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Clinical Study

Is focused magnetic resonance imaging adequate for treatment decision making in acute traumatic thoracic and lumbar spine fractures seen on whole spine computed tomography?

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Abstract

PURPOSE: To assess whether a focused magnetic resonance imaging (MRI) limited to the region of known acute traumatic thoracic or lumbar fracture(s) would miss any clinically significant injuries that would change patient management.
STUDY DESIGN/SETTING: A multicenter retrospective clinical study.
PATIENT SAMPLE: Adult patients with acute traumatic thoracic and/or lumbar spine fracture(s).
OUTCOME MEASURES: Pathology identified on MRI (ligamentous disruption, epidural hematoma, and cord contusion), outside of the focused zone, an alteration in patient management, including surgical and nonsurgical, as a result of the identified pathology outside the focused zone.
METHODS: Records were reviewed for all adult trauma patients who presented to the emergency department between 2008 and 2016 with one or more fracture(s) of the thoracic and/or lumbar spine identified on computed tomography (CT) and who underwent MRI of the entire thoracic and lumbar spine within 10 days. Exclusion criteria were patients with >4 fractured levels, pathologic fractures, isolated transverse, and/or spinous process fractures, prior vertebral augmentation, and prior thoracic or lumbar spine instrumentation. Patients with neurologic deficits or cervical spine fractures were also included. MRIs were reviewed independently by one spine surgeon and one musculoskeletal fellowship-trained emergency radiologist for posterior ligamentous complex (PLC) integrity, vertebral injury, epidural hematoma, and cord contusion. The surgeon also commented on the clinical significance of the pathology identified outside the focused zone. All cases in which pathology was identified outside of the focused zone (three levels above and below the fractures) were independently reviewed by a second spine surgeon to determine whether the pathology was clinically significant and would alter the treatment plan.
RESULTS: In total, 126 patients with 216 fractures identified on CT were included, with a median age of 49 years. There were 81 males (64%). Sixty-two (49%) patients had isolated thoracolumbar junction injuries and 36 (29%) had injuries limited to a single fractured level. Forty-seven (37%) patients were managed operatively. PLC injury was identified by both readers in 36 (29%) patients

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with a percent agreement of 96% and κ coefficient of 0.91 (95% CI 0.87–0.95). Both readers independently agreed that there was no pathology identified on the complete thoracic and lumbar spine MRIs outside the focused zone in 107 (85%) patients. Injury outside the focused zone was identified by at least one reader in 19 (15%) patients. None of the readers identified PLC injury, cord edema, or noncontiguous epidural hematoma outside the focused zone. Percent agreement for outside pathology between the two readers was 92% with a κ coefficient of 0.60 (95% CI 0.48–0.72). The two spine surgeons independently agreed that none of the identified pathology outside of the focused zone altered management.

CONCLUSIONS: A focused MRI protocol of three levels above and below known thoracolumbar spine fractures would have missed radiological abnormality in 15% of patients. However, the pathology, such as vertebral body edema not appreciated on CT, was not clinically significant and did not alter patient care. Based on these findings, the investigators conclude that a focused protocol would decrease the imaging time while providing the information of the injured segment with minimal risk of missing any clinically significant injuries.

Keywords: Spine Trauma; Magnetic Resonance Imaging; Spine Fracture; Posterior ligamentous complex injury; Spine stability; Thoracolumbar spine

Introduction

Fracture morphology and mechanical and neurological stability are the primary drivers of treatment decision making for thoracic (T) or lumbar (L) spine fractures [1–3]. Computed tomography (CT) is the standard imaging modality for the initial evaluation of suspected spine trauma and provides excellent visualization of the osseous anatomy and fracture patterns and can be performed expeditiously [4–6]. However, the most difficult determination is whether a fracture is mechanically stable. Although some fracture patterns are clearly unstable, such as those exhibiting dislocations, gross translational or rotational deformity, others have more equivocal findings, thereby placing the increasing importance on the ligamentous structures that are visualized only using Magnetic Resonance Imaging (MRI) [5]. The posterior ligamentous complex (PLC) is critical in serving as a stabilizing tension band, and its integrity is widely held as the key to stability [7–11]. In some scenarios, PLC status alone may be the determining factor in whether surgical treatment is recommended [1–3].

