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Research article

Dose-optimized computed tomography of the cervical spine in patients with shoulder pull-down: Is image quality comparable with a standard dose protocol in an emergency setting?

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ABSTRACT

Purpose: Superimposing soft tissue and bony structures in computed tomography (CT) of the cervical spine (C-spine) is a limiting factor in optimizing radiation exposure maintaining an acceptable image quality. Therefore, we assessed image quality of dose-optimized (DO) C-spine CT in patients capable of shoulder pull-down in an emergency setting.

Methods and materials: DO-CT (105mAs/120 kVp) of the C-spine in trauma settings was performed in patients with shoulder pull-down if C5 was not superimposed by soft tissue on the lateral topogram, otherwise standard-dose (SD)-CT (195 mAs/120 kVp) was performed. 34 DO (mean age, 68y ± 21; BMI, 24.2 kg/m^2 ± 3.2) and 34 SD (mean age 70y ± 19; BMI 25.7 kg/m^2 ± 4.4) iterative reconstructed CTs were evaluated at C2/3 and C6/7 by two musculoskeletal radiologists. Qualitative image noise and morphological characteristics of bony structures (cortex, trabeculae) were assessed on a Likert scale. Quantitative image noise was measured and effective dose (ED) was recorded. Parameters were compared using Mann-Whitney-*U*-test ($p < 0.05$).

Results: At C2/3, DO-CT vs. SD-CT yielded comparable qualitative noise (mean, 1.3 vs. 1.0; p = 0.18) and morphological characteristics, but higher quantitative noise (27.2 ± 8.8HU vs. 19.6 ± 4.5HU; $p < 0.001$). At C6/7, DO-CT yielded lower subjective noise (1.9; SD-CT 2.2; p = 0.017) and better morphological characteristics with higher visibility scores for cortex (p = 0.001) and trabeculae (p = 0.03). Quantitative noise did not differ (p = 0.24). Radiation dose was 51% lower using DO-CT ($ED_{DO\text{-}CT}$ 0.80 ± 0.1 mSv; $ED_{SD\text{-}CT}$ 1.63 ± 0.2 mSv; $p < 0.001$).

Conclusion: C-spine CT with dose reduction of 51% showed no image quality impairment. Additional pull-down of both shoulders allowed better image quality at lower C-spine segments as compared to a standard protocol.

1. Introduction

Cervical spine (C-spine) CT imaging increased in the past, as it is the recommended modality of choice in patients with suspected acute C-spine trauma [1–3]. Radiation dose optimization remains a concern, especially in young and middle-aged individuals, since they are at greater risk to develop cancer after radiation exposure [4].

Different dose reduction strategies include mathematical models such as iterative reconstructions (IR), automatic tube-current modulation as well as optimization of patient positioning [5–11]. For example,

Abbreviations: BMI, body-mass-index; C-spine, cervical spine; CT, computed tomography; CTDIvol, volume CT dose index; DO, dose optimized; DLP, dose–length product; ED, effective dose; HU, Hounsfield units; IR, iterative reconstruction; ROI, regions of interests; SD, standard dose; SAFIRE, sinogram-affirmed iterative reconstruction

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Table 1
Patient demographics and cervical spine-related body parameters.

	Dose optimized CT (n = 34)		Standard dose CT (n = 34)		P - value
	Mean ± SD	Median (25tth/75th percentile)	Mean ± SD	Median (25tth/75th percentile)	
Age **[years]**	68 ± 21	78 (44/87)	70 ± 19	77 (56/84)	0.71
BMI **[kg/m²]**	24.2 ± 3.2	23.8 (22.9/26.0)	25.7 ± 4.3	24.7 (23.0/27.4)	0.16
Circumference C2/3 **[cm]**	49.3 ± 3.3	49.2 (46.6/51.2)	53.4 ± 9.4	51.4 (49.1/49.1)	**0.01***
AP-diameter C2/3 **[cm]**	17.3 ± 1.8	17.4 (15.8/18.2)	18.0 ± 2.0	18.0 (17.0/19.0)	0.07
AP-diameter C6/7 **[cm]**	15.3 ± 2.4	15.1 (13.6/16.9)	16.4 ± 2.9	16.1 (14.4/18.6)	0.14
Shoulder level	C5 ± 1	C5 (5/6)	C3 ± 1	C3 (3/4)	< **0.001***

Note—Significant differences between both CT protocols are marked with an asterisk (P < 0.05).
M, male; F, female; BMI, body mass index; Ap, anteroposterior. Shoulder level was defined as the lowest vertebra, that was not superimposed by soft tissue of the shoulders.

when arms are positioned lateral to the body in thoracic CT, photon absorption is augmented in the x-axis and image quality is reduced, while an up-warded arm position may reduce radiation dose by 45% [12–14]. For C-spine CT it has been reported that shoulder position influences image quality and radiation dose when automated tube-current modulation is being used [8]. A reduction of tube-current to 105 mAs and the tube voltage to 120 kVp is sufficient for image quality in cadaveric specimens when the C-spine levels are not superimposed by the shoulder girdle [15].

