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BLUNT THORACOLUMBAR-SPINE TRAUMA EVALUATION IN THE EMERGENCY DEPARTMENT: A META-ANALYSIS OF DIAGNOSTIC ACCURACY FOR HISTORY, PHYSICAL EXAMINATION, AND IMAGING

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☐ **Abstract—Background: Delayed diagnoses of unstable thoracolumbar spine (TL-spine) fractures can result in neurologic deficits and avoidable pain, so it is important for clinicians to reach prompt diagnostic decisions. There are no validated decision aids for determining which trauma patients warrant TL-spine imaging. Objective: Our aim was to quantify the diagnostic accuracy of the injury mechanism, physical examination, associated injuries, clinical decision aids, and imaging for evaluating blunt TL-spine trauma patients. Methods: A search strategy for studies including adult blunt TL-spine trauma using PubMed, Embase, Scopus, CENTRAL, Cochrane Database of Systematic Reviews, and ClinicalTrials.gov was performed. Excluded studies lacked data to construct 2 × 2 tables, were duplicates, were not primary research, did not focus on blunt trauma, examined associated injuries without any utility in identifying TL-spine injuries, only studied cervical-spine fractures, were non-English, had a pediatric setting, or were cadaver/autopsy reports. Risk of bias was assessed using the Quality Assessment Tool for Diagnostic Accuracy Studies. Diagnostic predictors were analyzed with a meta-analysis of sensitivity, specificity, and likelihood ratios. Results: In blunt trauma patients in the emergency department, the weighted pretest probability of a TL-spine fracture was 15%. The estimates for detection of TL-spine fractures with plain film were: positive likelihood ratio (+LR) = 25.0 (95% confidence interval [CI] 4.1–152.2; I^2 = 94%; p < 0.001) and negative likelihood ratio (−LR) = 0.43 (95% CI 0.32–0.59; I^2 = 84%; p < 0.001), and for computed tomography (CT) were: +LR = 81.1 (95% CI 14.1–467.9; I^2 = 87%; p < 0.001) and −LR = 0.04 (95% CI 0.02–0.08; I^2 = 23%; p = 0.26). Conclusions: CT is more accurate than plain films for detecting TL-spine fractures. Injury mechanism, physical examination, and associated injuries alone are not accurate to rule-in or rule-out TL-spine fractures.**

☐ **Keywords—blunt trauma; spine trauma; diagnostic imaging; radiography; computed tomography**

Conflict of interest—CMM declares having received funding from Zimmer Biomet, United States for consulting, and holds a faculty position for AOTrauma/AOTrauma North America: which includes speaking and travel fees. The remaining authors declare no conflicts.

INTRODUCTION

Thoracolumbar-spine (TL-spine) injuries occur in approximately 7% of blunt trauma injuries, accounting for approximately half of vertebral injuries (1–3).

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Complications of misdiagnosis include radiculopathy or spinal cord injuries, with a 19–50% occurrence rate (4–6). Neurologic deterioration is up to eight-fold more likely with delayed or missed diagnosis (4,7,8). Plain films can miss injuries or assessments for instability. As depicted in Figure 1, computed tomography (CT) of the spine identifies fracture comminution more accurately.

Unlike imaging of the cervical spine (C-spine), there are no validated decision aids for determining which trauma patients warrant TL-spine imaging. This lack of evidence may explain why diagnostic guidelines vary. The Eastern Association for the Surgery of Trauma and the American College of Radiology recommend CT as the modality of choice, whereas Advanced Trauma Life Support and the National Institute for Health and Care Excellence recommend plain films initially (6,9–11).

CT is increasingly used to screen the torso for visceral trauma, raising the issue of whether dedicated TL-spine reformations are required to accurately identify clinically significant TL-spine injuries. Furthermore, it is unclear whether patients with minor trauma (who do not require initial CT screening) may have their TL-spine cleared by physical examination alone. The disadvantages of CT imaging include increased radiation exposure, incidental findings prompting consideration, or obtaining, of further testing, prolonged emergency department (ED) lengths of stay, and higher costs (12–15). Expert panels within the specialty of emergency medicine and other organizations and specialty societies, and larger guideline panels have identified the radiographic clearance of blunt TL-spine trauma patients as a priority for further investigation (3,16).

The primary objective of this systematic review was to quantify parameters of diagnostic accuracy of commonly used imaging modalities for blunt TL spine trauma in patients aged 14 years or older, with a focus on the mechanism of injury, physical examination findings, and commonly employed imaging modalities.

MATERIALS AND METHODS

Study Design

This article adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and the Meta-Analysis of Observational Studies in Epidemiology (MOOSE) reporting guidelines (17,18). Eligible studies included patients aged 14 years or older in an ED after blunt trauma, in whom evaluations for TL-spine injuries were reported in sufficient detail to reconstruct 2 × 2 tables. True positive (TP), false positive (FP), true negative (TN), and false negative (FN) were defined a priori. *Disease* indicated TL-spine injury and *non-disease* indicated the absence of TL-spine injury, as defined by the original study's criterion standard.

