Eur Spine J
DOI 10.1007/s00586-013-2854-x

ORIGINAL ARTICLE

Hidden discoligamentous instability in cervical spine injuries: can quantitative motion analysis improve detection?

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Received: 13 May 2012 / Revised: 5 November 2012 / Accepted: 3 June 2013

Abstract

Purpose Recent literature shows that occult discoligamentous injuries still remain difficult to diagnose in the first instance. Thresholds as indicators for discoligamentous segmental instability were previously defined. But, since supine radiodiagnostic is prone to spontaneous reduction of a displaced injury, and even some highly unstable injuries reveal only slight radiographic displacement, these criteria might mislead in the traumatized patient. A highly accurate radiographic instrument to assess segmental motion is the computer-assisted quantitative motion analysis (QMA). The aim was to evaluate the applicability of the QMA in the setting of a traumatized patient.

Methods Review of 154 patients with unstable cervical injuries C3–7. Seventeen patients (male/female: 1:5, age: 44.6 years) had history of initially hidden discoligamentous injuries without signs of neurologic impairment. Initial radiographs did not fulfill instability criteria by conventional analysis. Instability was identified by late subluxation/dislocation, persisting/increasing neck pain, and/or scheduled follow-up. For 16 patients plain lateral radiographs were subjected to QMA. QMA data derived were compared with normative data of 140 asymptomatic volunteers from an institutional database.

Results Data analysis of measurements revealed mean spondylolisthesis of −1.0 mm (−3.7 to +3.4 mm), for segmental rotational angle mean angulation of −0.9° (−11.1° to +17.7°). Analysis of these figures indicated positive instability thresholds in 5 patients (31.3 %). Analysis of center of rotation (COR)-shifts was only accomplishable completely in 3/16 patients due to limited motion or inadequacy of radiographs. Two of these patients (12.5 %) showed a suspect shift of the COR.

Conclusions Our data show a high rate of false negative results in cases of hidden discoligamentous injuries by using conventional radiographic analysis as well as QMA in plain lateral radiographs in a trauma setting. Despite the technical possibilities in a modern trauma center, our data and recent literature indicate a thorough clinical and radiographic follow-up of patients with cervical symptoms to avoid secondary complications from missed cervical spine injuries.

Keywords Cervical spine · Hidden discoligamentous injury · Diagnostics · Pathologic intervertebral motion · Instability

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Published online: 13 June 2013

Introduction

In traumatized patients, the late detection of occult unstable injuries of the subaxial cervical spine can have detrimental consequences. The incidence of initially hidden discoligamentous injuries is reported to be <0.7 % [1–3]. Particularly in the absence of an unstable fracture, gross destruction or a frank dislocation, it remains difficult to rule out discoligamentous injury on initial review. An appropriate diagnostic method that can lower the number of occult and misinterpreted injuries in acutely traumatized patients has not yet been defined. Several papers have discussed the potential of dynamic radiographs, CT scans and MRI in ruling out cervical spine injuries. Radiographic plain X-ray evaluations result in a false-negative rate of up to 46 % for cervical spine fractures and subluxation [1, 4, 5]. White and Panjabi [6] formulated the thresholds of a >3.5 mm anterior shear and a >11° angulation on plain supine injury radiographs or flexion–extension films as indicators of segmental instability. Another attempt to detect signs of instability by Schlicke et al. [7] defined pathologic motion on plain sagittal radiographs as a >1.7 mm translation or a change in the intervertebral angular rotation of a >5.7°. However, supine radiographs are prone to the spontaneous reduction of a displaced injury, and, thus, even some highly unstable injuries exhibit only slight signs of instability. Therefore, morphometric criteria can mislead physicians. Previous findings resulted in general acceptance that clearance of the cervical spine can be obtained safely with a CT scan and optionally by MRI [8–10]. An accurate radiographic assessment technique to measure segment motion is the quantitative motion analysis (QMA) method [11]. It has the potential to detect pathological shifts in the center of rotation (COR) as well as minimal shear and angular displacement. With the QMA technology, it is also possible to compute the COR by comparing the lateral images of patients radiographs in flexion and extension or in the neutral position obtained at different time points. In the setting of an acutely traumatized patient, it remains unclear if there is a sufficient angular segmental change (at least ±3°) at the injury level between the radiographic time points or on flexion–extension films to accurately calculate COR.

