40-Slice Multidetector CT: Is MRI Still Necessary for Cervical Spine Clearance after Blunt Trauma?

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We have recently demonstrated that 16-slice multidetector CT (MDCT) is insufficient for cervical spine (CS) clearance in patients with unreliable examinations after blunt trauma. The purpose of this study was to determine if a negative CS CT using 40-slice MDCT is sufficient for ruling out CS injury in unreliable blunt trauma patients or if MRI remains necessary for definitive clearance. In addition, we sought to elucidate the frequency by which MRI alters treatment in patients with a negative CS CT who have a reliable examination with persistent clinical symptoms. The trauma registry was used to identify all patients with blunt trauma who had a negative CS CT on admission using 40-slice MDCT and a subsequent CS MRI during their hospitalization from July 2006 to July 2007. Two hundred thirteen patients were identified. Overall, 24.4 per cent patients had abnormal MRIs. Fifteen required operative repair; 23 required extended cervical collar; and 14 had collars removed. A total of 8.3 per cent of patients with an unreliable examination and 25.6 per cent of reliable patients had management changed based on MRI findings. Overall, MRI changed clinical practice in 17.8 per cent of all patients. Despite newer 40-slice CT technology, MRI continues to be necessary for CS clearance in patients with unreliable examinations or persistent symptoms.

CERVICAL SPINE (CS) INJURIES continue to be a major concern after blunt trauma, and despite advances in technology, accurate and timely diagnosis remains a challenge. Its occurrence ranges from 2 to 6 per cent after blunt trauma with potentially catastrophic consequences if missed.[1–7] The hard collar, universally placed on all blunt trauma patients by prehospital providers, establishes temporary immobilization for a potentially unstable cervical spine while evaluation occurs. However, immobilization for as little as 5 days can result in pressure ulcer formation, compromised airway management, suboptimal pulmonary toilet, and limited central venous access.[1]

Asymptomatic patients who are awake, alert, and oriented without distracting injury or neurologic deficit may be cleared clinically without any radiographic evaluation. This approach has been supported by numerous studies and is considered standard practice.[8, 9] However, those who have an unreliable examination such as persistent neck pain or neurologic deficit need further imaging. When plain radiographs or CT demonstrate injuries, the appropriate consultants can be requested and care is often determined by the specialists. However, there are subsets of patients, those with a persistently unreliable examination and those with persistent symptoms, who have both plain radiographs and CT that demonstrate no acute traumatic injury. Currently, there is no universally accepted algorithm or specific recommendation on how to evaluate these patients for injury.

The approach to CS clearance in the unreliable patient varies between institutions and practitioners. No single protocol has been adopted and thus practice patterns differ. Some authors believe if the patient has a CS CT with reconstruction images that shows no acute injury, the cervical collar can be removed.[10–12] These authors contend that follow-up MRI does not demonstrate any unstable ligamentous injury or other significant injury[10–13] that warrants treatment. Others have added that if the patient is moving all extremities on admission and has a CS CT with no acute injury, MRI is not necessary before removal of CS immobilization.[14, 15] In contrast, some believe that MRI remains a necessary adjunct in the evaluation of the patient with a persistently unreliable examination after blunt trauma and that treatment is often altered based on the findings.[16–20]

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Patients with a negative CS CT who have persistent pain or neurologic symptoms, be it motor or sensory, represent an additional cohort in which the use of MRI continues to be debated. It is well established that MRI has become the imaging modality of choice for identifying ligamentous and spinal cord injuries in the trauma patient.[21–26] Schuster et al. demonstrated in those patients who have a normal motor examination and a negative CS CT on admission, an MRI for persistent cervical spine pain will not demonstrate any clinically significant injury and is thus unnecessary.[14] In contrast, others have demonstrated, using older CT technology, that CS CT misses injuries, including fractures, in examinable patients with persistent cervical spine pain or neurologic deficit and thus MRI is still warranted.[18, 27]

The purpose of this study was to determine if a negative CS CT using newer-generation multidetector CT (MDCT) is sufficient for ruling out cervical spine injury in the unreliable blunt trauma patient or if MRI is still necessary for definitive clearance. In addition, we sought to elucidate the frequency by which MRI alters treatment in reliable patients with a negative CS CT who have persistent clinical symptoms.

