Cervical spine MRI in patients with negative CT: A prospective, multicenter study of the Research Consortium of New England Centers for Trauma (ReCONECT)

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BACKGROUND: Although cervical spine CT (CSCT) accurately detects bony injuries, it may not identify all soft tissue injuries. Although some clinicians rely exclusively on a negative CT to remove spine precautions in unevaluable patients or patients with cervicalgia, others use MRI for that purpose. The objective of this study was to determine the rates of abnormal MRI after a negative CSCT.

METHODS: Blunt trauma patients who either were unevaluable or had persistent midline cervicalgia and underwent an MRI of the C-spine after a negative CSCT were enrolled prospectively in eight Level I and II New England trauma centers. Demographics, injury patterns, CT and MRI results, and any changes in cervical spine management as a result of MRI imaging were recorded.

RESULTS: A total of 767 patients had MRI because of cervicalgia (43.0%), inability to evaluate (44.1%), or both (9.4%). MRI was abnormal in 23.6% of all patients, including ligamentous injury (16.6%), soft tissue swelling (4.3%), vertebral disc injury (1.4%), and dural hematomas (1.3%). Rates of abnormal neurological signs or symptoms were not different among patients with normal versus abnormal MRI. (15.2 vs. 18.8%, $p = 0.25$). The c-collar was removed in 88.1% of patients with normal MRI and 13.3% of patients with an abnormal MRI. No patient required halo placement, but 11 patients underwent cervical spine surgery after the MRI results. Six of the eleven had neurological signs or symptoms.

CONCLUSIONS: In a select population of patients, MRI identified additional injuries in 23.6% of patients despite a normal CSCT. It is uncertain if this is a true limitation of CT technology or represents subtle injuries missed in the interpretation of the scan. The clinical significance of these abnormal MRI findings cannot be determined from this study group. (*J Trauma Acute Care Surg.* 2017;82: 263–269. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Therapeutic study, level IV.

KEY WORDS: Cervical spine injury; magnetic resonance imaging; MRI; computed tomography; CT.

Injuries to the cervical spine occur in approximately 2% to 6% of blunt trauma patients.[1,2] The majority of injuries are fractures whereas ligamentous injury and combined injuries are less common.[2] Although associated spinal cord injury (SCI) occurs in a minority of patients (0.07–0.26% of all patients), the impact on both patients' lives and healthcare expenditures is profound.[3] According to the National Spinal Cord Injury Statistical Center, there are approximately 17,000 new cases of SCI (all levels) each year and approximately 282,000 patients with SCI currently living in the U.S. The lifetime estimated costs for both health care and living expenses range from 3.4 to 4.7 million in 2015 dollars for a 25-year-old patient who develops cervical SCI. Furthermore, SCI is associated with a significantly decreased life expectancy compared to persons without SCI.[4] Missed diagnosis of SCI has been associated with high monetary awards in malpractice litigation ($2.9 million, IQR 1.5–12.5 million).[5]

It is therefore paramount to accurately and efficiently diagnose cervical spine injury with the goal of preventing SCI. Two clinical decision rules (Canadian C-spine rule and the National Emergency X-Radiography Utilization Study (NEXUS)) have been validated and accepted in multiple international guidelines for the evaluation of a stable and conscious trauma patient.[6,7] Both rules utilize criteria to determine which patients can be cleared clinically and which patients require additional imaging. Because of its superiority in detecting skeletal injuries, computed tomography (CT) has replaced conventional radiographs (3–4 views) as the preferred imaging modality.[8] However, some cervical injuries can be caused by isolated ligamentous or vertebral disk injury without bony fractures. Although these injuries are uncommon, they may potentially result in permanent neurological deficits if unstable. On the other hand, prolonged cervical spine precautions can lead to pressure ulcers, increased risk of pneumonia, and delirium as well as problems with airway access and cerebral venous drainage. Currently, there is controversy whether CT scans alone can reliably detect all injuries or whether additional imaging is required—especially in patients with persistent cervicalgia or altered levels of consciousness. Practice patterns vary across trauma centers and include routine magnetic resonance imaging (MRI), early or late dynamic radiography (flexion/extension), cervical immobilization with hard cervical collars until the patient is awake and asymptomatic, or simply removing cervical precautions after a normal CT.[1]