The authors hypothesized that the COR method might be a sensitive tool for the early detection of segmental instability in a population of patients with an otherwise undetected cervical injury or underestimated degree of instability.

Methods

A retrospective cohort analysis of 154 patients consecutively treated in a period of 10 years for unstable cervical spine injuries indicating surgical intervention with or without signs of osseous injury was conducted. The institutional database was searched for patients with a history of initially undetected unstable discoligamentous injuries. Seventeen patients with a delayed diagnosis and treatment were identified, medical records were reviewed, and demographics and treatment details were recorded. Only cases with complete radiographic data sets were included in the study, resulting in a total of 16 patients who were eligible for study.

In all patients, cervical spine clearance was conducted according to the institutional guidelines, including a clinical examination and a 3-view plain radiographic series (transoral and biplanar cervical spine radiographs). Initial CT scans were conducted for all but two patients whose injuries appeared to be clinically inconspicuous following a minor head trauma. In six cases an MRI was performed at the index treatment. A CT scan and MRI were performed if warranted based on radiographic evidence, for a non-displaced facet fracture or a discrepancy between the radiographs and the severity of clinical symptoms. None of the patients initially showed signs of neurological impairment. During the clinical course, the late progression of displacement was diagnosed on serial radiographs. Radiographs at the time of the index treatment, serial radiographs during follow-up and CT scans were analyzed to assess spondylolisthesis (mm) and the segmental rotation angle (SRA). Radiographic criteria of instability according to the Panjabi and White [6] definition were negative at the index treatment. Discoligamentous instability was identified by late displacement on serial radiographs during follow-up.

For each patient included in the analysis, two lateral plain radiographs from different time points were selected with the index segment not fulfilling the instability criteria, as measured using an orthopedic goniometer or PACS workstation image viewer for digital radiographs. These image pairs were analyzed using QMA (Medical Metrics, Houston/Texas/USA). All results obtained were compared against the instability criteria of White and Panjabi [6], whether they met those of Schlicke et al. [7], and whether there was any significant deviation compared to the 95 % confidence interval (CI) for intervertebral motion in asymptomatic volunteers [12]. The diagnostic pathway for detecting initially obscured traumatic cervical spine instabilities is displayed in Fig. 1.

Quantitative motion analysis (QMA)

The QMA software digitally quantifies the intervertebral motion from digital radiographs. Measures evaluated included spondylolisthesis, translation, the SRA, and changes in the SRA. Spondylolisthesis was measured as the