Methods

This was a retrospective chart review performed at the R Adams Cowley Shock Trauma Center, University of Maryland Medical Center, Baltimore, MD. The trauma registry was used to identify all patients with blunt trauma who had CS imaging using 40-slice multirow detector CT and CS MRI between July 2006 and July 2007. All patients were screened for an acute blunt traumatic CS injury on admission CT scan. Patients were excluded if they had an acute CS injury or suspicion of an acute CS injury, including prevertebral edema, interspinous or intervertebral space widening diagnosed on admission CT scan. Patients diagnosed with only degenerative joint disease of the admission CS CT remained in the study group. During the study period, a clinical guideline was in place whereby patients, once clinically stable, who had persistently unreliable examinations (Glasgow Coma Score [GCS] less than 15) had MRI despite a normal admission CT. For patients with a reliable examination (GCS = 15), common practice in the institution included a CS CT as the initial screening test and MRI if patients had persistent neurological deficit. If pain was the only indication, patients would typically be discharged in a hard cervical collar (Miami-J; Ossur Americas, Aliso Viejo, CA) and MRI was performed on an outpatient basis. However, a number of patients with pain as their only indication for MRI had the study performed during their initial hospitalization and were included for the purpose of this study. Medical records were reviewed for demographics, indication for MRI, GCS at the time of MRI, and injury-specific data.

Cervical spine CT scans were obtained using a 40-slice Philips Brilliance (Philips Medical Systems, Cleveland, OH). Scans were performed from the skull base to the T1 vertebral body. Forty-detector row CT was performed by using 40 × 0.625-mm collimation with 1-mm thick sections, 0.5-mm overlap, and a pitch of 0.675. The trauma protocol included axial as well as coronal and sagittal reconstruction views. Multiplanar reformations were reformatted to 2-mm thickness every 2 mm through the entire cervical spine. MRI used during the study period included Picker Eclipse (Philips Medical Systems), GE Signa Horizon (GE Medical Systems, Milwaukee, WI), and Siemens Avanto (Siemens Medical Solutions USA, Inc., Malvern, PA). All MRIs were 1.5 Tesla. The MR scans were performed using our standard trauma protocol for cervical spine injuries, including: short time inversion recovery, T1, T2, and proton-density sagittal images. In addition, axial images included gradient echo and T2 fast spin echo format. All images were reviewed by board-certified, attending radiologists with subspecialty training in trauma radiology.

The following findings on MRI were considered abnormal: ligamentous injury with cord contusion, ligamentous injury without cord contusion, cord compression with cord contusion, cord compression without cord contusion, isolated cord contusion, bony fracture/contusion, or prevertebral edema/soft tissue swelling indicative of a ligamentous injury. This study was approved by the Institutional Review Board at the University of Maryland School of Medicine, Baltimore, MD.

Results

Six thousand three hundred forty-seven injured patients were admitted to the R Adams Cowley Shock Trauma Center during the 12-month study period. Two hundred thirteen patients were identified who had an initial cervical spine CT using a 40-slice multirow detector helical CT demonstrating no acute traumatic CS injury and a subsequent cervical spine MR performed during their hospitalization. One hundred seventeen patients had a GCS of 15 and were considered examinable at the time of MRI, whereas 96 patients had a GCS less than 15 and were considered to have an unreliable examination at the time of MRI. The overall study population (213 patients) had a mean age of 41.4 (±18.7) years and mean Injury Severity Score (ISS) was 17.0 (±13.9). MRI was performed on postinjury Day 4.4 (±6.8) with patients having a GCS of 12.5 (±3.3) at the time of MRI. There were 155 (73%)

males. Mechanism of injury included: motor vehicle/motorcycle collision (45.5%), fall (26.8%), assault (7.5%), sporting (4.7%), pedestrian struck (4.2%), and other (11.3%). Fifty-two (24.4%) patients had an abnormal MRI (Table 1). Of those, 15 required operative fixation, 23 required extended cervical collar use, and 14 patients had their collar removed at the discretion of the spine attending. MRI changed the clinical practice for 17.8 per cent of patients who had a CS CT demonstrating no acute injury.