However, even with the attempt of pulling down the shoulders, not every patient is capable of doing so due to acute or chronic medical issues or anatomical restrictions.

Therefore, the need of varying imaging protocols depending on patients` shoulder level is necessary. Selecting automatically or manually scan protocols according to BMI, patient size or cross sectional measurements of body regions or patient positioning will increase in significance in the setting of personalized medicine and increasing awareness of radiation protection in the future [8,16–18]. A simple and time-efficient method is the evaluation of the shoulder level on a lateral topogram [15].

In our institution, C-spine CT protocols are routinely triaged by the shoulder level on lateral topograms: if C5 is not superimposed by the shoulders, indicating sufficient shoulder pull-down, a dose optimized (DO-CT) protocol is used; in all other cases, a standard dose (SD-CT) protocol is used. We hypothesized that image quality of DO C-spine CT is sufficient in patients capable of pulling down their shoulders. Therefore, the aim of the current study was to compare image quality of the C-spine CT with iterative reconstructions (IR) examined with the two aforementioned protocols.

2. Materials and methods

2.1. Patients and CT protocol

Institutional review board approval was waived for this retrospective investigation. 34 DO-CT examinations of the C-spine in 33 patients (mean age, 68 ± 21 years; 11 male/22 female; one female was examined at two different time-points) were included. 34 age- and body-mass-index- (BMI) matched patients with a SD-CT (13 male/21 female) served as controls and were selected out of 80 scanned patients. Age and BMI categorization was defined as follows: age (years; < 35, 35–55, 55–75, > 75), BMI (kg/m²; < 20, 20–25, 25–30, > 30). Demographics of both patient groups are shown in Table 1.

Unenhanced CT scans of the C-spine were performed using a 128 multidetector CT scanner (Somatom Definition AS+; Siemens Healthineers). Patients were in a supine position and asked to straighten their arms and place both hands, palms down, underneath their buttocks. A lateral topogram served as reference for the scan range from vertebrae C1 to T1. The position of the shoulder girdle was assessed on the lateral topogram and recorded (Fig. 1). Patients, in which

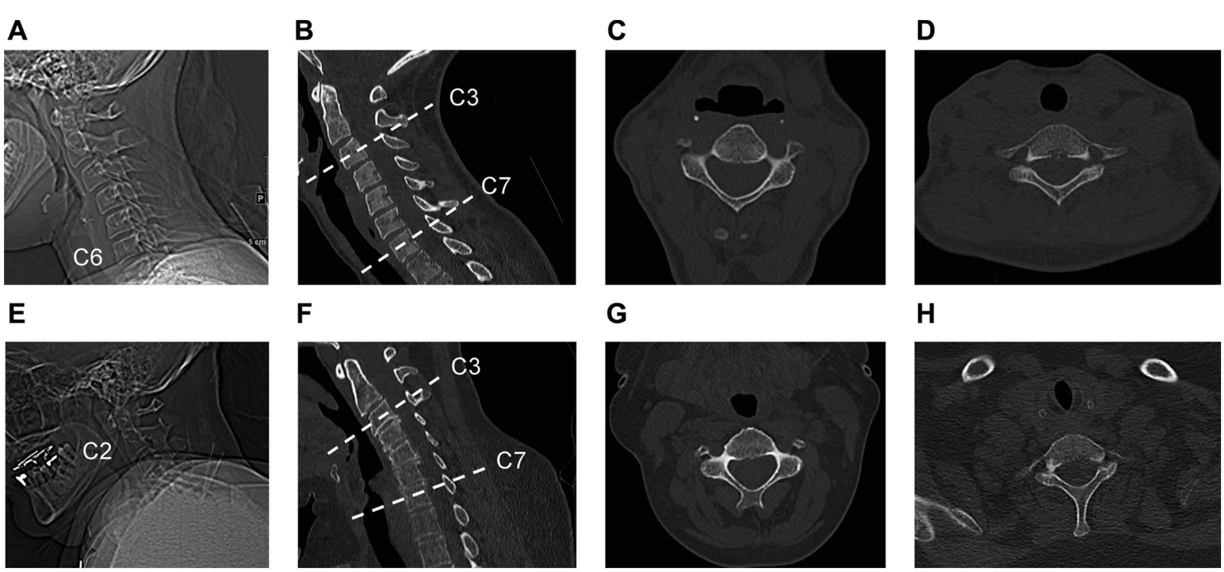

Fig. 1. CT of the C-spine in two different patients performed with the dose-optimized protocol of 105 mAs (A–D) and with the standard protocol of 195 mAs (E–H). Lateral topograms display a shoulder level below C6 (A) for the dose-optimized protocol and below C2 (E) for the standard protocol. Sagittal (B and F) and axial (C, D and G, H) reformatted images with sinogram-affirmed iterative reconstruction (SAFIRE, strength level 3) using bone convolution kernels (window level/width, 600/2000) show that image noise and quality is superior at the lower C-spine level with a dose-optimized protocol and capability of shoulder pull-down (A–D) as compared to a standardized protocol and elevated shoulders (E–H).