Not everyone supports the use of MRI, especially in polytrauma patients with multiorgan injuries that may require close monitoring and support. Criticisms include cost, length of the study, incompatible support devices, and wide variability in its reported accuracy and reliability in PLC injury detection [2, 12–18]. Hesitation regarding the use of MRI also stems from the common use of an unnecessarily exhaustive exam of the entire T and L spine to specifically address a ligamentous issue in a focal region. In other words, if the intended role of MRI is for additional characterization of a known fractured segment and not for additional injury screening or detection, a focused MRI including three levels above and three levels below the fractured segment may provide the required information. By its nature, a focused MRI would be shorter, relatively cost efficient to acquire, and may achieve greater spatial resolution by virtue of the shortened scan region. Centering the fractured level in the middle of the scan range would also avoid challenges of partially assessing the traumatized region at the caudal end of the thoracic spine MRI and at the cranial end of the lumbar spine MRI (Fig. 1). A countervailing concern is that a focused study range might miss injuries outside of this focused region.

To that end, the specific aim of this study was to assess whether a focused MRI protocol, limited to the region of known acute traumatic thoracic or lumbar fracture(s), would miss any clinically meaningful injuries and thereby change management.

Methods

Institutional Review Board approval was obtained for this retrospective study. The study was performed at two affiliated urban, academic hospitals, both of which are American College of Surgeons certified level 1 trauma centers and serve as tertiary referral centers.

Cohort identification

A query was performed of the shared electronic medical record system for adult patients (age at least 18 years) who underwent MRI of both the thoracic and lumbar spines between 2008 and 2015 within 10 days of their diagnosis of a thoracic or lumbar spine fracture by CT. A patient was included in the study if at least one fracture was detected on CT. Patients who were initially seen at an outside hospital and had a CT performed before transfer to one of the institutions were included if the outside hospital CT had been imported into the local Picture Archive and Communications System. All MRI studies were performed at one of the study institutions. The presence of fracture was identified by review of the CT report. The imaging studies were reviewed to ensure MRI coverage of the entire thoracic and lumbar spine. Patients with five or more fractured vertebrae were excluded as it was felt that a focused MRI including

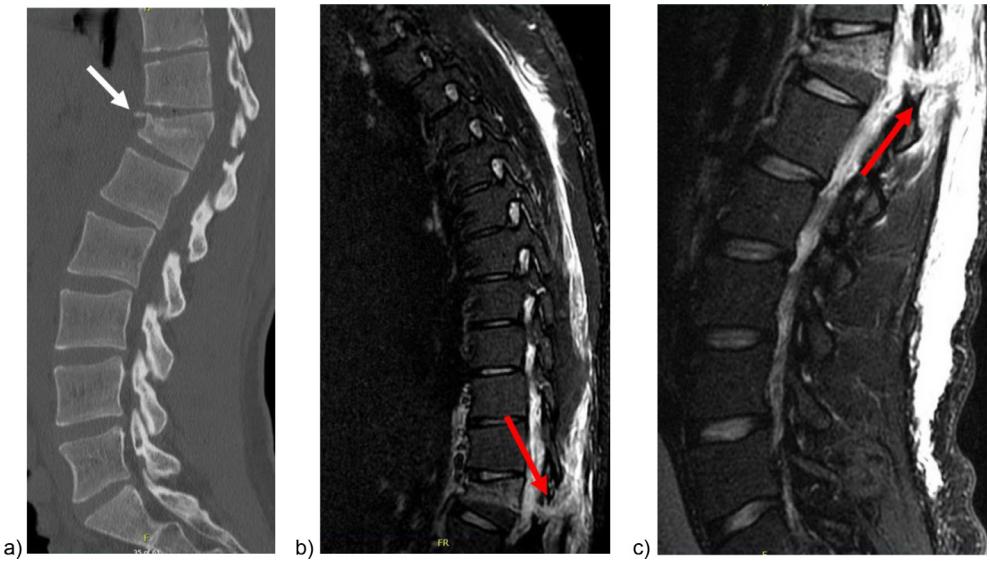


Fig. 1. CT (Left) and sagittal STIR MRI of the thoracic (Middle) and lumbar (Right) spine of a patient with a T12 compression fracture diagnosed on CT (white arrow). The fractured T12 vertebra is visualized at the bottom of the thoracic MRI and top of the lumbar MRI, making evaluation of this level cumbersome. In this example, there is a clear injury to the posterior ligamentous complex (PLC) (red arrows), but PLC evaluation in more equivocal cases can be hampered by the need for evaluation of two separate sequences.

all of these levels would be impractical. Other exclusion criteria were pathologic fractures related to primary malignancy or metastases, isolated transverse, and/or spinous process fractures on CT, prior vertebral augmentation, and prior spine instrumentation. Patients with neurologic deficits or cervical spine fracture(s) were included. A total of 126 patients met inclusion criteria.

