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Prevalence and Clinical Import of Thoracic Injury Identified by Chest Computed Tomography but Not Chest Radiography in Blunt Trauma: Multicenter Prospective Cohort Study

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Study objective: Chest computed tomography (CT) diagnoses more injuries than chest radiography, so-called occult injuries. Wide availability of chest CT has driven substantial increase in emergency department use, although the incidence and clinical significance of chest CT findings have not been fully described. We determine the frequency, severity, and clinical import of occult injury, as determined by changes in management. These data will better inform clinical decisions, need for chest CT, and odds of intervention.

Methods: Our sample included prospective data (2009 to 2013) on 5,912 patients at 10 Level I trauma center EDs with both chest radiography and chest CT at physician discretion. These patients were 40.6% of 14,553 enrolled in the parent study who had either chest radiography or chest CT. Occult injuries were pneumothorax, hemothorax, sternal or greater than 2 rib fractures, pulmonary contusion, thoracic spine or scapula fracture, and diaphragm or great vessel injury found on chest CT but not on preceding chest radiography. A priori, we categorized thoracic injuries as major (having invasive procedures), minor (observation or inpatient pain control >24 hours), or of no clinical significance. Primary outcome was prevalence and proportion of occult injury with major interventions of chest tube, mechanical ventilation, or surgery. Secondary outcome was minor interventions of admission rate or observation hours because of occult injury.

Results: Two thousand forty-eight patients (34.6%) had chest injury on chest radiography or chest CT, whereas 1,454 of these patients (71.0%, 24.6% of all patients) had occult injury. Of these, in 954 patients (46.6% of injured, 16.1% of total), chest CT found injuries not observed on immediately preceding chest radiography. In 500 more patients (24.4% of injured patients, 8.5% of all patients), chest radiography found some injury, but chest CT found occult injury. Chest radiography found all injuries in only 29.0% of injured patients. Two hundred and two patients with occult injury (of 1,454, 13.9%) had major interventions, 343 of 1,454 (23.6%) had minor interventions, and 909 (62.5%) had no intervention. Patients with occult injury included 514 with pulmonary contusions (of 682 total, 75.4% occult), 405 with pneumothorax (of 597 total, 67.8% occult), 184 with hemothorax (of 230 total, 80.0% occult), those with greater than 2 rib fractures (n=672/1,120, 60.0% occult) or sternal fracture (n=269/281, 95.7% occult), 12 with great vessel injury (of 18 total, 66.7% occult), 5 with diaphragm injury (of 6, 83.3% occult), and 537 with multiple occult injuries. Interventions for patients with occult injury included mechanical ventilation for 31 of 514 patients with pulmonary contusion (6.0%), chest tube for 118 of 405 patients with pneumothorax (29.1%), and 75 of 184 patients with hemothorax (40.8%). Inpatient pain control or observation greater than 24 hours was conducted for 183 of 672 patients with rib fractures (27.2%) and 79 of 269 with sternal fractures (29.4%). Three of 12 (25%) patients with occult great vessel injuries had surgery. Repeated imaging was conducted for 50.6% of patients with occult injury (88.1% chest radiography, 11.9% chest CT, 7.5% both). For patients with occult injury, 90.9% (1,321/1,454) were admitted, with 9.1% observed in the ED for median 6.9 hours. Forty-four percent of observed patients were then admitted (4.0% of patients with occult injury).

Conclusion: In a more seriously injured subset of patients with blunt trauma who had both chest radiography and chest CT, occult injuries were found by chest CT in 71% of those with thoracic injuries and one fourth of all those with blunt chest trauma. More than one third of occult injury had intervention (37.5%). Chest tubes composed 76.2% of occult injury major interventions, with observation or inpatient pain control greater than 24 hours in 32.4% of occult fractures. Only 1 in 20 patients with occult injury was discharged home from the ED. For these patients with blunt trauma, chest CT is useful to identify otherwise occult injuries. [Ann Emerg Med. 2015;■:1-12.]

Please see page XX for the Editor's Capsule Summary of this article.

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Editor's Capsule Summary*What is already known on this topic*

Chest computed tomography (CT) is better than chest radiograph for identifying traumatic chest injury, but it includes a burden of higher radiation exposure and cost.

What question this study addressed

What proportion of specific chest injuries are identified only by chest CT, and what is the level of severity of these injuries as suggested by subsequent interventions?

What this study adds to our knowledge

In 5,912 trauma patients at 10 Level I trauma centers who received chest radiograph and chest CT, 1,454 of 2,048 (71%) with chest injury had some or all injuries identified only on chest CT. Fourteen percent of these injuries were deemed major.

How this is relevant to clinical practice

This study provides substantial data on the current use of chest CT scanning in patients with significant chest trauma. The authors emphasize the need for development of a decision rule to guide clinicians.

INTRODUCTION

Modern trauma care is resource intensive, with frequent and comprehensive use of computed tomography (CT) to rapidly identify major injury or exclude subtle injury. With scanners frequently located within or adjacent to Level I trauma centers, inpatient beds at capacity, and trauma team human resources stretched thin, temptation for liberal CT use is great. However, the “pan scan” approach is discouraged by the American College of Surgeons Committee on Trauma to limit radiation exposure: “A study should be performed only for a valid clinical indication...[that] will help determine patient management. Total body imaging without clinical indication...[is] not indicated or warranted.”¹ CT use has increased of late,² although studies have shown low rates of intervention from chest CT results, and there is no clear documentation of benefit that justifies cost and radiation risk.

Background

Thoracic injuries from trauma are a significant cause of morbidity and mortality and account for approximately 25% of trauma-related deaths in the United States.³ Blunt chest trauma is the third most common injury in

polytrauma patients, after head and extremities. Furthermore, thoracic injuries are the second most common cause of death, head trauma being the primary cause.⁴ Most blunt thoracic injuries are caused by motor vehicle crashes (63% to 78%), with the remainder (10% to 17%) by falls, blows from blunt objects, or explosive devices.⁵

Imaging plays a critical role in the diagnosis and management of blunt chest trauma. Although some thoracic injuries are evident clinically and treated before imaging, a chest radiograph is the initial study of choice and identifies life-threatening conditions such as tension pneumothorax, hemothorax, multiple rib fractures with flail chest, gross pulmonary contusions, and some mediastinal hematomas from great vessel injury.⁶ “Occult injuries” are those observed on chest CT but not on initial chest radiography. However, the clinical import of these injuries is less defined, as is the degree to which they affect management.