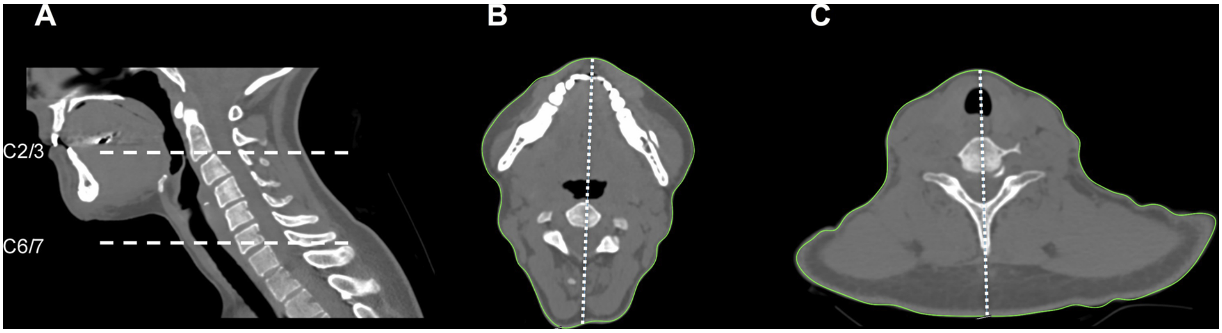

Fig. 2. Sagittal reformatted image (A) of the C-spine demonstrates measurement heights (dashed lines) to evaluate the volume of the neck at C2/3 and C6/7. Axial reformatted images at C2/3 (B) and 6/7 (C) show the measurements of neck-circumference (green lines) and anteroposterior distance (dashed white lines) in a patient with shoulder level below C6.

C5 was not superimposed by the shoulder girdle, reflecting shoulder pull-down, were examined with the DO-CT protocol (reference tube-current–time product, 105 mAs) [15]. Otherwise, the SD-CT protocol (reference tube-current–time product, 195 mAs), proposed by the manufacturer, was performed. The following scan parameters were used for both protocols: tube voltage, 120 kVp; detector configuration, 128 × 0.6 mm; pitch factor, 0.8; automatic tube-current modulation (Care Dose 4D, average strength, Siemens Healthineers). Images were reconstructed by using an IR (sinogram-affirmed iterative reconstruction, SAFIRE strength 3) algorithm as described elsewhere in bone (I70 h) and soft tissue (I30) convolution kernel [19–21]. The following image reconstruction parameters were used: field-of-view, 15 × 15 cm to 20 × 20 cm according to the patient constitution; section thickness/increment, 0.75/0.75 mm.

To address the influence of adjacent soft and bony tissue, mainly the shoulders, the C-spine was analysed at two anatomical levels: at C2/3, reflecting the upper C-spine, and at C6/7, reflecting the lower C-spine. Neck circumference and anteroposterior distance of the neck were measured at C2/3 and C6/7 on non-reformatted axial images (Fig. 2). Soft tissue measurements at C2/3 included part of the mandible in some patients depending on the head position. Neck circumference could not be exactly measured in 12 patients for the DO-CT and in 27 patients for the SD-CT at C6/7 as the soft tissue was not fully included in the reconstructed image, thus, these parameters were only statistically evaluated at C2/3.

Table 2
Assessment of morphological criteria of the bony cervical spine.

Assessment	Location	Score	Criteria
Cortex	Vertebral body (sag/ax)	0	Not visible
		1	Visible, but not analyzable
		2	Clearly visible
Trabeculae	Vertebral body (sag)	0	Not visible
		1	Clearly visible
Integrity	Anterior vertebral body line (sag)	0	Not visible
		1	Clearly visible
	Posterior vertebral body line (sag)	0	Not visible
		1	Clearly visible
Alignment	Anterior vertebral body (sag)	0	Not visible
		1	Clearly visible
	Posterior vertebral body (sag)	0	Not visible
		1	Clearly visible
	Maximal sum	7	

Note—Cortex, trabeculae and integrity were assessed on vertebral segments C3 and C7; alignment was assessed on cervical levels C2/3 and C6/7. The least visible cortex of each vertebral body was used for this analysis. A three-point scale was used for the assessment of the cortex as this is the most important structure to distinguish in fracture evaluation.
Sag = sagittal reformations, *ax* = axial reformations.

2.2. Analysis of quantitative image noise

For noise measurements four circular regions of interests (ROI), each of 100 mm^2, were placed in extracorporal air on IR reconstructed axial images at C2/3 and C6/7 [15]. Measurements were performed by one reader with 1 year of experience in spine CT imaging. The standard deviation of mean CT numbers measured in Hounsfield units (HU) within a ROI defined the image noise.

