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EMERGENCY RADIOLOGY SPECIAL FEATURE: FULL PAPER

Emergency radiology: straightening of the cervical spine in MDCT after trauma—a sign of injury or normal variant?

^{1,2}ULRICH LINSENMAIER, MD, PhD, ³ZSUSZSANNA DEAK, MD, ⁴AINA KRTAKOVSKA, MD, ⁵FRANCESCO RUSCHI, MD, ³NORA KAMMER, MD, ^{2,3}STEFAN WIRTH, MD, PhD, ³MAXIMILIAN REISER, MD, PhD and ^{2,3}LUCAS GEYER, MD

¹Institute for Diagnostic and Interventional Radiology, HELIOS Clinic München West & München Perlach, Munich, Germany

²Institute for Clinical Radiology, Ludwig-Maximilians-University, Munich, Germany

³Department of Radiology, University of Latvia, Riga, Latvia

⁴Department of Radiology, Azienda Ospedaliero Universitaria Pisana, University of Pisa, Pisa, Italy

⁵European Society of Emergency Radiology (ESER), Vienna, Austria

Address correspondence to: Dr Ulrich Linsenmaier

E-mail: Ulrich.Linsenmaier@helios-kliniken.de

Objective: To evaluate whether straightening of the cervical spine (C-spine) alignment after trauma can be considered a significant multidetector CT (MDCT) finding.

Methods: 160 consecutive patients after C-spine trauma admitted to a Level 1 trauma centre received MDCT according to Canadian Cervical Spine Rule and National Emergency X-Radiography Utilization Study indication rule; subgroups with and without cervical collar immobilization (CCI +/–) were compared with a control group ($n = 20$) of non-traumatized patients. Two independent readers evaluated retrospectively the alignment, determined the absolute rotational angle of the posterior surface of C2 and C7 (ARA C2–7) and grouped the results for lordosis ($< -13^\circ$), straight (-13 to $+6^\circ$) and kyphosis ($> +6^\circ$).

Results: In the two CCI–/CCI+ study groups, the straight or kyphotic alignment significantly ($p = 0.001$)

predominated over lordosis. The number of patients with straight C-spine alignment was higher in the CCI+ group (CCI+ 69% vs CCI– 49%, $p = 0.05$). A comparison of the CCI+ group vs the CCI– group revealed a slightly smaller number of kyphotic (10% vs 18%, $p = 0.34$) and lordotic (21% vs 33%, $p = 0.33$) alignments. Statistically, however, the differences were of no significance. The control group revealed no significant differences.

Conclusion: Straightening of the C-spine alone is not a definitive sign of injury but is a biomechanical variation due to CCI and neck positioning during MDCT or active patient control.

Advances in knowledge: Straightening of the C-spine alignment in MDCT alone is not a definitive sign of injury. Straightening of the C-spine alignment is related to neck positioning and active patient control. CCI has a straightening effect on the cervical alignment.

INTRODUCTION

Approximately 2–3% of all trauma patients in emergency departments suffer from cervical spine (C-spine) injury.¹ The incidence of C-spine injuries in association with brain injuries among adult trauma patients ranges from 1.7% to 8% and is actually $< 1\%$ among neurologically intact and alert patients, leading to a large number of normal imaging studies.^{1–3}

The overall sensitivity of conventional radiography (CR) for detecting C-spine injuries is only 39–52% compared with a sensitivity of 90–98% for multidetector CT (MDCT) reported in recent publications, the latter being by far superior to CR. Today, it is a clinically well-evaluated and evidence-based fact that MDCT is superior to CR regarding detection of C-spine injuries.^{4–7}

MDCT is becoming increasingly important for C-spine trauma imaging for adults. Having been accepted as the imaging modality of choice for cases of multiple trauma for more than a decade, MDCT is now also the preferred imaging modality for single-trauma cases among adult patients.^{8–10} The American College of Radiology (ACR), too, recently stated in its appropriateness criteria that MDCT is the imaging modality of choice for adult single C-spine trauma. While the diagnostic benefit of MDCT is undoubted, concerns have been raised about the increasing use of MDCT and the resulting increase in radiation exposure to patients compared with prior CR.^{11–14}

