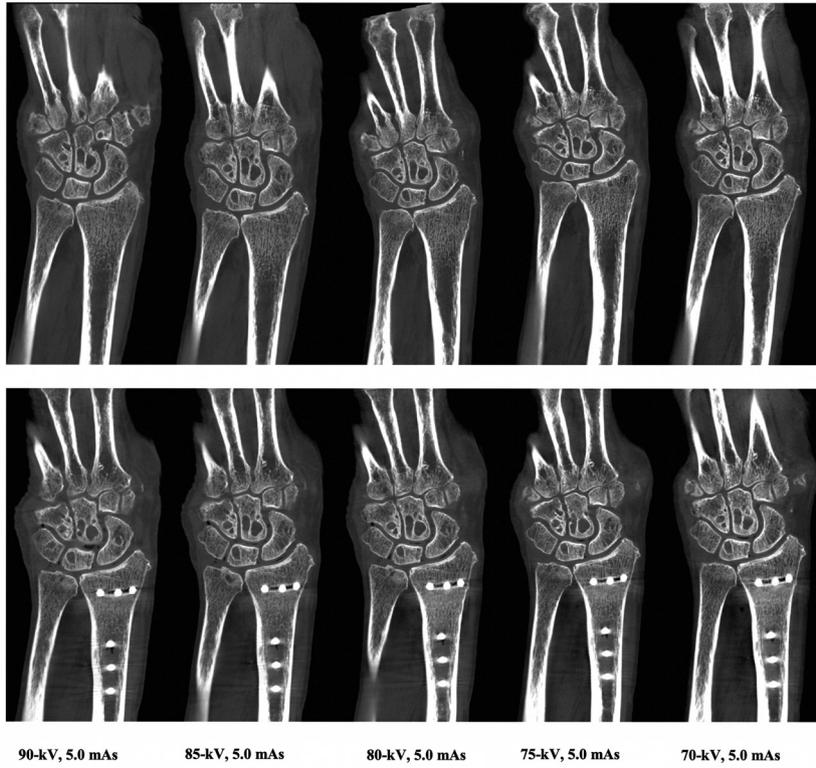
**2.6. Statistical analysis**

Results are listed as mean values ± standard deviation (SD) and range. Gaussian distribution of all data was assessed using a Kolmogorov–Smirnov test. Unpaired t-test and one-way ANOVA with Tukey multiple comparison post-tests was performed for normally distributed data. As for non-parametric test Mann–Withney–U-test was performed. Linear regression was used to analyse and assess the relation of radiation dose and the sum of the rating scores. A p-value of less than 0.05 was considered statistically significant. Interobserver agreement for image quality was assessed using Kendall’s W test [5]. The value was interpreted as slight agreement (< 0.20), fair agreement (0.20–0.39), moderate agreement (0.40–0.59), good agreement (0.60–0.79) and excellent agreement (≤ 0.8). The agreement was determined for the overall image quality. Statistical analysis was performed by using GraphPad Prism Version 7.0 (GraphPad Software; La Jolla, CA, USA) and IBM SPSS Statistics Version 21. (IBM SPSS statistics; Armonk, NY,

