Yield and Clinical Predictors of Thoracic Spine Injury from Chest Computed Tomography for Blunt Trauma

Mark I. Langdorf, MD, MHPE*
Nadia Zuabi, BS*
Nooreen A. Khan, BS*
Chelsey Bithell*
Armaan A. Rowther, BS*
Karin Reed, MD*
Craig L. Anderson, PhD, MPH*
Shahram Lotfipour, MD, MPH*
Robert Rodriguez, MD†

*University of California Irvine, Department of Emergency Medicine, Irvine, California
†University of California San Francisco, Department of Emergency Medicine, San Francisco, California

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Introduction: Cost and radiation risk have prompted intense examination of trauma patient imaging. A proposed decision instrument (DI) for the use of chest computed tomography (CT), (CCT) in blunt trauma patients includes thoracic spine (TS) tenderness, altered mental status (AMS) and distracting painful injury (DPI) as potential predictor variables. TS CT is a separate, costly study whose value is currently ill-defined. The objective of this study is to determine test characteristics of these predictor variables alone, and in combination, to derive a TS injury DI.

Methods: Prospective cohort study of blunt trauma patients age > 14 in a Level I Trauma Center who had either CCT or TS CT.

Results: Of 1,798 blunt trauma patients, 1,174 (65.3%) had CCT, and 46 (2.6%) had a TS CT at physician discretion. CCT identified 58 TS injuries in 1,220 patients (4.8%). For 1,032 patients without AMS, 18/35 had TS tenderness, for sensitivity of 51.4%, specificity 84.7%, positive (PPV) and negative predictive values (NPV) of 10.5% and 98.0%. Positive likelihood ratio (+LR) was 3.35, with negative (-LR) 0.57. Among the 58 TS injuries, 23 had AMS for sensitivity of 39.7%, with other test characteristics of 85.8%, 12.2%, 96.6%, with +LR 2.79 and -LR 0.70. Thirty-eight of 58 had DPI, for sensitivity 65.5%, with other test characteristics 65.7%, 8.7%, and 97.4%, with +LR 1.91 and -LR 0.52. Combining 3 predictor variables into a proposed DI found 56/58 injuries for test characteristics of 96.6% (95% CI 88.1-99.6%), 49.1% (46.1-52.0%), 8.6% (6.6-11.1%) and 99.7% (CI 98.7-100%), with +LR 1.90 (1.76-2.04) and -LR 0.07 (0.02-0.28). If validated, the DI would exclude 572/1,220 CCT patients from separate TS CT (46.9%, CI 44.1-49.7%), and 141/511 (27.6%, CI 23.8-31.7%) patients who actually had TS CT in our cohort. Medicare payment at our center for sagittal reconstructions of TS CT is $280 for professional plus technical charges ($3,312 per study). The DI, if validated, would save $39,000 –$160,000 in TS imaging payments.

Conclusion: TS CT is low yield and costly. Patients who are alert, have no TS tenderness and no DPI have a very low likelihood of TS injury (NPV 99.7% 95% CI lower limit 98.7%) with –LR=0.07, 95% CI upper limit 0.28). Avoiding TS CT may save considerable charges and payments. [West J Emerg Med. 2014;15(4):465–470.]

INTRODUCTION

Increased focus on cost-effective trauma evaluation has driven the development of clinical decision rules for high volume and high risk injuries, including cervical spine,[1,2] blunt head,[3] and chest[4,5] trauma, as well as high volume extremity injury.[6,7] Chest computed tomography (CCT) evaluation for blunt trauma varies widely. Thoracic spine (TS) injury, though uncommon, can lead to spinal cord injury and paralysis, and would be considered a no-miss condition. Twenty percent of patients with 1 spinal column injury are also found to have a second, non-contiguous fracture, and these are associated with high velocity mechanisms.[8] Therefore, it would be prudent to develop a decision instrument (DI) to identify all TS fractures, while not increasing cost with dedicated sagittal reconstructions of the TS from CCT.

Previous work has concluded that tenderness alone is insufficient to identify more than 50% of TS and lumbar-sacral spine (LS) fractures, and almost 25% that are clinically significant.[9] Therefore, a DI would need to include other predictive factors to capture the vast majority of injuries.[9]

Mancini and Burchard[10] found that chest/abdomen/pelvis CT identified all 35 patients with TS or LS fracture, and 98% of their sites of injury (78/80). However, their paper did not disclose the decision process that led to body cavity or selective spine imaging. Therefore, the current study would expand on previous work by creating a DI to govern the imaging decision, and describe the sensitivity of the body cavity CT vs. the criterion reference spine CT. In addition, we report the clinical significance of spine injuries missed by body cavity CT alone.