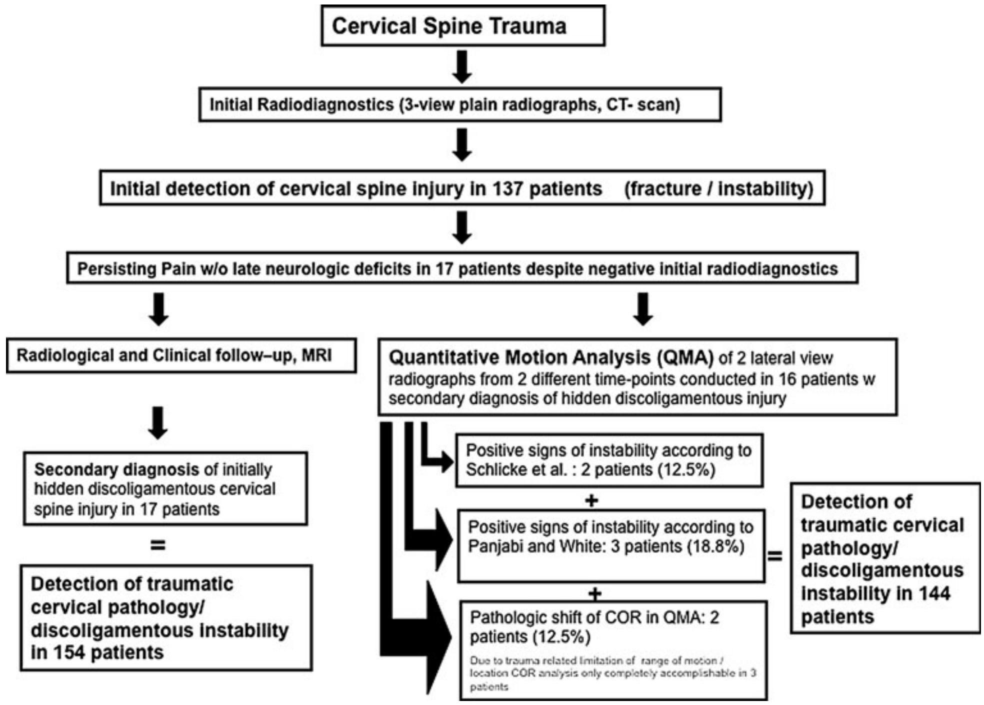

Fig. 1 Diagnosing hidden discoligamentous injuries in the current patient cohort

difference between the posterior-inferior section of the superior vertebra in a direction parallel to the endplate and relative to the posterior-superior section of the inferior vertebra. Translation was defined as the difference between the spondylolisthesis measured between time points. The SRA was defined as the angle between the inferior endplate of the superior vertebra and the superior endplate of the inferior vertebra. The SRA values of two lateral plain X-rays were compared, and changes were calculated. QMA also allows the assessment of the COR defined as the point about which the superior vertebra rotates relative to the inferior vertebra. It is found by locating the intersection of two perpendicular bisectors on lateral radiographs. COR is traditionally measured from radiographs of patients in maximum flexion and extension. This study represents a novel analysis of COR by determining its position using neutral lateral images obtained at two different time points. In an asymptomatic population the COR is located below the disc space and posterior to the midpoint of the disc. It is reported in a reference frame attached to the midpoint of the superior endplate of the inferior vertebra. In this reference frame, the *x*-axis is coincident with the superior endplate of the inferior vertebra and the *y*-axis is perpendicular to the superior endplate of the inferior vertebra. The assessment is visualized in Fig. 2. The COR can be compared with the 95 % confidence limits from a normative reference database of 140 asymptomatic volunteers to determine whether COR is within normal boundaries [12].The QMA software has been validated to be accurate to <0.5° and 0.3 mm on average, with a maximum error of 1.4° and 0.8 mm [11].

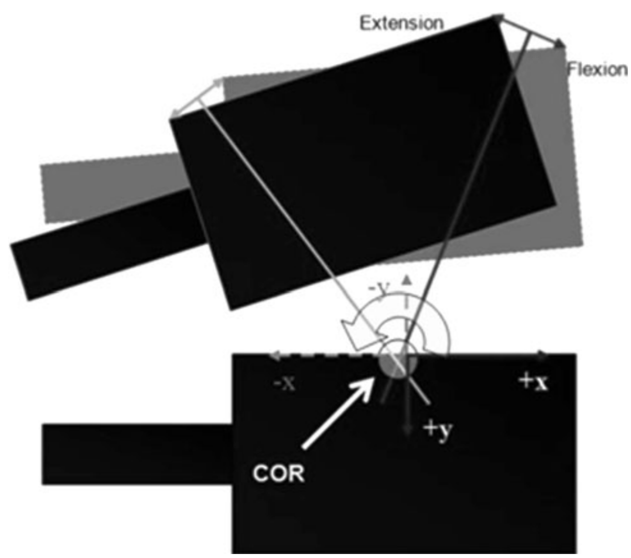

Fig. 2 Calculation of the center of rotation (COR). It is reported in a reference frame attached to the inferior vertebra. (Graph provided by Medical Metrics, Houston, TX, USA)

Results

Sample characteristics

The incidence of initially hidden discoligamentous instabilities among our cohort was 11 % (17/154). The mean patient age at the time of trauma was 44.6 years (range 19–76 years), and the male-to-female ratio was 11:5. After late displacement had occurred, classification of the injury pattern according to the AO classification revealed Type