2.3. Analysis of qualitative image noise and morphological characteristics

Qualitative image noise was assessed on a three-point Likert scale (1 = no noise, 2 = acceptable minor noise, 3 = unacceptable major noise) at two levels, C2/3 and C6/7, using sagittal reformations in bone and soft tissue windows. Morphological characteristics of cortex, trabeculae, vertebral integrity and alignment as well as spinal nerve and intervertebral disc were rated on a Likert scale as shown detailed in Tables 2 and 3. Examples for soft tissue evaluation are presented in Fig. 3.

CT scans were randomized and independently evaluated by two musculoskeletal fellowship-trained radiologists. Each reader was blinded to the scan parameters. The average ratings given by both readers were used to compare the CT protocols.

CT images were displayed with the window level/width set to 600/2000 for the bony assessment and 40/350 for soft tissue assessment. Axial and sagittal reformations were viewed in OsiriX (Version 4.1.2).

2.4. Analysis of radiation exposure

The volume CT dose index ($CTDI_{vol}$) and the dose–length product (DLP) were automatically generated by the CT. The effective dose was estimated by multiplying the DLP by an organ specific conversion coefficient of 0.0051 mSv/mGycm for an adult neck region at 120 kVp [22].

Table 3
Assessment of morphological criteria of the cervical spine soft tissue.

Assessment	Location	Score	Criteria
Foraminal spinal nerve	C2/3 and C6/7	0	Not visible
		1	Visible, but not analyzable
		2	Clearly visible
Intervertebral disc	C2/3 and C6/7	0	Not visible
		1	Visible, but not analyzable
		2	Clearly visible
	Maximal sum	4	

Note—Assessment was performed on sagittal reformations.

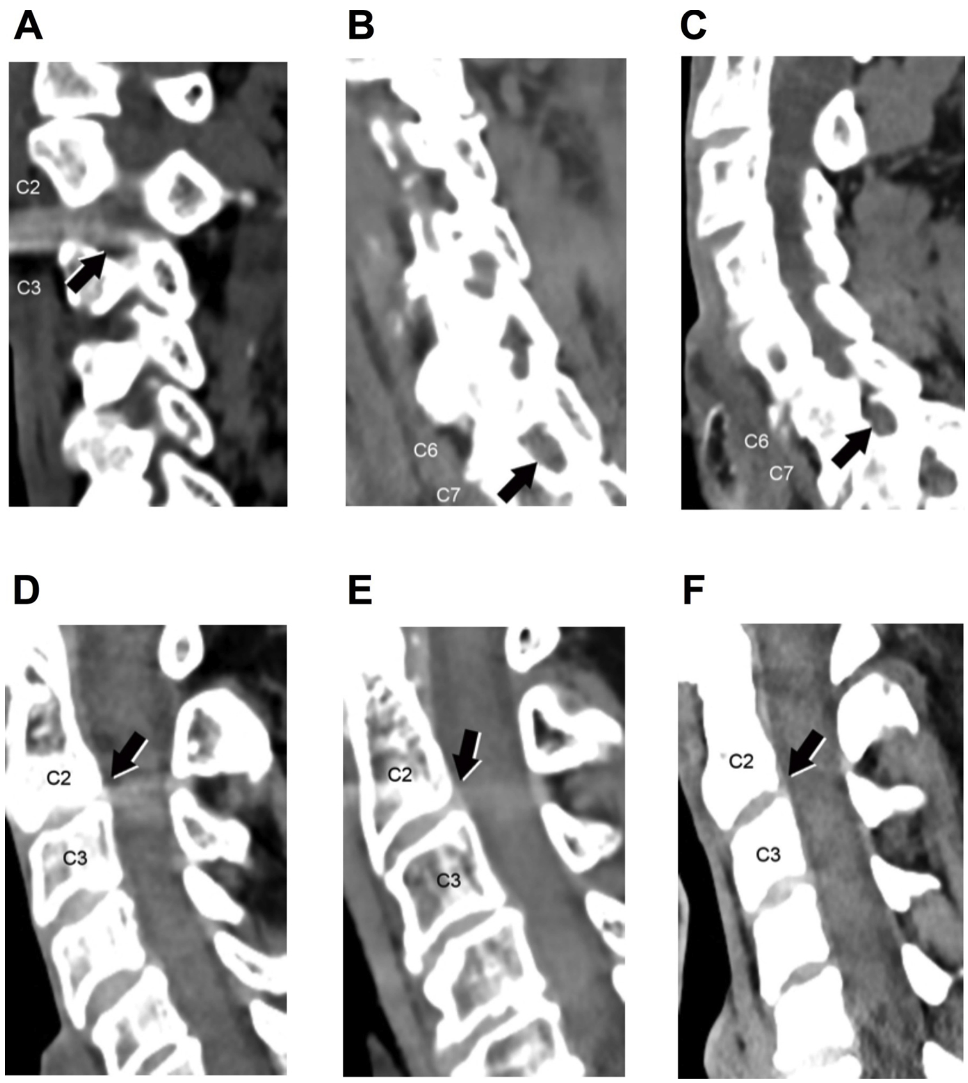

Fig. 3. Assessment of morphological characteristics of foraminal spinal nerve and intervertebral disc at C2/3 and C6/7 using sagittal reformatted soft-tissue window CT images with the following criteria: not visible (arrow in A and D), visible but not analyzable (arrow in B and E) and clearly visible (arrow in C and F).