Several investigators have shown enhanced sensitivity of chest CT over chest radiography to evaluate blunt chest trauma. In a 93-patient Swiss study, chest CT found significant injury in patients with a normal chest radiograph result in more than half, and 20% of the time found more injuries than even a positive chest radiograph result, leading to changes in management.⁷ Chest CT also adds to evaluation of the thoracic spine, which is limited on chest radiograph.⁸

Two larger retrospective studies from the same group came to differing conclusions about the utility of chest CT. The first (n=1,337) concluded that chest CT findings were associated with “minimal clinical consequences,”⁹ whereas the second (n=2,435) found that older male patients with abdominal or extremity injury should have chest CT to identify occult injury.¹⁰ However, chest CT may identify clinically unimportant and incidental findings that increase costs and observation in the emergency department (ED) and slow ED patient throughput. To our knowledge, our study is the largest of occult injury to date, and the only prospective one.

Importance

The decision to add chest CT to the testing of a patient with multiple blunt trauma is poorly informed by previous literature. When drawn from a large heterogeneous trauma population, the proportion of chest CT-only injuries (occult injuries) that resulted in major or minor interventions can help guide rational use of chest CT.

The National Emergency X-Radiography Utilization Study (NEXUS) Chest study¹¹ was conducted to develop a decision instrument to guide rational ordering of chest radiography in blunt trauma, according to 7 predictive factors: rapid deceleration, older than 60 years, distracting

painful injury, intoxication, altered mental status, chest pain, or chest wall tenderness.

The research group then studied the more expensive, time-consuming, and radiation-exposing chest CT to develop a decision instrument based on 13 candidate predictive factors (unpublished data). Chest wall tenderness was split into sternal tenderness and other chest tenderness. NEXUS Chest CT added new candidate predictive factors of thoracic spine and scapular tenderness, and whether there was peritoneal or pericardial fluid, or pneumothorax on extended focused assessment with sonography for trauma.

Goals of This Investigation

In this multicenter, prospective, 10-site study, we characterized the degree and pattern of improved sensitivity of chest CT over chest radiography for thoracic injuries and determined the clinical import by tracking subsequent management.

MATERIALS AND METHODS

Study Design and Setting

We conducted a secondary analysis of data collected during the NEXUS Chest¹¹ (January 2009 to March 2012) and NEXUS Chest CT (November 2011 to May 2013; unpublished data) studies, 2 prospective multicenter observational cohorts of patients with blunt trauma at 10 urban US American College of Surgeons verified Level 1 trauma centers (7 in California, and 1 each in Texas, Massachusetts, and New Jersey). Because of differing start and end times for the 2 studies at the 10 centers, patient recruitment did not overlap. Yearly trauma volume varied from 1,900 to 7,100 in these centers, with yearly ED volume of 44,000 to 180,000 patients.

We assessed injury severity of the cohort by median Injury Severity Score (ISS) and level of trauma activation.

Selection of Participants

Inclusion criteria for both parent studies were patients older than 14 years, blunt trauma within 24 hours of ED presentation, and chest imaging (chest radiography or chest CT) in the ED as part of trauma evaluation. Because of study personnel limits, we enrolled patients from 7 AM to 11 PM daily.

Methods of Measurement

The primary purpose of the parent study was to derive and then validate a decision instrument to guide chest imaging in blunt trauma. For this, we enrolled 14,553 patients who had either chest radiography or chest CT. In this article,

we analyze and present only patients who had both chest radiography and subsequent chest CT within 12 hours, at the discretion of the trauma team lead physician.

The first NEXUS Chest study focused on injury found on chest radiography alone. We report 4,409 of these patients, all of whom also had chest CT. The second NEXUS Chest CT study focused on occult injury found on chest CT and not observed on immediately preceding chest radiography. We report 1,503 additional patients who had both studies. Our total sample size was therefore 5,912, which represents 40.6% of all patients enrolled in the parent studies. The first study did not specifically identify outcomes of scapula or thoracic spine fracture, or esophageal or tracheal injury, because these are not readily observed on chest radiography alone. We therefore report these injuries in [Table 1](#) with the smaller sample size of 1,503. All other injuries are reported for the combined cohort (n=5,912).

CT scanners ranged from 64 to 256 slice at the 10 centers. Each could perform sagittal reconstructions for thoracic spine injuries and to clarify findings. Slice thickness varied from 1.25 to 5 mm, depending on application. Chest CT was conducted as CT angiograms with bolus intravenous contrast routinely. However, there was variability of timing of injection across centers, and we did not collect specific data on contrast administration for each scan. Chest radiography was conducted by portable or overhead machine with the patient supine for 98% of patients across all centers, with the remainder upright or with 2-view technique.

Nonchest CT imaging was performed as follows: focused assessment with sonography for trauma was conducted for 65% to 100% of patients across the 10 centers, except for 1 outlier with 10% assessment. Extended assessment (including chest for pneumothorax) was more variable, conducted for 75% to 98% of patients in 4 centers, approximately half in 3 centers, and not at all in 3 centers.

Concurrent abdominal CT was conducted nearly universally (>95%) in 8 of 10 centers and for at least 90% of 5,912 patients across all centers. Chest CT was conducted after chest radiography within 2 hours for more than 90% of patients across 8 centers, with 2 outliers at 80% within 2 hours. By 4 hours, more than 95% of patients had chest CT, and by 12 hours, 100% had it by inclusion criteria.

Outcome Measures

Primary outcome was prevalence and proportion of occult injury with major interventions of chest tube, mechanical ventilation, or surgery. Secondary outcome was minor interventions of admission rate or observation hours because of occult injury. We report odds ratios (ORs) for acute interventions for thoracic injuries identified on

Table 1. Percentage of patients for each injury that was an occult injury and proportions who had interventions of surgery (major intervention), or inpatient pain control or additional observation greater than 24 hours (minor intervention), with ORs for each injury comparing intervention for injuries found on chest CT only versus those found on chest radiography and CCT.