B1.1.3(10), B1.1.1(4), B1.1.2(1), and B3.1.2(1) injuries. The mechanism of trauma was either a motor vehicle accident or skiing accident in five patients, other sports accidents or a fall from a great height each in two patients, minor trauma in a domestic setting and a hit on the head by a heavy object in each one patient. Fourteen patients did not have accompanying injuries, one was multiple-injured with several fractures of the lower extremities and an L2 compression fracture, and another had an L1 compression fracture. Two patients were obtunded and/or ventilated at the time of presentation. The average time interval from the injury onset to the detection of segmental instability was 29 days (0–301 days). Late surgery was conducted in 13 patients and scheduled in another three.

Radiological results

Index radiographs and CT scans

Radiographs at the index treatment revealed non-displaced cervical spine fractures in five patients, which were regarded as stable in the absence of positive instability criteria according to White and Panjabi [6]. CT scan revealed two Hangman's fractures and one split-fracture of the C7 lamina.

MRI

In six cases with available MRI data from the index treatment, the anterior longitudinal ligament (ALL) was considered intact in two, partially ruptured/avulsed in three and completely ruptured in one patient. The intervertebral discs showed an indefinite heterogeneity in three patients (Fig. 3) and were judged as ruptured in another three by attending radiologists, whereas the posterior longitudinal ligament (PLL) was found to be intact in all patients.

QMA

Sixteen pairs of plain lateral radiographs that were taken at two different time points within the first 48 h after the trauma were subjected to QMA. Computer-assisted quantification of the intervertebral motion was possible in 12