Patients with a GCS of 15 (54.9%) had a mean age of 39.1 (±18.0) years and mean ISS of 9.6(±10.3). MRI was performed on postinjury Day 1.0 (±2.4). Indications for MRI in this cohort included: neurological deficit (89), pain only (20), and other (eight). Thirty-seven (31.6%) of the patients had an abnormal MRI. After consultation with the spine service, 14 (15.6%) patients had operative repair, 13 of which had a neurological deficit (Table 2), whereas 16 patients were discharged in a cervical collar and seven patients had their collars removed before discharge. Of note, two of the patients discharged in a cervical collar were recommended to have operative repair but refused. Of the 20 patients whose only indication for MRI was pain, 17 MRIs were normal and the cervical collars were removed. The remaining three patients had an abnormal MRI (Table 3). One patient had delayed presentation of a neurological deficit requiring operative repair, whereas the other two were maintained in a cervical collar.

Ninety-six (45.1%) patients with an unreliable examination had a mean age of 44.2 (±19.2) years with a mean ISS of 26.0 (±12.3). Mean GCS was 9.5 (±2.7) and MRI was performed on postinjury Day 8.5 (±8.0). Eighty-one (84.3%) patients had a normal MRI and collars were removed. Fifteen (15.6%) patients had an abnormal MRI. Table 4 illustrates the clinical examinations, MRI findings, and disposition of these patients.

Discussion

Evaluation of the cervical spine after blunt trauma remains a challenge. The practice of clearing the cervical spine based on clinical examination in patients who present awake, alert, and oriented without distracting injury or neurological deficit is well established and accepted.[8, 9] However, for those who have an unreliable examination, the evaluation process remains controversial and varies between institutions and practitioners. Additionally, in patients who have reliable examinations with a negative CS CT after injury who still have persistent pain or neurological deficit, the use of MRI continues to be an area of controversy.[14, 18]

TABLE 1. *Abnormalities Diagnosed on MR Not Seen on CT*

MRI Findings	n
Ligamentous injury	
With cord contusion	3
Without cord contusion	13
Cord compression	
With cord contusion	9
Without cord contusion	20
Isolated cord contusion	5
Fracture/boney contusion	2
Total injuries	52

Although still considered to be the initial evaluation tool for the cervical spine by Advanced Trauma Life Support, plain radiographs are no longer used by many trauma centers as a result of the high rates of missed injury.[27–31] CT has become the diagnostic screening tool of choice for the cervical spine and has increased the accuracy of detecting injuries.[32] However, it is insensitive for diagnosing spinal cord injury[33] and does not specifically evaluate for ligamentous injury.[34] Despite the lack of sensitivity, there is a growing body of literature supporting the clearance on the cervical spine in the obtunded patient based on a negative admission CS CT.[10–15]

In 2005, two reports advocated removal of cervical spine precautions based on a negative CS CT. Sanchez et al. reported that all CS injuries except one, a previously existing syringomyelia, were diagnosed by their protocol, which used CT with 3-mm cuts as the screening mechanism. MRI was only obtained for obvious neurological deficit. Although MRI was not used in all patients and the article did not describe the obtunded patient population, the authors commented that patients who arrived comatose with no obvious neurological deficit were cleared by a negative CS CT.[15] That same year, in a small study of 12 comatose patients moving all extremities on admission, whose admission CS CTs were normal, Schuster and colleagues demonstrated that follow-up MRI demonstrated no injuries.[14] All 12 patients had their collar removed and according to the authors, no patient had delayed neurological deterioration or need for further intervention .