The limitations of the current literature have been summarized in the recent practice management guideline from the Eastern Association for the Surgery of Trauma, which reviewed 12 single-center trials (1 prospective, 3 partial prospective, and 8 retrospective) comparing CT scan in obtunded patients to various adjunct studies including clinical follow-up, MRI, flexion/extension, and plain films. The number of patients in each study was low varying from 12 to 367. Although the authors conditionally recommended cervical collar removal after a negative high-quality CT, they recognized that the recommendation is "based on very low quality evidence."[9] Furthermore, although the authors concluded that the "goal should be to achieve the greatest good for the greatest number of patients at reasonable risk without significant over and under triage,"[9] there is no

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TABLE 1. MRI Results After Negative CT Scan for All Patients

	No Neurological Symptoms N (%)	Neurological Symptoms N (%)	Total N (%)
No acute injury	472 (73.3)	87 (70.7)	559 (72.9)
Ligamentous injury	104 (16.1)	23 (18.7)	127 (16.6)
Vertebral disc injury	6 (0.9)	5 (4.1)	11 (1.4)
Dural hematomas	6 (0.9)	4 (3.3)	10 (1.3)
Soft tissue swelling	31 (4.8)	2 (1.6)	33 (4.3)
Inconclusive	25 (3.9)	2 (1.6)	27 (3.5)
Total	644	123	767

currently established false-negative rate that would be acceptable for this potentially devastating injury.

We conducted a multicenter prospective observational trial to investigate whether MRI provided additional clinically relevant information in patients with a negative cervical spine CT who were either clinically unevaluable or had persistent cervicalgia. Our hypothesis was that the addition of MRI to CT scan would provide limited significant clinical data and rarely change management.

METHODS

This study was conducted by eight Level I and II New England trauma centers that are part of the Research Consortium of New England Centers for Trauma (ReCONECT). The participating centers were Baystate Medical Center (Springfield, MA), Beth Israel Deaconess Medical Center (Boston, MA), Boston Medical Center (Boston, MA), Bridgeport Hospital (Bridgeport, CT), Lahey Hospital and Medical Center (Burlington, MA), Maine Medical Center (Portland, ME), Massachusetts General Hospital (Boston, MA), and Yale New Haven Hospital (New Haven, CT). The study was designed and coordinated by Yale School of Medicine, but the study protocol was individually approved by the institutional review board at each trauma center.

Blunt trauma patients who underwent MRI of cervical spine after a negative CT spine were screened over a 30-month period. The decision to obtain MRI was at the discretion of the treatment team. Patients whose indications for MRI were persistent midline cervicalgia or who were deemed unevaluable thus precluding clinical exam were enrolled prospectively into the study. Each participating center utilized a 64- or 128-slice CT scanner, although some of the CT scans may have been from transferring institutions. All scans were reviewed by attending radiologists at the participating centers. The etiologies for being deemed unevaluable included traumatic brain injury, drug and alcohol intoxication or withdrawal, pre-existing neurological disorders, sedation, and mechanical ventilation. Demographics, injury patterns, presence or absence of any (even transient) neurological symptoms, CT and MRI results, and any changes in cervical spine management were recorded. De-identified data was submitted to the coordinating center by each participating site.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics 21 (IBM Corporation, Somers, NY) using a two-tailed Student *t* test, and chi square as appropriate; statistical significance was assumed for $p \leq 0.05$.

RESULTS

Seven hundred sixty-seven patients were enrolled during the study period. Enrollment at the eight centers was variable (418, 116, 28, 30, 42, 55, 23, and 55 subjects, respectively). The median age was 55 years (IQR 36–71) and 54% of patients were male with a median injury severity score (ISS) of 11 (IQR 5–21). The most common mode of injury was fall from standing (32.6%) followed by motor vehicle or motorcycle crash (29.6%) and fall from height (18.3%) (Table 4). Indications for MRI were equally divided between cervicalgia (43%) and unevaluable (44%). MRI was obtained in the remainder of the patients (13%) for both indications. One hundred twenty-three patients (16%) had neurological signs and symptoms. MRI was typically obtained early during the hospitalization (median hospital day 1, IQR 1–2).

