Cervical Spine Magnetic Resonance Imaging in Alert, Neurologically Intact Trauma Patients With Persistent Midline Tenderness and Negative Computed Tomography Results

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Study objective: We aim to determine the prevalence and factors associated with cervical discoligamentous injuries detected on magnetic resonance imaging (MRI) in acute, alert, neurologically intact trauma patients with computed tomography (CT) imaging negative for acute injury and persistent midline cervical spine tenderness. We present the cross-sectional analysis of baseline information collected as a component of a prospective observational study.

Methods: Alert, neurologically intact trauma patients presenting to a Level I trauma center with CT negative for acute injury, who underwent MRI for investigation of persistent midline cervical tenderness, were prospectively recruited. Deidentified images were assessed, and injuries were identified and graded. Outcome measures included the presence and extent of MRI-detected injury of the cervical ligaments, intervertebral discs, spinal cord and associated soft tissues.

Results: There were 178 patients recruited during a 2-year period to January 2009. Of these, 78 patients (44%) had acute cervical injury detected on MRI. There were 48 single-column injuries, 15 two-column injuries, and 5 three-column injuries. Of the remaining 10 patients, 6 had isolated posterior muscle edema, 2 had alar ligamentous edema, 1 had epidural hematoma, and 1 had atlanto-occipital edema. The injuries to 38 patients (21%) were managed clinically; 33 patients were treated in cervical collars for 2 to 12 weeks, and 5 patients (2.8%) underwent operative management, 1 of whom had delayed instability. Ordinal logistic regression revealed that factors associated with a higher number of spinal columns injured included advanced CT-detected cervical spondylosis (odds ratio [OR] 11.6; 95% confidence interval [CI] 3.9 to 34.3), minor isolated thoracolumbar fractures (OR 5.4; 95% CI 1.5 to 19.7), and multidirectional cervical spine forces (OR 2.5; 95% CI 1.2 to 5.2).

Conclusion: In patients with cervical midline tenderness and negative acute CT findings, we found that a subset of patients had MRI-detected cervical discoligamentous injuries and that advanced cervical spine degeneration evident on CT, minor thoracolumbar fracture, and multidirectional cervical spine forces were associated with increased injury extent. However, a larger study is required to validate which variables may reliably predict clinically important injury in such patients, thereby indicating the need for further radiographic assessment. [Ann Emerg Med. 2011;58:521-530.]

Please see page 522 for the Editor’s Capsule Summary of this article.

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Editor’s Capsule Summary

What is known on this topic
Among alert, neurologically intact trauma patients with midline cervical spine tenderness but negative computed tomography (CT) results, some have soft tissue injury on MRI scanning.

What question this study addressed
How frequent are such injuries, and what clinical features predict them?

What this study adds to our knowledge
In this prospective study of 178 patients with midline pain and a CT negative for acute injury, 44% had acute injury on MRI, 33 of 78 of whom were treated with cervical collars and 5 of 78 of whom received operative treatment. Advanced cervical degenerative disease, thoracolumbar fracture, and multidirectional forces predicted greater degree of injury.

How this is relevant to clinical practice
These results cannot yet be applied to the general population of trauma patients, pending further study to confirm the applicability of these findings. Further study may determine which variables are useful in decisionmaking and which injuries are clinically important.

INTRODUCTION

Background and Importance
In many cases, midline cervical tenderness after trauma is absent or resolves quickly, allowing clearance of the cervical spine in the absence of intoxication, altered conscious state, painful distracting injury, persistent focal neurologic deficit, and acutely abnormal cervical computed tomography (CT) findings. However, persistence of midline cervical tenderness on palpation in alert, neurologically intact patients presents a clinical dilemma because it is unclear which patients require further investigation. The presence of fractures alerts clinicians to the possibility of injury to other cervical structures, but the absence of acute, positive CT findings is often erroneously equated with lack of injury. The level of efficiency in identifying occult cervical disc or ligamentous injury in the absence of fracture is uncertain under many cervical spine clearance protocols. Detection of occult cervical spine injuries and the determination of their clinical significance are imperative in the avoidance of missed injuries, the assignment of appropriate management, and the mitigation of long-term morbidity.