Sagittal reconstruction of the TS generates substantial technical ($3,070) and professional ($242) charges in our trauma center, and might be necessary with suspicion for TS injury. A previous study found that 6.6% of spine injuries were missed on chest or abdomino-pelvic CT, but discovered on dedicated spine CT.[10] This author questioned whether this "false negative" subset of spine injuries was clinically important. A valid DI might guide omission of dedicated spine imaging if patients were determined sufficiently low risk for injury, or for clinically important injury, and might save charges, costs, and time.

Recently, a DI for all thoracic injuries was derived and is being validated, which includes 12 predictor variables: rapid deceleration, distracting painful injury (DPI), intoxication, altered mental status (AMS), chest pain, tenderness of the sternum, other chest wall, thoracic spine or scapula, and abnormal ultrasound of the chest, pericardium, or abdomen.

This retrospective analysis of prospectively collected trauma patient data sought to determine if a relevant subset of 3 of these predictive factors, DPI, AMS or TS tenderness would predict TS injury. If so, this would form the basis of a prospective validation study. This is the largest study of clinical features that led to identification of TS injury, and the first to propose a DI to guide clinical decision making.

We sought to determine test characteristics of these 3 predictor variables alone, and in combination, to postulate a TS-injury DI. To our knowledge, this is the first attempt to derive such a rule for this injury.

METHODS

We have previously described the derivation and inter-rater reliability assessment of our selective chest imaging DI. For 2 of our 3 predictive factors, AMS and DPI, Kappa values were >0.5 indicating good inter-rater reliability, while T-spine tenderness was not assessed.[12]

We conducted this single-center, prospective cohort derivation study at a high-volume (3,600 trauma activations

Table 1. Characteristics of 1,798 patients presenting with blunt chest trauma.

Sex	Male	1107	61.6%
Age	15-19	198	11.0%
	21-29	403	22.4%
	30-39	243	13.5%
	40-49	235	13.1%
	50-64	353	19.6%
	65+	366	20.4%
Mechanism	Motor vehicle collision	780	43.4%
	Two-wheeled vehicle*	187	10.4%
	Pedestrian†	143	8.0%
	Bicycle‡	126	7.0%
	Fall from standing	209	11.6%
	Other fall	149	8.3%
	Struck by blunt object	46	2.6%
	Struck by fists or kicked	51	2.8%
	Sports§	30	1.7%
	Other	15	0.8%
Intoxication‖	Yes	258	14.3
	No	1,531	85.2
	Unknown	9	0.5

*Two-wheeled vehicle: Includes motorized scooters, but not skateboards or rollerblades.

†Pedestrian: Pedestrian struck by motorized moving vehicle.

‡Bicycle: Fall from bicycle or crash into object on bicycle.

§Sports: Any injury that occurred while playing sports, including skateboards and rollerblades.

‖Intoxication: History of intoxication or recent ingestion, any positive alcohol level in blood or breath, urine toxicology screen positive for nine categories of drugs, physical evidence suggesting intoxication (see methods), or behavior consistent with intoxication and unexplained by medical or psychiatric illness.

per year) urban United States American College of Surgeons-verified Level I Trauma Center over 13 months from November 2011 to December 2012. These patients were a subset of 2 larger studies to validate and derive decision instruments for chest radiograph and CCT.

We enrolled patients with the following inclusion criteria: 1) age >14 years, 2) blunt trauma within 24 hours of emergency department (ED) presentation, and 3) receiving CCT with or without TS sagittal reconstruction or dedicated TS CT alone in the ED, as part of their evaluation for blunt trauma, per trauma captain clinical judgment.

Our research assistants enrolled subjects daily from 8AM to 12 midnight and collected demographic and mechanism data. We left the decision for chest or spine imaging to the discretion of treating trauma surgeon (PGY 4 or 5, trauma/critical care fellow, or surgical attending). After CCT was ordered, and prior to viewing images or report, the treating emergency physician (EP) completed a 1-page data sheet where they indicated presence or absence of AMS, DPI, and TS tenderness, the 3 components of our proposed DI. The DI was determined to be valid in each patient if none of the 3 predictive factors were present and the patient did not have a TS injury on any imaging (including cervical and abdominal CT). Conversely, the DI was ruled valid if a patient with TS injury had at least 1 of the 3 predictive factors.