Following today's established clinical indication guidelines such as the National Emergency X-Radiography Utilization Study (NEXUS) and Canadian Cervical Spine Rule (CCR),

Table 1. Study group, patient demographics: age, gender and incidence of degenerative spine disease

Patient demographics	With CCI	Without CCI
Mean age (years) irrespective of gender (SD)	34.0 ± 1 (9.5)	33.6 ± 4 (10.6)
Gender (<i>n</i> , %)	M (49, 61); F (31, 39)	M (57, 71); F (23, 29)
Gender/age correlation (years) (sex <i>vs</i> correlating mean age)	F (32.4); M (34.3)	F (34.1); M (33.2)
Signs of initial degenerative spine disease (%) ^a	30	34
Mean age (years) for patients with initial degenerative spine disease (SD)	42.9 (6.1)	43.5 (7.6)

CCI, corvical collar immobilization; F, female; M, male; SD, standard deviation.

^aDefined as mild narrowing of disc spaces, initial subchondral osseous sclerosis.

which are based on comprehensive prospective multicentre studies; CR imaging can be used instead of CT only for neurologically intact and alert patients, who are considered low risk. Other patients, even single-trauma cases among adults, should be treated as high-risk patients and regularly undergo MDCT.^{5,15,16}

Recently, low-dose MDCT protocols were developed and promoted for the use in C-spine imaging, leading to a rapid decrease of the use of CR for C-spine trauma patients in many emergency departments.⁶

Loss of lordosis and straightening are often considered to be signs of muscular strain of the C-spine and have served as an indirect sign of cervical trauma or distortion in CR imaging for a long time.^{7,17} However, it remains unclear whether or to what extent C-spine straightening can be observed in MDCT, and what impact cervical collar immobilization (CCI) can have on the straightening, which is obligatory for patients with assumed C-spine trauma.^{7,18–21}

Most studies addressing this issue have focused on lordosis measurements using CR imaging for patients without a history of head/neck trauma. For the purpose of these studies, however, imaging was performed in the upright position and mostly without CCI.^{18,22,23}

The emerging role of MDCT in C-spine evaluation raised the question as to what extent changes in C-spine alignment may be considered normal for immobilized and non-immobilized patients after trauma. A thorough survey of the literature on this topic revealed controversial opinions on the significance of a “normal” cervical curve in lateral CR radiographs.^{7,17–21}

In addition, different methods can be used to measure cervical lordosis, although the four-line Cobb method at C2–C7 and the Harrison posterior tangent method (PTM Harrison) are widely acknowledged to be the most reliable.^{7,17,19} The standard error of measurement (SEM) for the PTM Harrison is lower than for the Cobb method and was therefore used in this study.

To our knowledge, no study has been performed to date to investigate changes in the C-spine alignment in MDCT imaging of the C-spine after trauma and as to whether CCI significantly influences the values of normal cervical lordosis measurements.

The purpose of this study was:

- (1) to evaluate whether statistically significant differences in the cervical alignment, lordosis, kyphosis or straightening can be observed in adult patients undergoing MDCT after single trauma exposure
- (2) to evaluate whether loss of lordosis or straightening of the C-spine in the supine position alone can be considered a significant MDCT finding when screening for C-spine injuries and
- (3) to evaluate the influence of CCI on the cervical alignment in patients undergoing MDCT after head/neck trauma.

METHODS AND MATERIALS

The study design was retrospective, and a waiver of consent was granted from the institutional review board.