Table 1 demonstrates the MRI results based on the indication and subdivided by neurological symptoms. MRI was abnormal in 23.6% of all patients including ligamentous injury (16.6%), soft tissue swelling (4.3%), vertebral disc injury (1.4%), and dural hematomas (1.3%). There were no significant differences in the rates of abnormal MRI between patients with (27.6%) and without (22.8%) neurologic symptoms ($\chi^2 = 1.32$, $p = 0.249$). Subanalysis of patients with cervicalgia and those who were unevaluable demonstrated similar results (Tables 2 and 3). MRI in patients with cervicalgia was overall abnormal in 20.6% without significant differences based on neurologic symptoms (25.6% vs. 19.5%, $\chi^2 = 1.40$, $p = 0.237$). In patients who were considered unevaluable, MRI was abnormal in 24.6% also without differences in patients with (36%) or without (23.9%) neurological symptoms ($\chi^2 = 1.85$, $p = 0.173$). The rates of abnormal MRI did not change with the mechanism of injury (Table 4) ($p = 0.698$) but did vary across the study centers ranging from 8.7% to 37.9% ($\lambda^2 = 22.19$, $p = 0.002$).

Patients with abnormal MRI were more severely injured (median ISS 17 vs. 10, $p = 0.001$) with higher rates of rib, pelvic, lumbar vertebral, skull, facial, and upper and lower extremity fractures and traumatic brain injury (Table 5). There were no differences in neurological symptoms between the two groups.

Additional imaging was obtained in 15.5% of patients with abnormal MRI including flexion-extension, CT or MR angiography, repeat cervical spine MRI, and brachial plexus MRI. The c-collar was removed in 88.1% of patients with normal MRI

TABLE 2. MRI Results After Negative CT Scan for Patients With Cervicalgia

	No Neurological Symptoms N (%)	Neurological Symptoms N (%)	Total N (%)
No acute injury	257 (78.4)	54 (73.0)	311 (77.4)
Ligamentous injury	45 (13.8)	18 (24.3)	63 (15.7)
Vertebral disc injury	4 (1.2)	0 (0)	4 (1)
Dural hematomas	2 (0.6)	1 (1.4)	3 (0.7)
Soft tissue swelling	13 (4.0)	0 (0)	13 (3.2)
Inconclusive	7 (2.1)	1 (1.4)	8 (2.0)
Total	328	74	402

TABLE 3. MRI Results After Negative CT Scan for Unevaluable Patients

	No Neurological Symptoms N (%)	Neurological Symptoms N (%)	Total N (%)
No acute injury	273 (70.9)	15 (60)	288 (70.2)
Ligamentous injury	66 (17.1)	3 (12.0)	69 (16.8)
Vertebral disc injury	3 (0.8)	3 (12)	6 (1.5)
Dural hematomas	4 (1.0)	2 (8)	6 (1.5)
Soft tissue swelling	19 (4.9)	1 (4)	20 (4.9)
Inconclusive	20 (5.2)	1 (4)	21 (5.1)
Total	385	25	410

but only in 13.3% of patients with an abnormal MRI. No patient required halo placement, but 11 patients underwent cervical spine surgery after the MRI results (Table 6). Six of the eleven had neurological signs or symptoms.

DISCUSSION

In this prospective multicenter observation study of a select patient population, MRI detected additional injuries in 23.6% of patients who had a negative CT scan but were deemed unevaluable by clinical examination or had persistent cervicalgia. There were no significant differences between high and low energy mechanisms suggesting the mechanism of injury should not be utilized in decision making.