Study Setting and Protocol

A medical librarian created the electronic search strategy, which was completed on January 30, 2017, limited to

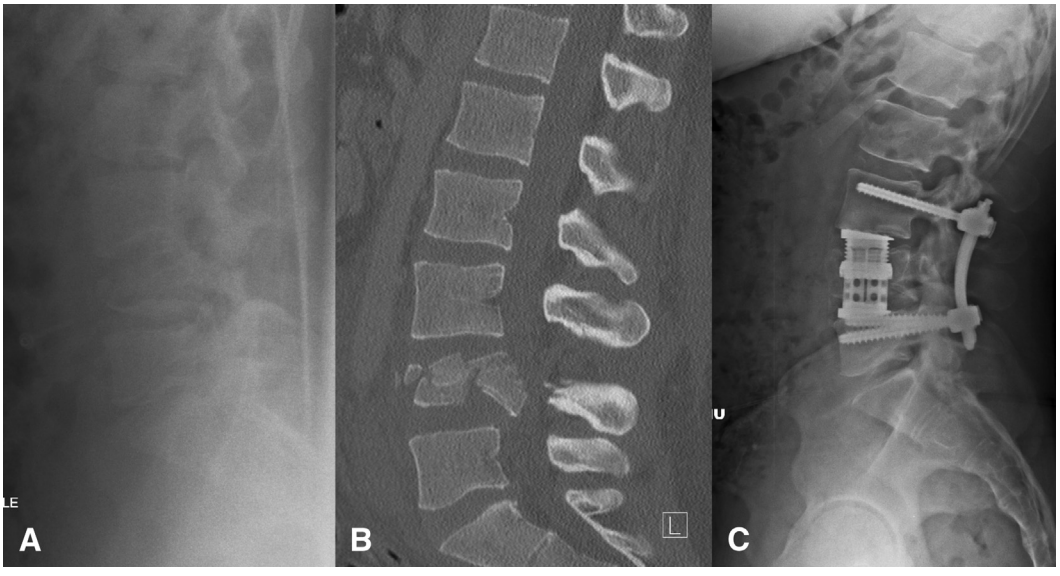

Figure 1. Three sagittal images of the lumbar-spine in a 28-year-old male involved in a motor vehicle crash. (A) Cross-table lateral lumbar-spine radiograph in the emergency department at the time of injury demonstrates a fracture of L4 with loss of vertebral height. (B) Sagittal reconstruction of the lumbar-spine computed tomography demonstrates more detail, including comminution of the fracture, retropulsion of fragments into the spinal canal, and a three-column injury. (C) Six-month follow-up after surgical stabilization and healing, upright lateral lumbar-spine radiograph with maintained alignment and implants.

English, and exported to EndNote. Full search strategies are available in Supplementary Appendix A. Two authors independently reviewed the titles and abstracts to identify relevant articles. Studies were excluded if they lacked data to construct 2 × 2 tables, were duplicates, were case reports/narrative reviews, lacked focus on blunt trauma, examined associated injuries without using them as predictive factors for identifying TL-spine injuries (such as using spine injuries to predict traumatic aortic injuries), only studied C-spine fractures, were not printed in the English language, were performed at a pediatric hospital, or were cadaver/autopsy reports. Authors were contacted if their articles lacked sufficient detail to reconstruct 2 × 2 tables. Two investigators independently hand-searched abstracts from scientific assemblies, including: *Academic Emergency Medicine*; *Annals of Emergency Medicine*; *American Journal of Roentgenology*; *Skeletal Radiology*; *The Spine Journal*; *Spine*; *Journal of Neurological Surgery: Spine, Journal of Trauma, Injury, Infection, and Critical Care*; *Journal of Trauma and Acute Care Surgery*; *Journal of Orthopaedic Trauma*; *Journal of Bone and Joint Surgery* (American and British editions), and society presentations from Orthopaedic Trauma Association meetings and American Association of Neurological Surgeons meetings.

Two authors independently evaluated a study's risk of bias and applicability using the revised Quality Assessment Tool for Diagnostic Accuracy Studies (QUADAS-2) (19). The QUADAS-2 evaluation was performed multiple times for studies examining multiple index tests. Responses were compared, disagreements recorded, and discussed. A third author adjudicated disagreements. The authors established several a priori considerations for the QUADAS-2 assessments:

- Increased risk of inappropriate exclusions occurred when studies excluded patients with difficult to diagnose TL-injuries; those who were not admitted or underwent spine surgery; or when certain patients did not receive the index/criterion test, but should have.
- A Level I or II trauma center represented the most relevant, least biased setting. Acute blunt trauma patients represented the patients of direct relevance. Studies in other settings or different populations were "low applicability."
- If there was no mention of blinding index test interpreters to the criterion standard or vice versa, then prospective studies were "uncertain" and retrospective studies were "high risk."
- If plain film radiography lacked anteroposterior (AP) and lateral views, or if CT test protocols used < 64 slices, the index test conduct or interpretation were "low applicability."
- Studies in which all patients received CT, magnetic resonance imaging (MRI), surgical confirmation, or clinical follow-up were low risk of bias.
- An appropriate interval between the index test and the criterion standard was when both tests occurred during the patient's ED visit or initial hospitalization.

Measures

Two authors independently abstracted study data: clinical setting, location, age, inclusion criteria, criterion standard, diagnostic modality specifications, TL-spine injury prevalence, study design, index tests, sensitivity (SN), specificity (SP), positive likelihood ratio (+LR), and negative likelihood ratio (−LR). Index tests or data included injury mechanism, history or physical examination findings of presence or absence of "associated injuries," results of plain film studies, and results of CT for diagnosing TL-spine fractures. CT studies had two groups: routine chest-abdomen-pelvis (CAP) CT scans, and reformatted CT images of the TL-spine, which required a specified axial magnification and bone algorithm reconstruction. We referred to these as "CAP CT" and "reformatted TL-spine CT," respectively. We also evaluated the accuracy of ultrasound (US) and MRI to detect injuries to the TL-spine posterior ligamentous complex (PLC). When possible, we distinguished all fractures from clinically significant fractures, as the latter required surgical stabilization, orthotics, or were deemed "unstable."