Patients

A consecutive series of 900 patient files with suspected C-spine trauma were initially extracted from the institutional radiology information system. From this pool, 160 continuous MDCT examinations (study group) that met the following criteria were considered for the study:

- (i) need for diagnostic imaging after head and/or neck trauma according to established clinical decision rules—the National Emergency X-Radiography Utilization Study and CCR—which were in use at our Level 1 trauma centre
- (ii) MDCT imaging performed on a 64-row MDCT scanner using a standard C-spine protocol within 1 h after admission
- (iii) patient age: 18–50 years. A cut-off age of 50 years was imposed to exclude age-dependent degenerative changes of the C-spine, which can impair the normal alignment before trauma
- (iv) no obvious signs of injury to the head, neck and spine; exclusion of skull and vertebral fractures as well as intra- and extra-axial haematoma and ligamentous injuries, which can alter the alignment by itself.

The study group was divided into two subgroups: (1) with CCI (*n* = 80) and (2) without CCI (*n* = 80); for more details, see Table 1.

In addition, a control group (*n* = 20) of normal non-traumatized patients was established, aged 18–50 years, that underwent head/neck MDCT for oncologic imaging. For this

Figure 1. Measurements of cervical spine alignment using absolute rotational angle of the posterior surface of C2 and C7 (ARA C2–7) criteria for patients with cervical collar immobilization in place. ARAs were calculated as the angle of intersection of the posterior tangents on the C2 and C7 vertebral bodies.

control group, the same exclusion criteria were applied, if applicable, as for the study group.

CT imaging

MDCT was performed on two 64-row scanners (VCT64 and HD750; GE, Milwaukee, WI) using a standard scanning protocol for patients with a suspected C-spine trauma: 120 kV, native helical scan with z-axis dose modulation (10–250 mA) at a noise index of 25 using the thinnest detector collimation available (64×0.625 mm). Axial reconstructions were calculated with a slice thickness of 1.25 mm and a high-resolution bone kernel, 2.5 mm and a soft-tissue kernel, and 0.65 mm for multiplanar reconstructions, applying slice thickness of 2 mm in the coronal and sagittal orientations.

Image evaluation

Two experienced, board-certified (7 and 12 years in radiology), independent, blinded readers evaluated all 160 data sets and performed all angle measurements on sagittal multiplanar reconstruction images. The SEM for the PTM Harrison ($1^\circ < \text{SEM} < 2^\circ$) is lower than the reported values for the Cobb method ($3^\circ < \text{SEM} < 10^\circ$), and it is considered to be both more reliable and reproducible.^{7,24} Therefore, in the present study PTM Harrison was used to evaluate changes in the C-spine curve.

The absolute rotational angle of the posterior surface of C2 and C7 (ARA C2–7) (Figure 1) was drawn from the angle (in degrees) between the posterior surface lines of the vertebral bodies of C2 and C7, representing the cervical alignment. Based on the ARA value, patients were classified as lordotic, kyphotic or straight. The relative rotational angle (RRA) was determined by measurements of the posterior surface of neighbouring segments and were significant at $> \pm 4^\circ$.¹⁹

As no definite C-spine curve angles and cut-off values have been reported in literature so far for patients in the supine position undergoing MDCT with or without CCI, values for ARA C2–7 were adapted from literature data for patients undergoing upright CR imaging.^{7,17,19,24,25}

Based on prior published data, the following cut-off angle/alignment values were defined to group the patients as follows: lordosis $< -13^\circ$; straight -13° to $+6^\circ$; kyphosis $> +6^\circ$.

All measurements were performed on standard picture archiving and communication system workstations (AGFA Impax™; Agfa Healthcare, Köln, Germany) using the manufacturer's software for angle measurements. ARAs C2–7 were obtained, and maximum and minimum values were calculated for all groups. Interobserver reliability and discrepancies in angle measurements between patient groups as well as patient sex, age and signs of

Table 2. Control group: absolute rotational angle (ARA) C2–7 values ($^\circ$)

ARA C2–7 in control group ($n = 20$)	Lordosis	Kyphosis	Straight
% (n)	35 (7)	5 (1)	60 (12)
Average	−22.00	14	−5.75
SD	6.39	0	5.01
Min.	−34	14	−13
Max.	−15	14	2

max., maximum; min., minimum; SD, standard deviation.