Injury Type	Total Injured, No. (%)	Imaging That Identified Injury, No. (%)		OI, %	OR (95% CI) for Intervention for Injury Observed on CCT Only vs CXR and CCT
		CXR and CCT	CCT Only		
>2 rib fractures	1,120	448	672	60.0	
Surgery, major	1	0	1	NCR	NCR (undefined 0/448 surgeries)
Pain control/observation >24 h, minor	314 (28.0)	131 (29.2)	183 (27.2)	58.3	0.91 (0.69–1.19)
No intervention	805 (71.9)	317 (70.8)	488 (72.6)	60.6	1.00 [Reference]
Sternal fractures	281	12	269	95.7	
Surgery, major	3 (1.1)	1 (8.3)	2 (0.7)	66.7	0.07 (0.004–5.01)
Pain control/observation >24 h, minor	83 (29.5)	4 (33.3)	79 (29.4)	95.2	0.74 (0.18–3.53)
No intervention	195 (69.4)	7 (58.3)	188 (69.9)	96.4	1.00 [Reference]
Great vessel injury	18	6	12	66.7	
Surgery, major	7 (38.9)	4 (66.7)	3 (25.0)	42.9	0.17 (0.01–2.08)
Observation >24 h, minor	11 (61.1)	2 (33.3)	9 (75.0)	81.8	1.00 [Reference]
Ruptured diaphragm	6	1	5	83.3	NCR (all 6 patients had operative repair)
Scapular fracture*	47	20	27	57.4	
Surgery, major	1 (2.1)	1 (5.0)	0	NCR	NCR
Pain control/observation >24 h, minor	38 (80.9)	18 (90.0)	20 (74.1)	52.6	0.16 (0.003–1.48)
No intervention	8 (17.0)	1 (5.0)	7 (25.9)	87.5	1.00 [Reference]
Thoracic spine fracture*	66	5	61	92.4	
Surgery, major	7 (10.6)	1 (20.0)	6 (9.8)	85.7	0.47 (0.04–26.99)
Pain control/observation >24 h, minor	55 (83.3)	4 (80.0)	51 (83.6)	92.7	1.00 [Reference]
No intervention	4 (6.1)	0	4 (6.6)	NCR	

CXR, Chest radiograph; CCT, chest computed tomography; OI, occult injury; NCR, not clinically relevant because of none or few interventions.

*Data only from NEXUS Chest CT study (n=1,503).

chest CT alone versus chest radiography and chest CT. We report interventions for occult injury without judging benefit or potential harm.

We used final readings by board-certified radiologists at each site (blind to study hypothesis and subject enrollment) to identify injuries. However, radiologists were not blinded to chest radiography findings when interpreting chest CT because all images for a given patient were available on the electronic system. We defined occult injury as any identified on chest CT but not the immediately preceding chest radiography. These were pneumothorax, hemothorax, sternal or greater than 2 rib fractures, pulmonary contusion, thoracic spine or scapula fracture, and diaphragm or great vessel injury.

We further defined occult injury as clinically important (significant intrathoracic injury) by whether patients had interventions. We used a method similar to that of Stiell et al.¹² We convened an expert panel of 6 associate-professor-level or higher academic emergency physicians and 4 associate-professor-level or higher trauma surgeons to derive our Radiologic Injury Clinical Significance Scale. We generated an inclusive list of chest injuries paired with management changes and interventions, eg, pneumothorax with chest tube placement. Panel members independently

reviewed this list and assigned the following values to each injury/intervention pair: major clinical significance=2 points, minor clinical significance=1 point, and no clinical significance=0 points. One investigator (R.M.R.) collated and calculated the means for these injury-intervention pairs, rounding to the first decimal place. Mean scores of 1.5 to 2.0, 0.5 to 1.49, and 0 to 0.49 were deemed to represent major, minor, and no clinical significance, respectively.¹³

We classified as having major interventions for occult injury patients who had surgery, mechanical ventilation for pulmonary contusion, or chest tube for pneumothorax or hemothorax. The data collection sheet specified that mechanical ventilation had to be for pulmonary contusion, not other factors such as shock or head injury. Minor interventions for patients with occult injury were inpatient (not ED) pain management or observation greater than 24 hours.

Research assistants recorded interventions for identified injuries from radiology reports and discharge summaries. Inconclusive radiology readings were marked as injury present. Data were recorded on standard data sheets from a priori specific definitions of findings and outcomes.

Blinded to clinical assessment, research assistants followed all enrolled subjects through their hospital course

Table 2. Demographics and mechanisms of injury for 5,912 patients with blunt trauma from 10 trauma centers that had both chest radiograph and chest CT.

Demographics and Mechanism	n	Percentage
Men	3,393	57.4
Age, y		
15–19	416	7.0
20–29	1,097	18.6
30–39	931	15.7
40–49	985	16.7
50–59	918	15.5
60–69	643	10.9
70–79	425	7.2
>80	433	7.3
Missing	64	1.1
Mechanisms of injury		
Motor vehicle crash	2,680	45.3
Fall from higher than standing	777	13.1
Pedestrian vs motor vehicle*	698	11.8
Motorcyclist, scooter, or ATV rider	697	11.8
Fall from standing	366	6.2
Bicyclist [†]	277	4.7
Blunt object/battery	173	2.9
Other (including 14 sports injuries)	130	2.2
Unknown (includes found down)	114	1.9

ATV, All-terrain vehicle.
 *Pedestrian: Pedestrian struck by motorized moving vehicle.
[†]Bicycle: Fall from bicycle or crash into object on bicycle.

to determine clinical outcomes (hospital admission and injury-associated interventions). To check abstractor reliability, a second abstractor independently abstracted patient outcomes (radiology reports, admission, and interventions) for a convenience sample of 80 consecutive patients of the first 1,000. Given that we found extremely high interabstractor agreement for all outcomes (radiology reports 99% agreement, $\kappa=0.97$; hospital admission and interventions 100% agreement, $\kappa=1.0$), we limited our subsequent checks of outcomes to random monthly audits.

Per Kaji et al,¹⁴ we conformed to the methods of proper chart abstraction for data collection and resultant injuries. Trained research assistants at all centers used a standardized instrument to collect age, sex, and mechanism of trauma from the paramedic report and clinicians in the resuscitation room. Abstractors were sufficiently trained before patient enrollment, inclusion and exclusion criteria were strictly defined, and categorization of injury and clinical significance were determined in advance. We monitored research abstractors for accuracy by double checking data entry, and we described our convenience sampling method. We had complete data on patients on which we report, except as noted in the description of the 2 parent studies (n=4,409 for NEXUS Chest and 1,503 for

NEXUS Chest CT; total 5,912). These studies excluded 0.5% of patients enrolled because of absence of chest imaging, blunt trauma, or appropriate age. We did not exclude patients for missing data because less than 0.1% of data elements were missing and findings were presumed absent. We did not use data imputation. Data abstractors were aware of the study hypothesis. Conflicting data were adjudicated by the site principal investigators.

For 1,503 patients from the NEXUS Chest CT study, we specifically collected data on scapular, thoracic spine, esophageal, and tracheal injuries. Data for these injuries in the earlier NEXUS Chest study were incomplete and therefore are not reported here.

In the earlier NEXUS Chest study, we used telephone follow-up for a subgroup of 212 patients who had no ED chest imaging and 221 who had negative chest imaging results, either chest radiography or chest CT. We did not find any missed major injuries. For the later NEXUS Chest CT study, we checked medical records for a subset of 100 patients at each site for unscheduled visits to the ED or clinic within 72 hours and found no new injuries.