Data collection

Two co-investigators who did not subsequently grade MRI exams recorded the patient demographics including age, gender, mechanism of injury, fracture levels, morphology of the fractured segment based on AOspine injury classification, and whether the injury was initially managed operatively or nonoperatively.

CT technique

Patients were scanned on a variety of multidetector CT scanners, but all patients had axial images of 5 mm slice thickness or thinner and coronal and sagittal reformatted images of 3 mm slice thickness or thinner using a bone algorithm, along with soft tissue algorithm axial reconstructions.

MRI technique

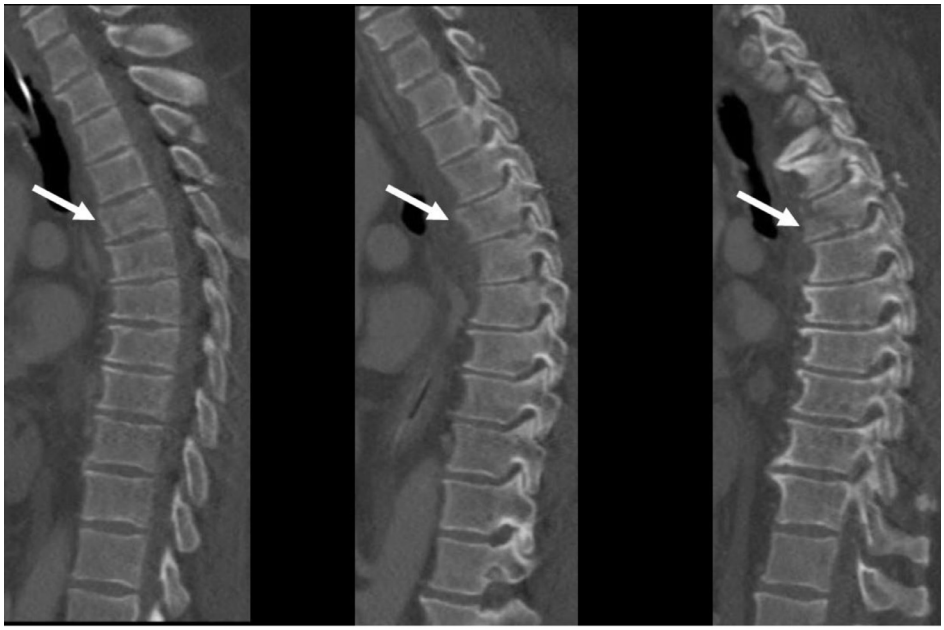
MRIs were performed on different scanners: 102 patients had scans using a 1.5-T unit (GE Healthcare, Waukesha, WI, USA) and 24 patients using a 3-T unit (GE Healthcare, Waukesha, WI, USA and Siemens Health Care, Malvern, PA, USA).

Review of MRI findings

MRIs were reviewed independently by a musculoskeletal fellowship-trained emergency radiologist with 12 years of clinical experience and a spine surgeon with 15 years of experience in spine trauma. Both readers had full access to the medical records including finalized radiology reports for CT and MRI, operative notes, clinical notes, and follow-up radiology studies.

A “fractured segment” was defined as a fracture isolated to a single vertebra, or fracture-dislocation involving two or more adjacent vertebrae. For instance, a fracture isolated to the T10 vertebra was termed a "single-level fractured segment," whereas a fracture-dislocation involving T9 to T11 was termed a three-level fractured segment.