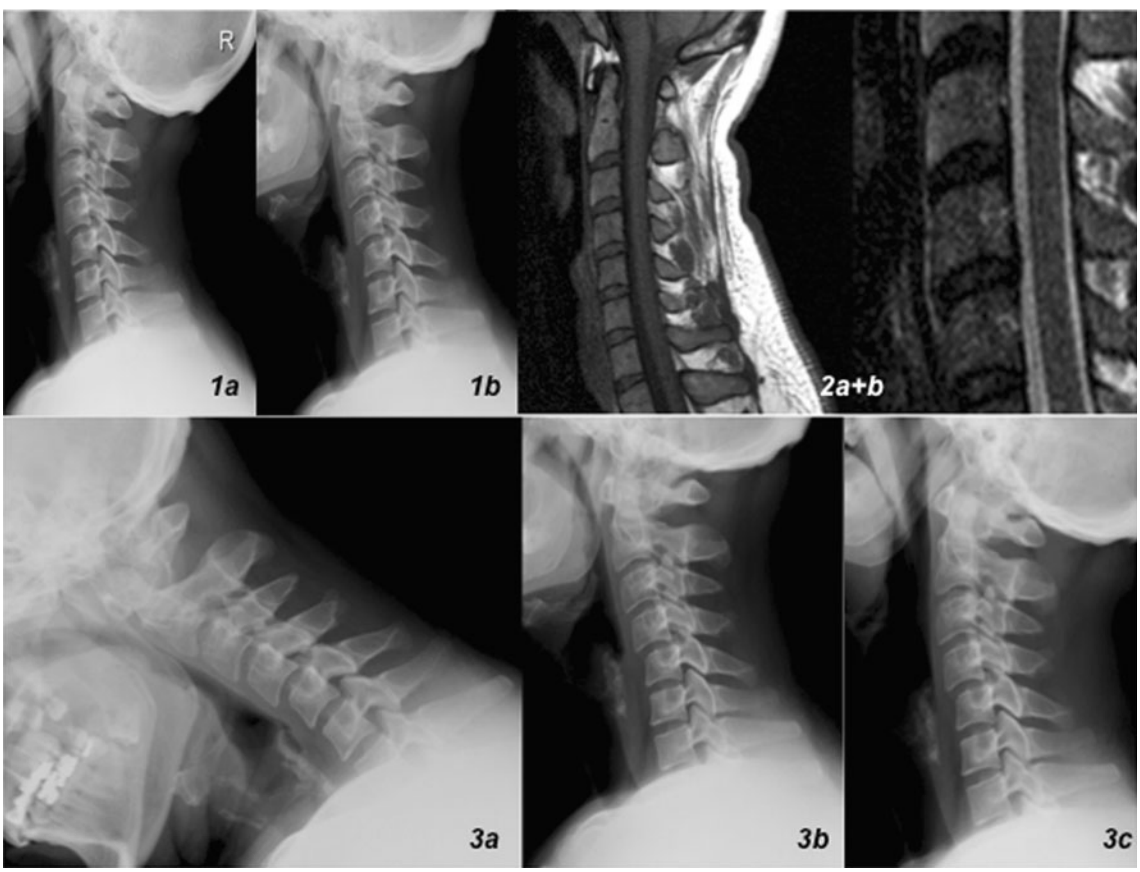

Fig. 3 Illustrative case I: 42-year-old male, Motor vehicle accident, negative instability criteria on initial and short term FU radiographs (1a,b)/MRI (2a,b), Quantitative motion analysis QMA negative regarding instability signs according to White and Panjabi and Schlicke et al. [7], Center of Rotation COR not assessable due to limited motion. At follow-up 8 weeks post trauma, dynamic radiographs (3a–c) conducted for persisting pain symptoms revealed discoligamentous instability at C4–C5

Table 1 Data of intervertebral motion obtained through quantitative motion analysis QMA

Patient ID	Index levels	X-ray	SRA (°)	Listhesis (mm)	Change in SRA (°)	Translation (mm)	Translation (%)
01-KR	C5–C6	1	−9.9	−2.2			
01-KR	C5–C6	2	**−11.1**	−2.3	−1.2	−0.1	−0.6
02-WA	C5–C6	1	−4.0	0.8			
02-WA	C5–C6	2	−3.9	−2.5	−0.1	*3.3*	24.8
03-FP	C6–C7	1	−7.4	−2.4			
03-FP	C6–C7	2	−0.6	−1.8	*6.7*	0.6	3.5
04-RP	C3–C4	1	−8.1	−0.1			
04-RP	C3–C4	2	−10.3	−0.8	−2.2	−0.7	−4.6
05-TA	C4–C5	1	−7.2	−2.5			
05-TA	C4–C5	2	−5.7	−2.2	−1.4	−0.3	−1.9
09-MM	C6–C7	1	8.5	0.5			
09-MM	C6–C7	2	8.6	0.5	−0.1	0.0	0.0
10-MJ	C2–C3	1	5.7	**−3.7**			
10-MJ	C2–C3	2	8.5	−2.8	2.7	0.9	5.6
11-KS	C2–C3	1	4.7	−1.0			
11-KS	C2–C3	2	4.7	−1.0	−0.1	0.0	0.3
13-EF	C6–C7	1	−0.8	−0.8			
13-EF	C6–C7	2	0.1	−0.7	−0.9	−0.2	−0.9
14-NK	C3–C4	1	**15.2**	3.4			
14-NK	C3–C4	2	**17.7**	2.6	−2.5	0.8	7.1
15-TG	C6–C7	1	2.5	−1.7			
15-TG	C6–C7	2	−1.9	−3.3	−4.4	−1.6	−9.7
16-FE	C4–C5	1	2.4	−1.6			
16-FE	C4–C5	2	−3.0	−2.3	−5.5	−0.8	−5.4

Measurements in bold indicate positive instability signs according to the White and Panjabi criteria [6]; in italics are positive according to Schlicke et al. [7]

SRA segmental rotational angle

cases (75 %). Evaluation of the COR was not possible in 13 patients (81.3 %). In one patient (6.3 %), the index injury level was out of range of measure at C7–T1. In three patients (18.8 %) with instability at C6–7 the image contrast in at least one radiograph at the inferior segment was insufficient for digital analysis or the angular segmental change between the two radiographs was lower than the minimum requirement of ±3° required for accurate COR measurements in nine patients (56.2 %).