In 2005, Hogan et al. compared CT and MRI directly in 366 patients over a 31-month period and concluded that in the obtunded patient, CT alone is sufficient to exclude unstable CS injuries and follow-up MR is unnecessary.[13] The authors diagnosed 12 (3.3%) injuries by MRI that were not evident on CT; however, none of the injuries appeared unstable radiographically. Unfortunately, the authors did not define what they considered to be "an unreliable examination" nor did they provide any associated injury information. In addition, radiographic findings do not always dictate treatment and unfortunately, it was not evident in the

TABLE 2. *Patients with Neurological Deficit Requiring Operative Repair*

Patient No.	Symptoms	MRI Findings
1	Intermittent paresthesias	Cord compression without contusion
2	UE weakness	Ligamentous injury with contusion
3	Bilateral UE/LE weakness (CCS)	Cord compression with contusion
4	UE weakness	Cord compression without contusion
5	UE paresthesias	Cord compression with contusion
6	Bilateral UE/LE weakness	Cord contusion
7	Bilateral sensory/motor deficit	Compression without contusion
8	Bilateral sensory/motor deficit	Compression without contusion
9	Unilateral UE weakness	Compression without contusion
10	UE greater than LE weakness (CCS)	Compression without contusion
11	Bilateral UE/LE weakness (CCS)	Compression with contusion
12	Bilateral UE/LE weakness	Ligamentous injury with contusion
13	Bilateral UE/LE weakness	Compression with contusion

UE, upper extremity; LE, lower extremity; CCS, central cord syndrome.

TABLE 3. *Abnormal MRI in Patients with Pain as the Sole Indicator for Imaging*

Patient	MRI Findings	Disposition
1	Bilateral C1/2 interfacet joint capsule strain	Cervical collar
2	ALL/PLL injury at C4–7, interspinous edema C7/T1	Operative repair
3	C6/7 interspinous ligament edema	Cervical collar

ALL, anterior longitudinal ligament; PLL, posterior longitudinal ligament.

article what the management was of the 12 injuries. Knowing the neurosurgical or orthopedic management decision would have provided clinical correlation of the radiographic findings. More recently, in 2007, Como et al. published data stating that a negative CS CT is sufficient for cervical spine clearance in the obtunded patient and that MRI imaging is unnecessary.[10] In addition, eliminating MRI from their cervical spine evaluation protocol enabled collar removal earlier.

These authors assume that patients do not have any neurological deficit. In addition, it appears the authors believe the presence of radiographic instability is needed to require treatment. This is not always the case because examinable patients with a normal CS CT can have a neurologic deficit with a radiographic stable-appearing injury on MRI as seen in patients with central cord syndrome. In fact, in over 75 per cent of our patients who had reliable clinical examinations and a normal CT, the indication for MRI was a neurologic deficient. Thus, it would seem prudent to assume unreliable patients may still have the potential for neurologic deficit with a normal CT.

We have previously demonstrated that a negative CS CT, using 16-slice technology, was insufficient for the clearance of the cervical spine in patients with an unreliable examination.[17] In that study, 18 (8.9%) patients who had a negative CS CT were found to have an abnormal MRI, two of which required operative repair and 14 required extended cervical collar use. Two patients had their collars removed at the discretion of the attending surgeon. The results from this current study confirm our previous work and again support the use of MRI in patients with an unreliable clinical examination. In this current study, 15 (15.6%) of these patients had MRI findings that were not evident by newer MDCT. Of those, eight (8.3%) patients had their management changed based on MRI findings; seven required extended cervical collar immobilization and one required operative repair. This is almost identical to our previous findings in which MRI altered the management in 8.7 per cent of patients with an unreliable examination and a normal CS CT.[17] In total, three of 33 (9.1%) patients who had a normal CS CT required operative fixation based on MRI. Of note, 11 of the 15 patients with abnormal MR were documented as moving all extremities. Our data disagree with previous reports by Schuster et al. that obtunded patients who are noted to be moving all extremities do not warrant MR imaging.[14]

The literature supporting the use of MRI for definitive CS clearance in the patients with unreliable examinations as well as those patients with reliable examinations who have a normal CS CT continues to grow.[16–18, 27, 35, 36] In 2001, Kihiczak et al. demonstrated that 10.5 per cent of their patients had MRI findings that were not seen on CS CT; however, none of the patients required operative fixation.[35] The authors suggested that all patients with an unreliable examination should undergo MRI to evaluate the spine. In 2002, Ghanta et al. conducted a retrospective evaluation of the Eastern Association for the Surgery of Trauma (EAST) guidelines for cervical spine clearance.[36] In their unreliable patient population, defined as persistent GCS of less than 14, 22 per cent had a normal CS CT and an abnormal MRI. The