Figure 2. Control group: distribution of cervical spine alignment types in a group of patients without head/neck trauma and undergoing oncologic imaging.

initial degenerative spine disease were analysed and compared across all groups. Possible discrepancies between the readers were resolved by consensus decision.

Student's *t*-test was used to determine the statistical significance of angle values between the two groups and for each subtype of cervical alignment (IBM Corp., New York, NY; formerly SPSS® Inc., Chicago, IL). Values were expressed as mean $\pm$ standard deviation (SD) in degrees. A *p*-value ≤ 0.05 was considered to be statistically significant.

RESULTS

Concerning interobserver variability, none of the recorded differences between angle values observed by the two independent readers proved to be statistically significant ($p \geq 0.05$). Therefore no consensus decisions were necessary.

Control group

The control group ($n = 20$), *i.e.* patients without history of trauma who underwent oncologic imaging studies, had a mean age of 33 years (SD ± 6.53) and was analysed in accordance with the criteria for the study group and evaluated against normal values known from upright CR imaging (normal upright-CR ARA C2–7) which had been obtained from literature data. Patient demographics, age and incidence of degenerative spine disease did not differ from the study group.

In this group, 35% ($n = 6$) of the patients revealed a lordotic alignment (mean 22.00; SD 6.39°), 60% of the patients ($n = 12$) revealed a straight C-spine alignment (mean 5.75; SD 5.01°), and one patient (5%) had a kyphotic alignment (+14°). The difference between lordotic and non-lordotic alignments was statistically significant ($p < 0.05$). If straight and kyphotic alignments are pooled, there were no statistical differences (65% *vs* 67%) to the study group without CCI. Three patients from the control group underwent MDCT of the C-spine repeatedly (in 2- to 3-month intervals), and there were obvious deviations in the C-spine alignment between individual

examinations. The detailed results for the control group are shown in Table 2 and Figure 2.

Study group

There were no significant differences in age between both patient groups with and without CCI (CCI+ and CCI–). However, in both groups, male patients (61% and 71%) tended to be more involved in traumatic accidents (Table 1).

Among patients with and without CCI, non-lordotic C-spine curves, either straight or kyphotic, statistically significantly ($p = 0.001$) predominated over lordotic alignment.

In the group with CCI (CCI+), 69% ($n = 55$) of the patients revealed a straight alignment, 10% ($n = 8$) had a kyphotic alignment and 21% ($n = 17$) showed a lordotic alignment. In the group without CCI (CCI–), 49% ($n = 39$) had a straight alignment, 18% ($n = 14$) a kyphotic alignment and 33% ($n = 27$) a lordotic alignment (Figure 4).

A comparison of the patient groups with CCI (CCI+) and without CCI (CCI–) showed a slightly lower number of patients with either kyphotic (10% *vs* 18%, $p = 0.34$) or lordotic (21% *vs*

Table 3. Study group: absolute rotational angle (ARA) C2–7 values (°), split into cervical spine alignment groups (lordosis, kyphosis and straight) according to defined angle values

Alignment groups	ARA C2–7 (mean, SD)		<i>p</i> -value
	With CCI	Without CCI	
Lordosis			$p > 0.05$
%	21	33	
Average	–23.72	–26.14	
SD	6.47	7.56	
Min.	–40	–42	
Max.	–15	–17	
Kyphosis			$p > 0.05$
%	10	18	
Average	+10.86	+11.76	
SD	4.02	5.16	
Min.	8	7	
Max.	20	21	
Straight			$p < 0.05$
%	69	49	
Average	–4.25	–2.95	
SD	5.54	5.00	
Min.	–13	–12	
Max.	7	6	

CCI, cervical collar immobilization; max., maximum; min., minimum; SD, standard deviation.