We deidentified and recorded data according to institutional review board approval, and waiver of informed consent was approved at each site.

Primary Data Analysis

We managed study data with Research Electronic Data Capture tools hosted by the University of California (available at <http://www.project-redcap.org/>). We calculated frequencies, proportions, and ORs with 95% confidence intervals (CIs), using Stata version 12.1 (StataCorp, College Station, TX).

RESULTS

Demographics of our cohort and mechanisms of injury are shown in Table 2. Most of our patients were men, young, and victims of motor vehicle crashes, but almost one fourth were aged 60 years or older. A total of 68.9% of patients in our cohort sustained injuries because of vehicular trauma.

Main Results

Of the 5,912 patients enrolled, 2,048 (34.6% [95% CI 33.4% to 35.9%]) had at least 1 injury identified by either chest radiography or chest CT, and 1,454 of these patients' injuries (71.0% of all injured patients [95% CI 69.0% to 72.9%], or 24.6% of all patients [95% CI 23.5% to 25.7%]) were observed on chest CT only (occult injury). Conversely, chest radiography found all injuries in only 594 patients, 29.0% (95% CI 27.1% to 31.0%) of injured

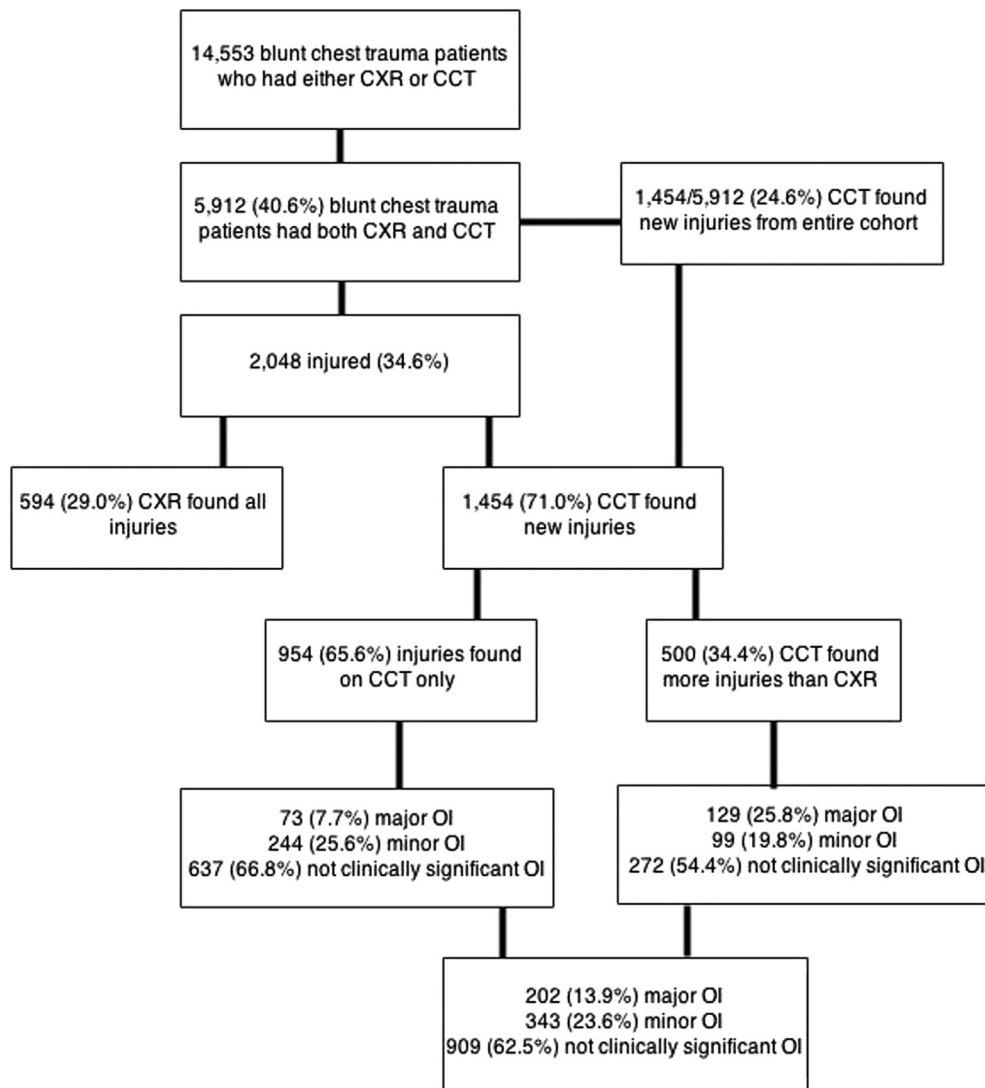


Figure. Graphic representation of all patients with blunt trauma who had either chest radiography or chest CT, the subset of patients who had both chest radiography and chest CT in this study, those injured, which modality identified thoracic injuries, and their clinical import (major, minor, and not clinically significant).

patients (Figure). There were 537 patients with multiple occult injuries.

Tables 1, 3, and 4 show these 2,048 injuries, the proportions that were occult injury, and those that had major (mechanical ventilation, chest tube, or surgery) or minor (inpatient pain management or observation >24 hours) interventions. We also present ORs for intervention between chest radiography–identified and chest CT only–identified injuries.

Data for the 1,454 patients with occult injury can be broken down further (Figure). For 954 of 5,912 patients (16.1% [95% CI 15.2% to 17.1%], or 46.6% of 2,048 injured patients [95% CI 44.4% to 48.7%]), chest CT alone identified injuries when chest radiography result was negative. For 500 of 5,912 additional patients (8.5%

[95% CI 7.8% to 9.2%], and 24.4% of all 2,048 injured patients [95% CI 22.6% to 26.3%]), chest radiography found at least 1 injury, but chest CT found additional occult injury.

Injuries from the later NEXUS Chest CT study of 1,503 patients (25.4% of 5,912 total enrolled) included scapula and thoracic spine fractures and esophageal and tracheal injuries. Because we found no esophageal or tracheal injuries in this subset, Table 1 reports only findings for these fractures.