Data Analysis

Abstracted data were used to recreate 2 × 2 tables and calculate SN, SP, +LR, and −LR. If studies used 3 × 2 tables, including a third "equivocal" result, 2 × 2 tables were created by conservatively adding the equivocal results with a true injury to the FN cell and those without injury into the FP cell (20). We also analyzed thoracic or lumbar injury subgroups. Data were preferentially abstracted based on the presence of injuries using individual patients as the population. Results presenting individual vertebrae as the population (e.g., fractured vs. unfractured vertebrae), were analyzed separately. If studies used multiple observers and calculated SN and SP based on mean averages, these values were used to recreate 2 × 2 tables. When more than one study assessed the same index test, we computed meta-analysis estimates using MetaDiSc (Hospital Univeritario Ramon y Cajal, Madrid, Spain) and forest tree plots for SN, SP, +LR, and −LR using a random-effects model (21). Pretest probability (prevalence) was estimated using a

weighted average. The DerSimonian-Laird random effects model was used to calculate interstudy heterogeneity among pooled SN and SP using the index of inconsistency (I^2) (22,23). QUADAS-2 between-rater agreement was quantified using Cohen's kappa (κ) with IBM SPSS Statistic for Windows, version 22.0 (Armonk, NY).

RESULTS

The primary search yielded 6420 articles, with 224 selected for review and 14 abstracts identified via hand search (Figure 2). The 48 included studies are summarized in Supplementary Appendix B. The mean age ranged from 35 to 44 years and the prevalence of TL-spine fractures ranged from 4% to 72%, thoracic-spine fractures from 2% to 61%, lumbar-spine fractures from 10% to 25%, and PLC injuries among those with TL-spine fractures was 28–67%. For studies with a criterion standard likely to correctly classify the presence of TL-spine fractures, the TL-spine fracture prevalence was 8–41% (24–35). Based on these studies, the estimated pretest probability (prevalence) for TL-spine fracture in blunt trauma was 15%.

Quality Assessment

The QUADAS-2 assessment inter-rater κ ranged from 0.49 to 1.00. Supplementary Appendix C shows the final adjudicated assessment for each study. The included studies were of variable quality. For patient selection, there were only two case-control studies (36,37). Eight studies only included "sicker" trauma patients, such as patients admitted to the hospital or intubated, which increases the risk of spectrum bias when applying these results to less-ill patients (24,29,32,33,38–41). Aside from the studies utilizing US or MRI, most occurred in the ED. Another source of bias involved the unblinded interpretation of index tests and criterion standards. Most studies were retrospective, and we assumed that index tests occurred with awareness of the criterion standard results unless otherwise specified. Lastly, because most criterion standards included the index test, incorporation bias likely falsely raised the SN and SP of the index (42).

Injury Mechanism

Ten studies examined injury mechanisms as predictors of TL-spine fractures (1,2,27,28,31,43–47). Injury incidents included falls, motor vehicle crashes, pedestrian struck, bicyclist accidents, motorcycle accidents, assaults, and "high-risk mechanisms," as defined by individual studies. Injury mechanism pooled +LR ranged from 0.5 to 1.7 and −LR ranged from 0.63 to 1.25 (see Supplementary Appendix D1). Thus, the mechanism of injury did not serve as a tool for highly confident decision making.

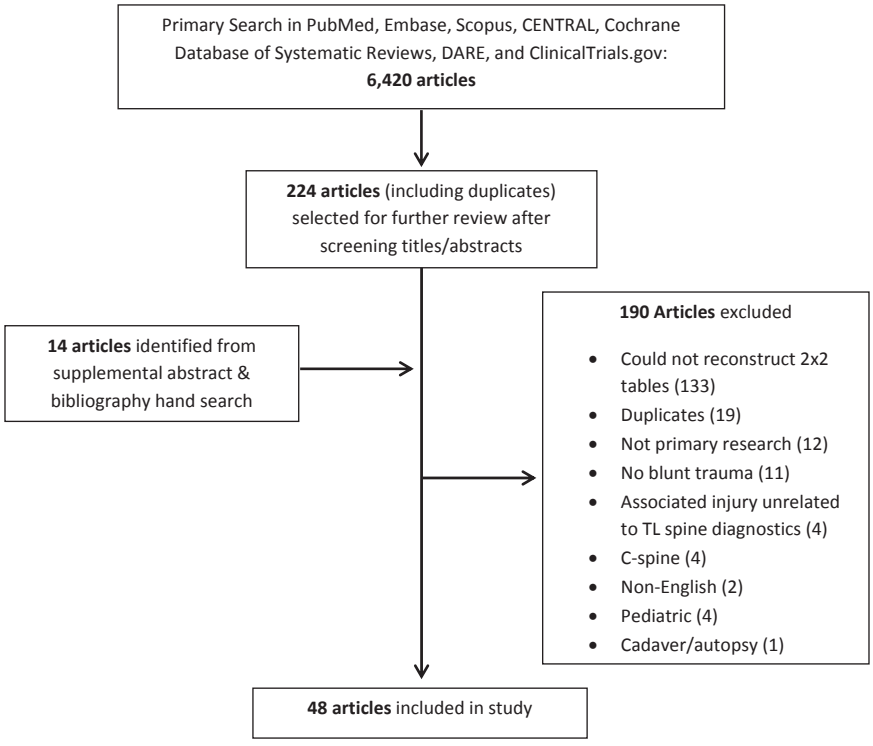

Figure 2. Study selection process.

History and Physical Examination

Eighteen studies examined the diagnostic accuracy of history or physical examination, including complaints of or findings of spine pain or tenderness upon palpation, lateral spine pain upon palpation, distracting injury, abnormal neurologic examination, altered consciousness, intoxication, palpable spine deformity, back bruising, skin abrasion/laceration, physician gestalt, and the whole physical examination (25,27,31,32,34,41,43–52). The most useful physical examination to rule-in a TL-spine fracture was a palpable spine deformity with +LR = 15.3 (95% confidence interval [CI] 7.1–33.0; I^2 = 0%; p = 0.79) (46,47). No single negative physical examination finding (such as lack of spine tenderness) significantly reduced the probability of a TL-spine fracture (see Supplementary Appendix D2).