TABLE 4. *Patients with Unreliable Examinations and an Abnormal MR*

Patient	Clinical Examination	MR Findings	Disposition
1	Moved all extremities	Ligamentous without contusion	Collar
2	Unexaminable	Ligamentous without contusion	Collar
3	Moved all extremities	Ligamentous without contusion	Collar
4	Unexaminable	Cervical fracture	Collar
5	Moved all extremities	Compression with contusion	Collar
6	Moved all extremities	Ligamentous without contusion	Collar
7	Moved all extremities	Ligamentous without contusion	Collar
8	Moved all extremities	Compression without contusion	Collar removed
9	Moved all extremities	Ligamentous without contusion	Collar removed
10	Unexaminable	Compression without contusion	Collar removed
11	Moved all extremities	Compression without contusion	Collar removed
12	Unexaminable	Compression without contusion	Collar removed
13	Moved all extremities	Compression without contusion	Collar removed
14	Moved all extremities	Ligamentous without contusion	Collar removed
15	Moved all extremities	Compression without contusion	Operative repair

injuries, which were described as clinically significant by the authors, included disc herniation, ligamentous injury, soft tissue injury, cord transection, and meningeal tear. The authors concluded that the EAST guidelines for cervical spine clearance in the unreliable patient may not be sensitive enough for diagnosing unstable ligamentous injury.

In 2005, Diaz et al. demonstrated 14 of 21 (67%) patients found to have a ligamentous injury on MRI had a normal CS CT.[27] At the time of admission, nine patients were intubated and sedated and thus unable to provide a reliable examination. Four patients had pain as their only complaint and one patient had neurological deficit on presentation. All 14 patients were treated with a cervical collar. The authors concluded that CT is poor in its ability to screen for ligamentous and soft tissue injury of the cervical spine despite the advances in technology. Stassen et al. showed that 30 per cent of their unreliable patients with a normal CS CT had significant findings on MRI requiring intervention.[16] In 2007, Sarani and colleagues demonstrated that five of 46 (11%) unreliable patients with a normal CT scan had findings on MRI.[18] Four of these five patients had ligamentous injury, which required prolonged cervical spine immobilization. Finally, in 2008, Steigelman et al. concluded that MRI did not "appear" to alter treatment in unreliable patients with a normal CS CT. However, when looking at the data, 5 per cent of patients with a normal CS CT had MRI abnormalities that were consistent with acute injury. Of these, 29 per cent had treatment altered based on MRI findings.[37]

In 2002, The British Trauma Society reported its cervical spine clearance algorithm for the unconscious patients. For patients who had normal radiographs and CS CT and were expected to remain unexaminable for more than 24 to 48 hours, MRI was recommended as the modality of choice to evaluate for instability.[38] The following year, the American College of Radiology (ACR) released their "ACR Appropriateness Criteria" for cervical spine imaging. For patients who were persistently, clinically unevaluable for longer than 48 hours, MRI was given a rating of 9 (most appropriate) for the evaluation of the cervical spine, including those with a normal CS CT.[20] Although some authors have questioned the low sensitivity of MRI more than 48 hours after injury,[22, 23] this notion is based on poorly documented anecdotes, poor image quality, and no evidence that the delay between injury and imaging was responsible for the false-negative MRI.[20] In 2003, the ACR stated in their "Appropriateness Criteria" that no evidence was found that MRI performed after 48 hours of injury is of lower sensitivity than acute imaging.[20] It may be possible that MRI performed early (less than 48 hours after injury) in this patient population may be misleading in that it diagnoses "insignificant injuries" that may resolve on a delayed MRI It is conceivable to think perhaps delayed (greater than 48 hours after injury) MRI is more appropriate for evaluating the CS in patients with unreliable examinations. It may be that injuries that persist and are diagnosed on delayed MRI would be of more clinical significance and truly require treatment, be it operative or nonoperative. Future studies delineating the appropriate time of MRI after injury are needed to answer this important question.