In recent years, magnetic resonance imaging (MRI) has emerged as a definitive and highly sensitive tool in the detection of acute cervical discoligamentous injury. However, in the setting of cervical CT findings that are negative for acute injury, MRI is generally indicated in patients with trauma-related neurologic symptoms and signs.

Goals of This Investigation
Our objective was to determine the presence of MRI-detected injury, if any, and the characteristics associated with injury extent in alert, neurologically intact trauma patients with CT findings negative for acute injury. Our scope was not limited to the detection of instability but focused more broadly on the characterization of injury that may also result either in delayed neurologic deficit or long-term pain or disability.

MATERIALS AND METHODS

Study Design and Setting
We report here the cross-sectional analysis of baseline information collected as part of a prospective cohort study conducted at a Level I adult trauma center. The institution is a referral center for metropolitan and regional major trauma patients and has 15,000 trauma presentations per year, of whom 1,500 patients are categorized as having major trauma. Institutional ethics committee approval was obtained and participating patients’ informed consent was obtained in writing.

Selection of Participants
Consecutive, adult, alert trauma patients (Glasgow Coma Scale = 15), presenting to the emergency department (ED) during a 2-year period to January 2009, were prospectively evaluated for inclusion in the study. The real-time electronic ED admissions information system was used to alert the study investigators to potential patients, and the ED medical and nursing staff was involved in the project, assisting by alerting the principal investigator to potential participants by pager or telephone at any hour of the day. The daily CT and MRI booking schedules were also used as a safety net to ensure that all eligible patients had been identified and screened. Those patients with persistent cervical midline tenderness on palpation in the setting of CT findings that were negative for acute injury, and who subsequently underwent MRI studies under the institutional protocol, were included (Figure 1). Patients were initially assessed by a board-certified emergency physician, and referral for spine review occurred when persistence of midline cervical tenderness was evident.

Exclusion criteria comprised:
- fractures of the base of skull or cervical or upper thoracic spine;
- painful distracting injury or evidence of intoxication according to the criteria of the National Emergency X-Radiography Utilization Study (NEXUS); persistent focal neurologic deficit;
- history of cervical spine surgery or injury; and
- MRI conducted greater than 96 hours postpresentation.

Patients with minor, single, stable, nondisplaced, low thoracic or lumbar transverse or spinous process fracture were included, as these injuries were not considered by the treating physician to be...
significantly distracting from the cervical tenderness, and MRI was ordered on the basis of the National Emergency X-Radiography Utilization Study criterion of midline tenderness alone. Also included were patients with transient neurologic deficit, which fully resolved shortly after presentation to the ED and before ordering of the MRI for investigation of midline tenderness.

Methods of Measurement

Admission cervical spine evaluation for all NEXUS-positive patients included 64-slice CT from the skull base to T5 (General Electric LightSpeed VCT; GE Healthcare, Waukesha, WI). The admission trauma CT scanning protocol included helical image acquisition at a 0.625-mm interval, with a pitch of 0.5 mm and a field of view of 20 cm. The images were transferred to the institutional Picture Archiving and Communication System after 2/2-mm axial and sagittal reconstruction on bone algorithm.

For the purposes of the study, the CT images were reviewed by a senior trauma radiologist for evidence of acute injury and cervical spondylosis. Evaluation of intervertebral disc height, vertebral apophyseal osteophytic morphology, spinal canal patency, vertebral body endplate condition, and facet and uncovertebral joint integrity was undertaken in the assessment of the severity of spondylosis. For study purposes, cervical spondylosis was classified as mild (no disc narrowing, osteophytes <2 mm and no significant canal stenosis), moderate (visible disc narrowing, osteophytes >2 mm and visible central or lateral canal stenosis), and severe (complete loss of disc height with or without a vacuum phenomenon, osteophytes >2 mm and significant canal stenosis). Further categorization of cervical spondylosis during statistical analysis included early (mild) degeneration and advanced (moderate and severe) degeneration.

As per the institutional spinal clearance protocol, cervical spine MRI was indicated for persistent midline cervical tenderness on palpation in the absence of cervical fracture or malalignment on CT imaging. MRI scans were performed on a 1.5-T scanner (General Electric Signa Excite; GE Healthcare, Milwaukee, WI), using the institutional trauma MRI scanning protocol: sagittal T1 spin echo sequence: recovery time 440 ms, echo time 9 ms, spacing 4 mm; short TI inversion recovery sequence: recovery time 3,240 ms, echo time 36 ms; T2 fast spin echo fat saturation sequence: recovery time 3,000 ms, echo time 99 ms; and axial T2 images: recovery time 500 ms, echo time 20 ms.