One study examined the diagnostic accuracy of history and physical examination for thoracic-spine fractures (53). Spine tenderness with palpation showed +LR = 3.4 (95% CI 2.4–4.8) and −LR = 0.57 (95% CI 0.41–0.81); altered consciousness +LR = 2.8 (95% CI 2.0–4.0) and −LR = 0.70 (95% CI 0.57–0.87); distracting injury +LR = 1.9 (95% CI 1.6–2.3) and −LR = 0.52 (95% CI 0.37–0.75); and the whole physical examination was +LR = 1.9 (95% CI 1.8–2.0) and −LR = 0.07 (95% CI 0.02–0.27).

In studies assessing clinician's gestalt for TL-spine fractures, a physician estimate of "greater than low pretest probability" (from a scale of very low, low, intermediate, high, and very high) had a +LR = 1.8 (95% CI 1.4–2.3) and −LR = 0.50 (95% CI 0.29–0.84). In comparison, a "greater than high pretest probability" had +LR = 12.6 (95% CI 4.2–37.3) and −LR = 0.80 (95% CI 0.67–0.96) (32). Reynolds et al. studied gestalt for lumbar-spine fractures and showed +LR = 2.5 (95% CI 1.7–3.7) and −LR = 0.47 (95% CI 0.26–0.87) for a greater than low pretest probability (54). In comparison to gestalt, the whole physical examination for TL-spine fractures showed a pooled +LR = 1.7 (95% CI 1.0–2.8; I^2 = 100%; $p < 0.001$) and a −LR = 0.40 (95% CI 0.27–0.59; I^2 = 76%; $p < 0.001$).

One study involved a diagnostic pathway requiring imaging (plain film, CT, or MRI) if patients had complaints of spine pain, tenderness upon palpation (of midline), local signs of TL-spine injury, neurologic deficits, or a C-spine fracture. In the absence of these, patients were imaged if Glasgow Coma Scale was <15. If it equaled 15, they received imaging in the presence of distracting injury or alcohol/drug intoxication. With this algorithm, 92% of patients would have received imaging, with a reported SN = 100% (95% CI 88–100%) and SP = 11% (95% CI 5–21%) for TL-spine fractures (46). A second study used the criteria of spine pain, midline tenderness on palpation, spine deformity, neurologic deficit, age ≥ 60 years, or high-risk mechanism to detect clinically significant TL-spine fractures with a reported SN = 99% (95% CI 97–100%), SP = 29% (95% CI 27–31%), and SN = 100% for clinically significant fractures. In this study, the addition of age ≥ 60 years appeared to help improve the SN of the history and physical examination findings, though SP was reduced (47).

Associated Injuries

Nine studies examined the accuracy of associated injuries for diagnosing TL-spine fractures (1,29,39,43,45,46,55–57). Associated injuries included C-spine injury, major injuries (defined as an Abbreviated Injury Scale ≥ 3), injuries divided anatomically (cardiac, pulmonary/thoracic, abdominal, orthopedic, ophthalmic/maxillofacial, or a combination of any of these injuries), and pelvic fractures. Supplementary Appendix D3 shows that the +LR ranged from 0.4 to 2.4, while −LR ranged from 0.83 to 2.49.

One study evaluated the accuracy of rib fractures to diagnose thoracic-spine fractures, and showed +LR = 1.6 (95% CI 1.2–2.0) and −LR = 0.76 (95% CI 0.63–0.93) (39). Another investigated the accuracy of the presence of abdominal aortic calcification and low bone mineral density with lumbar-spine fractures in blunt trauma. Two board-certified fellowship-trained radiologists interpreted the studies for the presence of fractures (55). Abdominal aortic calcification was studied, as its severity is associated with bone fragility and vertebral fractures (55,58). Abdominal aortic calcification resulted in +LR = 2.1 (95% CI 1.5–2.9) and −LR = 0.52 (95% CI 0.33–0.83), while low bone mineral density was +LR = 2.9 (95% CI 2.2–3.9) and −LR = 0.33 (95% CI 0.18–0.60).

Plain Film

Eight studies investigated the accuracy of plain films, all diagnostic accuracy results for TL-spine, thoracic-spine, and lumbar-spine studies are detailed in Appendix D4. Five studies evaluated the diagnostic accuracy of TL-spine plain films (24,29,33,59,60). As shown in the forest plots of Figure 3, plain films had a +LR = 25.0 (95% CI 4.1–152.2; I^2 = 94%; $p < 0.001$), and −LR = 0.43 (95% CI 0.32–0.59; I^2 = 84%; $p < 0.001$). Table 1 details the index tests and criterion standards for each study in this analysis. Three studies examined the diagnostic accuracy of plain films to detect thoracic-spine fractures, with +LR = 2.2 (95% CI 0.7–7.2; I^2 = 89%; $p < 0.001$) and −LR = 0.62 (95% CI 0.30–1.27; I^2 = 87%; p = 0.005) (33,61,62). Two studies investigated lumbar-spine fractures: +LR = 15.7