The “focused zone” was defined as the region of the spine extending from three levels above to three levels below the fractured segment identified on CT (Fig. 2). For instance, if a single-level fractured segment was at T12, the focused zone was defined as T9 to L3. If the fractured segment extended from T9 to T12, the focused zone was defined as T6 to L3. If there were multiple, noncontiguous fractured segments, and the focused zones for each fractured segment vertebra were overlapping (ie, T6 and T9), the focused zone was defined to extend from the top of the upper focused zone to the bottom of the lower focused zone (ie, T3 to T12). If the fracture involved multiple fractured segments on CT with nonoverlapping focused zones (ie, T4 and L1), separate focused zones were defined (T1 to T7 and T10 to L4). The “distant zone” was defined as the region of thoracic or lumbar spine outside the focused zone(s). For each focused and distant zones, the readers recorded the



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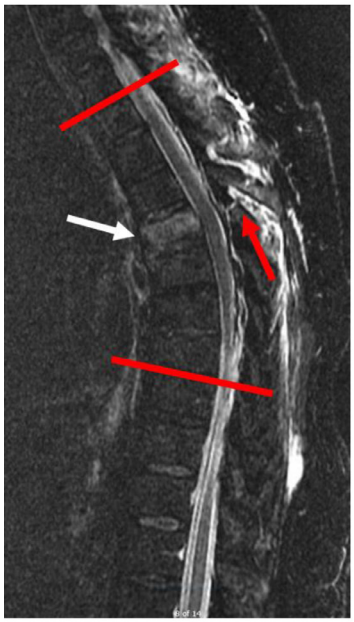

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Fig. 2. Sagittal and parasagittal CT images (Top) demonstrate a fracture disrupting both superior and inferior end plates at T5 (white arrows). Thoracic spine sagittal STIR MRI (Bottom) demonstrates increased signal at T5 consistent with an acute fracture (white arrow) as well as PLC injury (red arrow). A focused MRI, as defined in this study, would be limited to T2 through T8 in this case, as demarcated by the red lines in the Bottom panel.

injury of vertebra, PLC, and cord. The radiologist also commented on the presence of epidural hematoma in the distant zone. The spine surgeon commented on the presence of any pathology in this zone that would have been clinically significant and altered the patient's treatment plan in any way, including conversion from nonoperative to operative management, from no bracing to bracing (or vice versa), or from one type of brace to another. The surgeon had full access to the medical records including clinical notes and imaging studies to help him make this decision.

A second spine surgeon, who was blinded to the readings by the other two readers, independently reviewed all MRI studies that showed findings of vertebral injury, cord edema, and epidural hematoma in the distant zone. This surgeon had

Table 1
Inter-observer agreement for the posterior ligamentous complex (PLC) injury in the focused zone (n=139 focused zones)

PLC injury (139 zones)		Radiologist		Kappa	Percent agreement
		Present	Absent	0.91 (95% CI 0.87–0.95)	(36+98)/139=96%
Surgeon	Present	36	1		
	Absent	4	98		

access to the CT studies and was made aware of the fractured segment. The surgeon commented on the presence of any pathology in the distant zone that would be clinically significant or alter the patients' treatment plan as detailed above.

Statistical calculations included percentage of cases with pathology outside of the focused zone (ie, distant zone pathology) by one or both readers and percent agreement and Cohen kappa coefficient (κ) for vertebral injury and PLC tear. 95% confidence intervals for Cohen kappa coefficient were calculated. All calculations were carried out on Microsoft Excel 2010 (Microsoft Corporation, Redmond, WA, USA).

Results

Demographics

The study cohort comprised 81 (64%) males (median age 49 years; range 17–87 years) and 45 (36%) females (median age 41 years; range 17–92 years). The most common mechanism of injury was fall (55%) followed by motor vehicle collision (18%) and pedestrian struck (8%). The median interval between CT and MRI was 1 day (range of 0–10 days) with 92% of MRIs performed within 48 hours of the CT. A total of 79 patients (63%) were initially managed nonoperatively.

Focused zone

Among these 126 patients, a single level was fractured in 36 (29%), two levels in 63 (50%), three levels in 24 (19%), and four levels in 3 patients (2%). Based on CT, the injury was isolated to the thoracolumbar junction (T10–L2) in 62 out of 126 patients (49%). Ninety-four out of 126 patients had either a single-level fracture or contiguous fractures resulting in only one focused zone. Thirty-two patients (25%) had noncontiguous fractures. Of these, 19 patients had one overlapping focused zone and 13 had two nonoverlapping focused zones, resulting in a total of 139 focused zones in 126 patients.

The fractures were classified as type A (compression) in 91 patients (72%), type B (distraction) injuries in 26 patients (21%), and type C (translation) injuries in 9 patients (7%).