In addition to the controversy surrounding the evaluation of the CS in patients with an unreliable examination, the process for ruling out a CS injury in patients with a negative CS CT who have persistent pain on palpation, range of motion, or subtle neurological deficit, including paresthesias, remains an area of debate. In 2005, Schuster et al. reported that in patients who had persistent neck pain despite a negative CS CT, follow-up MRI did not demonstrate any "clinically significant injury" and thus was unnecessary.[14] Our data once again disagree with Schuster's findings. Of the 20 patients in our study whose MRI was performed solely for persistent neck

pain, three were found to have abnormalities. All three were found to have ligamentous injury, of which two required extended cervical collar use and one required operative fixation (Table 3). In 2007, Sarani et al. demonstrated 37 (31.4%) patients with injuries diagnosed on MRI that were not diagnosed by CS CT.[18] All patients were examinable and the indications for MRI included persistent pain, motor or sensory deficit, or inadequate flexion/extension films. The abnormalities on MRI included ligamentous injury, cord injury, herniated discs, fractures, and dislocations. The MRI findings dictated the management in 27 (22.8%) patients, including nine requiring operative repair. These numbers are almost identical to our results, which demonstrated 31.7 per cent of patients who were alert and oriented were found to have an abnormality on MR with negative CS CT. These findings altered the management in 25.6 per cent of our patients.

As to why many patients who had neurologic deficit on examination had a subsequent negative MRI is unclear. It is possible that subtle sensory deficits may be attributed to other causes or there remain injuries that MRI is still not sensitive enough to detect. Regardless, Sarani and colleagues' findings clearly support our results that examinable patients can have a neurological deficit with a normal CS CT and a CS MRI that does not demonstrate an unstable ligamentous injury and still require treatment. To not assume the same in patients with an unreliable examination seems unwise.

It is difficult to understand why some authors continue to assume that patients who have clinically unreliable examinations and cannot provide information regarding pain, or subtle neurological deficit, to be neurologically intact and without pain. It would seem prudent to assume patients have an injury until proven otherwise. As evident by our results, which agree with others,[18, 27] reliable patients have significant injuries diagnosed by MRI that were missed by CT. In addition and more importantly, MRI findings altered the management in a considerable number of patients. Based on this, it is imperative that prudent practice must assume that any patient without a reliable examination has a cervical spine injury until either ruled out clinically or radiographically with MRI being the definitive test.

There are several limitations to our study, including those inherent to a retrospective analysis. In addition, the institution has essentially abandoned plain films of the cervical spine. Thus, soft tissue abnormalities potentially seen on plain films were not available for analysis. However, in reality, CT may be a better modality for evaluating soft tissue findings. Furthermore, our institution guidelines, like many others, do not include flexion/extension films. As a result, the true stability, or more importantly the true instability, of the injuries remains unknown. However, because MRI does demonstrate soft tissue injury as well as ligamentous injury, there is evidence for possible cervical spine instability. What is clear, however, is that the neurosurgical and orthopedic consulting services at our institution do not consider a negative CT scan sufficient for CS clearance in the obtunded patient and continue to support the need for MRI in these patients. Based on their interpretation of the MRI, their standard practice pattern is to treat with either collar immobilization and follow-up imaging or operative repair when deemed appropriate. If the neurosurgeon or orthopedic consultants believe the MRI abnormalities to be chronic and not indicative of an acute traumatic injury, then collars are removed on their recommendation. Another limitation is that not all CTs and MRIs were interpreted by the same radiologist. However, we have a small group of dedicated, certified trauma-trained, attending radiology staff that provided all radiographic readings. The radiologists were not blinded to the admission CT scan; however, no CT scan interpretation was retrospectively changed from their initial reading.