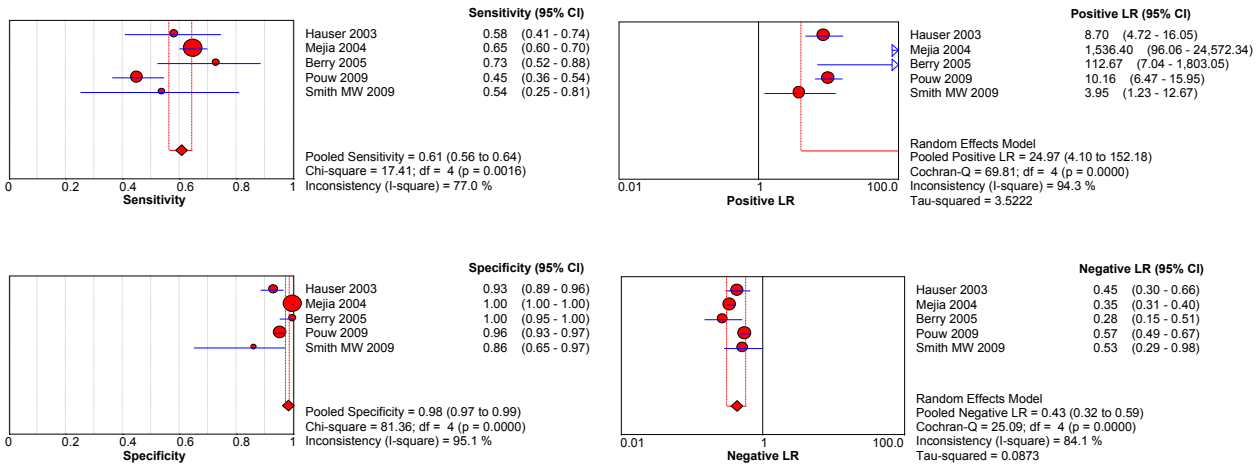

Figure 3. Forest plots of diagnostic accuracy of plain films for thoracolumbar spine fracture. CI = confidence interval; LR = likelihood ratio.

(95% CI 7.6–32.4; I^2 = 0%; p = 0.78) and −LR = 0.60 (95% CI 0.35–1.03; I^2 = 68%; p = 0.08) (33,38).

Barrios et al. evaluated the accuracy of chest x-ray study for thoracic-spine fractures in blunt trauma patients (63). The prevalence of thoracic-spine fractures was 2% (4 patients), with SN = 0% (95% CI 0–60%) and SP = 100% (95% CI 98–100%). Chen et al. and Deyle et al. reported the accuracy of the Lodox/Statscan, a digital x-ray device that can generate full-body anterior and lateral views (26,64). With this device, the set of plain radiographs called for in the primary survey can be replaced. As of 2012, it is installed in 50 sites throughout the world (65). Chen et al. examined TL-spine fractures with +LR = 16.7 (95% CI 8.3–33.5) and −LR = 0.18 (95% CI 0.07–0.43) (26). Deyle et al. evaluated thoracic-spine and lumbar-spine fractures separately, with +LR = 175.1 (95% CI 10.8–2846.0) and −LR = 0.57 (95% CI 0.44–0.73) for thoracic-spine fractures and +LR = 282.8 (95% CI 17.7–4524.8) and −LR = 0.26 (95% CI 0.17–0.41) for lumbar-spine fractures (64).

CAP CT

Eight studies investigated the accuracy of CT, and all diagnostic accuracy results are detailed in Supplementary Appendix D5. Six studies evaluated the diagnostic accuracy of CAP CT for diagnosing TL-spine fractures (24,28,30,33,59,60). As shown in the forest plots of Figure 4, CAP CT had +LR = 81.1 (95% CI 14.1–467.9; I^2 = 87%, $p < 0.001$) and −LR = 0.04 (95% CI 0.02–0.08; I^2 = 23%; p = 0.26). The index tests and criterion standards for each study in this analysis are shown in Table 2. Additional studies that were not included in the meta-analysis (2 × 2 tables could not be recreated) showed inter-radiologist κ range of 0.80–0.98 for detecting TL-spine fractures (37,66).

Smith et al. examined thoracic-spine fractures among individual patients, showing +LR = 77.3 (95% CI 4.8–1241.2) and −LR = 0.23 (95% CI 0.08–0.68) (33). Overall, 3-mm slices are superior to 5-mm slices, and multiplanar reformations improved accuracy. Using 3-mm slices with or without multiplanar reformations

Table 1. Plain Film Diagnostic Accuracy Study's Index Tests and Criterion Standards

Study First Author, Year	Index Test	Criterion Standard
Hauser, 2003 (59)	AP/lateral TL-spine plain film	Reformatted TL-spine CT (with reconstructions of 1–2 mm) or subsequent clinical examination when patient fully alert
Mejia, 2005 (60)	AP/lateral TL-spine plain film	NA
Berry, 2005 (24)	AP/lateral TL-spine plain film	All available clinical/radiologic data
Pouw, 2009 (29)	AP/lateral TL-spine plain film	Reformatted TL-spine CT (16-slice MDCT, with 120-kV tube potential, 200-mA effective tube current time product, detector configuration of 16 mm × 1.5 mm, reconstructions at 3-mm section thickness with 1.5-mm increments for bone kernel, and sagittal/coronal reformations of the spine)
Smith, 2009 (33)	AP/lateral TL-spine plain film	Reformatted TL-spine CT (either 16-slice MDCT or 64-slice scanner, reconstruction with ≤2-mm collimation, "thin-slice" in axial/sagittal/coronal planes)

AP = anteroposterior; CT = computed tomography; MDCT = multidetector computed tomography; NA = not available; TL = thoracolumbar.