Tables 1 and 3 show occult injury for each injury, proportions with major and minor interventions, and ORs comparing interventions for injuries found on chest CT only versus chest radiography and chest CT. The tables are separated into those injuries most likely to cause major

Table 3. Percentage of patients for each condition that was an occult injury and proportions who had interventions of mechanical ventilation, chest tube (both major interventions), and inpatient pain control or observation greater than 24 hours (minor intervention), with ORs for each injury comparing intervention for conditions found on chest CT only versus those found on chest radiography and chest CT.*

Injury Type	Total Injured, No. (%)	Imaging That Identified Injury, No. (%)		OI, %	OR (95% CI) for Intervention for Injury Observed on CCT Only vs CXR and CCT
		CXR and CCT	CCT Only		
Pulmonary contusion	682	168	514	75.4	
Mechanical ventilation, major	51 (7.5)	20 (11.9)	31 (6.0)	60.8	0.41 (0.22–0.80)
Pain control/observation >24 h, minor	148 (21.7)	46 (27.4)	102 (19.8)	68.9	0.59 (0.39–0.92)
No intervention	483 (70.8)	102 (60.7)	381 (74.1)	78.9	1.00 [Reference]
Pneumothorax	597	192	405	67.8	
Chest tube, major	234 (39.2)	116 (60.4)	118 (29.1)	50.4	0.33 (0.22–0.48)
Pain control/observation >24 h, minor	95 (15.9)	11 (5.7)	84 (20.7)	88.4	2.45 (1.20–5.39)
No intervention	268 (44.9)	65 (33.8)	203 (50.1)	75.7	1.00 [Reference]
Hemothorax	230	46	184	80.0	
Chest tube, major	101 (43.9)	26 (56.5)	75 (40.8)	74.3	0.65 (0.31–1.34)
Pain control/observation >24 h, minor	26 (11.3)	1 (2.2)	25 (13.6)	96.1	5.65 (0.81–244.2)
No intervention	103 (44.8)	19 (41.3)	84 (45.7)	81.6	1.00 [Reference]

*If a patient had both pneumothorax and hemothorax and received a chest tube, this was counted as a major intervention for both pneumothorax and hemothorax.

interventions in the ED, such as mechanical ventilation or chest tube insertion (Table 3), or other injuries, including those most likely to require surgery (Table 1).

From Table 3, for patients with CT-only-identified pulmonary contusion, 6.0% had mechanical ventilation. For pneumothorax and hemothorax, 29.1% and 40.8% had chest tubes placed, respectively.

For Table 1, as described in the “Materials and Methods,” we report data from 1,503 patients in the NEXUS Chest CT study because these injuries are not generally visible on chest radiography alone (scapula and thoracic spine). From Table 1, occult fractures had significant proportions of minor interventions of inpatient pain control or observation greater than 24 hours. Sternal and rib fractures had this less commonly (27.2% and 29.4%, respectively) than scapular

and thoracic spine fractures (74.1% and 83.6%, respectively). For more serious occult injury, 25% of great vessel injuries had surgery (3/12, the remainder presumably venous injuries), as did all ruptured diaphragms (6/6, with 5/6 occult injury).

Table 4 shows the percentage of patients with all significant intrathoracic injury, whether major or minor, and the percentage who had major (surgery, chest tube, or mechanical ventilation) or minor (inpatient pain control/observation greater than 24 hours) interventions. Significant intrathoracic injury is defined as receiving some intervention. Of all 305 major injuries, 66.2% were occult. However, the OR for major interventions (invasive procedures or mechanical ventilation) of these occult injuries was 0.35 compared

Table 4. Percentage of patients with all significant intrathoracic injuries, classified as major or minor, and the percentage who had major (surgery, chest tube, or mechanical ventilation) or minor (inpatient pain control or observation >24 hours) interventions.*

Injury Classification	Total Injured	Imaging That Identified Injury		OI, %	ORs (95% CI) of Intervention for Injury on CCT Only vs CXR and CCT
		CXR and CCT	CCT Only		
Patients with any injury	2,048 [†]	594	1,454	71.0	N/A
Any major SITI	305	103	202	66.2	0.23 (0.17–0.33)
Minor SITI only	396	53	343	86.6	0.78 (0.54–1.12)
Thoracic injury without clinical significance only	1,018	109	909	89.3	1.00 [Reference]
Patients with suspected injury on CXR not confirmed on CCT	329 (false-positive CXR)	329 (false-positive CXR)	0 (presuming CCT is criterion reference)	0	
Percentage of all patients (n=5,912)	N/A	N/A	1,454	24.6	

N/A, Not applicable; SITI, significant intrathoracic injury, whether major or minor, all of which had some intervention.

*SITI is defined as receiving some intervention.

[†]2,048=Total patients with suspicion of injury on CXR (eg, widened mediastinum) whether confirmed on CCT or not, plus actual injuries identified on CCT.

with injuries found on chest radiography. This indicates that chest CT identifies less severe forms of each injury than chest radiography.

We found 241 major interventions for occult injury in 202 patients with significant intrathoracic injury. There were 154 patients who had chest tubes placed for pneumothorax, hemothorax, or both. Thirty of these 154 patients had concomitant pneumothorax and hemothorax. Five others had combined pneumothorax and pulmonary contusion and had both chest tube and mechanical ventilation. These 154 patients represent 76.2% of the 202 patients who had major interventions, whereas the remainder had surgery or mechanical ventilation.

One hundred forty patients (of 5,912; 2.4%) died in the ED after chest CT or before hospital discharge. Of these, 66 patients (47.1%) had no injuries on chest CT and died of other causes. Thirty-six patients (25.7%) had only occult injury on chest CT, and 26 more (18.6%) had occult injury in addition to those observed also on chest radiography (total occult injury rate 62 patients; 44.3% of deaths). These 62 patients had the following occult injuries: 39 with greater than 2 rib fractures; 27 with pulmonary contusions; 18 with pneumothorax and 14 with hemothorax; 16 with sternal, 5 with thoracic spine, and 2 with scapula fractures; and 1 each with diaphragm and great vessel injury. Finally, 12 of 140 patients who died (8.6%) had injuries observed with both modalities. Of the 62 patients for whom chest CT found injury or additional injury not observed on chest radiography, 22 (15.7% of deaths) had major interventions of mechanical ventilation, chest tube, or surgery.

Our patients were moderately injured, according to ISS. The median ISS, calculated for 74% of patients in the NEXUS Chest CT study, was 6 (interquartile range 2 to 14), with 22.5% greater than 15 and 9.4% greater than 25. We did not, however, collect ISS universally, or in the NEXUS Chest study at all, because these were calculated only on hospital admission or death, and after all injuries were identified. Therefore, the ISS is not useful to guide initial testing decisions in the resuscitation room.

Levels of trauma activation varied across the 10 centers. Highest-level response was conducted for 9% to 30% of patients. There were 6 centers with only 2 levels of response, in which the lower level occurred for 63% to 80% of patients. For the 3 centers with 3-tiered response, the middle level occurred 30% to 68% of the time; the lowest level, 23% to 60% of the time. The remaining center had all trauma patients go directly to the trauma unit with 1 level of activation.

