Clinical Relevance of Magnetic Resonance Imaging in Cervical Spine Clearance
A Prospective Study

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IMPORTANCE A missed cervical spine (CS) injury can have devastating consequences. When CS injuries cannot be ruled out clinically using the National Emergency X-Radiography Utilization Study low-risk criteria because of either a neurologic deficit or pain, the optimal imaging modality for CS clearance remains controversial.

OBJECTIVE To investigate the accuracy of computed tomography (CT) and magnetic resonance imaging (MRI) for CS clearance.

DESIGN, SETTING, AND PARTICIPANTS A prospective observational study was conducted from January 1, 2010, through May 31, 2011, at a level I trauma center. Participants included 830 adults who were awake, alert, and able to be examined who experienced blunt trauma with resultant midline CS tenderness and/or neurologic deficits and were undergoing CT of the CS. Initial examinations, all CS imaging results, interventions, and final CS diagnoses were documented. The criterion standard for the sensitivity and specificity calculations was final diagnosis of CS injury at the time of discharge.

MAIN OUTCOMES AND MEASURES Clinically significant CS injuries, defined as injuries requiring surgical stabilization or halo placement.

RESULTS Overall, 164 CS injuries (19.8%) were diagnosed, and 23 of these (2.8%) were clinically significant. All clinically significant injuries were detected by CT. Fifteen of 681 patients (2.2%) with a normal CT scan had a newly identified finding on MRI; however, none of the injuries required surgical intervention or halo placement. There was no change in management on the basis of MRI findings. The sensitivity and specificity of CT for detecting CS injury was 90.9% and 100%, respectively. For clinically significant CS injuries, the sensitivity was 100% and specificity was 100%.

CONCLUSIONS AND RELEVANCE Computed tomography is effective in the detection of clinically significant CS injuries in adults deemed eligible for evaluation who had a neurologic deficit or CS pain. Magnetic resonance imaging does not provide any additional clinically relevant information.
Cervical spine (CS) injuries occur in 2% to 4% of all trauma patients.1,2 For survivors with a devastating neurologic deficit, the lifelong effect is immeasurable. These patients are forced to face mental and physical obstacles for the rest of their lives. The cost to the US health care system for the treatment of spinal cord injuries is estimated to be $9.7 billion annually.3 Because of this effect on patient outcomes, it is imperative that rapid and accurate diagnosis be obtained. This is most critical in the patient presenting with an unstable injury and intact neurologic examination. These patients require prompt diagnosis to prevent iatrogenic neurologic injury. A missed CS injury is a highly litigated event, with legal costs averaging $2.9 million and settlements reported as high as $8.9 million.4 Given the effect of a missed injury, the medicolegal implications, and the costs of long-term care, effective clearance of the CS remains a high clinical priority.

Using the National Emergency X-Radiography Utilization Study (NEXUS) criteria,5 the CS can be clinically cleared in patients who are alert, not intoxicated, without distracting injury, and without midline CS tenderness or neurologic deficits. For injuries that do not meet this standard, radiographic clearance using computed tomography (CT) is the next step.6–8 A substantial body of literature9–27 exists on injuries in patients that cannot be cleared owing to an unevaluable clinical examination. However, the optimal diagnostic study for patients whose CS cannot be cleared because of persistent pain or neurologic symptoms has been poorly studied. For patients with a normal CT scan and persistent midline tenderness or focal neurologic deficits, the next step in the evaluation is controversial because the additional diagnostic value of magnetic resonance imaging (MRI) remains unclear.7,8,28,29

The aim of this prospective observational study was to investigate the accuracy of CT and MRI for CS clearance in evaluable patients who are awake, alert, and able to be examined presenting with midline cervical tenderness or focal neurologic deficits.

Methods

Approval for this study was obtained from the University of Southern California Institutional Review Board. The need for informed consent was waived, and patients did not receive financial compensation. This was a prospective observational study of consecutive adult (aged >18 years) patients who sustained blunt trauma, underwent CT evaluation of the CS, and were admitted to the Los Angeles County + University of Southern California (LAC+USC) Medical Center from January 1, 2010, through May 31, 2011. The LAC+USC Medical Center is an American College of Surgeons–verified level 1 trauma center, admitting approximately 5000 trauma patients annually.