33%, $p = 0.33$) alignment, but these differences were not statistically significant. In the group with CCI (CCI+), there was a significantly higher number of patients with a straight C-spine alignment (69% vs 49%, $p = 0.05$). The differences of distribution of C-spine alignment among supine patients with and without CCI can be seen in Table 3.

The ARA measurements for the patient groups with and without CCI showed predominantly straight alignments (69%) (ARA -13 to $+6^\circ$) vs lordosis (21%) and kyphosis (10%). The RRA measurements for the patient groups with CCI (CCI+) showed segmental kyphosis in 17 (21%) individuals: 58% ($n = 10$) of them at the C5/6 level (mean $+8.81$, SD 3.22°), 29% ($n = 5$) of them at the C4/5 level (mean $+7.83$, SD 2.93°) and 12% ($n = 2$) of them at the C2–C4 level (mean $+6.00$, SD 2.00°) (Figure 4).

The RRA measurements for the patient group without CCI (CCI–) revealed segmental kyphosis in 15 (19%) patients: 33% ($n = 5$) of them at the C5/6 level (mean $+5.80$, SD 1.3), 18% ($n = 3$) of them at the C4/5 level (mean $+6.60$, SD 1.52), 26% ($n = 4$) of them at the C3/4 level (mean $+6.50$, SD 1.91) and 13% ($n = 2$) of them at the C2/3 level (mean $+5.00$, SD 1.00).

The resulting average ARA C2–7 values for both patient groups are represented in Table 3.

From these results, it can be concluded that segmental kyphosis in the group generally considered “straight” appeared mostly at segment C4–6, however, without a statistically significant difference between both patient groups. There is no difference in the segmental kyphotic frequency between the two groups based on RRA measurements.

DISCUSSION

There are no published scientific data to date based on supine MDCT C-spine alignment measurements among trauma patients with or without CCI. Therefore, the data drawn from this study could not be compared with other authors using MDCT, and a comparison with other studies based on upright CR imaging is methodically difficult and limited in this context.

Figure 4. Study group: distribution of the cervical spine alignment among supine patients with and without cervical collar immobilization.

As the standard of care for the diagnosis of C-spine trauma is shifting from CR to MDCT, a re-evaluation of normal anatomic alignment is needed. We aimed to define the normal anatomic variability in MDCT in a screening population after trauma with and without CCI and in comparison with a non-trauma control group; obvious injuries were initially excluded.

Following the analysis of our non-traumatized control group, we found that even in this group “straight” alignment in supine patients is statistically significantly predominant over lordotic alignment (60% vs 35%, respectively), and even if straight and kyphotic alignments were pooled, there were no statistical differences (control group 65% vs CCI– 67%) to the study group without CCI. Moreover, intraindividual alignment differences were found in the same patient, from different MDCT studies performed as follow-up examinations at two different dates with the same protocol using the same MDCT scanners (Figure 3). The latter is limited as an intraindividual observation. However, it shows that C-spine alignment in MDCT is intraindividually variable, most likely depending on the patient’s position on the CT table, as other factors remained unchanged.

Figure 3. Control group, examples of the cervical spine (C-spine) alignment of the same patient in different examinations. The same patient, with a 2-month interval between two multidetector CT examinations for oncologic reasons, no history of trauma. It is evident that the C-spine alignment has slightly changed from straight (a: ARA C2–7, 4°) to lordotic (b: ARA C2–7, 21°) due to a difference in the positioning of the head.

Figure 5. Extreme angulations of C2/3 and C6/7 producing a pseudolordotic pattern. According to defined absolute rotational angle values, these patients were classified as having a lordotic cervical spine curve, although upon subjective visual assessment, they appear generally straight at C3–C6.

Regarding the results from the study group, we suppose that supine patients' changes in C-spine alignment are common in MDCT and mainly associated with variations in positioning (Figure 4). These changes in alignment should not be considered primarily pathological or trauma related unless other significant traumatic changes are present. The comparison with the control group supports our hypothesis that straightening of the C-spine alignment curve in adult single C-spine trauma patients could be considered a biomechanical variation due to neck and shoulder girdle positioning during MDCT scanning or active patient C-spine control.