Based on initial and follow-up radiographs, spondylolisthesis was −1.2 ± 1.7 mm (range −3.7 to 3.4 mm). SRA averaged 0.2° ± 8° (range −11.1° to 17.7°). Mean translation was 0.2 ± 1.2 mm (range −1.6 to 3.3 mm) and 1.5 ± 8 % (range −9.7 to 24.8 %). Between the initial and follow-up radiographs, SRA changed by −1.2° ± 3.1° (range −5.5° to 6.7°). COR-X averaged −1.9 ± 3.3 mm (range −6.5 to 1.4 mm) and −11.1 ± 20.6 % (range −39.3 to 9.6 %). The COR-Y was 7.6 ± 7.6 mm (range 1.1–18.3 mm) and 46.9 ± 45.2 % (range 6.5–110.1 %). The findings are summarized in Table 1.

The QMA indicated positive instability thresholds according to Panjabi and White [6] in three patients (18.8 %). In one patient the morphometric threshold for spondylolisthesis was positive on the first radiograph (−3.7 mm). A pathologic SRA was found in two patients. Whereas it was revealed on both radiographs in one patient (13.7°/16.2°), in the other only the follow-up radiograph showed an abnormal SRA (−10°/− 11.2°). When applying the definition of a pathologic segmental displacement motion by Schlicke [7], a pathological SRA change (>6.7°) was found in one patient (6.3 %) and the threshold for a pathological translation (>3.3 mm) was met in another patient (6.3 %).

COR was able to be measured using QMA in three patients. In one patient (6.3 %) shifts of COR-X (−0.6 mm/− 3.7 %) and COR-Y (1.1 mm/6.5 %) was within normal bounds (Fig. 4). Another patient (6.3 %) showed an abnormal position of COR-X (1.4 mm/9.6 %) but not COR-Y (3.5 mm/24.2 %) while the third patient revealed a significantly abnormal COR-X (−6.5 mm/

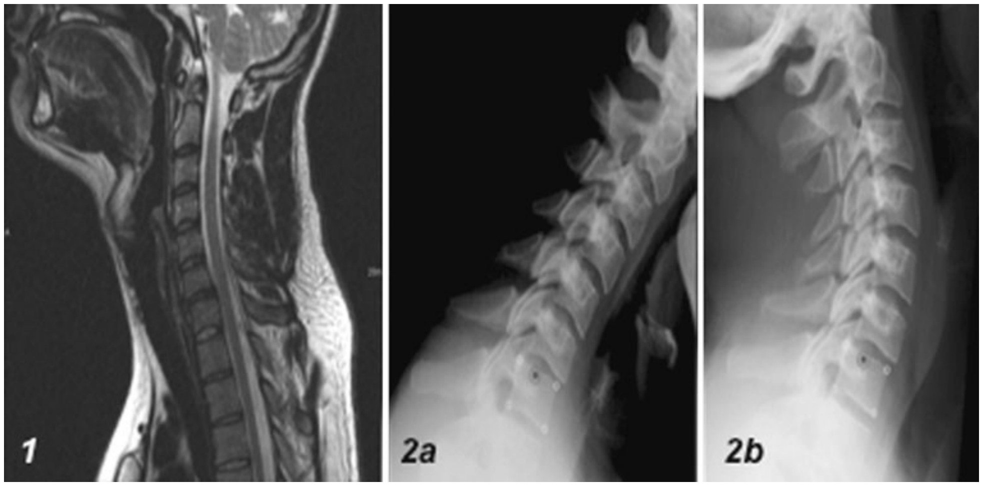

Fig. 4 Illustrative case II: 24-year-old male, skiing accident. Initial dynamic radiographs (2a + 2b) without clear instability signs at C6–C7, initial MRI inconspicuous (1). Quantitative motion analysis QMA with pathologic change of segmental rotational angle of 6.7°, Shift of COR within 95 % confidence intervals of asymptomatic population. Secondary diagnosis lead to surgical treatment: anterior longitudinal ligament and disc were found ruptured

Table 2 Analysis of pathologic center of rotation (COR) shifts was accomplishable in 3/16 patients