The initial 100 images were reviewed independently by 2 senior trauma radiologists from different institutions (D.K.V. and G.J.F.), who were not blinded to the purpose of the investigation but were blinded to patient identity, history, mechanism of injury, and results of other imaging modalities. The proportions of exact agreement between radiologists for the identification and grading of injuries were calculated. Due to the potential for a low rate of injury and the fact that only exact agreement was measured, the general level of fair agreement according to Altman was accepted.

Once these proportions were established as acceptable, the remaining images were reported in the same fashion by a single senior trauma radiologist. With an imaging reporting pro forma specifically designed for the study, the radiology review included particular attention to the status of the anterior longitudinal ligament, intervertebral discs, posterior longitudinal ligament,
spinal cord, ligamenta flava, and posterior ligamentous complex. Findings were categorized and graded according to presence and severity of acute injury. Additionally, comments were required to be made about the presence and extent of prevertebral and posterior muscle edema; the presence, extent, and maximum thickness of epidural hematoma; and the presence, extent, and severity of cervical spondylosis. Associated findings related to the integrity of minor ligaments and membranes were reported, as were incidental abnormalities. MRI-detected injury was categorized into spinal columns, adapted according to the thoracolumbar spine concept of Denis: the anterior column is formed by the anterior longitudinal ligament, anterior annulus fibrosus, and the anterior component of the vertebral body; the middle column is formed by the posterior vertebral body, posterior annulus fibrosus, and the posterior longitudinal ligament; and the posterior column extends from the ligamenta flava to include the posterior bony and ligamentous complexes.

**Data Collection and Processing**

Data collection included the findings of clinical and radiographic cervical spine assessment, patient medical history, demographic information, accident details, including paramedic evaluation and management, and patient-reported symptoms (Table 1). Given the fact that the patients were alert and recruitment occurred as soon after presentation as practicable, the primary source of information about mechanism of injury and accident details was the patient. Additional information provided by paramedics and witnesses to the accident was also collected. A study-specific standard data collection tool was used, and a single experienced researcher was responsible for data collection. The data collection tool was completed before the MRI, and therefore both the patients and the investigator were blinded to the MRI results at this stage. Specific mechanisms of injury were examined to ascertain the most dominant direction of force to the cervical spine during the trauma, and findings were categorized into flexion, extension, axial loading, lateral bending, and axial rotation. Multidirectional biomechanical forces were noted to have occurred when 2 or more such directions of force were present during the injury mechanism. For patients involved in road trauma, the vehicle crash status was categorized as no impact; collision with nonrigid objects, including other vehicles, animals, and freeway guardrails; and collision with rigid objects, including poles and trees.

**Outcome Measures**

The primary outcome measures included the presence and extent of MRI-detected injury of the cervical ligaments, intervertebral discs, spinal cord, and associated soft tissues. Secondary outcome comprised the association of factors with the extent of injury according to the number of spinal columns injured, as per the three-column theory of Denis.

**Primary Data Analysis**

Summary statistics were generated for patient-related, mechanism-related, radiographic, and clinical factors. The associations of such factors with cervical spine injury according to the number of cervical spine columns injured were determined with an ordinal logistic regression (proportional odds) model that included the covariates age, sex, mechanism of injury, object impacted, direction of initial spine force, quality of midline tenderness, transient neurology, additional injuries sustained, and CT-detected cervical spondylosis. The remaining variables were not included in the model because it was considered a priori that these variables were captured in the included covariates. There were no missing data on variables in the cross-sectional analysis. The associations are presented as odds ratios (ORs) with 95% confidence intervals (CIs) (SPSS WIN, version 17.0; SPSS Inc. [now IBM SPSS], Chicago, IL).

**RESULTS**

**Characteristics of Study Subjects**

There were 9,152 trauma patients who underwent admission cervical spine CT during the 2-year study period to January 2009. Of those patients, 741 had CT findings negative for acute injury and persistent midline cervical tenderness. From this group, 178 eligible patients were recruited to the study. The inclusion/exclusion information is presented in Figure 1 and patient characteristics are presented in Table 1.