2.5. Statistical analysis

Patient demographics, radiation dose, quantitative and qualitative parameters for the CT protocols were compared using the Mann Whitney *U* test because they showed a non-normal distribution. A *P*-value < 0.05 was considered statistically significant. Interobserver agreement was assessed by calculating Kappa values. According to Landis and Koch [23] a κ value of 0–0.2 is indicative of slight agreement, 0.21–0.4 fair agreement, 0.41–0.6 moderate agreement, 0.61–0.8 substantial agreement and 0.81–1 almost perfect agreement. Statistical tests were performed by using appropriate statistical software (Statistica 7, StatSoft, Tulsa, Okla; MedCalc).

3. Results

3.1. Patient demographics

Since groups were matched, no statistical significant differences were found for gender, age and BMI in our patient population (Table 1). Shoulder height was at C5 for the DO-CT and at C3 for the SD-CT. Neck circumference was larger in patients examined with SD-CT than in patients with DO-CT at C2/3. In contrast, anteroposterior distance of the neck showed no significant difference between the two groups (Table 1).

3.2. Analysis of quantitative image noise

Quantitative noise measurements in bone window images of patients with DO-CT displayed higher noise than patients with SD-CT ($P < 0.001$) at the upper C-spine (C2/3). No significant difference of noise was found at the lower C-spine (C6/7; $P = 0.24$; Fig. 4a).

3.3. Analysis of qualitative image noise and morphological characteristics

3.3.1. Bony structures

Comparison of qualitative image noise in bone window displayed no difference for the upper C-spine ($P = 0.18$). Significantly less image noise was evident at the lower C-spine using DO-CT ($P = 0.02$; Figs. 1 and 4b; Table 4).

Analysis of morphological characteristics in bone window revealed no difference between DO-CT (P = 0.29) at the upper C-spine but significantly better scores for DO-CT at the lower C-spine (P = 0.002). Detailed structural analysis revealed higher scores for cortex, trabeculae and anterior integrity at the lower C-spine using DO-CT compared to SD-CT, whereas posterior integrity and vertebral alignment showed no differences between both protocols (Fig. 5; Table 4).

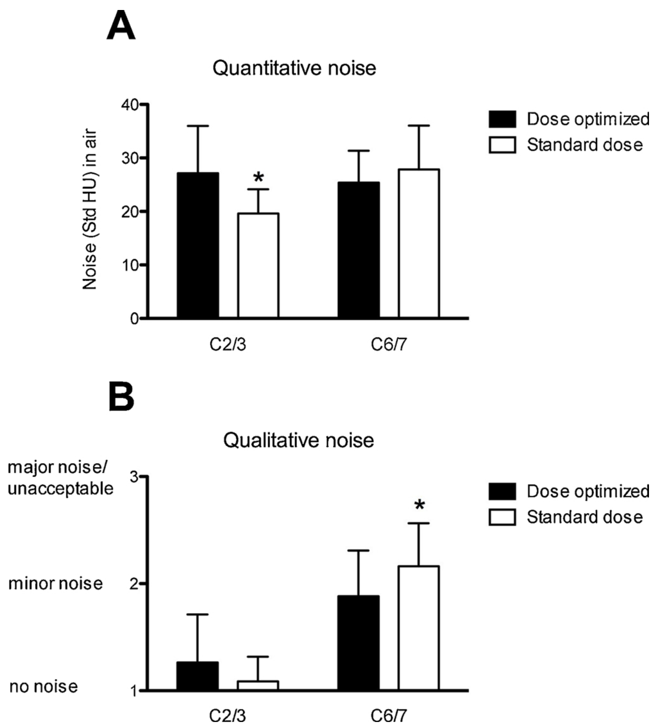

Fig. 4. Quantitative (A) and qualitative (B) image noise was evaluated at C2/3 and C6/7. A: Quantitative image noise was significantly higher in DO-CT than in SD-CT at C2/3, whereas no significant difference was seen at C6/7. B: Qualitative image noise showed no significant difference between both protocols at C2/3, but was significantly lower in DO protocol at level C6/7 in patients capable of shoulder pull-down. Data are presented as mean ± standard deviation. Asterisks indicate significant differences ($P < 0.05$).

