
ORIGINAL ARTICLE

Radiation Dose Reduction in Cervical Spine Computed Tomography in Cervical Spine Trauma: Comparison of Low-dose with Standard-dose Multidetector Computed Tomography

KY Man, KM Mo, HT Sung, KY Cho, CW Tam

Department of Radiology, Pamela Youde Nethersole Eastern Hospital, Chai Wan, Hong Kong

ABSTRACT

Objectives: To evaluate radiation dose reduction, and any effect on image quality, in low-dose cervical spine multidetector computed tomography (MDCT) in patients with cervical spine trauma.

Methods: A total of 54 consecutive patients from July 2016 to May 2017 underwent cervical spine MDCT: a standard-dose group (group A, $n = 18$, pitch = 0.641), a low-dose group with an increased pitch (group B, $n = 18$, pitch = 0.828), and a low-dose group with an increased pitch and low-dose auto mA quality factor (group C, $n = 18$, pitch = 0.828, quality factor standard deviation 15). Radiation dosimetry was recorded and image quality was assessed by evaluation of image noise, signal-to-noise ratio, and contrast-to-noise ratio in bone algorithm images, and by subjective assessment by two independent radiologists.

Results: The mean volume CT dose indices were 70.7 mGy, 48.3 mGy, and 32.6 mGy for groups A, B, and C, respectively. The mean dose-length products were 859.9 mGycm, 590.1 mGycm, and 453.9 mGycm for groups A, B, and C, respectively. These differences in mean volume CT dose indices and dose-length product were statistically significant among the three groups (post-hoc Tukey: both $p < 0.001$). There were no significant differences in image quality (analysis of variance/Kruskal-Wallis test: all $p > 0.05$) or subjective evaluation of image quality (Chi squared test: all $p > 0.05$) among the three examination groups.

Conclusion: Low-dose cervical spine MDCT in patients with cervical spine trauma resulted in a substantial 47.2% to 53.9% dose reduction, compared with standard-dose MDCT.

Key Words: Multidetector computed tomography; Radiation dosage; Tomography, spiral computed

Correspondence: Dr KY Man, Department of Radiology, Pamela Youde Nethersole Eastern Hospital, Chai Wan, Hong Kong.
Email: dsgundam@hotmail.com

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Ethics Approval: The study protocol was approved by the Hong Kong East Cluster Research Ethics Committee (Ref HKECREC-2017-049). The requirement for patient consent was waived by the ethics board.

中文摘要

頸椎外傷多探頭電腦斷層掃描的輻射劑量的減少：比較低劑量與標準多探頭電腦斷層掃描

文家潤、巫冠文、宋咸東、曹君彥、譚枝慧

目的：評估頸椎低劑量多探頭電腦斷層掃描對輻射劑量的減少及圖像質量的影響。

方法：比較54名於2016年7月至2017年5月期間接受頸椎多探頭電腦斷層掃描患者的輻射劑量和圖像質量（A組18例，標準劑量，CT螺距因子0.641；B組18例，低劑量及大螺距，CT螺距因子0.828；C組18例，大螺距低劑量mA自動調節，CT螺距因子0.828，質量因子標準差15）。記錄輻射劑量，並由兩位放射科醫師的獨立主觀評價來評估骨算法圖像質量，包括圖像噪聲、信噪比和噪聲比。

結果：三組的平均容積CT劑量指數分別為：A組70.7 mGy、B組48.3 mGy、C組32.6 mGy，差異顯著（ $p < 0.001$ ）。三組的圖像質量相比均沒有顯著差異。

結論：與標準多探頭電腦斷層掃描相比，頸椎低劑量多探頭電腦斷層掃描的輻射劑量顯著降低（47.2%至53.9%）。

INTRODUCTION

Advances in multidetector computed tomography (MDCT) have resulted in its being the preferred initial imaging technique in the evaluation of patients with acute blunt cervical spinal trauma. The main reasons that make MDCT a better choice over standard radiography include accuracy, speed, and reduced patient manipulation.¹

In order to achieve optimal patient protection, the dose to the patient should be as low as reasonably achievable while still successfully completing the required clinical diagnostic task. Several previous studies have demonstrated a dose reduction in cervical spine/neck MDCT using tube current modulation and lower tube voltage settings.^{2,3} The downside of low-tube-voltage CT scanning, however, is the parallel increase in image noise, if the tube current-time product is not correspondingly increased, especially in larger patients. There are other available options, through modification of acquisition protocols, to achieve MDCT radiation dose reduction.⁴

We aimed to explore the effectiveness of radiation dose reduction in cervical spine MDCT by modification of the scanning parameters in patients with cervical spine trauma and to assess the image quality after the modification.