Results for PLC injury are summarized in Table 1. Both readers independently agreed that the PLC was injured in 36 focused zones (26%) and intact in 98 (71%). The spine surgeon identified PLC injury in one focused zone (0.7%) that the radiologist did not, whereas the radiologist identified PLC injury in four focused zones (3%) that the spine surgeon did not. The percent agreement for PLC injury was 96% with a κ coefficient of 0.91 (95% CI 0.87–0.95). For the subset of 91 type A injuries, κ coefficient was 0.86 (95% CI 0.78–0.94).

Distant zone

The prevalence of vertebral injury in the distant zone is summarized in Table 2. Both readers independently agreed that there was no distant zone vertebral injury in 107 patients (85%). In nine patients (7%), both readers observed marrow edema in the distant zone that they attributed to either contiguous or noncontiguous compression fractures, as shown in Fig. 3. In 10 other patients (8%), there was disagreement due to the potential etiology of marrow edema as degenerative or post-traumatic. The percent agreement for vertebral injury outside the focused zone was 92% with a κ coefficient of 0.60 (95% CI 0.48–0.72). The presence of vertebral fracture or marrow edema of unclear etiology in the distant zone was not deemed by either spine surgeon to be clinically significant in any of these 19 patients (15%). Both readers independently agreed that there was no PLC injury in the distant zone in any patient. None of the readers identified any instance of cord edema or contusion in the distant zone. The radiologist did identify the presence of epidural hematoma in the distant zone in six patients (5%), though all started in the

Table 2
Inter observer agreement for vertebral injury outside of the focused zone (n=126 patients)

Vertebral injury (126 patients)		Radiologist		Kappa	Percent agreement
		Present	Absent	0.60 (95% CI 0.48–0.72)	(9+107)/126=92%
Surgeon	Present	9	1		
	Absent	9	107		