3.3.2. Soft tissue structures

Comparison of qualitative image noise in soft tissue window displayed no difference for the upper C-spine (DO: 1.54 ± 0.63 vs. SD: 1.45 ± 0.56; P = 0.65), but was significantly inferior using DO-CT at the lower C-spine (DO: 1.76 ± 0.48 vs. SD: 2.18 ± 0.41; $P < 0.001$).

Visibility scores of intervertebral disc ($P = 0.30$) and foraminal spinal nerve ($P = 0.20$) in soft tissue window showed no difference between both protocols at the upper C-spine. However, visibility scores were significantly higher for both structures (intervertebral disc, $P = 0.001$; spinal nerve, $P < 0.001$) at the lower C-spine using DO-CT (Fig. 6; Table 4).

3.4. Interobserver agreement

Kappa values were substantial (0.67) for the analysis at bone window and moderate for the analysis at soft tissue window (0.43).

3.5. Analysis of radiation exposure

Detailed results are summarized in Table 5. Mean $CTDI_{vol}$, DLP and effective dose were lower at DO-CT compared to SD-CT ($P < 0.001$). Mean overall effective mAs was 51% lower for DO-CT than for SD-CT ($P < 0.001$). The effective tube-current time product at the respected evaluated segments was likewise lower for DO-CT than for SD-CT, 54% lower at level C2/3 and 51% lower at level C6/7 (Table 5).

4. Discussion

The goal of our study was to compare CT images of the C-spine using two different protocols, a dose optimized protocol (105 mAs) with shoulder pull-down and a standard protocol (195 mAs) without shoulder pull-down. We postulated that image quality of dose-optimized C-spine CT is sufficient in patients capable of pulling down their shoulders.

At the upper C-spine, subjective image quality proved to be comparable for both protocols, only quantitative image noise was higher for the dose optimized protocol.

At the lower C-spine, image quality was superior using the dose-reduced protocol compared to a standard protocol, because patients were capable of pulling down their shoulders below C5. Adjusting CT protocols according to patient positioning or habitus is common practice in pediatric radiology. In adult imaging customized protocols have become increasingly important. For example, elevated arms in thoracic CT and arms in neutral position in head and neck CTs are recommended

Table 4
Image noise and morphological characteristics.

	Dose optimized CT		Standard dose CT		P - value
	Mean ± SD	Median (25th/75th percentile)	Mean ± SD	Median (25th/75th percentile)	
Bone window					
Quantitative Noise					
C2/3	27.2 ± 8.8 HU	25.5 (21.7/30.3) HU	19.6 ± 4.5 HU	19.3 (17.3/21.0) HU	< 0.001*
C6/7	25.4 ± 5.9 HU	23.6 (21.3/30.0) HU	27.9 ± 8.2 HU	26.8 (21.8/31.5) HU	0.24
Qualitative Noise					
C2/3	1.3 ± 0.4	1.0 (1.0/1.5)	1.3 ± 0.2	1.0 (1.0/1.0)	0.18
C6/7	1.9 ± 0.4	2.0 (1.5/2.0)	2.2 ± 0.4	2.0 (2.0/2.5)	0.02*
Morphological characteristics					
C2/3	6.8 ± 0.5	7.0 (7.0/7.0)	6.9 ± 0.2	7.0 (7.0/7.0)	0.29
C6/7	5.7 ± 1.2	6.0 (5.0/7.0)	4.7 ± 1.5	5.0 (4.0/6.0)	0.002*
Soft tissues					
Qualitative Noise					
C2/3	1.5 ± 0.6	1.5 (1.0/2.0)	1.5 ± 0.6	1.3 (1.0/2.0)	0.65
C6/7	1.8 ± 0.5	2.0 (1.5/2.0)	2.2 ± 0.4	2.0 (2.0/2.5)	< 0.001*
Intervertebral disc					
C2/3	1.6 ± 0.6	2.0 (1.5/2.0)	1.7 ± 0.4	2.0 (1.5/2.0)	0.30
C6/7	1.5 ± 0.5	1.5 (1.0/2.0)	1.0 ± 0.5	1.0 (0.5/1.5)	0.001*
Spinal nerve					
C2/3	1.5 ± 0.6	1.8 (1.0/2.0)	1.7 ± 0.5	2.0 (1.5/2.0)	0.20
C6/7	1.6 ± 0.4	1.5 (1.5/2.0)	1.2 ± 0.4	1.0 (1.0/1.5)	< 0.001*

Note.—Quantitative noise was measured on axial bone window reconstructed images. Qualitative noise and morphological characteristics were evaluated in bone and soft tissue windows. Higher scores reflect better image quality for evaluation of morphological characteristics of bone and soft tissue. For qualitative image noise, lower scores reflect better image quality. Significant differences between both CT protocols are marked with an asterisk ($P < 0.05$).