There were 329 patients (16.1% of 2,048) for whom the chest radiograph was suspicious for injury that was not confirmed on chest CT. These were widened mediastinum (n=287; 87.2%), pulmonary contusion (n=22), pneumothorax (n=15), greater than 2 rib fractures (n=13), hemothorax (n=3), and thoracic spine (n=2) and scapula (n=1) fractures. These 343 false-positive chest radiography injuries occurred in 329 patients.

Half of the 1,454 patients with occult injury (50.6%) had repeated imaging (88.1% of these had chest radiography, 11.9% chest CT, and 7.5% both). Most patients with occult injury (1,321/1,454; 90.9%) were admitted after CT, whereas 9.1% (n=133) were observed in the ED for median 6.9 hours (interquartile range 6 to 9 hours). Forty-four percent of 133 observed patients were then admitted (4.0% of 1,454 patients with occult injury; 58 patients), whereas 56% (5.1% of 1,454 patients with occult injury; 75 patients) were discharged home from the ED.

Twenty-nine of the 31 patients (93.5%) with mechanical ventilation for pulmonary contusion also had pneumothorax or greater than 2 rib fractures. Conversely, we found only 2 patients (6.5%) with isolated pulmonary contusion identified on chest CT only who required mechanical ventilation. For all 4 fracture types in aggregate, regardless of occult injury (rib, sternal, scapular, and thoracic spine), 490 of 1,514 (32.4%) had inpatient pain control or observation greater than 24 hours (rib 28.0%, sternal 29.5%, scapular 74.1%, thoracic spine 83.3%). For all 4 fracture types, 1,029 of 1,514 (68.0%) were occult injury, and 331 of 1,029 (32.4%) of these had inpatient pain control or observation greater than 24 hours (rib 27.2%, sternal 29.4%, scapular 74.1%, and thoracic spine 83.6%).

LIMITATIONS

There were a number of important limitations. We could not determine whether mechanical ventilation was conducted solely because of thoracic injury rather than head injury or shock. The decision process may not have been evident in the record and may have been instituted as late as 24 hours from injury. Although excluded on the data sheet, mechanical ventilation may have been due to nonthoracic injury.

We did not collect data on Abbreviated Injury Scale score components for each patient, so we were unable to further assess the incremental value of chest CT by severity of injury to body regions, as was done in the article by Kaiser.⁹ However, assignment of Abbreviated Injury Scale score and ISS is done accurately only retrospectively when all injuries have been identified. Therefore, the clinician can only estimate the Abbreviated Injury Scale score or

given body regions on patient presentation, limiting this strategy for use prospectively to determine need for or yield of chest CT.

In many cases, it is unclear whether a chest tube was placed for an abnormal chest radiograph or chest CT result. Thus, we might overstate the effect of chest CT in driving chest tube placement. We did not collect data or ask physicians whether the chest radiograph or chest CT drove intervention, nor did we track timing of chest tube placement versus imaging. Similarly, we did not query physicians specifically about whether the occult injury drove the decision for ED observation or admission.

We collected data for a convenience sample of patients with blunt trauma. Other than the night shift, when research assistants were not present, patients were entirely consecutive, which may minimize bias. We also do not know whether interventions based on chest CT were truly necessary or beneficial because we did not study patient outcomes. Interventions could have caused harm; our study design did not assess this. Decisions for intervention were largely made by residents (usually) or fellows in our academic medical center sites. This may also have led to more liberal observation and admission thresholds for any abnormal findings on chest CT, inflating its perceived value. Local culture of observation and admission thresholds, CT equipment, trauma center volume, and hospital capacity might all influence management of identified injuries. These would be expected to vary between institutions.

Interventions may not have been based on official chest radiography or chest CT reports, which are not routinely quickly available in our academic centers. In addition, trauma captains made decisions in concert with clinical events and data. We recognize, for example, that the decision to perform mechanical ventilation is at least as much based on physiologic parameters as imaging. Therefore, our study may grossly overstate the value of the chest CT in this and other injuries.

Although by study design patients may have had chest CT up to 12 hours after initial chest radiography, the majority of chest CT scans were conducted immediately after stabilization in the resuscitation bay. However, it is possible that a chest CT delayed by as much as 12 hours would identify injuries too subtle for chest radiography and therefore overstate the value of the scan. Furthermore, progressive findings from injuries such as hemothorax, pneumothorax, mediastinal hematoma, and pulmonary contusion would be more likely identified by the later study, chest CT, than early chest radiography.

We combined data of patients from 2 studies, NEXUS Chest and NEXUS Chest CT. For 4,409 patients, we did not

collect specific esophageal, tracheal, thoracic spine, and scapular injuries because the focus of the initial study was chest radiography utility, unlikely to find these injuries. We then sought to identify these specific injuries in the remaining 1,503 patients through specific comparison of chest radiography and chest CT. It is impractical to assess the chest radiography results of the initial group of patients for these rare injuries.

Some less-injured patients may never have had chest CT, which would reduce the incidence of occult injury findings. Conversely, some patients are too critically injured to have chest CT and go directly to the operating room or die. Such patients, if they had chest CT, would be expected to have increased occult injury findings. Both circumstances would affect the utility of chest CT in opposite directions. We studied patients from 10 centers in a real-world scenario to best reflect the spectrum of injury in which chest CT is typically used.

Radiologists were not blinded to chest radiography findings when interpreting chest CT and vice versa because all images for a given patient were available. This confounder may have enhanced the identification of injury in both studies, depending on which was read first.

The high yield of occult injury identified on chest CT presented here is likely a consequence of a more seriously injured cohort of 5,912 patients who had both chest CT and chest radiography (rather than 14,553 who had only chest radiography). This should not be extrapolated to a yield rate of all patients with blunt trauma who present to Level I trauma centers.

We did not collect data on incidental findings on chest CT, and because this was viewed as the criterion reference, we cannot know the rate of incidental findings that may have led to additional, perhaps unnecessary, evaluation or intervention.

We report only patients who actually had chest CT, and not which patients should receive chest CT, because we did not know the decision process of the trauma captain. However, our broad sample from 10 centers likely reflects which patients do receive chest CT in a resource-rich US health care system.

DISCUSSION

Previous work has faulted chest CT as overly sensitive, identifying incidental injuries of little or no clinical consequence, and increasing cost with no patient benefit.^{9,10} Our findings add substantially to the literature, with a larger sample size, prospective design, and comprehensive injury identification stratified into major, minor, and no clinical significance.