METHODS

To formulate a dose reduction goal, a national dose survey was used as a reference.⁵ The national reference

dose value for volume CT dose index ($CTDI_{vol}$) per sequence was 28 mGy.⁵ The national reference dose value for dose-length product (DLP) per examination was 600 mGycm.⁵

Study Design

A retrospective analysis of cervical spine MDCT examinations was conducted to compare standard-dose with low-dose examinations in patients with suspected cervical spine injury.

The two main outcome parameters were dose and image quality. Dose was expressed as $CTDI_{vol}$ (mGy) and DLP (mGycm). The image quality was assessed by image noise, signal-to-noise ratio (SNR), and contrast-to-noise ratio (CNR). Two independent radiologists assessed subjective image quality.

Study Population

To estimate the sample size, we performed a priori sample size estimation (G Power 3.1.0) [power: 0.8; α : 0.05] by using data from a previous study that examined the radiation dose reduction in patients with cervical spine trauma who underwent cervical spine MDCT.² With a calculated effect size of 1.29 (Cohen's d), it was estimated that at least 11 subjects would be needed in each group.

Inclusion criteria were referral from the emergency, neurosurgical, orthopaedic, or medical departments,

with a history of suspected acute cervical spine injury, who underwent unenhanced cervical spine MDCT examinations. Patients with severe polytrauma who underwent cervical spine MDCT as part of a whole-body CT were excluded because the alternating imaging protocol with uncertain image quality or clinical impact is unsuitable for this group of unstable patients. Patients with metallic implants in the neck region causing significant artefacts, or segmental or otherwise incomplete cervical spine examination were also excluded.

Patients underwent cervical spine MDCT with 64-MDCT (Aquilion CX 64-detector MDCT; Toshiba Medical Systems Corporation, Otawara, Japan).

From July to August 2016, March to April 2017, and April to May 2017, consecutive patients were included for analysis, respectively: a standard-dose (group A) with tube voltage of 120 kV, pitch 0.641, automated tube current modulation (auto mA quality factor = standard deviation [SD] 10), 0.5 mm × 64 collimation and 235 effective mAs; a low-dose MDCT with increased pitch 0.828 (group B); and a low-dose MDCT with increased pitch 0.828 and low-dose auto mA quality factor SD 15 (group C).

Correlations between age and mass or cross-sectional area (as assessed from estimates of transverse and anteroposterior [AP] dimensions in the middle of the scan range) were poor (correlation coefficient, $R = -0.06$ and 0.04 , respectively).⁵ The cross-sectional area and mass appeared more reasonably correlated (correlation coefficient, $R = 0.78$).⁵ Transverse and AP dimensions in the middle of the scan range from the CT images, age, and sex were recorded.

Computed Tomography Examinations

All of the patients were examined in the supine position without contrast material. Frontal and lateral scout images preceded the helical acquisition, which reached from the foramen magnum to the inferior edge of the first thoracic vertebral body.

Overlapping 0.5-mm-thick image sections (0.3-mm recon increment, 0.2-mm overlap) were reconstructed from the raw data with a bone filter algorithm. From these MDCT data, 3-mm sagittal and coronal images were generated.