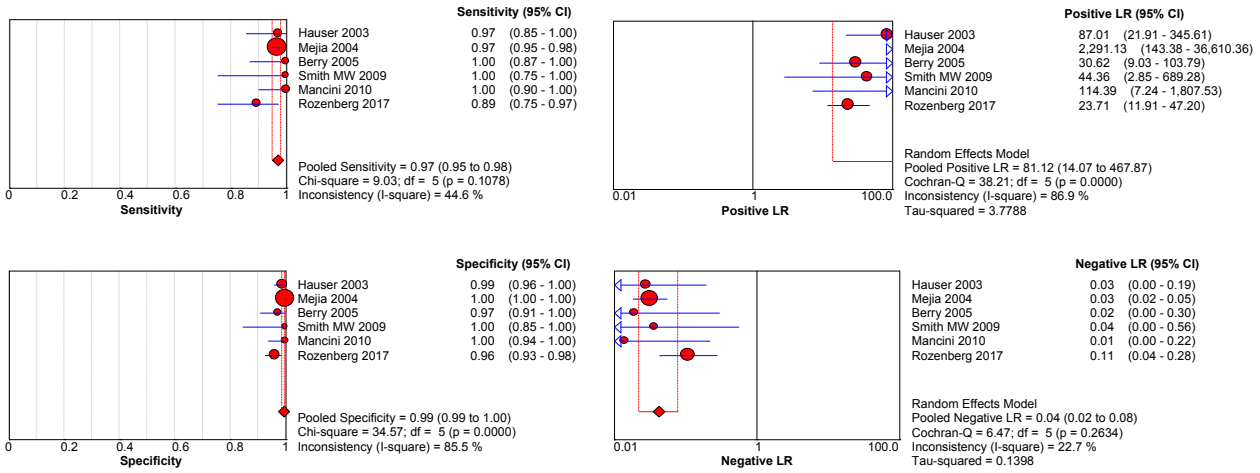

Figure 4. Forest plots of diagnostic accuracy of computed tomography for thoracolumbar spine fracture. CI = confidence interval; LR = likelihood ratio.

demonstrate +LR = 45.0 (95% CI 2.9–697.8) and −LR = 0.02 (95% CI 0.0–0.4); 5-mm slices with multiplanar reformations demonstrate +LR = 42.9 (95% CI 2.8–666.4) and −LR = 0.07 (95% CI 0.01–0.33); and 5-mm slices without showed +LR = 38.7 (95% CI 2.5–603.6) and −LR = 0.16 (95% CI 0.06–0.43) (40).

Three studies investigated the diagnostic accuracy of CAP CT for diagnosing lumbar-spine fractures (33,38,67). The pooled estimate for +LR = 202.5 (95% CI 41.1–998.7; I^2 = 0%; p = 0.46) and −LR = 0.02 (95% CI 0.00–0.11; I^2 = 0%; p = 0.63).

Reformatted TL-Spine CT and Other CT Studies

Rozenberg et al. investigated the diagnostic accuracy of reformatted TL-spine CT with +LR = 40.2 (95% CI 16.8–95.8) and −LR = 0.05 (95% CI 0.01–0.21) (30). Carter et al. also examined reformatted TL-spine CT, but was excluded (2 × 2 tables could not be recreated) (68). They showed reformatted TL-spine CT had a SN = 97% (95% CI 89–100%). No included study examined inter-radiologist agreement, but a previous study showed κ = 0.98 using a reformatted TL-spine CT protocol (66).

Sroka et al. demonstrated that the scout AP and lateral CT images of the TL-spine from a four-slice scanner had +LR and −LR of 187.5 (95% CI 11.7–2999.5) and 0.12 (95% CI 0.03–0.52), respectively (34). A study by Karaca et al. compared the diagnostic accuracy of 256-slice dual-source CT scans (DSCT) to MRI in detecting bone marrow edema (69). Bone marrow edema served as a predictive factor for vertebral compression fractures. The study showed that DSCT had +LR = 72.4 (95% CI 18.2–288.0) and −LR = 0.11 (95% CI 0.05–0.25). Inter-observer agreement for the determination of bone marrow edema had a κ = 0.82 and intra-observer agreement κ = 0.80.

Clinically Significant Fractures for Plain Film and CT Studies

The summary data for clinically significant fractures are shown in Table 3. Wintermark et al. evaluated the accuracy of plain films for clinically significant TL-spine fractures, reporting +LR = 61.6 (95% CI 3.5–1079.4) and −LR = 0.66 (95% CI 0.44–0.98) (35).

Plain films missed 66.7% clinically significant fractures (35). In comparison, Hauser et al. showed that no clinically significant fractures were missed and Berry et al. showed that 7.7% of clinically significant fractures were missed (1 patient who required an orthotic brace) (24,59). Mejia et al. provided no abstractable data, but noted that 12 clinically significant fractures were missed on plain film (1 requiring surgical stabilization and 11 orthoses), whereas CT missed none (60). For clinically significant thoracic-spine fractures, SN for plain films reportedly ranged from 75% to 100% (33,62). Huddleston et al. also reported on plain film's ability to detect "severe" thoracic-spine fractures based on the Thoracolumbar Injury Classification and Severity Score (61,70). They found that the SN of plain films did not improve with increasing injury severity: "least severe" SN = 55%, "moderate" SN = 67%, and "most severe" injuries SN = 59%. For clinically significant lumbar-spine fractures the SN = 63% (33).

Mancini et al. showed +LR = 138.9 (95% CI 8.8–2200.8) and −LR = 0.02 (95% CI 0.00–0.34) for CAP CT, while Wintermark et al. demonstrated +LR = 166.6 (95% CI 10.5–2651.8) and −LR = 0.06 (95% CI 0.01–0.51) (28,35). The remaining studies reported that CAP

Table 2. Computed Tomography Diagnostic Accuracy Study's Index Tests and Criterion Standards

Study First Author, Year	Index Test	Criterion Standard
Hauser, 2003 (50)	Helical CAP CT with i.v. contrast (collimation 5 mm, pitch 1.6, reconstructions with 5-mm image spacing)	TL-spine CT (with reconstructions of 1–2 mm-thick slices) or subsequent clinical examination when patient fully alert
Mejia, 2005 (60)	Helical CAP CT	NA
Berry, 2005 (24)	Helical CAP CT (pitch 1, reconstructions at 5-mm-thick slices)	All available clinical/radiologic data
Smith, 2009 (33)	CAP CT (16-slice MDCT or 64-slice machines, volume acquisition post-processed at axial collimation 5 mm, pitch of 1.375–1.000, "thick-slab" coronal reconstructions)	Reformatted TL-spine CT (either 16-slice MDCT or 64-slice scanner, reconstruction with ≤2 mm collimation, "thin-slice" in axial/sagittal/coronal planes)
Mancini, 2010 (28)	CAP CT (16-slice CT machine, reconstructions with 5-mm image spacing)	Reformatted TL-spine CT (16-slice CT machine, reformations with 2.5-mm image spacing, sagittal/coronal planes)
Rozenberg, 2017 (30)	CAP CT with i.v. contrast (64-slice CT machine, reconstructions with 3-mm slice thickness)	Consensus among imaging modalities (using 64-slice MDCT with i.v. contrast, CAP CT with reconstructions at 3-mm slice thickness, and reformatted TL-spine CT with axial slice thickness at 1.25 mm, with coronal/sagittal images reconstructed at 3-mm slice thickness); among indeterminate fractures discharge diagnosis of spinal fracture was used (determined by clinical symptoms or MR imaging in certain patients)

CAP = chest-abdomen-pelvis; CT = computed tomography; MDCT = multidetector computed tomography; MR = magnetic resonance; TL = thoracolumbar.