Patient ID	Index levels	COR-X (mm)	COR-Y (mm)	COR-X (%)	COR-X (%) asymptomatic	COR-Y (%)	COR-Y (%) asymptomatic
03-FP	C6–C7	−0.6	1.1	−3.7	−7.9	6.5	8.9
15-TG	C6–C7	−6.5	18.3	**−39.3**	−7.9	**110.1**	8.9
16-FE	C4–C5	1.4	3.5	**9.6**	−7.4	24.2	35

Measurements in bold indicate positive instability signs compared to the normative data of an asymptomatic population

39.3 %) and COR-Y (18.3 mm/110.1 %). Notably, in these three cases the thresholds for a pathological translation and SRA comparing serial static X-rays were not met, ranging from −1.6 to 0.6 mm and −7.4° to 2.5°, respectively. Results for the position of the COR and 95 % CI for asymptomatic volunteers serving as controls are listed in Table 2. In total, two cases of abnormal intervertebral motion could have been diagnosed earlier using QMA rather than later in the clinical course, during which instability was detected in these cases after 3 and 301 days.

Discussion

The purpose of this study was to evaluate the feasibility of using QMA detecting hidden discoligamentous segmental instability in serial radiographs as an additional tool for clearing the cervical spine. Assessment of spondylolisthesis, translation, the SRA, changes in the SRA, and position of the COR through QMA resulted in the detection of seven (43.8 %) unstable traumatic pathologies in our study. Instability was diagnosed by the application of the Panjabi and White [6] criteria in three cases, the application of Schlicke's [7] criteria in two and the assessment of the position of the COR compared to normalcy in another two. Notably, none of the cases was unstable by more than one of the three applied morphometric thresholds for instability. Nine unstable discoligamentous cervical spine injuries remained undetected by this thorough investigation of pathological intervertebral motion in the setting of the acute traumatized patient. Most of the missed instabilities were missed due to insufficient angular changes in the index segment and poor contrast at C7. Furthermore, the ability of QMA to detect abnormal intervertebral motion in the cervical spine was limited to segmental changes from C2–3 to C6–7. Review of the data showed that of the seven patients with pathologic intervertebral motion detected with QMA, the interval from injury to detection of the discoligamentous instability would have been significantly reduced using QMA in two patients only, in which instability was detected only after 3 and 301 days. In the other five cases, the standard clinical protocol for clearing the cervical spine revealed segmental discoligamentous injuries within the first 48 h after the initial diagnostics. QMA would not have provided information leading to an earlier diagnosis or an alteration in the treatment in these cases.

Analysis of our study cohort revealed initially undetected cervical injury in 11 % (17/154) of cases. In comparison, the rate of hidden discoligamentous instability was reported to <0.7 % [1–3]. Although previous reports [8] have questioned the existence of unstable, purely ligamentous lesions in the absence of a neurological deficit, fracture or bony malalignment, our analysis of 17 patients with initially occult traumatic instability showed that 12 patients, 8 % of the overall cohort, did not display any objective signs of fracture or acute segmental instability at the index treatment.

In the current study, the authors reviewed the intraoperative discoligamentous status and MRI findings in those patients for whom data were available. It showed that several patients with an intact or avulsed ALL had a ruptured disc and posterior element incompetency revealing a grossly mobile segment during anterior surgery even though radiographs revealed only moderate angulation or shear. Due to the limited number of MRI conducted, a further statistical analysis was not performed. The results echoed those of a previous study comparing the discoligamentous status at C2–3 assessed intraoperatively to the preoperative morphometric degree of displacement in 34 discoligamentous unstable Hangman's fractures, which did not reveal any statistically significant correlation between the radiomorphological measurements and the discoligamentous status at C2–3 [13].

