Derivation of a Decision Instrument for Selective Chest Radiography in Blunt Trauma

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Background: To derive a decision instrument (DI) that identifies patients who have virtually no risk of significant intrathoracic injury (SITI) visible on chest radiography and, therefore, no need for chest imaging.

Methods: This is a prospective observational study. At three Level 1 trauma centers, physicians caring for blunt trauma patients aged 14 years were asked to record the presence or absence of 12 clinical criteria before viewing chest imaging results. SITI was defined as pneumothorax, hemothorax, aortic/great vessel injury, two or more rib fractures, ruptured diaphragm, sternal fracture, and pulmonary contusion on official radiograph readings. The χ² (interrater reliability) and screening performance of individual criteria were determined. By using recursive partitioning, the most highly sensitive combination of criteria for SITI was derived.

Results: Of the 2,628 subjects enrolled, 271 (10.3%) were diagnosed with a total of 462 SITIs, with rib fractures (73%), pneumothorax (38%), and pulmonary contusion (29%) as the most common injuries. Chest pain and chest wall tenderness had the highest sensitivity for SITI (65%). The DI of chest pain, distracting injury, chest wall tenderness, intoxication, age >60 years, rapid deceleration, and altered alertness/mental status had the following screening performance: sensitivity 99.3% (95% confidence interval [CI], 97.4–99.8), specificity 14.0% (95% CI, 12.6–15.4), negative predictive value 11.7% (95% CI, 97.4–99.8), and positive predictive value 99.4% (95% CI, 97.8–99.8), and positive predictive value 11.7% (95% CI, 97.4–99.8).

Conclusions: We derived a DI consisting of seven clinical criteria that can identify SITI in blunt trauma patients with extremely high sensitivity. If validated, this instrument will allow for safe, selective chest imaging with potential resource savings.

Key Words: Blunt trauma, Chest radiography, Chest CT, Decision instrument.

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The chest X-ray (CXR) is the most commonly performed radiographic study in acute blunt trauma patients. However, the diagnostic yield of intrathoracic injuries from CXRs is low, ranging from 6.3% to 12.4% in previous studies. Excessive chest radiography (including chest computed tomography [CT] ordered subsequent to indeterminate or inconclusive CXRs) exposes many patients to potentially harmful ionizing radiation, interrupts trauma resuscitation flow, contributes to emergency department (ED) over-crowding, and generates substantial radiographic charges.

Validation of clinical decision instruments (DIs), such as the National Emergency X-Radiography Utilization Study (NEXUS) and Canadian cervical spine rules, has shown that selective radiography may be implemented in blunt trauma evaluation without compromising patient safety. Substantial resource savings could similarly be realized by developing a DI for chest imaging in blunt trauma; our preliminary work has demonstrated the feasibility and merit of pursuit of such a rule.

The long-term goal of this research is to reduce unnecessary chest radiography in patients with blunt trauma and safely conserve resources. Toward this goal, the objective of this study was to derive a DI consisting of clinical criteria that identifies patients who have virtually no risk of significant intrathoracic injury (SITI) visible on chest radiography. Foregoing chest imaging in such a group with low risk for SITI may result in significant resource savings.

PATIENTS AND METHODS

At three urban Level 1 trauma centers, we prospectively evaluated patients who received chest imaging in the ED as part of their workup for acute blunt trauma. The inclusion criteria were (1) age > 14 years, (2) blunt trauma occurring within 24 hours of ED presentation, and (3) receipt of a CXR and/or chest CT in the ED as part of their evaluation for trauma. Patients transferred from another hospital were excluded. Enrollment occurred from July 2007 to August 2009 at two sites and from August 2008 to February 2009 at the third site, whenever research assistants were available (typically between 8:00 AM and 9:00 PM).

Before viewing chest imaging or chest imaging reports, the physician (primarily surgery and emergency attending and resident physicians) caring for a study subject was asked to indicate the presence or absence of each of the following a priori defined candidate criteria: (1) age >60 years; (2) rapid deceleration mechanism defined as fall >20 feet or motor vehicle crash >40 miles per hour; (3) hypoxia defined as oxygen saturation on ED presentation of <95% (with or without oxygen); (4) chest pain; (5) shortness of breath; (6)
intoxication; (7) distracting injury; (8) tenderness to chest wall palpation; (9) pain on lateral chest compression; (10) abnormal auscultation; (11) abnormal alertness/mental status; and (12) visible chest wall skin injury. See Appendix for the definitions of these criteria that were made available to the physicians during evaluations. Research assistants also collected data regarding trauma mechanism, presenting vital signs and Glasgow Coma Score.