This study included only patients who had both chest radiography and chest CT, which were 40.6% of all 14,553 patients with blunt trauma who were enrolled in the parent studies. This subset of patients with both types of imaging would be expected to be more severely injured because the trauma captain believed that chest CT was necessary beyond the screening chest radiography. This explains the high yield of chest CT for occult injury in our study.

We found that a quarter of all enrolled patients had occult injury identified by chest CT and that two thirds of major and four fifths of minor injuries were occult. On the other end of the spectrum, four fifths of clinically unimportant injuries were occult as well.

Previous work reports wide variation in occult injury rate, from 8.4% to 73.8%, depending on severity of injury of the cohort.^{7,9,10,13,15-18} For example, with severe injury (ISS means 24 and 30) occult injury rates were 73.8% and 65.0%, respectively.^{15,18} Contrast this with our rate (ISS median 6) of 24.6% of patients who received both chest radiography and chest CT.

Our 24.6% (95% CI 23.5% to 25.7%) rate of occult injury in our entire cohort of 5,912 patients is higher than that of Kea et al,¹³ who used similar methodology with 589 chest CT patients and found 18.0% occult injury (95% CI 15.1% to 21.3%). However, our categorization of an occult injury includes additional injuries found on chest CT, even if the chest radiograph showed some abnormality. For example, a chest-CT-only pulmonary contusion was considered occult injury in this study even if the chest radiograph showed a pneumothorax. By contrast, Kea et al¹³ and Kaiser et al¹⁰ reported as having occult injury only patients with a completely normal chest radiograph result. Therefore, one would expect the present study to have higher occult injury rates than previous reports.

Only 1 of these previous studies stratified injuries by intervention into major, minor, or no clinical import. Kea et al¹³ found 2.0% (95% CI 1.7% to 3.5%) of major occult injuries compared with our 3.4% (95% CI 3.0% to 3.9%), with 13.2% minor interventions compared with our 5.8%. Although definitions of injury between these 2 studies were the same, we included a more injured group of patients with some chest radiograph abnormality, whereas Kea et al¹³ did not. Hence, the denominator to which we compared our minor interventions group was larger, yielding a smaller proportion of patients with intervention.

Sixty to 80% of common thoracic injuries (pulmonary contusion, pneumothorax, and hemothorax) were occult injury, found on chest CT alone. However, the ORs for intervention for these 3 injuries compared with those discovered on chest radiography alone varied (0.41, 0.33,

and 0.65, respectively) (Table 3). This indicates that when injuries were occult, patients were less likely to have major intervention of mechanical ventilation or chest tube, as would be expected if the degree of injury were smaller. Conversely, patients were considerably more likely to undergo observation greater than 24 hours or inpatient pain control when occult injury was identified by chest CT (OR 2.45 for pneumothorax and 5.65 for hemothorax) (Table 3). Our study did not determine whether these periods of observation were necessary for better patient outcome. However, chest CT did identify occult fractures in 1,019 patients (50.2% of 2,048 injuries and 17.4% of 5,912 patients) (Table 3) for which pain control would be both clearly indicated and better justified. More than half of these (n=672) were multiple rib fractures.

Although sample size was small, two thirds of great vessel injuries were occult, and 3 of the 12 injuries identified were surgically repaired. The others presumably were identified as venous hematomas on further evaluation. Catastrophic vascular outcome without surgery in these 3 patients would likely be high. Our findings ask whether it is worth the cost and radiation to identify 3 of 5,912 patients (0.05%) who would likely die without chest CT.

More than 90% of 66 thoracic spine fractures (1.1% of all 5,912 patients) were found on chest CT alone. The potential for cord injury is substantial, and further evaluation, along with continued strict spine immobilization, is indicated. A recent decision instrument for thoracic spine injury found that any one of tenderness, distracting painful injury, or clinical intoxication was moderately predictive of fracture on sagittal reconstruction of chest CT.⁸ Because of the prevalence of occult thoracic spine fracture, this decision instrument, if validated, should help identify patients who benefit from sagittal reconstruction of chest CT after normal chest radiography result.

Only 6% of patients with pulmonary contusion identified on chest CT alone had mechanical ventilation. Imaging is only a part of this diagnosis, whereas serial measures of oxygenation and respiratory function determine need for intubation.¹⁹

Although our study design does not inform whether chest tubes were necessary, we believe that the other major intervention of surgery was likely necessary for occult great vessel injury (3/12), thoracic spine fractures (6/61), and diaphragm ruptures (5/5). These surgeries, driven by chest CT, would be lifesaving or avoid paralysis. We maintain that chest radiography remains an important screening tool for blunt trauma because it drives early chest tube placement and uncommonly obviates the need for chest CT with presumed isolated pneumothorax or hemothorax.

Discovery of occult injury on chest CT led to substantial further evaluation, with more than 9 in 10 patients

admitted outright, with slightly less than half of those observed in the ED ultimately admitted as well. Repeated imaging (mostly chest radiography) was nearly universal, with almost 1 in 13 patients receiving both chest radiography and chest CT again. Our study did not determine whether repeated imaging was necessary or affected outcome, or whether findings changed.

Even though chest CT identified many occult injuries (major 66.2%, minor 86.6%) (Table 4), patients were less likely (OR 0.35 and 0.78, respectively) to receive intervention because the additional chest CT-identified injuries were either more minor or had already had intervention solely on the chest radiography findings.

Although chest CT is clearly more sensitive than chest radiography in identifying injury, it is also more specific. We found that 329 of 2,048 patients (16.1%) had suspected injuries that were not confirmed on chest CT. Assuming chest CT is the criterion reference, it excludes chest radiography false-positive findings, especially those of possible great vessel injury, which composed 87.2% of all our false-positive chest radiography findings. This is not surprising, given that the majority of blunt trauma chest radiography is conducted with the patient supine, accentuating mediastinal width because of positioning and fat. Hence, chest CT may provide additional benefit by excluding injury, potentially saving observation time and cost.

We found that fewer patients with occult hemothorax or pneumothorax had pleural drainage (32.8%), contrary to clinical expectations. We offer 2 explanations. We enrolled only patients who had both chest radiography and chest CT. However, some patients with large pneumothorax or hemothorax on initial chest radiography may have had chest tube placement for the obvious finding and then never had chest CT at all and would not be included in this study. Conversely, patients with small pneumothorax or hemothorax not requiring immediate drainage until confirmed by chest CT also may not have had chest tubes. Furthermore, when official radiology reports hinted at the possibility of pneumothorax (“cannot exclude small”) or hemothorax (“blunting of costophrenic angle, consider pleural fluid”), the chest radiography was credited with having identified the injury, if confirmed on chest CT. Therefore, some potentially inconsequential chest radiography findings confirmed but not worse on chest CT were considered identified by chest radiography. The combination of these factors explains why our chest tube rate for pneumothorax or hemothorax identified on both chest radiography and chest CT is lower than expected.