According to the UK national dose survey, the mean pitch

for cervical spine MDCT is 0.8.⁵ There were four auto mA quality factor options available with our MDCT scanner for adult cervical spine examinations, namely 'High Quality-SD 7.5', 'Quality-SD 10', 'Standard-SD 12.5', and "Low Dose-SD 15". The main purposes for cervical spine MDCT examinations include looking for fractures, haematomas, and traumatic disc ruptures. According to the manufacturer recommendation, because the neck is a small part of the body, the High Quality-SD 7.5 auto mA option is unnecessary to achieve adequate image quality for cervical spine evaluation. Taking the above into consideration, low-dose MDCT examinations were performed with increased pitch (from 0.641 to 0.828) and with two different auto mA quality factors (Quality-SD 10 or Low Dose-SD 15), other scan parameters being unchanged as in the standard dose protocol. The changes had been discussed and a consensus reached among the expert panel in the Working Group on Radiation Safety in our institution. The issue of confidentiality (as this study involved retrospective review of clinical data and radiological images) was the major ethical issue and would be solved by recording the data in a manner that did not allow the participants to be identified. The Hong Kong East Cluster Research Ethics Committee approved the study.

The $CTDI_{vol}$ per sequence and the DLP of the helical scan were displayed at the end of the examination and were recorded in our study. Helical CT scan time and scan length were also recorded.

Evaluation of Image Quality

Determination of image quality was based on the evaluation of image noise, SNR, and CNR in bone algorithm images (predominantly used for fracture detection), using a Picture Archiving and Communication System (PACS, Carestream, New York, United States) [Figure 1]. This was done by the same radiologist in all examinations.

Image noise was defined by measurements of the pixel value SD in CT numbers in Hounsfield units (HU) from a standard 2-cm diameter (3.14 cm^2) circular region of interest, placed in air outside the body.⁶

Region of interests (1 cm diameter) were also placed in bone (middle of the vertebral body) and soft tissue (sternocleidomastoid muscle)³ [Figure 2]. The SNR was calculated for bone and soft tissue. The SNR for bone was defined as signal in bone (HU) divided by the image noise. The SNR for soft tissue was defined as signal in