All patients were prospectively screened by a senior surgical resident (postgraduate year 4 or higher) or attending surgeon (K.I., P.T., and D.D.). Patients deemed eligible for evaluation (Glasgow Coma Scale score, 15; not intoxicated; and with no distracting injury) had a standardized physical examination of their CS. Any patient deemed ineligible for evaluation (Glasgow Coma Scale score, <15; intoxicated; or with a distracting injury) was excluded from further analysis in this study. With in-line immobilization in the supine position maintained by an assistant, the CS collar was removed. The senior resident or attending surgeon then examined the CS for deformities and midline bony tenderness to palpation. In addition, a complete peripheral neurologic examination was performed and documented. Patients who were awake, alert, and able to be examined and had persistent midline CS pain, tenderness to palpation, or a focal neurologic deficit were enrolled, and the results of their CT of the CS were documented. Magnetic resonance imaging was ordered at the discretion of the attending surgeon or neurosurgeon. All patients were monitored to the day of discharge.

All patients underwent multidetector-row helical CT (MDCT) (Toshiba Aquilion 64 FX multislice CT scanner; Toshiba Medical Systems Corp). Images were acquired through the CS from the occiput to T4. The 64-slice scanner variables for all imaging are as follows: no intravenous contrast, 120 kV(p), 100–250 mA (depending on the size of the patient, using dose modulation), gantry revolution speed of 0.5 seconds, beam pitch 0.95, and beam collimation of 64 × 0.5 mm. Reconstruction was performed with a 2-mm section thickness in the axial, coronal, and sagittal planes. Images were reviewed in multiple window width and level settings on a picture archiving and communication system workstation (Fuji Synapse 3.1.0; Fujifilm Medical Systems) at a 3-megapixel resolution.

All MRI scans were obtained on a 1.5-T system (GE Signa, General Electric Medical Systems). All scans included the following sequences: sagittal T1 fast spin echo (FSE) (repetition time [TR] 500–750 ms, echo time [TE] 14–30 ms), sagittal T2 FSE fat-saturated (TR 2000–4000 ms, TE 110–115 ms), sagittal short tau inversion recovery (TR 3500–4000 ms, TE 50 ms, TI 140–180 ms), axial T2 FSE (TR 4600 ms, TE 110 ms), and axial T1 TR 600–700 ms, TE 15–30 ms. Images were reviewed on a picture archiving and communication system workstation (Fuji Synapse 3.1.0; Fujifilm Medical Systems) at a 3-megapixel resolution. The final radiology reading as provided by a board-certified radiologist was used for the analysis.

A CS injury was defined as any abnormal finding observed on CT consistent with acute traumatic injury. Any CT reading as equivocal for CS injury was considered a positive finding. As a screening imaging modality, because it was not normal, an equivocal CT was treated as a positive finding requiring further diagnostic workup. An abnormal MRI was defined as the finding of any acute trauma-related injuries that were not detected on CT including ligamentous, nonligamentous soft tissue, central nervous system contusion or edema, epidural or subdural hematoma, acute fracture, or disc herniation.

All patients with a diagnosis of CS injury based on the results of CT or MRI had their cases reviewed by a neurosurgeon to determine the need for intervention. An injury was considered clinically significant if it required either surgical intervention for stabilization or halo placement. Mandatory use of a hard collar to protect an unstable ligamentous injury was classified as a clinically significant injury. Stable injuries that required continued use of a CS collar for comfort were not included in the clinically significant injury group.
Continuous variables were dichotomized using clinically relevant cut points: age (≤55 vs >55 years), systolic blood pressure on admission (<90 mm Hg vs ≥90 mm Hg), Injury Severity Score (≤15, 16-24, or ≥25), Abbreviated Injury Scale (<3 vs ≥3), and heart rate on admission (<120 bpm vs ≥120 bpm). Categorical variables were compared using the Fisher exact test or Pearson χ² test, as appropriate. Continuous variables were compared using an unpaired, 2-tailed t test. Values are reported as mean (SD) for continuous variables and as percentages for categorical variables. All analysis was performed using SPSS Windows, version 12.0 (SPSS Inc).

Using the final diagnosis at the time of discharge, including the results of all imaging and operative findings as the criterion standard, sensitivity, specificity, and the negative and positive predictive values for CT in the diagnosis of CS injury and of clinically relevant CS injury were calculated.