We found that a minor portion of patients with occult pneumothorax (20.7%), hemothorax (13.6%), pulmonary contusion (19.8%) (Table 3), greater than 2 rib fractures (27.2%), and sternal fracture (29.4%) (Table 1) had

inpatient pain control or greater than 24-hour observation. Although the identification of the injury on chest CT alone may trigger the observation period, if pain control alone was provided, we believe it is important to identify the cause. In an era of scrutiny of reimbursement, insurers could question the necessity of further care without an identified injury, which the chest CT provides.

Selective chest CT use should consider charges and costs to patient, insurers, and society. In our center, the charges for chest CT with intravenous contrast total \$4,178 per patient (\$3,919 technical and \$259 professional). Medicare allowable charges are approximately \$378 for technical and \$78 for professional fees (total US federal government reimbursement of \$456 per study).²⁰

A recent study determined diagnostic yields and charge estimates for chest imaging. The mean charges per injury diagnosis on chest radiography, chest CT, and chest CT after normal chest radiography result were \$3,845, \$10,597, and \$20,347, respectively. Despite enhanced diagnostic yield, chest CT generates substantially higher charges, thus driving need for a decision instrument to guide care and reduce costs.²¹

In conclusion, we studied 5,912 of 14,553 patients (40.6%) with blunt chest trauma who had chest CT in addition to chest radiography. In this more-injured subset, occult injuries were found in 71% of 2,048 injured patients and a quarter of 5,912 patients with blunt chest trauma. More than one third of patients had some intervention (37.5%). Three quarters of major interventions (76.2%) were chest tubes, with minor intervention of observation or inpatient pain control greater than 24 hours triggered in 27% to 84% of occult fractures. Only 1 in 20 patients with occult injury was discharged home. Although these proportions suggest that chest CT identifies a large proportion of occult injury, these findings should not be extrapolated to the 59.4% of patients who never had chest CT. Therefore, a validated decision instrument to support clinical judgment is needed to identify patients likely to benefit from chest CT.

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REFERENCES

1. *Optimal Care of the Trauma Patient: Resources for Optimal Care of the Injured Patient 2014*. American College of Surgeons Committee on Trauma. Rotondo MF, Cribari C, Smith RS, eds. Chicago, IL; 2014. page 80.
2. Medicare Payment Advisory Commission. A data book: healthcare spending and the Medicare program. Page 107, chart 7–19. June 2014. Available at: <http://www.medpac.gov/documents/publications/jun14databookentirereport.pdf?sfvrsn=1>. Accessed March 4, 2015.
3. Kaewlai R, Avery LL, Asrani AV, et al. Multidetector CT of blunt thoracic trauma. *Radiographics*. 2008;28:1555-1570.
4. American College of Surgeons Committee on Trauma Leadership. National Trauma Data Bank (NTDB) annual report 2007. In: Clark DE, Fantus RJ, eds. Chicago, IL: American College of Surgeons; 2007: 1–64.
5. Mayberry JC. Imaging in thoracic trauma: the trauma surgeon's perspective. *J Thorac Imaging*. 2000;15:76-86.
6. Peters S, Nicolas V, Heyer CM. Multidetector computed tomography-spectrum of blunt chest wall and lung injuries in polytraumatized patients. *Clin Radiol*. 2010;65:333-338.
7. Exadaktylos AK, Sclabas G, Schmid SW, et al. Do we really need routine computed tomographic scanning in the primary evaluation of blunt chest trauma in patients with "normal" chest radiograph? *J Trauma*. 2001;51:1173-1176.
8. Langdorf MI, Zuabi N, Khan NA, et al. Yield and clinical predictors of thoracic spine injury from chest computed tomography for blunt trauma. *West J Emerg Med*. 2014;15:465-470.
9. Kaiser M, Whealon M, Barrios C, et al. The clinical significance of occult thoracic injuries in blunt trauma patients. *Am Surg*. 2010;76:1063-1066.
10. Kaiser ML, Whealon MD, Barrios C Jr, et al. Risk factors for traumatic injury findings on thoracic computed tomography among patients with blunt trauma having a normal chest radiograph. *Arch Surg*. 2011;146:459-463.
11. Rodriguez RM, Anglin D, Langdorf MI, et al. NEXUS Chest: validation of a decision instrument for selective chest imaging in blunt trauma. *JAMA Surg*. 2013;148:940-946.
12. Stiell IG, Wells GA, Vandemheen KL, et al. The Canadian C-spine Rule for radiography in alert and stable trauma patients. *JAMA*. 2001;286:1841-1848.
13. Kea B, Gamarallage R, Vairamuthu H, et al. What is the clinical significance of chest CT when the chest x-ray result is normal in patients with blunt trauma? *Am J Emerg Med*. 2013;31:1268-1273.
14. Kaji A, Schriger D, Green S. Looking through the retrospectroscope: reducing bias in emergency medicine chart review studies. *Ann Emerg Med*. 2014;64:292-298.
15. Traub M, Stevenson M, McEvoy S, et al. The use of chest computed tomography versus chest X-ray in patients with major blunt trauma. *Injury*. 2007;38:43-47.
16. Omert L, Yeane WW, Protetch J. Efficacy of thoracic computerized tomography in blunt chest trauma. *Am Surg*. 2001;67:660-664.
17. Renton J, Kincaid S, Ehrlich PF. Should helical CT scanning of the thoracic cavity replace the conventional chest x-ray as a primary assessment tool in pediatric trauma? an efficacy and cost analysis. *J Pediatr Surg*. 2003;38:793-797.
18. Trupka A, Waydhas C, Hallfeldt KK, et al. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. *J Trauma*. 1997;43:405-411; discussion 411–412.
19. Simon B, Ebert J, Bokhari F, et al. Management of pulmonary contusion and flail chest: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg*. 2012;73:S351-S361.
20. Centers for Medicare & Medicaid Services. Physician Fee Schedule Search. Available at: <http://www.cms.gov/apps/physician-fee-schedule/search/search-results.aspx?Y=0&T=0&HT=0&CT=3&H1=71260&M=2>. Accessed September 18, 2014.
21. Rodriguez RM, Baumann BM, Raja AS, et al. Diagnostic yields, charges, and radiation dose of chest imaging in blunt trauma evaluations. *Acad Emerg Med*. 2014;21:644-650.