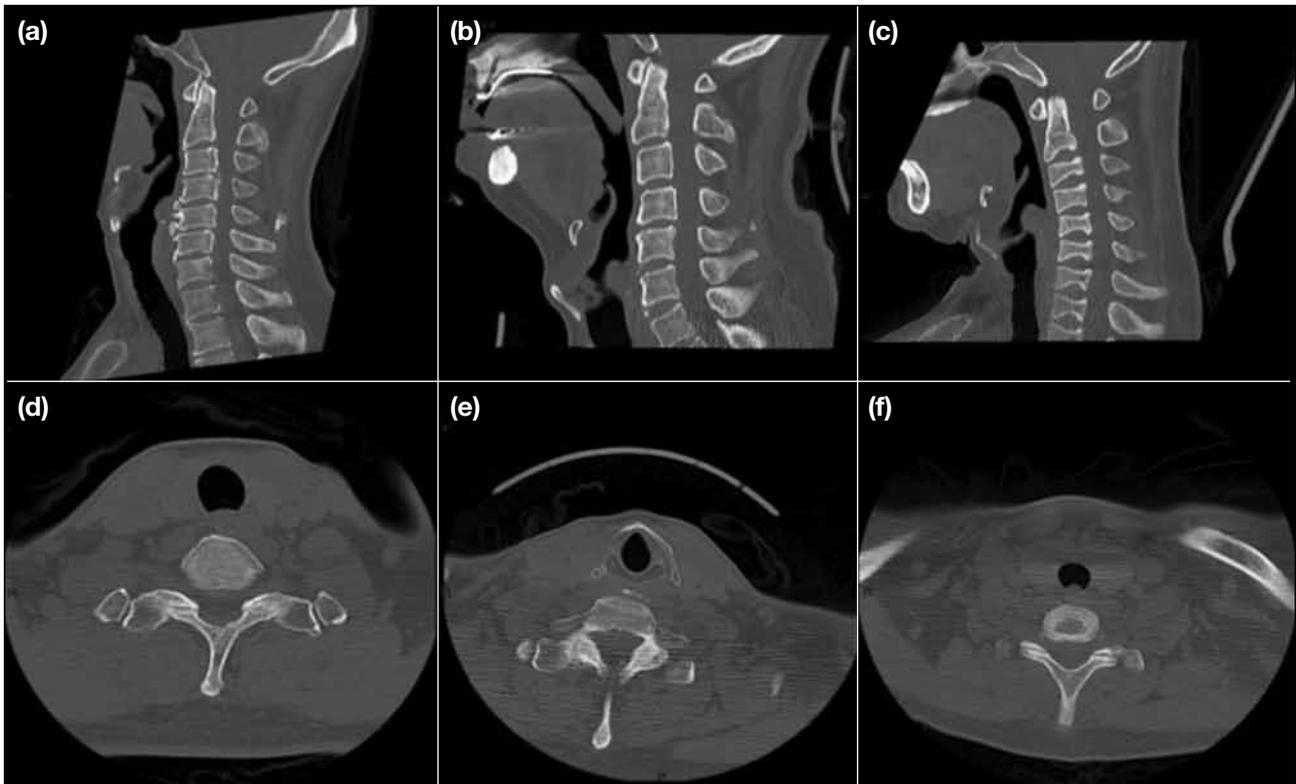


Figure 1. Multidetector computed tomography (MDCT) images of patients with cervical spine trauma. (a to c) Sagittal reformatted cervical spine MDCT images and (d to f) axial CT images at the C7 level. Images a and d were from group A (standard dose examination: pitch, 0.641; auto mA quality factor standard deviation [SD] = 10). Images b and e are from group B (low-dose examination: pitch, 0.828; auto mA quality factor SD = 10). Images C and f are from group C (low-dose examination: pitch, 0.828; auto mA quality factor SD = 15). There is a mild increase in image noise in low-dose images. The CTDIs_{vol} were 83 mGy for group A, 79 mGy for group B, and 38 mGy for group C. The DLPs were 1039 mGycm for group A, 609 mGycm for group B, and 492 mGycm for group C.

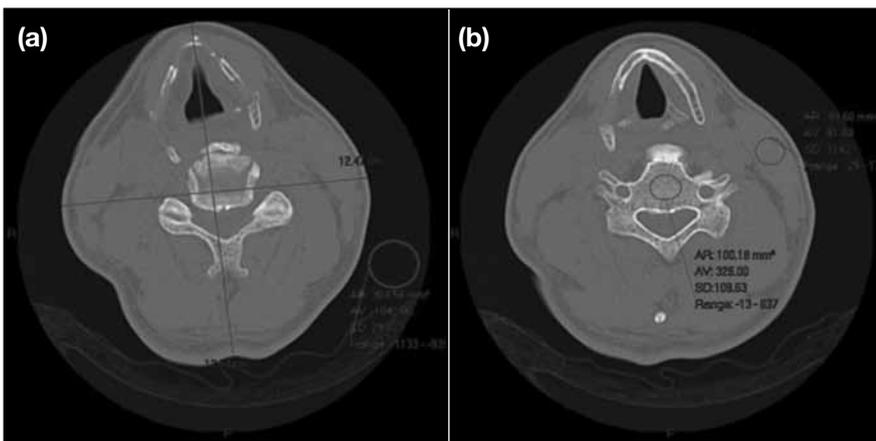


Figure 2. Multidetector computed tomography (MDCT) images of a patient with cervical spine trauma. (a) Measurement of anteroposterior (13.6 cm) and transverse (12.5 cm) dimension in the midrange of an axial cervical spine MDCT scan. Image noise was defined by measurement of the standard deviation of pixels in Hounsfield units (HU) from a standard 2-cm diameter circular region of interest (ROI) placed in air outside the body. It was 29.0 HU in this example. (b) ROIs (1 cm diameter) were also placed in bone (middle of the vertebral body) and soft tissue (sternocleidomastoid muscle). The mean HU was 326 HU for bone and 81 HU for soft tissue in this example.

sternocleidomastoid muscle (HU) divided by the image noise. CNR was defined as the difference between the signal from the bone and the soft tissue divided by the noise: $\text{HU in bone} - \text{HU in soft tissue} / \text{image noise}$.⁶

Subjective evaluation of image quality was performed using a scoring system for image noise,² ranging from 0 to 4 (4 - excellent image quality: absent or very minimal noise; 3 - good image quality: minimal image noise; 2 - moderate image quality: moderate image noise but

not interfering with diagnostic quality; 1 - poor image quality: too much noise which may interfere with diagnostic quality; and 0 - very poor image quality: very much noise, not useful for diagnostic imaging). The readers were blinded to the scan parameters. Two independent radiologists aware of the clinical information were asked to record the presence of fracture, fracture type, and subjective image quality score.