Helliwell *et al*²⁰ reported in their cross-sectional study that 42% of their normal patient population—without significant complaints or neck pain or history of trauma—revealed a straight alignment of the C-spine in upright CR, and about 33% of these patients showed a cervical kyphosis, also probably reflecting differences in positioning. They concluded that loss of cervical lordosis is most likely a predictor of muscle spasm caused by pain in the neck.

Other authors, such as Grob *et al*,¹⁹ also could not demonstrate a correlation between cervical alignment changes, straightening or kyphosis and neck pain and muscle spasm.

Marshall *et al*²⁶ reported a correlation of reduced cervical lordosis measurements following motor vehicle accidents, although the differences in lordosis values between analysed groups were not statistically significant.

All studies mentioned, however, were based on upright CR studies only.

In a current publication, Jun *et al*,²⁷ analysed 50 asymptomatic patients with regard to parameters such as T1 slope, Cobb angle at C2–C7 and thoracic inlet angle of the cervical sagittal alignment obtained from cervical MDCT and from CR. They concluded that the T1 slope from CR is significantly correlated with the T1 slope from MDCT, and so it may be used as a guide for the assessment of the sagittal balance of the C-spine in MDCT.

Another group, Beltsios *et al*,²² recently studied the incidence of normal cervical lordosis among 60 and 100 healthy patients

using MDCT and compared their results with the changes in patients with a neck injury, applying CR and MDCT. They observed no significant differences between the trauma and non-trauma groups, and they concluded that the coincidental alterations in normal cervical lordosis may not necessarily be related to the trauma itself.

Rojas *et al*²⁸ examined the normal anatomic relationships of the occipitovertebral articulation in MDCT, finding significantly different values between MDCT and plain CR radiographs and proposing new normal MDCT values for the adult population.

In our study, we could demonstrate that among patients with CCI (CCI+), the number of “straight” C-spine alignment was statistically significantly higher than in the group without CCI, an easily expectable result as CCI is hypothesized to have a straightening impact on the C-spine itself.

In the group without CCI (CCI–), compared with the group with CCI (CCI+), C-spine alignment was more heterogeneous among a reduced number of patients with straight C-spine alignment, and there was a slight increase in kyphotic and lordotic alignments. This supports an earlier stated hypothesis of the stabilizing and therefore straightening effect of CCI on the C-spine.

It was also observed that in both trauma patient groups, straight alignment and segmental kyphosis appeared in 19–21% of the cases, and it was more common at the C5/6 segment. This finding is in agreement with literature data, where the C5/6 segment was proven to be the most mobile segment in the lower C-spine.^{29,30}

In both trauma patient groups, but mainly among patients with CCI+, it was also noted that sharp segmental lordosis was mostly visualized because of negative (lordotic) angulation for the C2/3 or C6/7 segments in otherwise generally straight C-spine alignments (Figure 5). These patients were classified according to defined ARA values as “lordotic”, although upon subjective visual assessment, they could be classified as “straight”. This could also increase the number of “straight” C-spine cases among patients with CCI and the difference in C-spine alignment distribution between both trauma patient groups. We suppose that the straight alignment of the C3–C5 segments in

these patients was due to CCI impact, but the most proximal or distal segments of the C-spine remained partially mobile, probably because the cervical collar was not fastened tightly, hence the angulation result in a generally straightened C-spine.

It can be concluded that non-lordotic, straightened or kyphotic C-spine alignment in supine adult single-trauma

patients with or without CCI undergoing screening MDCT is most likely based on a normal biomechanical reaction of the C-spine to position changes, active patient control or due to the immobilization device itself. Therefore “straightening” of the C-spine alone should not be considered a reliable pathological imaging sign in screening trauma patients undergoing MDCT.

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