For the study cohort, cervical spine MRI was conducted at a median of 37.5 hours after presentation to the ED (interquartile range [IQR] 22.5 to 55.1 hours). Of these patients, there were 28 (15.7%) who underwent MRI while in the ED. Patients were admitted to the ED short-stay unit for observation of soft tissue injury or ongoing significant pain. The median time to MRI for this subgroup was 19 hours (IQR 10.0 to 27.1). There were 30 patients (16.9%) who were discharged from the ED in cervical collars to return for outpatient MRI, at a median of 49 hours postpresentation (IQR 31.8 to 62.1 hours), and the remaining 120 patients (67.4%) were admitted to the hospital at the discretion of the trauma unit; the median time to MRI for this group was 40 hours (IQR 24.0 to 59.8 hours).

The proportions of exact agreement between radiologists for the identification and grading of injuries to the anterior longitudinal ligament, disc, posterior longitudinal ligament, cord, ligamenta flava, and posterior ligamentous complex for the initial 100 patients were found to be 85%, 87%, 96%, 97%, 99%, and 88%, respectively.

**Main Results**

Seventy-eight patients (44%) had acute cervical spine injuries detected on MRI. Of these patients, 62% had a single-column injury (n=48), 19% had two-column injuries (n=15), and 6% had three-column injuries (n=5). Of the remaining 10 patients, 6 had isolated posterior muscle edema, 2 had lar ligamentous edema, 1 had epidural hematoma, and 1 had atlanto-occipital edema. Of the injured patients, 38 (21% of the total cohort) had injuries managed clinically, with 33 patients treated in cervical collars for 2 to 12 weeks and 5 patients undergoing operative management by anterior cervical discectomy and fusion (Figure 1). The rationale for operative management included cord....
Compression, combined compression and edema, and delayed instability (Table 2). There were no cases of neurologic deterioration. The CT and MRI images for patient 1, who was managed operatively, are presented in Figures 2 and 3.

Cervical spondylosis was detected on CT images before MRI in 62 of 178 patients (35%), with early and advanced degeneration in equal proportions (Table 1). For patients with MRI-detected injury, 14 of 78 patients (18%) had early and 24 of 78 patients (31%) had advanced spondylosis. In the subgroup of patients with injury to 2 or 3 spinal columns, early and advanced degeneration was evident on CT images in 2 of 20 (10%) and 13 of 20 (65%) cases, respectively. Highlighting the proportions of patients with CT-detected spondylosis who were injured, of the patients with early degeneration, 14 of 31 (45%) had injury detected on MRI, and of the patients with advanced degeneration, 24 of 31 (77%) had MRI-detected injury. Incidentally, all 5 patients requiring

<table>
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<th>Table 1. Patient characteristics according to spinal columns injured.12*</th>
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<tr>
<td><strong>Factor</strong></td>
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<tr>
<td>Age, y, median (IQR)</td>
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<td>Sex</td>
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<td>Mechanism of injury</td>
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<td>Direction of initial spine force</td>
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<tr>
<td>Vehicle rollover</td>
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<td>Patient-reported neck pain at scene</td>
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<td>Head strike</td>
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<td></td>
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<td>LOC</td>
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<td>Midline cervical tenderness</td>
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<td>Transient neurology</td>
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<td>Additional injuries</td>
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<td>CT-detected cervical spondylosis</td>
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MVC, Motor vehicle crash; MBA, motorbike accident; LOC, loss of consciousness at accident scene; *, fracture.

*Data are presented as No. (%) unless otherwise indicated.

Minor injury: no columns—isolated posterior muscle edema, epidural hematoma, or alar ligamentous edema. Sport/recreation—football, rugby, waterskiing, snowboarding. Falls—ladders, trampolines, from horses, high (>1 m) and low falls.
operative management of cervical spine injury in our study had advanced cervical spondylosis (Table 2).

Ordinal logistic regression analysis revealed that advanced CT-detected cervical spondylosis (OR 11.6; 95% CI 3.9 to 34.3) was associated with a greater extent of injury according to the number of cervical columns injured. The interpretation therefore is that patients with advanced spondylosis on CT have an 11.6-fold increase in the log odds of having a higher number of spinal columns injured, given that all of the other variables in the model

Table 2. Operative stabilization cases.