**Table 2**  
Dosimetric parameters: Mean values ± SD (range).

		A) Depending on kV-changes						B) Depending on mAs-changes									
		85-kV		80-kV		75-kV		70-kV		2.9 mAs		2.6 mAs		2.3 mAs		2.0 mAs	
		90-kV	85-kV	80-kV	75-kV	70-kV	75-kV	70-kV	75-kV	2.9 mAs	2.6 mAs	2.3 mAs	2.6 mAs	2.3 mAs	2.0 mAs	2.6 mAs	2.0 mAs
<b>CTDI<sub>vol</sub></b> (mGy)		3.1 ± 0.9 (1.8–4.5)	2.7 ± 0.8 (1.5–3.9)	2.3 ± 0.6 (1.3–3.2)	1.8 ± 0.5 (1.1–2.6)	1.4 ± 0.4 (0.8–2.0)	1.8 ± 0.5 (1.1–2.6)	1.4 ± 0.4 (0.8–2.0)	1.4 ± 0.4 (0.8–2.0)	1.8 ± 0.6	1.7 ± 0.5	1.5 ± 0.4	1.7 ± 0.5	1.5 ± 0.4	1.3 ± 0.4	1.3 ± 0.4	p < 0.001
<b>DLP</b> (mGy × cm)		78.3 ± 22.3 (44.8–111.9)	67.7 ± 19.2 (38.7–96.7)	57.0 ± 16.2 (32.6–81.4)	46.3 ± 13.2 (26.5–66.1)	35.6 ± 10.1 (20.3–50.9)	46.3 ± 13.2 (26.5–66.1)	35.6 ± 10.1 (20.3–50.9)	35.6 ± 10.1 (20.3–50.9)	47.2 ± 14.0 (29.5–64.9)	42.3 ± 12.3 (26.4–58.2)	37.5 ± 11.1 (23.4–51.5)	42.3 ± 12.3 (26.4–58.2)	37.5 ± 11.1 (23.4–51.5)	32.6 ± 9.7 (20.3–44.8)	32.6 ± 9.7 (20.3–44.8)	p < 0.001
<b>Tube current-exposure time product</b>																	
<b>CTDI<sub>vol</sub></b> (mGy)		3.2 ± 1.0 (2.0–4.5)	2.8 ± 0.8 (1.8–3.9)	2.4 ± 0.7 (1.5–3.4)	2.0 ± 0.6 (1.3–2.9)	1.7 ± 0.5 (1.1–2.3)	2.0 ± 0.6 (1.3–2.9)	1.7 ± 0.5 (1.1–2.3)	1.5 ± 0.4 (0.9–2.1)	2.6 ± 0.8 (1.7–3.6)	2.4 ± 0.7 (1.5–3.4)	2.2 ± 0.7 (1.4–3.2)	2.0 ± 0.6 (1.3–2.9)	1.8 ± 0.6 (1.2–2.6)	1.5 ± 0.4 (0.9–2.1)	1.3 ± 0.4 (0.8–1.8)	p < 0.001
<b>DLP</b> (mGy × cm)		81.4 ± 24.1 (50.9–111.9)	71.6 ± 21.2 (44.8–98.5)	61.9 ± 18.3 (38.7–85.1)	52.1 ± 15.5 (32.5–71.6)	42.3 ± 12.3 (26.4–58.2)	52.1 ± 15.5 (32.5–71.6)	42.3 ± 12.3 (26.4–58.2)	37.5 ± 11.1 (23.4–51.5)	66.7 ± 19.8 (41.7–91.8)	61.9 ± 18.3 (38.7–85.1)	57.0 ± 16.2 (35.6–78.3)	66.7 ± 19.8 (41.7–91.8)	47.2 ± 14.0 (29.5–64.9)	37.5 ± 11.1 (23.4–51.5)	32.6 ± 9.7 (20.3–44.8)	p < 0.001

(A)



(B)