The results are comparable to previous studies reported in the literature. In a retrospective single-center study of 203 patients, Menaker et al. reported that MRI detected additional injuries in 8.9% and changed the management in 7.9% including two patients who required operative repair.[10] In another retrospective study, Tomycz et al. reported that MRI detected acute traumatic findings in 21.1% of patients with normal CT.[11] None of the patients had an unstable injury or required surgery. Furthermore, in a systematic review of 11 studies and 1535 patients, MRI was abnormal in 16.2% of patients.[12]

The clinical significance of these injuries is less clear. In the present study, 157 patients (20.4% of total) were kept in a cervical orthotic c-collar secondary to the MRI results and 11 patients underwent operative management. Although ligamentous injury to all three columns is well established as an unstable spine injury,[13] currently there is no clear consensus among spine surgeons regarding the significance and management of lesser injuries. The current data cannot discern whether the 157 patients truly required c-collar immobilization to prevent spinal cord injury or whether the management simply reflected conservative approach of the treating spine surgeons. In addition, it cannot determine whether the acute management was influenced by the exacerbation of chronic disease. In a recent systematic review, which included 7 studies (1686 patients), no significant injuries were missed after negative CT. The review's overall conclusion was, however, tempered by some of the limitations of the included studies including 10% loss to follow-up in one of the larger studies.[1]

Operative intervention occurred in 11 patients (1.4%) of the patients including six who had neurological symptoms. An argument could be made that patients with neurological finding represent a special subgroup that most clinicians would evaluate further despite a negative CT scan and therefore should be excluded from analysis. However, we have included them as the study encompassed all patients that underwent MRI after a negative CT scan without consideration of any variables that could affect the pretest probability. Furthermore, the presence or absence of such symptoms cannot be reliably determined in the exact population we were studying, i.e., unevaluable patients, and therefore should not be utilized in discussing the value of MRI.

It is uncertain whether the study findings represent a true limitation of CT technology or represents subtle injuries missed

TABLE 5. Comparison of Patients Based on MRI Results

	Normal MRI	Abnormal MRI	*p*
Median age, y	54 (IQR 35–72)	56 (IQR 43–70)	0.073
Male gender, %	52.0	61.3	0.029
Median ISS	10 (IQR 5–18)	17 (IQR 10–27)	0.001
Rib fractures, %	21.5	29.3	0.031
Pelvic fractures, %	5.5	11.0	0.009
Thoracic vertebral fractures, %	11.8	14.9	0.103
Lumbar vertebral fractures, %	9.7	15.5	0.031
Traumatic brain injury, %	36.2	46.9	0.009
Subdural hematoma, %	19.4	27.6	0.053
Epidural hematoma, %	3.4	4.9	0.372
Subarachnoid hemorrhage, %	21.5	29.3	0.08
Skull fractures, %	10.8	16.6	0.021
Facial fractures, %	14.7	20.4	0.034
Upper extremity fractures, %	8.4	14.4	0.011
Lower extremity fractures, %	8.5	18.8	0.001
Liver injury, %	3.4	3.9	0.772
Spleen injury, %	2.7	6.6	0.014
Renal injury, %	1.5	2.8	0.281

TABLE 4. MRI Results Based on the Mode of Injury

	MVC/MCC N (%)	Pedestrian Struck N (%)	Fall from Standing N (%)	Fall from Height N (%)	Assault N (%)	Sports N (%)	Other N (%)	Total N (%)
Normal MRI	165 (72.7)	41 (75.9)	199 (79.6)	105 (75.0)	27 (77.1)	10 (83.3)	39 (79.6)	586 (76.4)
Abnormal MRI	62 (27.3)	13 (24.1)	51 (20.4)	35 (25)	8 (22.9)	2 (16.7)	10 (20.4)	181 (23.6)
Total	227	54	250	140	35	12	49	767

$\chi^2 = 3.85$, $p = 0.698$.
MVC, motor vehicle crash; MCC, motorcycle crash.