Conclusion

CT technology may not be designed to diagnose ligamentous or spinal cord injuries. However, practice patterns among some trauma centers continue to use CT alone to rule out cervical spine injuries. Although some suggest that a normal CS CT excludes unstable CS injuries, it does not exclude a spinal cord injury and the need for treatment. Our study demonstrates that despite new CT technology, CT scan continues to miss significant cervical spine injuries in patients with an unreliable examination. Prudent practice assumes that any patient without a reliable examination has a cervical spine injury and as such, MRI must be part of the evaluation algorithm because it often alters management in this patient population. In addition, we demonstrated findings on MRI in patients with persistent neck pain or subtle neurological deficit continues to assist in management and should be considered standard as part of their evaluation. We therefore recommend the continued use of MRI as an adjunctive modality in the evaluation of the cervical spine in both patient populations. Finally, future research should be aimed at enabling MRI technology to be quicker and more easily accessible.

REFERENCES

1. Ajani AE, Cooper DJ, Scheinkestel CD, et al. Optimal assessment of cervical spine trauma in critically ill patients: a prospective evaluation. Anaesth Intensive Care 1998;26:487–91.

2. Demetriades D, Charalambides BS, Chahwan S, et al. Non-skeletal cervical spine injuries: epidemiology and diagnostic pitfalls. J Trauma 2000;48:724–7.

3. Schenarts PJ, Diaz J, Kaiser C, et al. Prospective comparison of admission computed tomographic scan and plain films of the upper cervical spine in trauma patients with altered mental status. J Trauma 2001;51:663–9.

4. Pasquale M, Fabian TC. Practice management guidelines for trauma: EAST ad hoc committee on guideline development-identifying cervical spine instability after trauma. J Trauma 1998; 44:941–56.

5. Hendey GW, Wolfson AB, Mower WR, et al. Spinal cord injury without radiographic abnormality: results of the National Emergency X-Radiography Utilization study in blunt cervical trauma. J Trauma 2002;53:1–4.

6. Grossman MD, Reilly PM, Gillett T, et al. National survey of the incidence of cervical spine injury and approach to cervical spine clearance in US trauma centres. J Trauma 1999;47:684–90.

7. Berne JD, Velmahos GC, El-Tawil Q, et al. Value of complete cervical helical computed tomography scanning in identifying cervical spine injury in the unevaluable blunt trauma patient with multiple injuries: a prospective study. J Trauma 1999;47:896–903.

8. Hoffman JR, Mower W, Wolfson AB, et al. Validity of a set of clinical criteria to rule out injury to the cervical spine in patients with blunt trauma. National emergency x-radiography utilization study group. N Engl J Med 2000;343:94–9.

9. Marion DW, Domeier R, Dunham CM, et al. EAST practice management guidelines for identifying cervical spine injuries following trauma, 2000 update. Available at: www.EAST.org. Accessed July 2008.

10. Como JJ, Thompson MA, Anderson JS, et al. Is magnetic resonance imaging essential in clearing the cervical spine in obtunded patients with blunt trauma? J Trauma 2007;63:544–9.

11. Tomycz ND, Chew BG, Chang YF, et al. MRI is unnecessary to clear the cervical spine in obtunded/comatose trauma patients: the four-year experience of a Level I trauma center. J Trauma 2008;64:1258–63.

12. Stelfox HT, Velmahos GC, Gettings E, et al. Computed tomography for early and safe discontinuation of cervical spine immobilization in obtunded multiply injured patients. J Trauma 2007;63:630–6.

13. Hogan GJ, Mirvis SE, Shanmuganathan K, et al. Exclusion of unstable cervical spine injury in obtunded patients with blunt trauma: is MR imaging needed when multi detector row CT findings are normal? Radiology 2005;237:106–13.

14. Schuster R, Waxman K, Sanchez B, et al. Magnetic resonance imaging in not needed to clear cervical spines in blunt trauma patients with normal computed tomography results and no motor deficit. Arch Surg 2005;140:762–6.

15. Sanchez B, Waxman K, Jones T, et al. Cervical spine clearance in the blunt trauma: evaluation of a computed tomography-based protocol. J Trauma 2005;59:179–83.

16. Stassen NA, Williams VA, Gestring ML, et al. Magnetic resonance imaging in combination with helical computed tomography provides a safe and efficient method of cervical spine clearance in the obtunded trauma patient. J Trauma 2006;60: 171–7.