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<thead>
<tr>
<th>Patient</th>
<th>Age/ Sex</th>
<th>Mechanism of Injury</th>
<th>Degenerative Change</th>
<th>Injury</th>
<th>Comments</th>
<th>Management</th>
<th>Rationale</th>
</tr>
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<tbody>
<tr>
<td>2</td>
<td>42 M</td>
<td>Rear seat passenger, rear-end collision at 60 km/h.</td>
<td>Mild to moderate multilevel spondylosis with C4/5 &amp; 5/6 disc space narrowing and osteophytes.</td>
<td>Acute C5/6 disc edema, partial tear ALL, focal cord edema without hemorrhage, interspinous edema.</td>
<td>During operative procedure, PLL found to be torn, with prolapsed disc material and posterior osteophytes causing cord compression. No abnormal neurology.</td>
<td>ACDF C5/6 for cord edema and compression.</td>
<td></td>
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<tr>
<td>3</td>
<td>50 M</td>
<td>Cyclist vs truck.</td>
<td>Moderate disc degeneration most pronounced at C5/6, where there is a large posterior disc.</td>
<td>C5/6 disc extrusion with cord flattening and edema, disrupted PLL, C3–7 posterior ligamentous edema.</td>
<td>Transient neurology.</td>
<td>ACDF C5/6 for cord edema and compression.</td>
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M, Male; ALL, anterior longitudinal ligament; PLL, posterior longitudinal ligament; ACDF, anterior cervical discectomy and fusion, 6/52=6 weeks; F, female.

Figure 2. A, Sagittal CT image indicating multilevel spondylosis with severe loss of intervertebral disc height and associated osteophytes, particularly at C6/7. B, Sagittal T2 MRI image indicating injury to the C5/6 intervertebral disc, which is immediately superior to the greatest degree of spondylosis evident in Figure 2A. C5/6 disc extrusion and resultant cord compression (patient 1, Table 2).

Figure 3. A, Sagittal short TI inversion recovery sequence image: rupture of PLL suggested at C5/6, and associated cord edema. B, Axial T2 image at C5/6 level, indicating the degree of cord compression (patient 1, Table 2).
are held constant. Similarly, minor thoracolumbar fractures (OR 5.4; 95% CI 1.5 to 19.7) and multidirectional cervical spine forces (OR 2.5; 95% CI 1.2 to 5.2) were also associated with increased extent of MRI-detected injury in this patient group.

LIMITATIONS

The main limitation of our study was the potential for measurement (observer) bias, given that the study personnel were not blinded to the hypothesis of the study. A single, experienced researcher recruited the study participants and was responsible for data collection. However, a standard data collection tool was used, the demographic data were collected before MRI, and the data were consistently complete. In addition, the reporting radiologists were cognizant that participants had all undergone MRI for injury screening as a result of persistent midline tenderness. Despite this, the radiologists were senior trauma MRI specialists with extensive experience, were blinded to patient, mechanism, and clinical presentation information, and were from different institutions. Also, the imaging data collection tool was standardized, and the proportions of interrater agreement were consistently fair. These measures assisted in the minimization of observer bias in our study.

Patient selection also represents a bias, given that the institution is a major referral center for trauma from metropolitan and regional trauma services. Although none of the patients in our study was finally classified as having major trauma, the participants were probably representative of patients presenting to metropolitan and regional centers. As a result of the reputation of our institution as a major trauma center, patients with minor trauma may have elected to present to the ED for cervical spine assessment, and hence selection bias may exist. Additionally, only patients who underwent MRI were included in our study, and our institutional practice of ordering MRI for patients with persistent midline cervical tenderness and negative CT may not be part of trauma protocols at other institutions.

Further limitations included the single center and the potential inaccuracy of history reporting from patients, whose quality of recall about mechanism of injury is often unable to be validated.