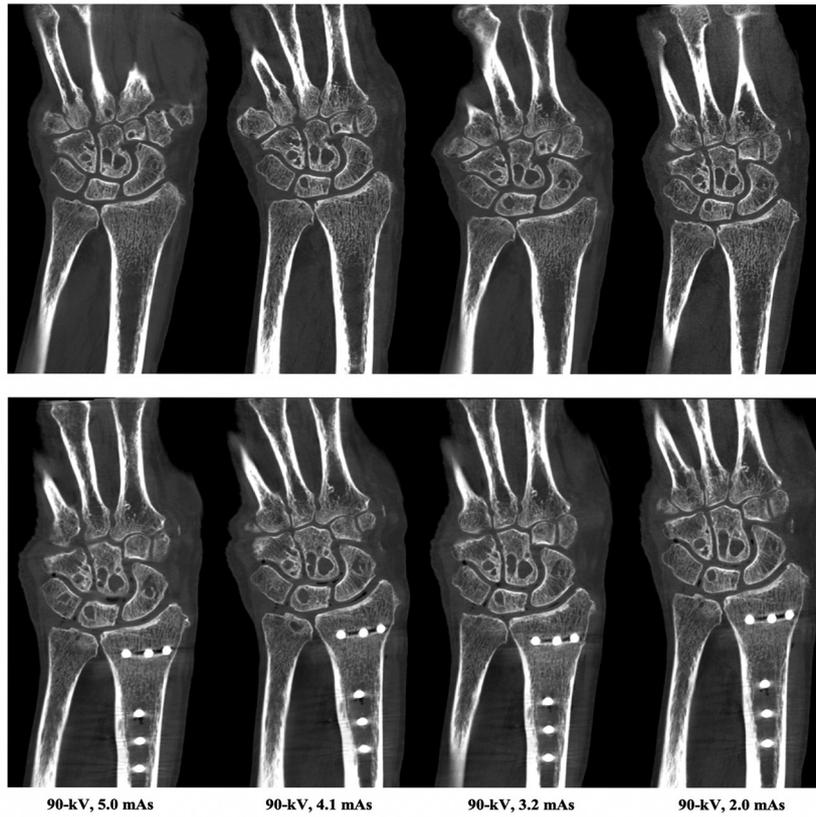


Fig. 4. CBCT images (without and with osteosynthesis material) obtained with A) 5.0-mAs and varying kV settings; B) 90-kV and varying mAs settings.

**Table 3** Mean data of subjective image quality assessment for depiction of cortical bone, cancellous bone and overall image quality (A) for various kV-settings, (B) for various mAs-settings.

A) Various kV-settings		90-kV		85-kV		80-kV		75-kV		70-kV	
Parameters	5.0 mAs	4.7 mAs	4.4 mAs	4.1 mAs	3.8 mAs	3.5 mAs	3.2 mAs	2.9 mAs	2.6 mAs	2.3 mAs	2.0 mAs
<b>Cortical bone</b>	4.1 ± 0.4 (3.8–4.6)	4.2 ± 0.4 (3.6–4.6)	4.1 ± 0.5 (3.6–4.8)	4.1 ± 0.4 (3.6–4.4)	4.1 ± 0.3 (3.8–4.4)	3.9 ± 0.3 (3.6–4.2)	4.1 ± 0.3 (3.6–4.4)	4.0 ± 0.4 (3.6–4.4)	4.1 ± 0.2 (3.8–4.2)	4.2 ± 0.3 (3.8–4.4)	4.0 ± 0.3 (3.6–4.4)
<b>Cancellous bone</b>	4.0 ± 0.6 (3.4–4.6)	4.1 ± 0.4 (3.6–4.6)	4.0 ± 0.3 (3.6–4.4)	4.0 ± 0.3 (3.6–4.2)	4.0 ± 0.5 (3.4–4.4)	3.9 ± 0.3 (3.6–4.2)	4.0 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.4–4.2)	3.9 ± 0.2 (3.6–4.0)	4.0 ± 0.3 (3.6–4.4)	3.8 ± 0.3 (3.2–4.4)
<b>Overall image quality</b>	4.0 ± 0.6 (3.4–4.8)	4.0 ± 0.3 (3.6–4.4)	4.0 ± 0.4 (3.6–4.6)	4.0 ± 0.2 (3.8–4.2)	4.0 ± 0.3 (3.6–4.4)	3.9 ± 0.2 (3.6–4.2)	3.9 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.4–4.2)	3.9 ± 0.3 (3.8–4.4)	3.9 ± 0.3 (3.4–4.2)