TS tenderness was elicited by log-rolling the patient off the spine board with maintenance of cervical spine (CS) immobilization and progressively pushing on the TS from the border of the cervical collar to the sacrum, repeatedly asking the patient "does this hurt here." Any positive response from the patient was considered "tenderness" regardless of degree.

We defined DPI as any condition thought by clinician to be producing sufficient pain to distract the patient from a second injury, including long bone fractures, visceral injuries requiring surgical consultation, large laceration, degloving or crush injury, large burns, or any other injury producing acute functional impairment.

We defined AMS as a patient who was not alert or not able to appropriately respond to "yes" or "no" questions, for example Glasgow Coma Scale $\leq$14, disorientation to person, place, time or event, or delayed or inappropriate response to external stimuli. Insurmountable language barrier at the time initial evaluation was also considered in this category.

We defined "intoxication" as history of intoxication or recent ingestion provided by patient or observer, any positive alcohol level in blood or breath, urine toxicology screen positive for 9 categories of drugs, physical evidence suggesting intoxication (odor of alcohol, slurred speech, ataxia, dysmetria or other cerebellar findings), or behavior consistent with intoxication and unexplained by medical or psychiatric illness.

CT was performed predominately with a Siemens 256-slice scanner immediately adjacent to the ED. Sagittal reconstructions were done using the same data acquired for CCT and did not involve additional radiation or scan time. Post-processing time was approximately 3 minutes.

Outcome Determination

We used official reports by board-certified radiologists, blind to subject enrollment, to determine the presence or absence of acute TS injury, including vertebral body, spinous or transverse process fractures. We included TS injury identified on CT of the chest, abdomen, or CS, even if sagittal reconstructions of the TS were not done.

Regarding clinical significance of identified TS injuries, we defined major clinical significance as patients who received surgical stabilization, minor clinical significance as those who received inpatient pain management, inpatient observation >24 hours, or were treated as an outpatient with a TLSO (thoraco-lumbar-spine orthotic) brace. Injuries of no clinical importance received none of these interventions.

Per the recommendations of Worster and Bledsoe,[13] we conformed to methods of retrospective chart reviews in 10 of 12 areas: our abstractors were trained before data collection, inclusion and exclusion criteria were defined, and categorization of injury and clinical significance were determined in advance. We used standard data abstraction forms, monitored research abstractors for accuracy by double checking data entry for each patient, the clinical predictors underwent inter-observer reliability testing, and we described our convenience sampling method. Regarding missing data, we excluded such patients and did not use data imputation, and the study was institutional review board (IRB) approved. However, we did not blind the data abstractors to the study hypothesis, nor did we perform inter-observer reliability testing between them.

We de-identified and recorded data in a manner that precluded individual patient identification. IRB approval with a waiver of informed consent was obtained.

Statistical Analysis

We managed study data using Research Electronic Data Capture (RedCAP) tools hosted by the blinded for review. We performed statistical tests using STATA version 12.1 (StataCorp, College Station, TX). We summarized and reported demographic data in aggregate form and calculated screening performance characteristics (sensitivity, specificity, positive predictive value, negative predictive value, and positive and negative likelihood ratios) using standard formulae.

RESULTS

We studied 1,798 total blunt trauma patients with demographics, mechanism of injury, and intoxication status shown in Table 1. Of these, 1,174 (65.3%) had CCT and 46 (2.6%) had a dedicated TS CT without CCT. These 2 CT modalities identified 58 TS injuries in 1,220 total imaged patients (4.8%). Of the 1,174 who had CCT, 465 (39.6%) had TS sagittal reconstructions, and 709 did not. Of all 511 patients who had one or the other form of TS CT, 465 had a

Table 2. Thoracic spine tenderness as a predictive factor among patients with normal mental status (n=1032)

Computed tomography for spinal fracture	Thoracic spine tenderness Yes	No
Positive	18	17
Negative	153	844
Total	171	861

Table 3. Altered mental status as a predictive factor for T spine injury. (n=1220).