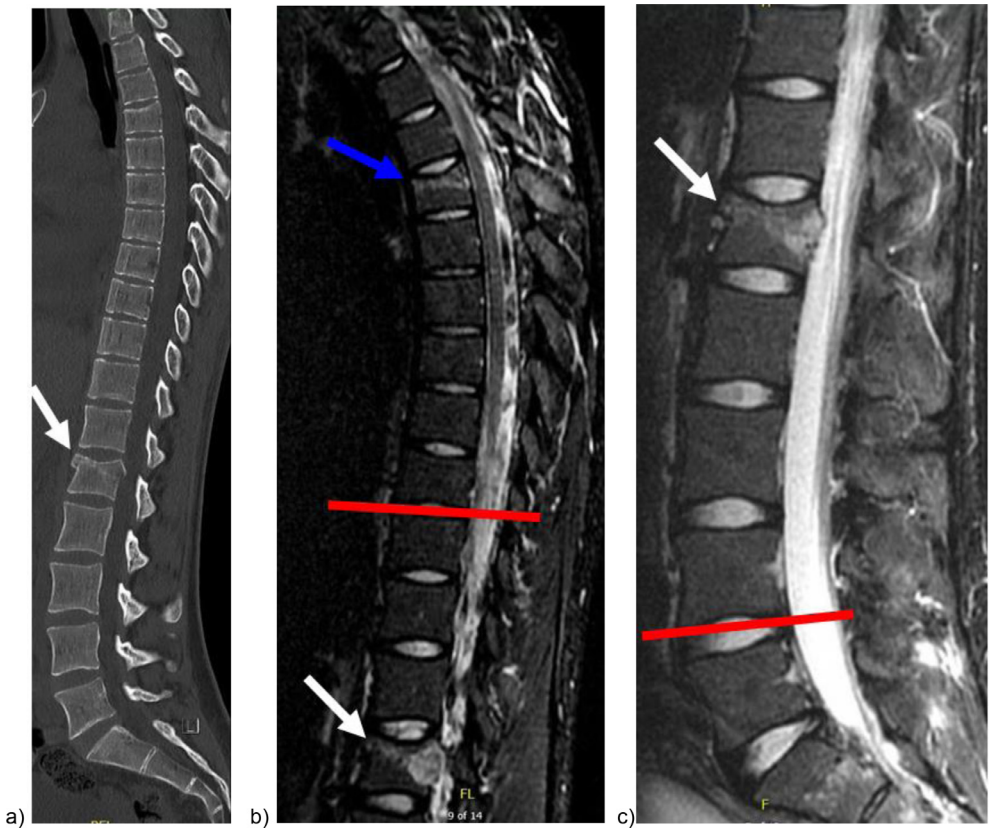

Fig. 3. Sagittal CT (Left) demonstrates an incomplete burst fracture involving superior end plate at L1 (white arrow). Thoracic (Middle) and lumbar (Right) spine sagittal STIR MRI images demonstrate L1 fracture (white arrows). The proposed focused zone would be limited to T10 through L4 in this case, as demarcated by the red lines in b and c. Thoracic spine sagittal STIR MRI in b demonstrates increased signal at T4 consistent with an acute compression fracture (blue arrow) occurring in the distant zone (i.e. outside of the focused zone). This injury would be missed on a focused MRI.

focused zone and extended outside. All six patients with epidural hematoma in the distant zone also had vertebral injury in the distant zone reported by both readers. The extension of epidural hematoma from the focused zone into the distant zone was not deemed to be clinically significant by either spine surgeon, and none resulted in compression of the cord in the distant zone.

In summary, a total of 19 patients (15%) showed potential vertebral injury in the distant zone. None of these patients showed any cord edema, PLC injury, or noncontiguous epidural hematoma outside of the focused zone. Of these 19 patients, both spine surgeons independently found that none of the findings in the distant zone would change the patient's treatment plan, including the decision for surgery versus nonoperative management, operative plan, and type of brace or activity restrictions relative to the treatment plan that would be rendered based on the CT and an MRI isolated to three levels above and below the fractured level (s) identified on CT.

Discussion

In this retrospective, multicenter study of two academic level 1 trauma centers, the investigators sought to address whether a focused MRI that evaluates only the region of known injury (ie, three levels above and three levels below the fractured segment) as established by CT would miss any clinically significant pathology outside of this focused zone. It was found that injuries outside the focused zone were limited to detection of bone marrow edema in vertebral bodies and contiguous extension of epidural hematomas. When both are considered, 15% of the 126 patients in our cohort had injuries outside of the focused zone. Although this seems to be substantial, no patients had PLC injuries or a change of management based on findings outside the focused zone.

A complete T and L spine MRI for trauma at the authors' institutions requires at least 40 to 45 minutes of imaging time (Supplementary Table 3). Thus, strategies to reduce the time of acquisition by utilizing a focused MRI would be helpful, particularly in patients with other injuries that might require close monitoring and intervention. Reducing the time of MRI acquisition might also be helpful in preventing patient movement, which is more feasible for a 15-minute study compared to a 45-minute study. This focused MRI protocol will not only reduce the study duration but also would improve MRI access for other patients. The proposed focused MRI protocol consists of a sagittal short tau

inversion recovery (STIR), sagittal T2, sagittal T1, and axial T2 sequences of the focused zone (Supplementary Table 4).

Advocates of complete thoracic and lumbar spine MRI may cite the high rates of noncontiguous spine fractures diagnosed on whole spine MRI. Indeed the current study found distant pathology in 15% of patients in the form of minor fractures with bone edema outside the focused zone. Marrow edema can represent bone contusion or subtle fracture, usually in the presence of osteopenia or osteoporosis that is not visualized on CT. MRI is known to have exquisite sensitivity for detection of these findings. Green and Saifuddin reported an overall incidence of secondary injuries on whole spine MRIs of 77.6% and a 34% rate of noncontiguous fractures. However they did not compare MRI to CT, and many of these injuries would likely have been detected by CT [19]. Consistent with the findings in the current study, this group found that the majority (57%) of noncontiguous injuries were bone bruises, which would not have been clinically significant in terms of affecting treatment plan [19].

Although it should not be considered a screening tool to replace CT, an alternative option for those who feel strongly about using MRI in such a manner might be to acquire sagittal STIR images of the entire thoracic and lumbar spine to screen for pathology in the distant zone in lieu of a comprehensive study that would take much longer. In fact, replacing only focused sagittal STIR with full thoracic and lumbar sagittal STIR would increase the total acquisition time from 15 minutes to 18 minutes with the additional benefit of including bone marrow edema and full extent of epidural hematoma in the distant zone.

Before this study, the surgeon investigators expressed a concern about whether a planned fusion may have been extended cranially or caudally based on new injuries detected in the distant zone. However, none of the injuries found in the distant zone were considered significant enough to warrant extension of the surgical construct. Again, the surgeons a priori felt that PLC injury extending outside of the focused zone could have affected the surgical plan, though there were no such instances in the study cohort. There were also no instances in which the treatment recommendation would have changed from nonoperative to operative management on the basis of distant zone pathology seen on the MRI.