Six of the above 12 criteria were chosen because they were the most useful screening candidate criteria in our pilot study. The other six candidate criteria were included based on the recommendation of a consensus panel of trauma experts and because they had been demonstrated to be useful criteria in other validated trauma decision rules.4,5

We convened an expert consensus panel consisting of two practicing Professors of Emergency Medicine and a Professor of Surgery (practicing Attending Trauma Surgeon) to define a priori the injuries that would meet the primary endpoint of SITI. The panel determined that the following injuries would qualify as SITI: pneumothorax, hemothorax, aortic or other great vessel injury, two or more rib fractures, ruptured diaphragm, sternal fracture, and pulmonary contusion. The finding of an isolated rib fracture was omitted because it is generally treated in the same manner as a chest wall contusion and does not otherwise generally modify patient care.6,7 Pericardial tamponade and cardiac contusion were also not considered SITI because these entities are not generally diagnosed by CXR. Similarly, flail chest was not considered SITI because it is diagnosed by physical examination; all cases of flail chest would nonetheless be picked up under the category of multiple rib fractures. Injuries of the shoulders, clavicles, and neck imaged incidentally on CXRs were not considered to be SITI, because they are extrathoracic and they would primarily be diagnosed via imaging studies other than CXR.

SITI was analyzed by official CXR and CT readings, which were performed by board-certified radiologists blinded to the study protocol. In cases in which chest CT was performed, the CT result was used to analyze the presence or absence of SITI. When upper level cuts of an abdominal CT showed a pneumothorax or rib fractures, SITI was deemed present. Investigators reviewed the ED and inpatient charts of subjects with inconclusive chest imaging results to analyze whether SITI was present.

Data were entered into Microsoft Access (Microsoft Corp, Seattle, WA) and analyzed primarily using Stata version 9.0 (StataCorp, College Station, TX). To establish the clinical characteristics that can be consistently assessed, we evaluated the interrater reliability of potential candidate criteria. Two physicians independently assessed 4% of blunt trauma subjects, and their responses were compared. A $\kappa$ > 0.50 was determined a priori to represent acceptable interrater reliability for final DI criteria.

We analyzed the screening performance (sensitivity, specificity, positive predictive value, and negative predictive value) for SITI of each of the individual criteria. When individual criteria were omitted or marked as “unknown,” they were deemed as absent to ensure internal validity of the derived instrument. To derive the DI, we used sorting and formulae to perform recursive partitioning with maximization of sensitivity as the primary outcome driving the analysis.9

Our stopping rules were (1) attainment of >99% sensitivity, (2) attainment of a partitioning level such that available criteria no longer discriminated among patients with and without SITI, (3) exhaustion of candidate variables, and (4) exhaustion of study cases. This study was approved by the Committees on Human Research at the three study sites.

RESULTS

Of the 2,628 subjects enrolled, 271 (10.3%) were diagnosed with SITI. Chest imaging consisted of CXR alone in 2,044 (78%), CXR and CT in 554 (21%), and CT alone in 30 subjects (1%). See Table 1 for subject characteristics and Table 2 for their significant injuries. The $\kappa$ values for the individual criteria ranged between 0.41 for visible chest wall injury and 0.81 for intoxication; visible chest wall injury was the only criterion that failed to meet the predetermined cutoff for acceptable reliability and, therefore, was not considered for the DI.

Among the other individual criteria, chest pain and chest wall tenderness had the highest sensitivity (65%) for SITI. Table 3 summarizes individual criteria screening performance. Recursive partitioning produced the classification tree DI shown in the Figure 1. This combination of chest pain, distracting injury, chest wall tenderness, intoxication, age > 60 years, rapid deceleration, and abnormal alertness/mental status had the following screening performance: sensitivity 99.3% (95% confidence interval [CI], 97.4–99.8), specificity 14.0% (95% CI, 12.6–15.4), negative predictive value 99.4% (95% CI, 97.8–99.8), and positive predictive value 11.7% (95% CI, 10.5–13.1).

Use of this instrument in this cohort would have led to a 14% reduction in chest radiography and would have detected all but two of the patients with SITI. One missed
patient was diagnosed with two posterior rib fractures and was sent home from the ED with pain medicine. The other missed patient, who had multiple rib fractures and the candidate criterion of lateral chest wall compression tenderness by the evaluating physician, was noted to have altered level of consciousness on review of his chart. Because we defined chest wall tenderness as tenderness on palpation of any part of the chest including the lateral chest wall and altered mental status was one of the DI criteria, this missed case may actually represent a failure of patient allocation by the evaluating physician or poor clarity of the definitions of the candidate criteria.