Computed tomography for spinal fracture	Altered mental status Yes	No
Positive	23	35
Negative	165	997
Total	188	1032

Table 4. Distracting painful injury as a predictive factor for T spine injury. (n=1220).

Computed tomography for spinal fracture	Distracting painful injury Yes	No
Positive	38	20
Negative	398	764
Total	436	784

Table 5. Performance of the proposed decision instrument incorporating all 3 predictive factors (T spine tenderness, altered mental status, and distracting painful injury) to identify T spine injury, (n=1220).

Computed tomography for spinal fracture	Decision instrument Yes	No
Positive	56	2
Negative	592	570
Total	648	572

CCT from which TS sagittal images were reconstructed, and 46 had a dedicated TS CT without chest CT.

The performance of the 3 components of the DI was as follows: For 1,032 patients with normal mental status, 18 had TS tenderness among 35 injuries, for sensitivity of 51.4%, specificity 84.7%, positive and negative predictive values (PPV, NPV) of 10.5% and 98.0%, respectively. Positive likelihood ratio (+LR) was 3.35, while negative (-LR) was 0.57 (Table 2).

Among the 58 TS injuries, 23 had AMS for sensitivity of 39.7% with other test characteristics of 85.8%, 12.2%, 96.6%, with +LR 2.79 and -LR 0.70 (Table 3).

Thirty-eight of 58 patients had DPI for sensitivity of 65.5% with other test characteristics of 65.7%, 8.7%, and 97.4%, with +LR 1.91 and -LR 0.52. (Table 4).

Combining all 3 predictor variables into a proposed DI captured 56/58 injuries for test characteristics of sensitivity of 96.6% (95% CI 88.1-99.6%), specificity 49.1% (46.1-52.0%), PPV 8.6% (6.6-11.1%) and NPV 99.7% (CI 98.7-100%), with +LR 1.90 (1.76-2.04) and -LR 0.07 (0.02-0.28) (Table 5).

The DI, if validated, relies on all 3 predictive factors being absent to potentially forego TS imaging. Conversely, if any of the 3 predictive factors are present, then TS imaging would be indicated.

Such a DI, if validated, would exclude 572/1,220 CCT patients from additional TS imaging (46.9%, CI 44.1-49.7%) and 141/511 (27.6%, CI 23.8-31.7%) patients who actually had specific TS imaging in our cohort. Technical charge for each TS sagittal reconstruction at our center was $3,070, and professional charge for radiologist interpretation was $242, for combined charge of $3,312 per study. Medicare reimbursement at our center for sagittal reconstructions of TS CT is $280 per study (professional $53 plus facilities $227). If validated in an external cohort, the proposed DI would therefore save $39,000 –$160,000 in TS imaging reimbursement.

We found 58 total TS injuries, 41 of which were diagnosed on the 53 patients who had CCT (12 false negative, sensitivity 77.4%), while 17 were diagnosed by other CTs (6 on TS alone, 5 on CS alone, 5 on both TS + abdominal CT, and 1 on abdominal CT alone). Five of 58 (8.6%) had no dedicated TS CT performed (TS injury found on other CT).

Two patients with TS injuries failed to be identified by our proposed DI. The first was a 52-year-old man who fell from 20 feet from a ladder onto his buttock and complained of low back pain. He was alert, not intoxicated, and had no other injury than a T12 burst fracture identified. He had lumbar but not thoracic spine tenderness on exam. There was no retropulsion of bone into the spinal canal or neurological deficit. He was fitted with a TLSO back brace and did not require surgery. He was therefore categorized as minor clinical significance.

The second patient with TS injury missed by the proposed DI was a 51-year-old helmeted non-intoxicated and alert man riding a motorcycle that collided with a bicycle. He complained of forehead pain with a 3 x 3 cm hematoma and a 3 cm lip laceration. He had no CS or TS tenderness. The radiologist identified a "subtle non-displaced" T1 transverse process fracture which was thought inconsequential by the spine consultant. He was therefore categorized as no clinical significance.

There were 11 TS injuries identified on sagittal reconstruction CT that were not reported on the patient's CCT. Two were categorized as major (underwent spine surgery), 5 were minor (pain control and inpatient observation), and 6 were not clinically important. Hence, 2/11 (18%) TS injuries identified only on dedicated sagittal reconstruction CT were of obvious import, while 45% needed pain control. Of the entire cohort, 2/58 (3.5%) TS injuries were major and identified only on dedicated imaging. This proportion was 2/46 (4.3%) using the denominator of dedicated TS CT without CCT, 2/1220 (0.2%) for any chest or spine imaging, and 2/1798 (0.1%) for all patients enrolled.