B) Various mAs-settings		90-kV		85-kV		80-kV		75-kV		70-kV	
Parameters	5.0 mAs	4.7 mAs	4.4 mAs	4.1 mAs	3.8 mAs	3.5 mAs	3.2 mAs	2.9 mAs	2.6 mAs	2.3 mAs	2.0 mAs
<b>Cortical bone</b>	4.1 ± 0.4 (3.8–4.6)	4.2 ± 0.4 (3.6–4.6)	4.1 ± 0.5 (3.6–4.8)	4.1 ± 0.4 (3.6–4.4)	4.1 ± 0.3 (3.8–4.4)	3.9 ± 0.3 (3.6–4.2)	4.1 ± 0.3 (3.6–4.4)	4.0 ± 0.4 (3.6–4.4)	4.1 ± 0.2 (3.8–4.2)	4.2 ± 0.3 (3.8–4.4)	4.0 ± 0.3 (3.6–4.4)
<b>Cancellous bone</b>	4.0 ± 0.6 (3.4–4.6)	4.1 ± 0.4 (3.6–4.6)	4.0 ± 0.3 (3.6–4.4)	4.0 ± 0.3 (3.6–4.2)	4.0 ± 0.5 (3.4–4.4)	3.9 ± 0.3 (3.6–4.2)	4.0 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.4–4.2)	3.9 ± 0.2 (3.6–4.0)	4.0 ± 0.3 (3.6–4.4)	3.8 ± 0.3 (3.2–4.4)
<b>Overall Image quality</b>	4.0 ± 0.6 (3.4–4.8)	4.0 ± 0.3 (3.6–4.4)	4.0 ± 0.4 (3.6–4.6)	4.0 ± 0.2 (3.8–4.2)	4.0 ± 0.3 (3.6–4.4)	3.9 ± 0.2 (3.6–4.2)	3.9 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.6–4.2)	3.9 ± 0.3 (3.4–4.2)	3.9 ± 0.3 (3.8–4.4)	3.9 ± 0.3 (3.4–4.2)

USA).

### 3. Results

#### 3.1. Radiation dose

Radiation dose results are shown in Table 2.

Highest radiation dose with a DLP of 111.91 mGy\*cm and CTDI<sub>VOL</sub> of 4.49 mGy was achieved using the manufacturers' suggested standard protocol (90-kV and 5.0 mAs). The lowest radiation dose was achieved with the ultimate combination the device could provide (70-kV and 2.0 mAs), resulting in a DLP of 20.34 mGy\*cm and a CTDI<sub>VOL</sub> of 0.79 mGy.

#### 3.2. Subjective image quality

Representative CBCT images of the cadaver forearm obtained using different kV and mAs settings are shown in Fig. 4, illustrating the overall spatial resolution, contrast resolution and field of view of datasets, without and with osteosynthesis.

The scores of the five observers were averaged for each subjective image quality parameter (Table 3). Each parameter for image quality criteria was rated as moderate to excellent.

Depiction of cortical bone in 90-kV was superior to 75-kV and 70-kV settings (p < 0.001), in 85-kV superior to 80-kV, 75-kV and 70-kV (p ≤ 0.017) as well as in 80-kV superior to 75-kV and 70-kV (p ≤ 0.038). Cancellous bone could be better depicted in 90-kV vs. 75-kV and 70-kV (p ≤ 0.001) as well as in 85-kV vs. 75-kV and 70-kV (p < 0.001). Overall image quality was significantly higher in 90-kV vs. 80-kV/75-kV/70-kV (p ≤ 0.027) and in 85-kV vs. 75-kV (p = 0.006).

No significant differences resulted by varying the tube current – exposure time product (p ≥ 0.063).

Comparing the subjective rating of the 55 images without osteosynthesis individually to their counterpart – after the distal plate was placed inside the cadaver arm – ratings for datasets with metal artefacts only resulted in a significantly lower perception (p < 0.001) in overall image quality (Table 4). Linear regression analysis between the sum of the rating scores for each scan protocol versus DLP resulted in a R-square of 0.435 with a level of significance with p < 0,001. Fig. 5 showing the best fit line for the relation between rating values and DLP.

Interobserver agreement for image quality parameters was good with mean Kendall's Coefficient of Concordance of 0.69. Kendall's W<sup>a</sup> for cortical bone was 0.71, for cancellous bone 0.78, for artefacts 0.61 and for overall image quality 0.67.