DISCUSSION

In 1963, Holdsworth defined spinal instability as rupture of the posterior ligamentous complex, after the development of his two-column thoracolumbar theory, in which the anterior column comprised the anterior longitudinal ligament, intervertebral disc, and posterior longitudinal ligament and the posterior column involved all components that were posterior to the posterior longitudinal ligament. Subsequent biomechanical studies, however, found that instability in flexion, for example, also required rupture of the posterior longitudinal ligament and posterior annulus fibrosus. As a result, after a retrospective study of 412 thoracolumbar injuries, the three-column theory of Denis was developed in 1983. This theory introduced a middle column, including the posterior component of the vertebral body, the posterior longitudinal ligament, and the posterior annulus fibrosus. Further cadaver model and biomechanical studies have validated and modified the three-column theory. The model remains the most popular and clinically useful and has subsequently been widely applied to the cervical spine, allowing the extent of discoligamentous and osseous injury to be described in terms of the risk to neurologic integrity, with instability defined as injury to 2 or 3 spinal columns.

Nonfracture-related discoligamentous injury, as found in our study, although often of less risk to neural structures than injury involving osseous compromise, can be unstable and is more difficult to detect in the acute setting, particularly when normal alignment is evident. With a higher number of columns injured representing a greater risk of instability, particularly that related to the disruption of ligamentous integrity, knowledge of the extent of cervical column compromise is important in alerting clinicians to the potential for delayed instability.

Although devastating neurologic deficit attributable to acute cervical spine injury is uncommon, the detection of potential instability and the prevention of secondary injury remain the primary goals of cervical spine clearance protocols. As a result, comparatively minor symptoms, such as isolated midline cervical tenderness, are often underestimated as indicators of injury when traditional, first-line imaging results are negative. There is no clear consensus on the need for further screening of such patients. The cervical spine practice management guidelines of the Eastern Association for the Surgery of Trauma recommend that MRI be one of 3 options available to clinicians, along with management with cervical collar and flexion-extension radiography. In contrast, the American College of Surgeons advocates that flexion-extension radiography be performed in such cases, whereas the American College of Radiology suggests that flexion-extension radiographs are of little value until pain subsides and advocates the use of MRI for possible ligamentous injury without directly recommending MRI for persistent midline cervical tenderness.

Much of the evidence regarding MRI-detected cervical spine injury published to date involves obtunded patients, who are presumed to have sustained multiple injuries and lack the ability to participate in clinical assessment. To our knowledge, few studies have focused on alert trauma patients with CT findings that are negative for acute injury, and no studies have specifically centered on the relationship between midline cervical tenderness and MRI findings in this group. Instead, cervical MRI has generally been conducted in alert patients as a result of neurologic deficit or patient-reported neck pain.

Two particular variables appear to be of importance in studies in which MRI findings constitute the primary outcome: the time to MRI from injury and the strength of the magnetic field, as measured in Tesla (T). In the absence of serial MRI studies, anecdotal evidence suggests that the magnetic properties of edema and hemorrhage reduce over time, such that MRI conducted greater than 72 hours after injury is considered less efficient for non-osseous injury detection. Clinical MRI systems generally tend to have field strengths of 0.2 to 3-T, whereas research systems of 8-T and above are available. Generally, the field strength affects the image resolution.
persistent neck pain in the study by Schuster et al. There are 3 main differences in methodology between Schuster’s study and ours. First, the purely patient-reported symptom of persistent neck pain in the study by Schuster et al.33 differs considerably from the clinician-elicited sign of persistent midline cervical tenderness in our study. In many cases, patients report generalized neck pain lateral to the midline, which may be attributed to paraspinal muscle edema and is less likely to be an indication of disc or ligamentous injury. In addition, minor muscular strain can result in neck pain but may not be sufficiently significant or extensive to allow detection of edema on MRI. The other main difference between the symptom of neck pain and the sign of midline cervical tenderness is that palpation allows for a degree of reproducible elicitation of pain. As a result, patients reporting neck pain, but without midline tenderness on palpation, were excluded from our study. Second, the time to MRI, which was not specified by Schuster et al., may be an important factor in the lack of injury detected. MRI was conducted at a median time of 37.5 hours in our study, hence the potential for false-negative results was minimized. Third, Schuster et al.33 hypothesized that significant ligamentous injury without fracture will manifest in immediate neurologic deficit. However, following discoligamentous injury that initially presents without neurologic deficit, particularly with significant flexion/extension mechanisms, delayed instability and resultant secondary neurologic deficit is possible after subsequent caudal migration of disc matter via a ruptured posterior longitudinal ligament. In our study, MRI-detected posterior longitudinal ligament rupture constituted the rationale for operative management in 3 of 5 cases, and in a further case, the presence of focal cord edema manifested suspicion of a lack of posterior longitudinal ligament integrity, which was confirmed visually during the procedure.