Statistical Analysis

Statistical analysis was performed with SPSS (Windows version 22.0; IBM Corp, Armonk [NY], United States). Comparison of demographic, CT examination variables, CTDI_{vol} and DLP was done with the Chi squared test and analysis of variance (ANOVA) with comparative post-hoc Tukey/Dunnnett tests among the three patient groups.

Objective image quality variables, including image noise, SNR, and CNR were compared with the ANOVA/Kruskal-Wallis test among the three groups. The subjective image quality score was compared with the Chi squared test.

Standard multiple regression was first used to determine the significant predictors of CTDI_{vol} and DLP. Relevant variables found to have significant differences in the above comparison or known to have an association with CTDI_{vol} and DLP were included in the model. Age, sex, scan length, AP, and transverse dimension at mid-range were added into regression model as predictors.

Preliminary analyses were performed to ensure no violation of assumptions. A one-way between-groups analysis of covariance (ANCOVA) was conducted to further explore significant differences in CTDI_{vol} and DLP across the three groups while controlling for possible covariates/confounders. Statistical significance for all tests was set at $p < 0.05$.

Interobserver agreement of the subjective image quality score was measured the using kappa statistic. The K strengths were categorised as follows: <0.20 poor, 0.21-0.40 fair, 0.41-0.60 moderate, 0.61-0.80 good, and 0.81-1.00 very good.

RESULTS

Patients

In total, 54 consecutive patients were included for analysis: from July to August 2016, 18 patients (group A); from March to April 2017, 18 patients (group B); and from April to May 2017, 18 patients (group C).

Radiation Dose Reduction

The mean CTDI_{vol} was 70.7, 48.3, and 32.6 mGy for groups A, B, and C, respectively. The mean DLP was 859.9, 590.1, and 453.9 mGy^{cm} for groups A, B, and C, respectively. These differences in mean CTDI_{vol} and DLP were statistically significant among the three examination groups (ANOVA: $p < 0.001$), with post-hoc comparative tests showing significant differences among all three examination groups. The mean helical CT scan time was 5.9, 4.9, and 4.3 for groups A, B, and C, respectively (ANOVA, $p < 0.001$; Table 1).

Table 1. Comparison of demographic and computed tomography variables across three groups.*

Variables	Total (n = 54)	Group A† (n = 18)	Group B† (n = 18)	Group C† (n = 18)	p Value
Sex					0.195 [‡]
Men	33 (61.1%)	13 (72.2%)	12 (66.7%)	8 (44.4%)	
Women	21 (38.9%)	5 (27.8%)	6 (33.3%)	10 (55.6%)	
	Total (n = 54)	Group A (n = 18)	Group B (n = 18)	Group C (n = 18)	p Value[§]
Age (years)	65.4 ± 20	65.5 ± 19	65.4 ± 21.6	65.4 ± 20.3	1.000
Scan length (mm)	188.8 ± 20.7	194 ± 18.7	187.7 ± 21.7	184.8 ± 21.7	0.405
Anteroposterior dimension at mid-range (mm)	132.6 ± 15.3	140.6 ± 14.1	126.6 ± 15.4	130.6 ± 13.6	0.016
Transverse dimension at mid-range (mm)	114.9 ± 14.1	119.1 ± 12.3	111.6 ± 14.7	113.9 ± 14.8	0.271
Helical computed tomography scan time (sec)	5.0 ± 0.9	5.9 ± 0.5	4.9 ± 0.6	4.3 ± 0.8	<0.001 [¶]
Dose-length product (mGy ^{cm})	634.6 ± 231.7	859.9 ± 159.6	590.1 ± 177.1	453.9 ± 141.7	<0.001 [¶]
CTDI _{vol} (mGy)	50.5 ± 22.4	70.7 ± 11.7	48.3 ± 19.8	32.6 ± 15.8	<0.001 ^{**}

* Data are shown as No. (%) or mean ± standard deviation, unless otherwise specified.