Results

During the study period, 6464 patients with blunt trauma were admitted to the LAC+USC Medical Center. Of these, 906 (14.0%) were pediatric patients and 1757 (27.2%) had a Glasgow Coma Scale score of less than 15, were intoxicated on initial examination, or had sustained a distracting injury and were therefore deemed ineligible for evaluation; these groups were excluded from further analysis. Most of the remaining 3801 patients who were awake, alert, and able to be examined went on to be cleared clinically. However, 830 (12.8%) patients had persistent midline CS tenderness or a focal neurologic deficit and were included in the analysis.

The study population was predominantly male (586 [70.6%] with a mean age of 42.6 years (range, 20-81). Motor vehicle collision was the predominant mechanism of injury (330 [39.8%]) followed by falls (262 [31.6%]). Patients in this cohort had a mean Injury Severity Score of 3.3. Patient characteristics are reported in Table 1.

Of the 830 patients who were awake, alert, and able to be examined and had persistent symptoms requiring CT clearance, 164 individuals (19.8%) received a diagnosis of CS injury. Overall, 23 (2.8%) of the patients studied had CS injuries that were clinically significant, requiring either surgical intervention or halo placement. The Figure shows the imaging results and final management of the CS injuries. Computed tomography correctly identified all clinically significant injuries. Three of these patients had additional findings observed on MRI; however, these findings did not change the prescribed treatment based on the original CT findings. Of the 23 clinically significant CS injuries, 14 were CS fractures and the remaining 9 were nonbony injuries resulting in an unstable CS.

Computed tomography was normal in 681 patients (82.0%). None of these patients at the time of discharge received a diagnosis of a clinically significant CS injury. Of these patients, 15 (2.2%) had injuries identified on MRI. None of the new findings observed on MRI changed the management of care or required surgical intervention. Five patients were discharged with CS collars for comfort. A full description of the 15 patients with normal CT and abnormal MRI findings is provided in Table 2.

Overall, 100 MRIs were performed. The most frequent indication for MRI was an equivocal CT reading (61 [61.0%]) followed by persistent midline CS tenderness or sensory deficit (26 [26.0%]). In patients who underwent MRI, 46 individuals (46.0%) had findings that had not been noted on the CT scan. The most common additional findings on MRI were ligamentous injury (42 [42.0%]) followed by soft-tissue injury (17 [17.0%]). In 2 patients, a new fracture was found on MRI. Both were spinous process fractures of C7 and did not require treatment. A full description of the additional findings is presented in Table 3. In all patients with a clinically significant MRI finding, CT was also positive for injury. No clinically significant injury was missed on CT.

Comparison of CT with the criterion standard of final diagnosis at time of discharge demonstrated a specificity of 100% with a positive predictive value of 100% for detecting CS injury. The sensitivity of a CT scan for detecting any injury was 90.9% with a negative predictive value of 97.8%. However, for clinically significant injuries, the CT scan had a sensitivity of 100% and specificity of 100% and positive and negative predictive values of 100%. The addition of MRI provided no clinically relevant data beyond the findings of CT.

Discussion

Clearing the CS in a trauma patient remains a major challenge, with very little tolerance for error. In patients who are awake, alert, and able to be examined with no NEXUS-based
Clinical examination findings concerning for CS injury, clearance can be completed without imaging. In the obtunded patient or a patient with persistent CS tenderness or neurologic deficit detected on examination, clearance requires imaging. Our study focused on the latter population of patients who were awake, alert, and able to be examined who had CS tenderness or neurologic deficit that prevented clinical clearance. The obtunded patients who were ineligible for evaluation were excluded from this analysis.

When the NEXUS low-risk criteria have failed in diagnosis and patients require imaging, the initial imaging modality of choice is MDCT. However, if the MDCT is normal, its adequacy as the sole imaging modality is unclear and was the primary focus of this study. Patients in whom NEXUS has failed can be categorized into 2 subgroups: those who are not able to be evaluated and those who are awake, alert, and able to be examined and have residual tenderness or neurologic deficit. For the patient who cannot undergo evaluation, a comprehen-
et al,29 178 neurologically intact patients with persistent cer-
ficient for clearance of the CS. However, in a study by Ackland
that as long as the motor examination was normal, CT was suf-
fimaging was not found to be useful. The authors concluded
tients with residual cervical pain and a normal CT, further
ies, and implementing more cost-effective protocols are critical
tients’ lengths of stay, eliminating excess radiographic stud-
before factoring in the additional costs of transport, radiol-
atively rare injury.23-27