In a further prospective study of 40 alert trauma patients, also with patient-reported neck pain, who underwent MRI within 48 hours of injury, no acute pathology was found. The MRI, however, was conducted on a 0.5-T scanner, which may have resulted in false-negative findings due to poor image quality. Similarly, in a larger prospective study, Kongsted et al.43 examined the MRI findings of 178 patients with acute neck pain, after 0.2-T imaging conducted at a median of 13 days post injury. Traumatic disc bulge or protrusion was evident in 0.5% of patients, but again the magnetic field strength and time to MRI were suboptimal and may have resulted in missed injury.

The majority of the remaining evidence is conflicting and based on retrospective data, with wide variation in methodologies. In one such retrospective study, a subset of 20 patients with Glasgow Coma Scale score of 15, whose only indication for MRI was neck pain, was assessed after normal 40-slice CT.44 Three patients (15%) were found to have 1.5-T MRI-detected cervical spine injury, 2 of whom were treated in collars for joint capsule strain and interspinous ligamentous edema and 1 of whom was managed operatively for a three-column injury. The authors concluded that MRI should be included in the evaluation of the cervical spine in this patient group.

Our study found a higher proportion of occult discoligamentous injury overall, and a higher proportion of operatively managed injury, than studies in which the rationale for MRI was patient-reported neck pain, in contrast to midline cervical tenderness. In addition to the presence of tenderness on palpation, the prospective nature of our study and the strict selection criteria may have contributed to this finding. Additionally, as our patients presented to a Level I trauma center, a high level of expertise in image interpretation was available, the CT and MRI imaging protocols were consistent, and MRI was conducted in a timely manner, thereby minimizing false-negative results. However, in other centers the need for surgery in some of these patients may be assessed differently.

We found that advanced spondylotic degeneration, the presence of minor isolated thoracolumbar fracture, and multidirectional spine forces were associated with a greater extent of injury in terms of the number of spinal columns involved. Intervertebral disc degeneration occurs as the nucleus pulposus progressively loses hydration over time, resulting in brittleness, loss of disc height, and bulging. These changes occur as a result of reduction in the integrity of the annulus fibrosus through fissure development. Subsequently, the mechanical characteristics of the cervical vertebral column alter, such that the discs and ligaments above and below the spondylotic area are at risk of increased motion and potential injury during future traumatic mechanisms, as evident in Figure 2, and this finding is supported by those of other studies.

The association of thoracolumbar injury with cervical spine fracture has been well documented, and additional attention to clinical and radiographic thoracolumbar assessment after fracture detection under meticulous cervical spine protocols has resulted. Velocity or impact direction of spine force that is significant enough to result in thoracolumbar spinous or transverse process fracture may therefore have also been absorbed to a degree by the
cervical spine, resulting in occult disc or ligamentous injury presenting as midline cervical tenderness, which may account for our finding.

The association of occult cervical spine injury with multidirectional spine forces found in our study is supported in human cadaver model studies, in which force and velocity have been correlated with cervical spine structure responses during various biomechanical mechanisms. The combining of one force vector with another has the potential to magnify the energy acting on the cervical structures, and the result is the induction of additional changes in the components of the spine. When the tolerance of cervical structural components is exceeded by the strength of the force, injury occurs. Additionally, certain structures offer greater protection against force and vector direction than others. For example, in comparison with the supraspinous ligament, a component of the posterior ligamentous complex that strongly attaches to the spinous processes, the intervertebral discs and other cervical ligaments offer relatively weak protection against injury.

Despite the absence of cervical spine injury on CT images, persistent midline cervical tenderness can indicate the presence of occult discoligamentous injury, detectable on MRI. In our study, advanced cervical spondylosis, minor isolated thoracolumbar fracture, and multidirectional spine forces were found to be associated with greater degrees of cervical spine trauma, as defined by the number of spinal columns injured. However, further study is required to determine which variables reliably predict injury in patients with persistent midline cervical tenderness and which of these injuries are clinically important and require identification at the time of the ED visit.

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REFERENCES