CT did not miss any clinically significant TL-spine fractures (24,30,33,59,60). Gestring et al. provided sufficient data for clinically significant lumbar-spine fractures and showed +LR = 122.4 (95% CI 7.6–1967.1) and −LR = 0.10 (95% CI 0.01–1.40) (67). Deunk et al. showed that CT led to a change in management in 21% of patients with lumbar-spine fractures when compared to plain films (38).

Rozenberg et al. was the only included study that compared both reformatted TL-spine CT and CAP CT, showing that neither missed any clinically significant TL-spine fractures (30). Carter et al. was excluded because of inadequate detail to reconstruct 2 × 2 tables, but reported that reformatted TL-spine CT missed no clinically significant TL-spine fractures, while CAP CT missed 29% (all of which required orthotic bracing) (68).

Ligamentous Spinal Injuries (US, CT, MRI)

Three studies used US to examine injuries to the PLC (36,71,72). These studies also examined individual components of the PLC, including the supraspinous ligament and interspinous ligament. Supplementary Appendix D6 shows all diagnostic accuracy summary data. US was most accurate for detecting interspinous ligament injuries, with a +LR of 4.8 (95% CI 0.1–379.9; I^2 = 89%; p = 0.002) and −LR of 0.20 (95% CI 0.03–1.36; I^2 = 0%; p = 0.32).

Haba et al. used MRI to detect supraspinous or interspinous ligament injury (73). The diagnostic accuracy for detecting supraspinous ligament injuries was +LR = 11.6 (95% CI 1.6–82.8) and −LR = 0.11 (95% CI 0.03–0.38), and interspinous ligament injuries +LR = 7.7 (95% CI 1.8–33.7) and −LR = 0.02 (95% CI 0.00–0.48). Ghanem et al. evaluated MRI's accuracy in detecting adjoining intervertebral disc injury (PLC and anterior/posterior longitudinal ligaments) in TL-spine fractures with a +LR = 3.7 (95% CI 1.4–10.0) and −LR = 0.09 (95% CI 0.01–0.61) (74).

DISCUSSION

History and physical examination findings are generally inaccurate to rule-in or rule-out TL-spine fractures. The data source for these findings were based mostly on retrospective studies, which are inherently prone to diagnostic bias (42). The criterion standard for many included the

Table 3. Plain Film and Computer Tomography Diagnostic Accuracy of Clinically Significant Thoracolumbar Spine Fractures

Study	SN%	SP%
Plain film		
Hauser, 2003 (59)	100	—
Wintermark, 2003 (35)	33	100
Berry, 2005 (24)	92	—
CAP CT		
Hauser, 2003 (59)	100	—
Mejia, 2005 (60)	100	—
Wintermark, 2003 (35)	97	100
Berry, 2005 (24)	100	—
Smith, 2009 (33)	100	—
Mancini, 2010 (28)	100	100
Rozenberg, 2017 (30)	100	—

CAP = chest-abdomen-pelvis; CT = computed tomography; SN = sensitivity; SP = specificity.

composite of all clinical/radiologic information (including the index test), introducing incorporation bias that raises both the observed SN and SP of the index test (42). Though history and physical examination had a lower accuracy than CT imaging, decision aids to guide TL-spine imaging exist and await prospective validation (46,47,75).

+LR > 10 and −LR < 0.1 are regarded as diagnostic tests with sufficient accuracy to rule-in or rule-out disease, respectively (76). Pooled LRs of CT accuracy were within these thresholds. The CT studies with the lowest SN were due to clinically insignificant fractures, and missed fractures may be attributable to imaging technique (30,35,40). In contrast, plain film's diagnostic accuracy for TL-spine fractures had pooled +LR = 25.0 (95% CI 4.1–152.2). The +LR point estimate exceeds 10, but the lower margin of the CI is 4. While thoracic-spine plain films were inadequate for ruling in fractures, lumbar-spine plain films may be an adequate alternative to CT as the +LR = 15.7 (95% CI 7.6–32.4).

For clinically significant fractures, plain film had a wide SN range: 33–100% (Table 3) (24,35,59). While the CT studies had a consistently high SN, one excluded study compared the diagnostic accuracy of CAP CT to reformatted TL-spine CT, and reported that CAP CT had a SN = 64% (95% CI 51–75%) for all TL-spine fractures and missed 28.6% of clinically significant fractures (68). Therefore, CAP CT can also miss both clinically significant and insignificant TL-spine fractures.

Reformatted TL-spine CT is not associated with improvements in management when compared to CAP CT (30,66). The missed fractures on CAP CT generally required only conservative management (30,68). The American College of Radiology deemed the use of reformatted images as appropriate because it may enhance the visualization of spinal alignment at no additional cost or radiation. However, it should be noted that a 3-megapixel diagnostic display is used in most instances within the reading rooms of radiology departments. This is in contrast to the usual 1-megapixel display that can be found within the clinical areas of an ED. Given the difference pixel density, subtle findings may be more apparent to radiologists.