For the second group, patients who are awake, alert, able to be examined, and have residual tenderness or neurologic deficits, the adequacy of a normal CT scan also remains unclear. For these patients, there have been few studies examining the role of additional imaging after a normal CT scan. In a retrospective study conducted by Schuster et al28 of 93 patients with residual cervical pain and a normal CT, further imaging was not found to be useful. The authors concluded that as long as the motor examination was normal, CT was sufficient for clearance of the CS. However, in a study by Ackland et al,29 178 neurologically intact patients with persistent cervical tenderness and a normal CT scan were prospectively enrolled over a 2-year period. According to the results, 44% of these patients had an acute cervical injury detected by MRI, with 2.8% requiring operative intervention. All patients requiring operative stabilization had advanced cervical spondylosis, which was not seen in our patient population. Patients with severe cervical spondylosis require special consideration, and further evaluation will be necessary before the conclusions from the present study can be applied to the severe cervical spondylosis population. In our large prospective evaluation of 830 patients, CT was sufficient to detect all clinically significant injuries, and the addition of other imaging studies, including MRI, was not of value.

Overuse has been identified as a major contributor to inflated health care costs in the United States.30,31 Reducing patients’ lengths of stay, eliminating excess radiographic studies, and implementing more cost-effective protocols are critical for controlling expenditures.32 The MRI is a costly study, even before factoring in the additional costs of transport, radiology personnel, and wait times.25,33 In addition, MRI availability at many institutions is limited. In our institution, MRIs are not routinely performed on weekends or holidays. Patients who are medically cleared and are awaiting MRI to complete evaluation of their CS must be admitted and remain in-house until the imaging is completed. In the present study, the mean interval between CT and MRI was 2.6 (1.3) days (range, 0–8 days). Discharging patients in a cervical collar and having them return for outpatient MRI is not feasible with our patient population, who often lack reliable transportation and are commonly lost to follow-up. All of these delays in obtaining the MRI add to patient discomfort and increase hospital costs.34 In the present study, the yield of MRI in patients with blunt trauma whose CT scan was normal was zero. By not performing an MRI, patient care could have been streamlined without negatively affecting the outcomes.

The major limitation of the present study is the lack of follow-up after discharge. Although unlikely, it is possible that there were patients with missed injuries diagnosed after their discharge. Additionally, the CT scanners used in our study were 64-slice MDCT, available in the United States since approximately 2005.35 Our conclusions cannot be generalized to less modern scanners that are still in use.

Finally, for patients who are awake, alert, and able to be examined, the 2 reasons for obtaining imaging were persistent tenderness and neurologic deficits. These study findings apply to patients with tenderness, likely due to stable bony or soft-tissue injury. All neurologic deficits in the present study were sensory. Patients with true motor deficits are likely to have an abnormal CT scan, as was seen in this study. If a patient presents with a motor deficit and a normal CT scan, this study provides insufficient data to guide management and an MRI may be indicated.

Conclusions

Computed tomography is effective at detecting clinically significant CS injuries in patients with blunt trauma who are able to undergo evaluation and cannot be cleared clinically because of focal neurologic deficits or CS tenderness. In this prospective study, patients with a normal CT scan had no clinically significant injuries identified at the time of discharge. The use of MRI did not alter the management of patients’ care. Elimination of MRI from the routine workup of the CS in patients with blunt trauma and a normal CT scan who are awake, alert, and able to be examined is safe and cost-effective.

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**Table 3. Findings on MRI**

<table>
<thead>
<tr>
<th>Finding</th>
<th>Value</th>
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<tbody>
<tr>
<td>Ligamentous injury</td>
<td>42</td>
</tr>
<tr>
<td>Muscle injury</td>
<td>17</td>
</tr>
<tr>
<td>Spinal cord hemangioma</td>
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</tr>
<tr>
<td>Spinal cord edema</td>
<td>2</td>
</tr>
<tr>
<td>C7 spinous process fracture</td>
<td>2</td>
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<tr>
<td>Nontraumatic/incidental finding</td>
<td>2</td>
</tr>
</tbody>
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Abbreviation: MRI, magnetic resonance imaging.

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**REFERENCES**

1. Grossman MD, Reilly PM, Gillett T, Gillett D. National survey of the incidence of cervical spine...