Balancing the importance of PLC assessment and the inherent time and cost limitations of an MRI, we sought to answer the question of whether a shorter, focused MRI study would allow for PLC evaluation without missing clinically significant, distant injuries. The results from this study support our hypothesis that clinically important injuries would not be missed on a focused MRI study. It is possible that the decreased burden of a focused MRI would lower the threshold for surgeons to request an MRI in equivocal cases, perhaps leading to more informed treatment decisions. Additionally, the actual images obtained would be centered on the region of known injury and would hence provide more easily interpretable visualization of the often-injured thoracolumbar junction in particular. This would be particularly beneficial to the spine surgeons in the operating room where often one key sagittal image is displayed on the monitor at the time of surgery. Surgeons are often frustrated in that a thoracolumbar injury is partially imaged on two separate studies. A focused study will display the injured segment on one single sagittal image. Although it is possible to request a stitched or composed MR image that can project the entire injured segment on one image, this results in an additional step for the MRI technologist working on emergent cases.

At the authors' institution, MRI technologists and radiologists have supported the implementation of focused MRI in evaluating traumatic T or L spine fractures. The routine long imaging time in these multitrauma patients requiring close monitoring and support device often forces the MRI technologists to acquire thick axial sections to cover the entire T and L spine for the sake of completeness. These thick sections are challenging to the interpreting radiologists as they result in poor characterization of the ligamentous injury and decrease the conspicuity of focal cord edema and/or small epidural hematoma at the level of injured segment. With the shorter focused protocol, the technologist acquires axial sections only through the injured segment resulting in overall higher resolution and better quality study for both radiologists and spine surgeons.

Though not the focus of the investigation, results from this study also lend support for MRI as a reliable tool for PLC assessment. We found excellent interobserver reliability with kappa of 0.91 for all 126 fractures and 0.86 for the 91 type A fractures. Kappa values for interobserver variability of PLC injury have been previously reported with a wide range of values from 0.188 to 0.803, likely due to lack of standardization of what characterizes a true PLC injury on MRI [18]. Strengths of our data include a large number of cases and the inclusion of a spine surgeon as the second reader.

Our study certainly has limitations, primarily related to its retrospective nature. The most notable is selection bias in obtaining the cohort for this study. Our study included only patients with T or L spine fractures who also had MRI of the entire thoracic and lumbar spine. There are a considerable number of patients with fractures diagnosed on CT who did not undergo an MRI study, usually because the injury is felt to be clearly stable or unstable and no further advanced imaging is deemed necessary by the treating team. In other situations, an MRI of either the T or the L spine was obtained, depending on the level of injury. Our study cohort included only those patients who had the MRI performed within 10 days of their CT study, and therefore, the decision making was restricted to only 10 days. Although 92% of patients obtained the MRI within 48 hours, we chose the window of 10 days to include the patients in whom spine management was deferred due to other associated life-threatening injuries. Another limitation of the study was to not specifically address the patients with

osteoporosis even though they are likely to fracture more levels. Our goal with the study was to evaluate whether the focused protocol could be generalized to all patients regardless of osteoporosis. Use of MRI machines with different field strength resulted in heterogeneity in our study cohort due to difference in spatial and temporal resolution. Again, this mirrors the typical clinical practice in after hours and emergent situations when the availability of MR machine becomes a limiting factor. We did not measure the MR duration or potential cost savings in this study due to its retrospective nature. Our study is susceptible to recall bias as the radiological studies were not de-identified; however, the surgeon reviewer was the treating physician in only 8% of patients and the second spine surgeon had not provided clinical care to any of the patients. We included patients regardless of their neurologic status as the study sought to look for the incidence of radiologic pathology outside of the focused zone in all comers. It is possible that the presence of neurological deficit not explained by the fracture level would justify obtaining entire T and L spine MRI.

Conclusions

In patients with thoracic, thoracolumbar, or lumbar spine fractures identified on dedicated thoracic and lumbar spine CT for whom MRI is sought for further characterized of the injured segment, a focused MRI limited to three levels above and below the level of known injury would detect all clinically significant pathology and provide better visualization of the injured zone.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spinee.2018.08.010.

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