† Group A = Pitch 0.641, auto mA quality factor 10; Group B = Pitch 0.828, auto mA quality factor 10; Group C = Pitch 0.828, auto mA quality factor 15.

‡ Chi squared test.

§ Analysis of variance.

|| Significant difference between Groups A and B (post-hoc Tukey).

¶ Significant difference between Groups A and B; Groups A and C; Groups B and C (post-hoc Tukey).

** Significant difference between Groups A and B; Groups A and C; Groups B and C (post-hoc Dunnnett T3).

The mean $CTDI_{vol}$ and DLP for the low-dose examination (group C) were 53.9% and 47.2% lower than the standard dose examination (group A). The mean DLP was 24.4% below the UK national reference level.

There were no statistically significant differences in age, sex, scan length, or transverse dimension in the middle of the scan range among the three study groups. There was a significant difference in AP dimension in the middle of the scan range between groups A and B (ANOVA, $p = 0.016$).

In the model with $CTDI_{vol}$ as a dependent variable (adjusted $R^2 = 0.21$, $p = 0.005$), only transverse dimension at midrange made a statistically significant contribution to the prediction of the dependent variable (standardised Beta = 0.305, $p = 0.047$). In the model with DLP as dependent variable (adjusted $R^2 = 0.358$, $p < 0.001$), only scan length (standardised Beta = 0.334, $p = 0.004$) and transverse dimension at midrange (standardised Beta = 0.345, $p = 0.013$) were making a statistically significant unique contribution to the prediction of the dependent variable.

A one-way between-groups analysis of covariance was conducted to further explore significant differences in $CTDI_{vol}$ and DLP across three groups while controlling for possible covariates/confounders. Transverse dimension at midrange was used as covariate in analysis of $CTDI_{vol}$. Scan length and transverse dimension at midrange were used as covariates in analysis of DLP.

After adjusting for transverse dimension at midrange, there were significant differences among the three groups in $CTDI_{vol}$ ($p < 0.001$, partial $\eta^2 = 0.522$).

After adjusting for scan length and transverse dimension at midrange, there were significant differences among the three groups on DLP ($p < 0.001$, partial $\eta^2 = 0.571$).

Image Quality Analysis

For objective image quality analysis, the differences in image noise, SNR (for bone and soft tissues) and CNR among the three examination groups were not statistically significant (ANOVA/Kruskal-Wallis test: all $p > 0.05$; Table 2).

Evaluation of subjective image quality by two independent radiologists showed no significant difference in image quality score among the three examination groups (Chi squared test, all $p > 0.05$; Table 2).

The interobserver agreement on subjective image quality was very good ($kappa = 0.841$; Table 2).

Computed Tomography Diagnosis

Forty-two of 54 (77.8%) patients underwent cervical spine MDCT examination due to fall or collapse, followed by 8/54 (14.8%), 3/54 (5.6%) and 1/54 (1.9%) patients due to motor vehicle accident, fall from a height, and hanging, respectively (Table 3).

Of the 54 patients, MDCT showed 12 patients with

Table 2. Comparison of image quality variables across three groups.*

Variables	Total (n = 54)	Group A† (n = 18)	Group B† (n = 18)	Group C† (n = 18)	p Value
Image noise index (Hounsfield units)	36.0 (6.3%)	35.0 (8.5%)	33.5 (18%)	37.5 (5.5%)	0.332 [‡]
Signal-to-noise ratio (bone)	9.9 ± 3.2	10.4 ± 3.2	10.3 ± 3.5	9.0 ± 2.6	0.330 [§]
Signal-to-noise ratio (soft tissue)	2.0 ± 0.5	1.9 ± 0.6	2.0 ± 0.5	1.9 ± 0.5	0.737 [§]
Contrast-to-noise ratio	8.0 ± 2.8	8.4 ± 2.8	8.3 ± 3.1	7.1 ± 2.4	0.342 [§]
Subjective image quality score by radiologist A [¶]					
3 - Good quality	21 (38.9%)	7 (38.9%)	6 (33.3%)	8 (44.4%)	0.938
4 - Excellent quality	33 (61.1%)	11 (61.1%)	12 (66.7%)	10 (55.6%)	
Subjective image quality score by radiologist B [¶]					
3 - Good quality	19 (35.2%)	7 (38.9%)	6 (33.3%)	6 (33.3%)	1.000
4 - Excellent quality	35 (64.8%)	11 (61.1%)	12 (66.7%)	12 (66.7%)	