The current data are sparse, and observational studies providing quantitative estimates of SN and SP represent the lowest tier of diagnostic evidence, evidence that does not equate to patient-centric benefit (77). Diagnostic randomized controlled trials are often non-existent and fail to evaluate patient-oriented outcomes (78). In lieu of randomized controlled trials, researchers substitute trauma registries and highlight missed spine fractures when advanced imaging is not obtained, but usually fail to measure the potential harms of reformatted imaging, including incidental findings and downstream consequences of overdiagnosis and overtreatment (79,80). However, as reformatted TL-spine CT has no additional cost or radiation to the patient, it would be beneficial to investigate larger-scale prospective studies to delineate their impact on immediate management and downstream outcomes (10).

Accelerating patterns of CT utilization over the past 2 decades, and overlying controversies of the management for neurologically intact TL-spine injury patients shape the contemporary research landscape for blunt trauma victims. This meta-analysis includes CT studies from 2002 to 2017, a period when advancing CT technology fueled the role of advanced imaging in the first-line ED evaluation of trauma patients (12,81,82). As a result, the need for imaging in blunt trauma patients is debatably limited to patients who do not require CAP CT for visceral torso injury. None of the studies included in our meta-analysis focused on this population and, therefore, more research is needed in this area. Additionally, certain injuries, including TL-spine burst fractures without neurologic deficit, can often be managed nonoperatively (83,84). Moreover, a recent multicenter prospective randomized study in Canada revealed no benefit in short- or long-term outcomes in terms of pain relief or disability assessment in patients with incomplete TL-spine burst fractures treated with orthotic bracing vs. no bracing (85,86). Surgical intervention or orthotics traditionally define what constitutes a "clinically significant" injury. Further investigations into which patients warrant TL-spine imaging after blunt trauma should incorporate rigid definitions for clinically significant injuries based upon patient-centered outcomes of available interventions, with input from spine surgeons, rather than being based solely upon whether or not a medical intervention (such as an orthotic) or a surgical intervention ensued.

Limitations

The overall quantity and quality of the available evidence is imperfect and far from ideal for deriving a clinical decision rule. The applicability of our findings to older populations is limited, because the majority of our studies had a mean age between 30 and 50 years, and advanced age may have an influence upon the accuracy of combined physical examination data. Incorporating advanced age (60 years and older) has been shown to improve the accuracy of TL-spine fracture decision aids (47).

Temporal bias exists in radiology, as advancing technology improves image quality and accuracy (87). While scan quality may be similar between different CT scanners, 64-slice scanners have increased image quality, scan speed, and advanced image post-processing applications (88). If an older CT scanner was used as a criterion standard and misclassified patients as having no fracture,

imperfect gold standard bias is possible, which could decrease the observed SN and SP of the index test (assuming the errors of the index test and criterion standard are independent). Conversely, if errors of the index test and criterion standard are correlated, then this increases the observed SN and SP (42).

Numerous studies were excluded, usually because of an inability to create 2 × 2 tables. We contacted authors when appropriate to clarify reported data, but some did not respond or could not supply the required data. Adherence to the Standards for Reporting Diagnostic Accuracy (STARD) reporting guidelines improves the quality of reported data, and would improve the pool of available evidence for future meta-analyses (89).

CONCLUSIONS

High-quality research to guide evidence-based diagnostic decision making for TL-spine fractures in blunt trauma victims is lacking. In acute blunt trauma patients with suspected TL-spine injuries, the prevalence of a TL-spine fracture is approximately 15%. No injury mechanism, physical examination, or associated injury accurately ruled in the presence of a TL-spine fracture. CT is superior to plain film in both the detection of all TL-spine fractures and clinically significant fractures. While reformatted TL-spine CT is more accurate than CAP CT, it is unknown whether these differences impact management or patient-centric outcomes. Of course, individual clinicians may occasionally obtain plain films when they have a low but non-0% suspicion of significant injury, or when an injury that could be clearly demonstrated with a plain film series is anticipated. This review does not advocate that plain films be abandoned or that CT is the new "standard of care" for blunt spine trauma. However, this article has delineated certain advantages and disadvantages of various diagnostic techniques, as applied to patients with blunt trauma and possible TL-spine injury.

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SUPPLEMENTARY DATA

Supplementary Data can be found at https://doi.org/10.1016/j.jemermed.2018.10.032.

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ARTICLE SUMMARY

1. Why is this topic important?

No validated decision aids for determining which blunt trauma patients warrant thoracolumbar-spine (TL-spine) imaging exists. Therefore, a high practice variability and the presence of inconsistent clinical practice guidelines or recommendations are associated with this topic. Because delayed recognition of significant spine injuries risks preventable neurologic complications, while overutilization of diagnostic imaging increases cost, waiting times, and radiation exposure, a quantitative understanding of the diagnostic accuracy of history, physical examination, and commonly ordered imaging tests may improve diagnostic efficiency.

2. What does this review attempt to show?

This systematic review and meta-analysis quantifies the diagnostic accuracy of history, physical examination, and diagnostic imaging modalities for blunt trauma–related TL-spine injuries, and to identify any knowledge gaps in the existing research literature.

3. What are the key findings?

No injury mechanism, physical examination, or associated injury accurately ruled in the presence of a TL-spine fracture. Computed tomography (CT) is superior to plain film both in the detection of all TL-spine fractures and clinically significant fractures. While reformatted TL-spine CT is more accurate than chest-abdomen-pelvis (CAP) CT, the impact of these differences on management decisions or patient-centric outcomes is unknown.

4. How is patient care impacted?

CT is currently the most accurate imaging test to diagnose TL-spine fractures in blunt trauma patients. As compared with other imaging choices, CT misses fewer TL-spine fractures and reformatted TL-spine CT can be done without any additional cost or radiation to the patient, with added accuracy compared to CAP CT. Whether the additional fractures identified yield improved patient outcomes is uncertain, as are the potential harms of overdiagnosis that might be associated with more widespread CT imaging.