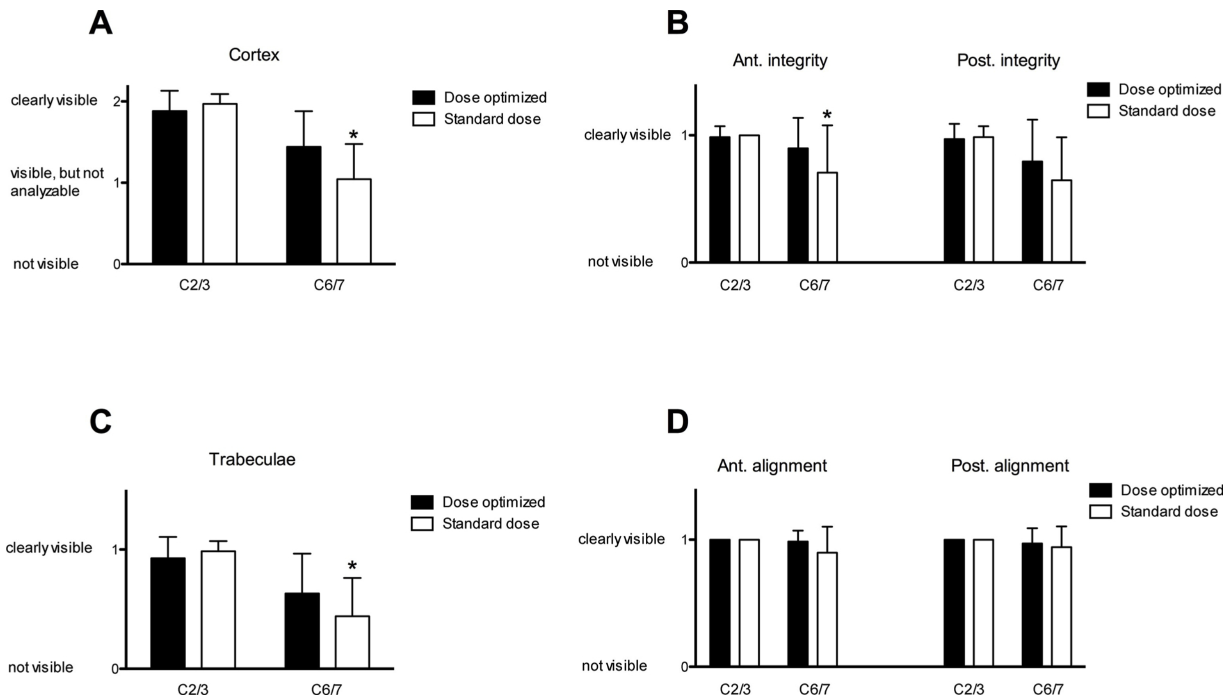

Fig. 5. Analysis of morphological characteristics of cortex (A), integrity (B), trabeculae (C) and alignment (D) in bone window at C2/3 and C6/7, respectively. No significant difference is seen at level C2/3 between both imaging protocols. At C6/7, scores for morphological characteristics were significantly better for cortex, anterior integrity and trabeculae at DO-CT than at SD-CT. Asterisks indicate significant different values between both protocols ($P < 0.05$). Data are presented as mean ± standard deviation.

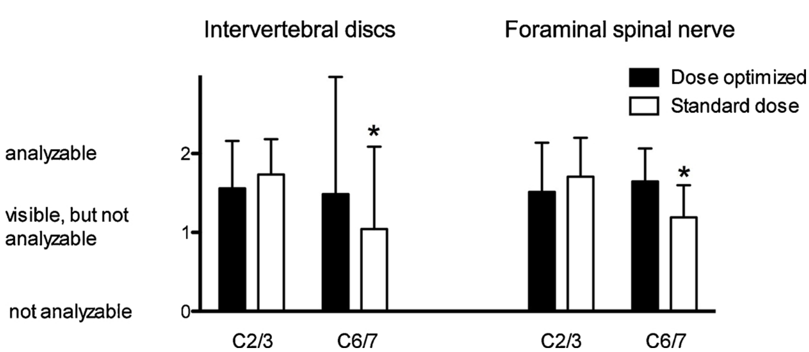

Fig. 6. Analysis of morphological characteristics for intervertebral disc (A) and foraminal spinal nerve (B) in soft tissue window at C2/3 and C6/7, respectively. No significant difference is seen at C2/3. At C6/7, scores were significantly better for intervertebral discs and foraminal spinal nerve at DO-CT than at SD-CT. Asterisks indicate significant different values between both protocol ($P < 0.05$). Data are presented as mean ± standard deviation.

Table 5
Analysis of radiation exposure.