* Data are shown as No. (%), mean ± standard deviation or median (interquartile range), unless otherwise specified.

† Group A = Pitch 0.641, auto mA quality factor 10; Group B = Pitch 0.828, auto mA quality factor 10; Group C = Pitch 0.828, auto mA quality factor 15.

‡ Kruskal-Wallis test.

§ Analysis of variance.

|| Chi squared test.

¶ Interobserver agreement of subjective image quality score between radiologist A and B: measurement of agreement by Kappa statistic = 0.841.

Table 3. Indications for cervical spine multidetector computed tomography and fracture detection in three examination groups.*

Variable	Total (n = 54)	Group A (n = 18)	Group B (n = 18)	Group C (n = 18)
Indication				
Fall or collapse	42 (77.8%)	14 (77.8%)	14 (77.8%)	14 (77.8%)
Motor vehicle accident	8 (14.8%)	4 (22.2%)	2 (11.1%)	2 (11.1%)
Fall from height	3 (5.6%)		1 (5.6%)	2 (11.1%)
Hanging	1 (1.9%)		1 (5.6%)	
	Total (n = 12)	Group A (n = 4)	Group B (n = 5)	Group C (n = 3)
Fracture levels				
C1	2	1	1	
C2	6	2	3	1
C5-C7	4	1	1	2

* Group A = pitch 0.641, auto mA quality factor 10; Group B = pitch 0.828, auto mA quality factor 10; Group C = pitch 0.828, auto mA quality factor 15.