Several previous studies suggested that angulation and spondylolisthesis might not be appropriate measures for detecting discoligamentous injuries in cases without gross instability whereas analysis of COR would lead to early detection [14–17]. In a biomechanical study [14] with serial sectioning of the anterior ligamentous structures, less damage to the anterior structures was required to demonstrate a pathological shift of the COR than that required to cause a radiographical abnormality in the SRA or spondylolisthesis. However, even with the calculation of the COR after the complete sectioning of the anterior discoligamentous structures and uncovertebral joints, 30 % of injuries were not detected as pathological. These findings concur with those of Brown [17], who used a cadaveric model in which a pathological rotational sagittal plane motion was detected only after eliciting massive destruction of posterior elements. Brown [17] and Subramanian [14] support that in cases with abnormal findings based on QMA, substantial damage to the ligamentous restraints is highly likely. Authors from both studies concluded that individual pre-trauma motion characteristics compared to that after injury would provide more reliable data regarding significant changes of intervertebral motion than a sample with individual posttraumatic data compared to normalcy. Since pre-existing degenerative changes lead to an abnormal baseline COR, this effect might also have influenced the current findings.

Cadaveric experiments cannot represent the effects of muscle activity or pain guarding, which might limit the cervical range of motion (ROM) in clinical studies and thereby confound the radiographic assessment of stabilizing structures. QMA requires sufficient angular change between radiographs to obtain accurate measurements. Severe pain or muscle spasms can limit neck movement and the reliability of radiographic examination. Widder [18] reported a high rate of inadequacy for initial plain radiographs, which frequently leads to false-negative traumatic instability diagnoses. This also applies to the collection of dynamic cervical spine radiographs in flexion–extension where for which the threshold cervical ROM necessary to detect pathological motion was defined at >60° [15]. However, a study by Wang [19], 34 % of flexion–extension radiographs with inadequate ROM precluded the assessment of cervical stability, and signs of instability were found in only 1/290 patients (0.3 %).

Adequate protocols for clearing the cervical spine in traumatized patients are frequently discussed especially in the hard to diagnose entity of unstable discoligamentous injuries. Clearing the cervical spine following institutional protocol did not initially detect the severity of instability in 11 % of injuries in the present study. In light of its ability to detect ligamentous and soft tissue lesions and osseous edema, MRI is accepted as the most reliable imaging modality for discoligamentous injuries with a reported negative predictive value of up to 100 % [20–23], thus precluding unstable discoligamentous injuries [20, 21, 24]. The false-negative rate for secondary MRI to detect discoligamentous injuries where the initial CT scan was negative was reported to be up to 25 % [8–10, 24, 25]. Several studies have addressed secondary MRI findings when the initial CT scan did not identify cervical instability [8–10, 26]. A meta-analysis of Schoenfeld [27] including 1,550 patients found injuries in 6 % initially undetected on CT or radiography, but later detected by MRI altering treatment. Recent literature has suggested that MRI may be limited in detecting minor discoligamentous injuries: Brandenstein [28] found a false-negative rate of 0.2 % for unstable cervical spine injuries even though cervical spine clearance was performed by radiographs, CT scan and MRI. Several studies [29–32] correlated MRI findings of patients with discoligamentous injuries with intraoperative findings and found a high false-negative rate of up to 52 %. MRI was also reported to have a high false-positive rate in detecting traumatic discoligamentous cervical instability [33], which might lead to a misinterpretation of findings and inadequate treatment if used as the sole means of diagnosis.

Conclusion

Our study showed a meaningful rate of hidden discoligamentous instability when conventional radiographic analysis was used to rule out cervical instability. Previously defined morphometric thresholds for segmental instability [6, 7] failed to detect segmental instability, even when an accurate technique for the assessment of radiographs (QMA) was used. The study showed that the application of QMA to detect an abnormal position of the COR in patients with cervical trauma was limited. However, the early detection of segmental instability was achieved in several patients using this novel technique. Analysis of serial X-rays using QMA may improve accuracy with stratification of the degree of segmental instability. Future development is needed to improve the ability of QMA to detect the pathological deviation of the COR as a result of discal or ligamentous trauma, which may warrant further cadaveric work or clinical studies.

In perspective of a selective literature review this study stresses that a thorough clinical and radiographic follow-up of patients with cervical symptoms is still indicated to avoid late consequences of missed cervical spine injuries or an underestimated degree of instability.

Acknowledgments The authors thank Nicholas Wharton and Prof. John Hipp of Medical Metrics Inc., Houston, TX, USA for technical assistance and illustration of the COR analysis.

Conflict of interest None.

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