DISCUSSION

Gross[11] in 2008 found a 6.6% false negative rate for chest and abdominal CT in identifying T and LS spine injuries and questioned their clinical import. Similarly, our study found that 11/58, or 19.0% of our TS injuries were found only on dedicated spine CT (6 on TS and 5 on CS CT), but 7 of these 11 had some clinical import (2 major, 5 minor). Therefore, 7/58 injuries of some importance (12.1%) required dedicated spine imaging for identification, higher than the previous study. However, only 2/58 required surgery.

It appears as if the cost of these dedicated sagittal reconstructions of spine CT is increasing. While Gross quoted $2,450 incremental cost for the reconstruction in 2008,[11] our center charged $3,070 in 2013. Although these are different centers, this amounts to a 25% increase in 5 years. With the advent of the Affordable Care Act in 2014, pressure on prices and their connection to quality care are coming under more intense scrutiny.[11]

Inaba et al[9] opined in 2011 that a combination of both clinical examination and CT screening based on mechanism will likely be required to ensure adequate sensitivity with an acceptable specificity for the diagnosis of clinically significant injuries of the thoracic-lumbar (TL) spine. However, our data suggests that clinical criteria alone may be reliable to identify TS injuries if our DI is subsequently validated.

Finally, the prevalence of TS injuries in our cohort was small (58/1,798, 3.2%) if we assume that patients who did not have CCT or dedicated TS imaging indeed had no injury. Therefore, the NPV without this proposed DI would be 96.8% (1740 true negatives/1,798 total subjects). If this DI is shown to be valid, the NPV would increase to 99.7% (570 true negatives/572 patients who had a positive DI, which missed 2 injuries). This suggests that chest and TS imaging to identify a low prevalence of TS injury may not be cost-effective. In our cohort, we performed dedicated TS CT on 1,220 patients at a charge of $3,312 per patient and found 56/58 injuries. That equates to $72,154 in charges per identified TS injury. With increasing pressure to control healthcare costs, this may not be justified or sustainable.

LIMITATIONS

This study reports patients from a single site and cohort of physicians. Though the sample of patients enrolled is moderate, the identified injuries are small. We used convenience sampling and some subjective adjudication of injury severity.

We used predictive factors, which were a subset of a larger group of predictors of chest injury in general. If we had set out to develop a specific TS injury DI, we might have considered other mechanistic factors that would predict injury, including lateral impact on driver's side, ejected from vehicle, lap belt without shoulder belt, or head-on collision. Since there are no further clinical predictors (only mechanistic ones), it is reasonable to use this study as a derivation set to be externally validated. Had TS injury been the singular focus of this study, other factors may have been found to be important. Therefore, if validation of the DI fails, then other predictive factors may need to be considered.

We did not CT all patients we enrolled, which opens the possibility of further missed injuries, reducing the sensitivity of the DI. However, the prevalence of chest plus TS CT in this trauma center was 68%, the highest of 5 trauma centers enrolling patients for the overall chest CT DI. Therefore, it is less likely that we would have missed a significant number of TS injuries with this liberal CT culture, by not imaging all patients.

We did not enroll patients on the night shift, where intoxication may be more prevalent. However, since one of our predictive criteria was altered mental status, the predictive value of this factor should remain constant. Had we enrolled patients 24 hours per day, this likely would have increased our sample size of T spine injuries.

Since our study included patients with T spine injuries on either CCT or dedicated T spine reconstructions, but many patients did not have the latter, it is possible that we missed some T spine injuries. This may reduce the sensitivity and predictive value of our proposed DI.

CONCLUSION

Sagittal reconstructions of TS from CCT imaging are of low yield and generate significant charges. Patients are highly unlikely to have TS injury if they are alert, without TS tenderness or DPI (-LR 0.07, 95% CI upper limit 0.28, NPV 99.7% 95% CI lower limit 98.7%). Excluding them from such reconstructive imaging may save considerable charges and payments.

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Address for Correspondence: Mark I. Langdorf, MD, MHPE. Department of Emergency Medicine, 200 S Manchester Ave, Suite 710, Orange, CA 92868. Email: milangdo@uci.edu.

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