	Dose optimized CT Mean ± SD	Standard dose CT Mean ± SD	P - value
Tube current time product **[mAs]**			
Reference mAs	105	195	
Overall effective mAs	103.4 ± 4.5	209.1 ± 12.1	< **0.001***
C2/3 effective mAs	66.7 ± 5.2	145.3 ± 17.2	
C6/7 effective mAs	90.5 ± 7.7	186.5 ± 11.6	
$CTDI_{vol}$ **[mGy]**	7.0 ± 0.3	14.1 ± 0.8	< **0.001***
DLP **[mGy*cm]**	156.4 ± 21.8	319.7 ± 31.9	< **0.001***
Effective dose **[mSv]**	0.8 ± 0.1	1.6 ± 0.2	< **0.001***

Note.—34 patients were included in each dose optimized and standard dose CT protocol. Significant differences between both CT protocols are marked with an asterisk ($P < 0.05$). Statistics for effective mAs at C2/3 and C6/7 were not tested separately. CTDIvol, volume CT dose index; DLP, dose length product.

[8,12]. Brink et al. showed, that improvement of image quality and dose reduction up to 45% could be achieved by the number of arms elevated in thoracic CT [12]. Similar results were gained by Kane et al. who investigated the lower C-spine in the swimmers position at which one arm was elevated and the other was placed in a neutral position [24]. With this technique, Kane showed improved image quality of the lower C-spine and reduction of beam hardening artefacts in almost all patients which occurred due to the high-riding shoulder girdle of the elevated arm [24].

Kranz et al. reported the importance of lowering down both shoulders during CT of the C-spine in patients with and without the use of table straps in order to reduce superimposition of shoulder girdle [8]. Before starting this investigation, we tested several methods to lower down patients' shoulders, including a strap around the feet at which the patient was holding with both hands, hand rails at both sides of the CT table, pulling down the shoulders on instruction and to straighten the arms and place both hands with palms down underneath the buttocks. The latter was the most convenient, simplest and fastest technique to apply in C-spine CTs and has been applied ever since. With this technique, the neck circumference at the upper C-spine was smaller in patients capable of shoulder pull-down most likely due to less soft tissue and chin overlap. However, patients in the standard dose group without shoulder pull-down not only had larger neck circumferences at the examined level C2/3 but also a trend towards higher BMI, even though not statistically significant. Thus, capability of shoulder pull-down level might be influenced by patients` body characteristics.

Capability of pulling down the shoulders, which might be achieved with the use of a cervical spine splint in an acute trauma setting or with a simple method as shown in this study is of utmost importance for an ideal image quality in CT of the C-spine and additionally allows dose-optimized protocols as low as 105mAs and 120 kVp [8,15].

We used automatic tube-current modulation (ATCM). Effective tube-current time product using DO-CT was lower than the applied tube-current time product (103 mAs vs. 105 mAS), whereas in patients examined with SD-CT effective tube current time product was higher than the applied one (209 mAs vs. 195 mAs). ATCM changes tube-current according to size and attenuation of the body part, which explains that effective tube-current was lower at the upper C-spine than at the lower C-spine. In addition, overall effective mAs was comparable to the applied reference mAs for DO protocol but higher than the applied reference mAs for SD protocol in patients with higher shoulder level and thus larger neck circumferences, especially at lower C-spine levels [7,9,10,25].

Decreasing the reference tube-current-time from 195 mAs to 105 mAs at 120 kVp, reduced the estimated effective dose by 51% from 1.63 to 0.80 mSv. Similarly, Geyer et al. [26] showed that scans performed with adaptive statistical iterative reconstructions (ASIR) using a tube voltage of 120 kVp at an estimated effective dose of 1.1 mSv is possible [26]. Additional dose reduction might be possible with changes of tube voltage as reported by Gleeson for whole body CTs at 140 kVp as a result of consecutive reduction of the tube-current, which might especially be helpful for the lower C-spine because higher kVp levels have been suggested to be less susceptible to variations in body-mass [27]. However, further studies are needed in order to support this hypothesis.

Our study has several limitations. First, we only compared two tube-currents (195 mAs and 105 mAs), which were recommended in the literature. It would be interesting to evaluate, if a further tube-current reduction or even optimization of post-processing data might allow additional dose reduction, which we think is possible due to sufficient image quality of the upper C-spine with both protocols. Second, we only measured noise in the air due to anatomical restrictions of the C-spine scans, which might not be representative of noise in bone or soft tissue. Third, by applying automatic tube-current modulation in the current study, the technical parameters cannot be transferred automatically to protocols of other CT vendors. However, the published CTDI values of our study can be used to optimize protocols of our vendor in patients with a low shoulder position. Fourth, our proposed manoeuvre cannot be applied in all trauma settings and it requires good patient cooperation and painless upper extremity movements. Thus, the shoulder pull-down method might not be applicable in all patients.

5. Conclusion

C-spine CT with dose reduction of 51% showed no image quality impairment. Additional pull-down of both shoulders allowed better image quality at lower C-spine segments as compared to a standard protocol.

Declaration of Competing Interest

There are no relevant conflicts of interest related to the work under consideration for publication. There are no relevant conflicts of interest related to activities outside the submitted work. We have no patents relevant to the work. There are no other relationships/conditions/circumstances that present a potential conflict of interest.

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