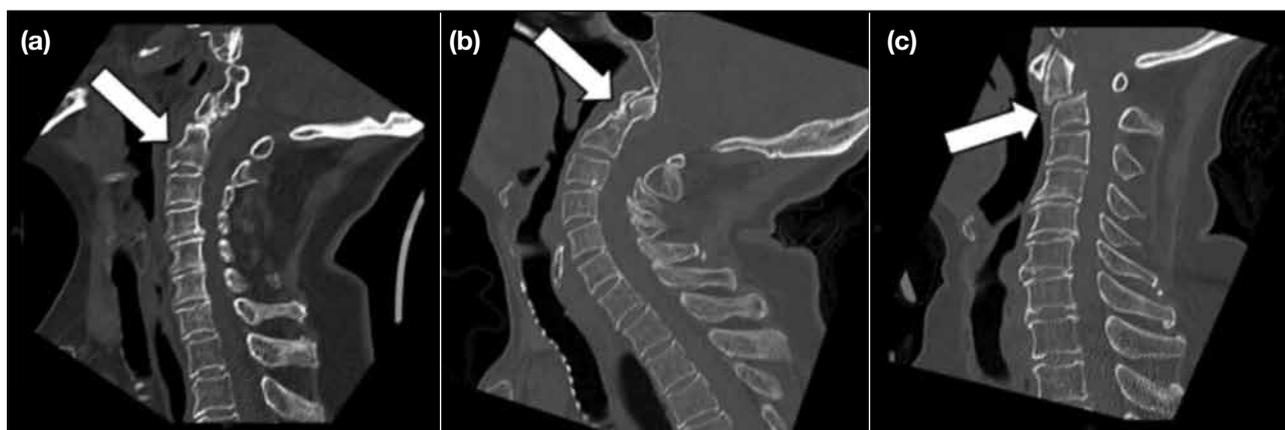


Figure 3. Multidetector computed tomography (MDCT) images of three patients with C2 fractures (arrows). Sagittal reformatted cervical spine MDCT images for (a) a 95-year-old woman from examination group A (standard dose examination: pitch, 0.641; auto mA quality factor standard deviation [SD] = 10), (b) a 93-year-old woman from examination group B (low-dose examination: pitch, 0.828; auto mA quality factor SD = 10), and (c) an 88-year-old woman from examination group C (low-dose examination: pitch, 0.828; auto mA quality factor SD = 15). The respective CTDI_{vol} and dose-length product were: (a) 62 mGy and 790 mGycm; (b) 35 mGy and 516 mGycm; and (c) 29 mGy and 363 mGycm. There is a mild increase in image noise in the low-dose images.

fractures (22.2%): four in the standard-dose examination (group A), five in group B, and three in group C. Of these 12 fractures, most fractures involved C2 (n = 6) [Figure 3]. Both radiologists correctly detected the 12 fractures.

DISCUSSION

Since the introduction of MDCT, there has been an increase in the use of CT for complete examination of the cervical spine in trauma patients. This results in a higher radiation dose in otherwise healthy individuals.⁷ In recent study, a relatively high effective dose of 1 to 5 mSv was reached with cervical spine helical CT,^{2,5} which is approximately 4 to 20 times higher than the dose of a standard radiographic study (0.25-0.30 mSv).⁸ The

nearby thyroid, lens, and breasts are particularly at risk.⁹ For example, the radiation doses to the thyroid were up to 0.84 mGy in cervical spine radiography and 43.9 mGy in cervical spine CT examination. The attributable risks of thyroid cancer of diagnostic radiographs plus CT scans in the UK have been reported as 0.4% for male and 0.8% for female patients.¹⁰

With the use of higher pitch and low-dose auto mA quality factors, we reached a dose reduction of 47.2% to 53.9%, without significant difference in image quality, irrespective of patient size. We avoided lowering tube voltage settings since, as shown in previous studies,^{2,3} it would produce increased image noise in large size patients. A calculated mean effective dose

of approximately 2.5 mSv was achieved, which is approximately 10 times higher compared with the dose from standard radiography.

Automatic exposure control systems for MDCT scanners are available from all major scanner manufacturers. These dose modulation systems operate in a variety of ways, but their main purpose is to adjust radiation dose according to the patient's attenuation and ultimately to reduce the radiation dose to the patient while sustaining diagnostic image quality.

Pitch is defined as ratio of table feed per gantry rotation to nominal beam width. Dose is inversely proportional to pitch. Increasing the pitch decreases the dose, increases the image noise, increases the effective section thickness, and reduces the scanning time, with all other factors remaining constant in MDCT.¹¹

Our study proposed a simple approach for MDCT radiation dose reduction. By increasing the pitch and with the help of the automatic exposure control system, we would be able to adjust the exposure to patients of varying sizes, while keeping the image quality comparable to average-sized patients.

The following limitations in our study have to be acknowledged. First, there was a relatively low number of positive patients: only 12 patients were diagnosed with fracture(s). We did no long-term follow-up of the patients in the present study, so we have no data on possible missed fractures or other injuries in the acute setting with our MDCT protocols. We did not compare the results of the use of MDCT with other imaging techniques, such as standard radiography and/or magnetic resonance imaging. We treated MDCT as the 'gold standard' in our study for the detection of fractures: the use of the CT data as the 'gold standard' may represent a false end point for truly clinically relevant cervical spine injuries. Second, use of a thermoluminescent dosimeter could better reflect effective dose to adjacent organs at risk (thyroid, lens, and breast). It was not applied in the current study due to the possibility of extended examination times and additional manipulation in an acute trauma scenario. Third, this was a retrospective

observational study. Further studies with higher validity are recommended, to determine the optimal protocol that balances radiation dose against diagnostic image quality for the cervical spine and soft tissues.

CONCLUSION

Our proposed low-dose cervical spine MDCT protocol offers radiation dose reduction without compromising the image quality. Further research is recommended to assess the possibility of further radiation dose reduction (eg, by adjusting other scanning parameters) and the consequential effect on diagnostic quality of the cervical spine MDCT.

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