TABLE 6. Summary of Spine Surgeries

Patient	MRI Findings	Symptoms	Surgery
23	Ligamentous injury	No	Anterior cervical discectomy and fusion C5–6 and C6–7
98	Ligamentous injury	Yes	C3 through C7 laminectomies with bilateral foraminotomies and partial facetectomies
168	Ligamentous injury	No	Anterior cervical decompression and fusion, C5–6
186	Ligamentous injury soft tissue swelling	Yes	C3, C4, C5, and C6 bilateral cervical laminectomies and decompression of spinal cord
215	Ligamentous injury	No	Anterior cervical decompression and fusion, C5–6
259	Ligamentous injury	No	Occipital-cervical fusion
352	Dural hematoma	Yes	Complete anterior cervical decompression and fusion, C4–5 and C5–6
520	Ligamentous injury vertebral disc injury	No	Anterior cervical discectomy, decompression of the spinal cord and bilateral exiting nerve roots at C6–C7. Intervertebral arthrodesis, removal of disrupted disc material at C6–C7
639	Ligamentous injury	Yes	Anterior cervical discectomy, decompression of the spinal cord and bilateral exiting nerve roots at C6–C7. Intervertebral arthrodesis, removal of disrupted disc material at C6–C7
693	Ligamentous injury	Yes	Anterior cervical corpectomies C4 and C6 with iliac crest allograft at the corpectomy sites
746	Ligamentous injury dural hematoma	Yes	Application of Gardner-Wells tongs. Anterior cervical discectomy C6–7/ foraminotomy C6–7, left. Evacuation epidural hematoma

in the interpretation of the scan. Previous studies have suggested that specific interpretation of the CT scan by looking for both direct and indirect signs of injury obviates the need for either clinical examination or MRI.[14] However, such expert interpretation has not yet been directly compared with MRI and may not be available to all providers. Because the present study utilized the final interpretation by radiology attendings at multiple verified trauma centers, it likely represents a more accurate (if not actually an overestimation) of the available resources and skill sets nationally. The study group is currently considering a follow-up study to blindly review CT images by a panel of experts and directly compare them to the MRI results.

This study has several limitations. The decision to obtain an MRI was at the discretion of the clinical team. Different centers may have had different thresholds for ordering MRI and thus may have selected patients with a higher pre-test probability for cervical spine injuries. Clustering or within specific center similarities between the subjects and their management also decreases the study's power to detect differences between groups through variance introduced by intra-center correlation. Furthermore, because the study included a select patient population at risk for cervical spine injury, the results may not represent the overall trauma population. In addition, the presence of neurological symptoms was captured only as a binary variable without recording the specific details. The study therefore cannot analyze whether the MRI results varied with the degree of symptoms.

In summary, although this study demonstrates that MRI identifies additional injuries not recognized on CT scans, the clinical significance of these injuries remains unclear. Further consensus from both the trauma and spine surgery disciplines will be required to define not only which injuries require treatment but the acceptable rate of missed injuries.

AUTHORSHIP

A.A.M., D.C.J., G.C.V., and K.A.D. designed this study. A.A.M., D.C.J., K.B., T.P., T.M., D.M., G.K., R.I.G., K.C.S., R.J.W., W.C., S.R.O., and K.L.B. contributed to data collection. A.A.M., D.C.J., K.B., and K.A.D. performed data analysis. A.A M., K.A.D., T.P., G.C.V., D.M., G.K., R.I.G., M.S.R., and R.J.W. participated in data interpretation. A.A.M., D.C.J., G.C.V., and R.J.W. wrote the article.

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DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Kenji Inaba (Los Angeles, California): Thank you. I'd love to thank the Program Committee and the AAST for the privilege of being here and discussing this great paper.

The authors have performed a very nice study examining the role of cervical spine MRI in patients who are unevaluable or with midline tenderness and a negative CT. This was a prospective trial from the ReCONECT trials group. They have addressed an important and practical question and the authors should be congratulated on their efforts.

I've got six specific questions for you today, Adrian.

Only patients who underwent MRI, performed at the discretion of the clinical team, were included. This is a very select segment of the population at risk of injury who required CT clearance. The overarching question we really need answered is, what is the sensitivity of CT for the detection of clinically significant injury. During the study time frame, how many of the patients at these eight centers had their spines evaluated by CT but did not undergo MRI, and were there any missed injuries? Without these patients, a true understanding of the diagnostic performance of CT cannot be assessed.

Patients who were unevaluable or had persistent midline tenderness were enrolled. 16% of these also had neurologic abnormalities. What about the other patients who could not be cleared clinically, specifically with isolated neurologic abnormalities or distracting injuries-were these patients excluded?