Defining a total rating score equal or more than 80 out of 100 points as a good and sufficient diagnostic image quality, 19 possible scan protocol settings can be considered (Table 5). The highest DLP among them was achieved with the manufacturers' suggested standard protocol (90-kV and 5.0 mAs). The lowest radiation dose belonged to the combination of 80-kV and 2.0 mAs, with a dose reduction by 70.9% compared to the standard protocol. Best overall subjective image quality score was achieved with the combination of 85-kV and 4.7 mAs with an DLP of 90.85 mGy\*cm. Since all of the in Table 5 listed scan protocols provide an accurate and satisfying diagnostic level, the combination of 85-kV and 80-kV with 2.0 mAs had an notable low radiation dose with 38.66 mGy\*cm and 32.55 mGy\*cm, achieving an up to 65% drop in radiation exposure.

#### 3.3. Objective image quality

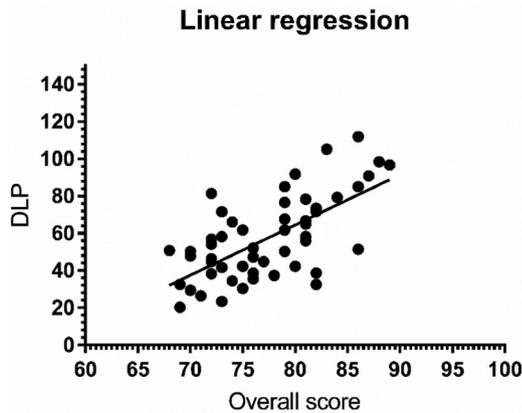
Mean SNR is summarized in Table 6. SNR values showed no significant changes between the different scan protocols (p ≥ 0.125).

Mean CNR-values are listed in Table 7 and also do not present significant changes between varying scan settings (p ≥ 0.086).

However, after implantation of distal radius plate, mean SNR (5.2 ± 1.7) as well as mean CNR (12.1 ± 3.5) were significantly

**Table 4**  
Mean data ± SD (range) of subjective image quality assessment for datasets without and with osteosynthesis.

	Without osteosynthesis	With osteosynthesis	<i>p</i> - value
Cortical bone	4.2 ± 0.3 (3.8–4.8)	4.0 ± 0.4 (3.6–4.7)	<i>p</i> = 0.09
Cancellous bone	4.0 ± 0.3 (3.7–4.6)	3.8 ± 0.5 (3.2–4.6)	<i>p</i> = 0.17
Overall image quality	4.3 ± 0.4 (3.8–4.8)	3.7 ± 0.3 (3.4–4.2)	<i>p</i> < 0.001



**Fig. 5.** Scatter plot with best fit line demonstrating linear regression analysis between the rating scores and the DLP.

**Table 5**  
Scan protocols with at least 80 score points in subjective rating; the two protocols with the lowest radiation dose are Shaded in Gray.

Total rating score	Scan protocol	DLP [mGy*cm]
89	85 kV – 4.7 mAs	90.85
88	90 kV – 4.4 mAs	96.65
87	85 kV – 5.0 mAs	98.48
86	90 kV – 5.0 mAs	111.91
86	90 kV – 3.8 mAs	85.05
86	90 kV – 2.3 mAs	51.48
84	85 kV – 4.1 mAs	79.25
83	90 kV – 4.7 mAs	105.2
82	90 kV – 3.2 mAs	71.63
82	85 kV – 3.8 mAs	73.45
82	85 kV – 2.0 mAs	38.66
82	80 kV – 2.0 mAs	32.55
81	90 kV – 3.5 mAs	78.34
81	90 kV – 2.9 mAs	64.91
81	90 kV – 2.6 mAs	58.20
81	85 kV – 2.9 mAs	56.06
81	80 kV – 4.1 mAs	66.73
81	90 kV – 4.1 mAs	91.77
80	80 kV – 2.6 mAs	42.32

lower than in metal-free images (mean SNR: 9.6 ± 2.7; mean CNR: 23.2 ± 6.1) (*P* < 0.001).