17. Menaker J, Philp A, Boswell S, Scalea TM. Computed tomography alone for cervical spine clearance in the unreliable patient—are we there yet? J Trauma 2008;64:898–903.

18. Sarani B, Waring S, Sonnad S, et al. Magnetic resonance imaging is a useful adjunct in the evaluation of the cervical spine of injured patients. J Trauma 2007;63:637–40.

19. Richards PJ. Cervical spine clearance. Injury 2005;36: 248–69.

20. Daffner RH, Dalinka MK, Alazaki N, et al. Suspected cervical spine trauma. American College of Radiology ACR Appropriateness Criteria. 2003. Available at: www.acr.org. Accessed: March 6, 2009.

21. Warner J, Shanmuganathan K, Mirvis SE, et al. MRI of ligamentous injury of the cervical spine. Emerg Radiol 1996;3:9–15.

22. D'Alise MD, Benzel EC, Hart BL. Magnetic resonance imaging evaluation of the cervical spine in the comatose or obtunded trauma patient. J Neurosurg 1999;91:54–9.

23. Benzel EC, Hart BL, Ball PA, et al. Magnetic resonance imaging for the evaluation of patients with occult cervical spine injury. J Neurosurg 1996;85:824–9.

24. Keiper MD, Zimmerman RA, Bilaniuk LT. MRI in the assessment of the supportive soft tissues of the cervical spine in acute trauma in children. Neuroradiology 1998;40:359–63.

25. Albrecht RM, Kingsley D, Schermer CR, et al. Evaluation of cervical spine in intensive care patients following blunt trauma. World J Surg 2001;25:1089–96.

26. Silberstein M, Tress BM, Hennessy O. Prevertebral swelling in cervical spine injury: identification of ligament injury with magnetic resonance imaging. Clin Radiol 1992;46:318–23.

27. Diaz JJ, Aulino JM, Collier B, et al. The early work-up for isolated ligamentous injury of the cervical spine: does computed tomography scan have a role? J Trauma 2005;59:897–904.

28. Besman A, Kaban J, Jacobs L, et al. False-negative plain cervical spine x-rays in blunt trauma. Am Surg 2003;69:1010–4.

29. Woodring JH, Lee C. Limitations of cervical radiography in the evaluation of acute cervical trauma. J Trauma 1993;34:32–9.

30. Nunez DB Jr, Zuluaga A, Fuentes-Bernardo DA, et al. Cervical spine trauma: how much more do we learn by routinely using helical CT? Radiographics 1996;16:1307–21.

31. Mower WR, Hoffman JR, Pollack CV Jr, et al. Use of plain radiography to screen for cervical spine injuries. Ann Emerg Med 2001;38:1–7.

32. Barba CA, Taggert J, Morgan AS, et al. A new cervical spine clearance protocol using computed tomography. J Trauma 2001;51:652–7.

33. Holmes JF, Mirvis SE, Panacek EA, et al. Variability in computed tomography and magnetic resonance imaging in patients with cervical spine injuries. J Trauma 2002;53:524–30.

34. Widder S, Doig C, Burrowes P, et al. Prospective evaluation of computed tomographic scanning for the spinal clearance of obtunded patients: preliminary results. J Trauma 2004;56: 1179–84.

35. Kihiczak D, Novelline RA, Lawrason JN, et al. Should an MR scan be performed routinely after a normal clearance CT scan in the trauma patient? Experience with 59 cases. Emerg Radiol 2001;8:276–8.

36. Ghanta MK, Smith LM, Polin RS, et al. An analysis of Eastern Association for the Surgery of Trauma practice guidelines for cervical spine evaluation in a series of patients with multiple imaging techniques. Am Surg 2002;68:563–8.

37. Steigelman M, Lopez P, Dent D, et al. Screening cervical spine MRI after normal cervical spine CT scans in patients in whom cervical spine injury cannot be excluded by physical examination. Am J Surg 2008;196:857–63.

38. British Trauma Society. Guidelines for initial management and assessment of spinal injury. Injury 2003;34:405–25.