Next, this was a prospective study. Who performed the clinical exam? How was it standardized and how was the quality and consistency of the exam controlled for? According to the methods, "some of" the CT scans were from outside hospitals. What proportion and who read the CT results? Also, for these patients, who did the index clinical examination on these patients used for the analysis?

Additional imaging was obtained in 15.5% but was not specified in the results, what was this imaging and was the final diagnosis made on MRI or this additional imaging?

Finally, there were five missed injuries in patients without neurologic abnormalities that required instrumentation. Were these unevaluable or midline tenderness patients and were the CT scans reviewed for any abnormalities?

Dr. Patrick Reilly (Philadelphia, Pennsylvania): I enjoyed the presentation, just a quick question. Maybe it a little off the mark, but in your awake patients are flection extension films dead? Are they just not something that any of your patients did or you simply focused your study on people who got an MRI?

Dr. Thomas M. Scalea (Baltimore, Maryland): It's really nicely done. Why can you not get your centers to agree on a protocol, Adrian?

It would seem to me you have eight very high-quality centers. Put everybody in a room and nobody is allowed to leave until all agree to do it the same way. You could then really prospectively answer this question. We have been at this forever and still cannot seem to agree.

Dr. Walter Biffl (Honolulu, Hawaii): I believe that the senior author was the president of EAST when they released their guidelines suggesting CT only for clearance. And they published a paper out of Mass General indicating that they had changed to a CT-only protocol because of significant increases in delirium and pneumonia among patients who are kept in collars for prolonged lengths of time. Are CT-only clearance protocols in use at MGH, Yale, or any other centers?

Additionally, you noted a bunch of ligamentous injuries found on MRI; were these actually tears, or were they reported as sprains or strains which our spine surgeons say are irrelevant?

Dr. Adrian A. Maung (New Haven, Connecticut): Thank you for those insightful questions. I agree that this is a pretty select patient population and the results, especially the numbers, may not be generalizable to all trauma patients.

Because we used MRI as the gold standard we only looked at people who got both a CT scan and an MRI so I can't give you any numbers of people who got CT scans and were cleared.

We did include everybody who was unavailable for various reasons so we included distracting injuries, neurological injuries etc. We did not exclude those patients.

Although this was a prospective study, it was a prospective observational study so we didn't direct the clinical care of these patients in any shape or form so there was no standardization of the exam.

We didn't specifically look at how many CT scans were from outside facilities. We are making the assumption that some of those CT scans would have been from outside as many of these centers are regional referral centers. But we did stipulate that all CT scans had to be deemed as normal by an attending radiologist at that center and that it had to be documented in the medical record.

The final diagnosis was based on the MRI. The additional imaging included flex-ex, which is still used sometimes, additional repeat MRI and CTA. And there were one or two patients who underwent a brachial plexus MRI based on findings on the c-spine MRI.

The five patients without symptoms that underwent surgery were mixed. Three of them had pain and two were considered unavailable.

We didn't over-read the CT scans for the study. We discussed whether we should over-read just the CT scans that were positive but then agreed that this would induce potential bias. We are however preliminarily planning to actually have a study to look at all the CT scans so we can identify – whether our panel of experts can identify, these injuries that were potentially missed or whether that panel of experts can then over-call things. So instead of just looking at limited people with positive MRIs we want to look at everybody.

To Dr. Reilly's question, I think I answered that. Flex-ex films are utilized occasionally. At our center we don't use it as a routine.

Dr. Scalea, it's a very good question. We could although we had a lot of discussion about even actually how to conclude what our results meant as many of the authors have very strong opinions about the role of MRI and they're not necessary congruent.

But I think we agreed that MRI does detect additional injuries. The big question, which is still unanswered, is what is the significance of these injuries.

I know that at least ten years ago when I trained at Mass General, they did have a protocol that everybody would get cleared by CT scan only. Clearly, some of their patients do get MRIs so I'm not sure how much they're using that protocol currently. And, although Dr. Davis was the president of EAST at the time of the guideline but I don't believe she had any influence on how the recommendation was devised.

Thank you, again.