**4. Discussion**

Accurate diagnosis in traumatology, as well as treatment planning and monitoring in orthopaedics essentially rely on high resolution imaging. The success of extremity CBCT requires an overall good image quality to provide the necessary information. However, good image quality can easily be associated with high radiation exposure, if no critical review and evaluation of scanning protocols has been performed. Therefore, establishing an appropriate compromise between image quality and radiation dose is crucial, especially when considering multiple follow-up exams, according to the ALARA principle (as low as

reasonably achievable).

Since the scan time and the size of field of view (FOV) are technically not changeable in many CBCT systems, tube current-time product and tube voltage are the only variables that can be modified to reduce the radiation dose [6].

Our data indicate that all scan settings for examinations of the extremity using the investigated CBCT system provided at least fair diagnostic image quality and this observation hold true even with the lowest dose protocol. The differences in image quality were frequently very subtle with hardly visible changes in the images acquired. In particular, adjustments in the tube current-time product with constant kV seem to have no relevant impact on the image quality. Wang et al. reported an evident relationship between mAs and patient dose when other exposure factors were kept constant [7]. However, in our study we could not verify a noticeable change in radiation dose by varying mAs, probably because of the limited range settings of the device (2.0–5.0 mAs) and small (0.3 mAs) intervals between different scan protocols. Due to the same reasons, mAs alteration might not show any noticeably impact on image quality as well. Additionally, there could be a positive effect of the iterative reconstruction techniques used in the process of image acquisition [8].

However, we could demonstrate that higher kV-settings (90-kV, 85-kV and 80-kV) resulted in significant superior subjective image quality than lower parameters. This may be explained by the fact that the effect of kV on dose and image quality is more intricate and complex owing to a combination of several energy-dependent X-ray interactions. A higher kV value increases not only the mean energy of the photons in an X-ray beam, but the number of emitted photons as well [7]. Even though subjective perception of image quality increased with higher kV, objective image quality as indicated by SNR and CNR did not show an improvement regardless of the tube voltage differences. This discrepancy might derive from the fact, that rating 110 captures (with sometimes very subtle changes between the images) in a randomized order, could bias human perception, especially when high kV-images might have been followed by low kV-images.

The only significant changes in objective image quality and subjective overall image quality evaluation after the implantation of a distal radius plate are likely based on increased amount of beam hardening, photon starvation and aliasing artefacts [9,10]. The presence of artefacts probably explains the subjectively lower perception in overall image quality, while the rating of cortical and cancellous bone, being high contrast structures, was not affected after osteosynthesis.

The effect of changing one or both exposure factors on image quality and dose is not straightforward and should be properly balanced. Our results indicate that it is possible to adjust the scan settings in this CBCT device without a noticeable loss in image quality. Notably, we achieved a dose reduction of 18,9% combined with a higher (but not significantly differing) total score in subjective image quality when using 85-kV and 4.7 mAs compared to the manufacturer's recommended protocol (90-kV and 5.0 mAs).

This study showed following limitations:

Body habitus and size of the patient are important factors for the radiation dose delivered, especially for paediatric patients and bariatric adults [11]. Since we performed the scans on only one cadaver arm, we couldn't evaluate the impact of different habitus on image quality.

Furthermore, we only used a CBCT of one manufacturer restricting a generalization of our results for other systems.

**Table 6**  
Objective image quality (SNR) in datasets without or with a distal radius plate inside the cadaver arm (A) for kV-changes, (B) for mAs-changes.

A) Various kV-settings		90-kV	85-kV	80-kV	75-kV	70-kV	p-value
SNR (without distal plate)		17.1 ± 1.6 (13.8–19.8)	15.5 ± 2.4 (10.1–18.6)	15.3 ± 4.2 (10.8–18.9)	15.0 ± 2.6 (10.7–18.5)	14.2 ± 2.5 (10.5–18.2)	p = 0.146
SNR (with distal plate)		6.7 ± 1.7 (4.3–10.9)	6.5 ± 1.4 (5.2–10.2)	5.7 ± 2.4 (4.3–10.2)	5.3 ± 0.6 (4.2–6.2)	5.3 ± 0.4 (4.4–5.9)	p = 0.125
B) Various mAs-settings		5.0 mAs	4.4 mAs	3.8 mAs	3.2 mAs	2.6 mAs	2.0 mAs
SNR (without distal plate)		16.7 ± 3.2 (12.3–18.9)	15.4 ± 2.8 (12.1–18.6)	15.1 ± 3.1 (12.0–19.4)	14.9 ± 1.9 (12.8–17.4)	14.9 ± 1.4 (13.5–16.8)	13.8 ± 2.1 (10.1–15.5)
SNR (with distal plate)		6.9 ± 1.9 (5.6–10.9)	5.6 ± 0.8 (4.5–6.3)	6.1 ± 1.4 (4.5–8.0)	6.6 ± 2.1 (5.3–10.2)	6.5 ± 2.6 (4.6–10.8)	5.8 ± 1.3 (5.6–6.9)

**Table 7**  
Objective image quality (CNR) in datasets without or with a distal radius plate inside the cadaver arm (A) for kV-changes, (B) for mAs-changes.

A) Various kV-settings		90-kV	85-kV	80-kV	75-kV	70-kV	p-value
CNR (without distal plate)		25.5 ± 3.1 (19.8–32.6)	24.6 ± 4.4 (17.1–30.6)	24.1 ± 4.7 (17.7–29.9)	23.5 ± 4.2 (17.4–30.5)	22.4 ± 3.5 (16.5–26.2)	p = 0.086
CNR (with distal plate)		14.2 ± 3.6 (10.2–19.1)	12.8 ± 3.1 (8.3–18.6)	12.4 ± 3.6 (6.4–18.2)	11.6 ± 1.5 (9.8–14.4)	11.5 ± 1.8 (9.4–14.9)	p = 0.144
B) Various mAs-settings		5.0 mAs	4.4 mAs	3.8 mAs	3.2 mAs	2.6 mAs	2.0 mAs
CNR (without distal plate)		24.7 ± 2.5 (20.8–27.6)	22.8 ± 2.5 (19.3–25.1)	22.4 ± 1.2 (20.1–23.7)	22.2 ± 5.3 (18.3–28.2)	21.6 ± 1.5 (19.6–23.3)	20.9 ± 1.2 (20.1–21.9)
CNR (with distal plate)		14.9 ± 4.1 (8.8–19.1)	14.3 ± 2.9 (9.1–17.2)	13.1 ± 2.3 (8.2–17.9)	11.8 ± 3.3 (7.4–10.5)	11.3 ± 2.2 (7.6–13.8)	10.1 ± 2.9 (6.4–13.1)

## 5. Conclusion

In our study we could demonstrate that even the lowest exposure settings revealed a moderate to good overall image quality, with the best subjective image quality achieved with 85-kV / 4.7 mAs (18,9% dose reduction compared to manufacturers' suggested protocol). Important results were achieved with 85-kV or 80-kV combined with 2.0 mAs, since these protocols maintained high image quality at low radiation dose levels.

## Conflict of interest

- Ibrahim Yel, nothing to declare.
- Christian Booz, received a speaker's fee from Siemens Healthineers.
- Moritz H. Albrecht, received speaker's fees from Siemens Healthineers.
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- Christoph Polkowski, nothing to declare.
- Martina Jacobi, nothing to declare.
- Lukas Lenga, nothing to declare.
- Martin Schulz, nothing to declare.
- Johannes Frank, nothing to declare.
- Ingo Marzi, nothing to declare.
- Thomas J. Vogl, nothing to declare.
- Katrin Eichler, nothing to declare.
- Benjamin Kaltenbach, nothing to declare.

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