Limitations

It is critical to note that our DI should not yet be used to direct imaging decisions. Prospective testing of its performance on a larger, separate population (currently underway) will be necessary to analyze whether the DI retains favorable operator characteristics and exhibits external validity.

Our gold standard (injuries seen by radiologists on CXRs and chest CTs) may be imperfect in that radiographs may miss some of the particular injuries of interest, e.g., a pneumothorax may have been missed in a patient who received only a CXR. However, our goal was not to identify all intrathoracic injuries — our goal was to identify all intrathoracic injuries that are visible on chest imaging, thereby providing a guideline for the ordering of radiographs. The guideline provides no information about injuries that do not show up on imaging.

Some clinicians may contend that other injuries, such as a single rib fracture, should be deemed significant in certain patients such as the elderly patients. Although we mostly enrolled patients during the day and evening, we doubt that clinical characteristics would predict important injury differently among blunt trauma patients presenting in the middle of the night. Our findings should not be extrapolated to patients younger than 15 years.

### TABLE 2. Injuries in 271 Patients Diagnosed With SITI

<table>
<thead>
<tr>
<th>Type of Injury</th>
<th>Total, n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two or more broken ribs</td>
<td>199 (73)</td>
</tr>
<tr>
<td>Pneumothorax</td>
<td>103 (38)</td>
</tr>
<tr>
<td>Pulmonary contusion</td>
<td>79 (29)</td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>41 (15)</td>
</tr>
<tr>
<td>Sternal fracture</td>
<td>24 (9)</td>
</tr>
<tr>
<td>Ruptured diaphragm</td>
<td>14 (5)</td>
</tr>
<tr>
<td>Aortic injury</td>
<td>2 (1)</td>
</tr>
</tbody>
</table>

### TABLE 3. Screening Performance of Individual Criteria for Prediction of SITI

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Sensitivity % (95% CI)</th>
<th>Specificity % (95% CI)</th>
<th>PPV % (95% CI)</th>
<th>NPV % (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest pain</td>
<td>65 (59–72)</td>
<td>65 (63–67)</td>
<td>16 (14–18)</td>
<td>94 (94–96)</td>
</tr>
<tr>
<td>Chest wall tenderness</td>
<td>65 (58–71)</td>
<td>67 (65–69)</td>
<td>17 (14–19)</td>
<td>95 (94–96)</td>
</tr>
<tr>
<td>Distracting injury</td>
<td>54 (48–60)</td>
<td>60 (58–62)</td>
<td>13 (11–15)</td>
<td>92 (90–93)</td>
</tr>
<tr>
<td>Lateral chest wall tenderness</td>
<td>47 (40–54)</td>
<td>79 (77–80)</td>
<td>18 (15–21)</td>
<td>93 (92–94)</td>
</tr>
<tr>
<td>Rapid deceleration</td>
<td>46 (39–52)</td>
<td>70 (68–72)</td>
<td>15 (12–17)</td>
<td>91 (90–93)</td>
</tr>
<tr>
<td>SOB</td>
<td>36 (30–42)</td>
<td>90 (89–91)</td>
<td>28 (23–33)</td>
<td>93 (92–94)</td>
</tr>
<tr>
<td>Age ≥60 yr</td>
<td>28 (23–33)</td>
<td>81 (79–82)</td>
<td>13 (11–16)</td>
<td>91 (90–92)</td>
</tr>
<tr>
<td>Intoxication</td>
<td>25 (19–30)</td>
<td>83 (81–84)</td>
<td>13 (10–17)</td>
<td>91 (89–92)</td>
</tr>
<tr>
<td>AMS/abnormal alertness</td>
<td>23 (18–28)</td>
<td>96 (95–97)</td>
<td>38 (31–46)</td>
<td>92 (90–93)</td>
</tr>
<tr>
<td>Abnormal auscultation</td>
<td>20 (15–25)</td>
<td>95 (94–95)</td>
<td>31 (24–38)</td>
<td>91 (90–92)</td>
</tr>
<tr>
<td>Hypoxia</td>
<td>17 (12–21)</td>
<td>95 (94–96)</td>
<td>28 (21–36)</td>
<td>91 (90–92)</td>
</tr>
</tbody>
</table>

PPV, positive predictive value; NPV, negative predictive value; SOB, shortness of breath; AMS, altered mental status.

### Figure 1. Classification tree analysis deriving DI for low risk of SITI in blunt trauma patients.
It is also important to note that this DI is designed to maximize sensitivity and, therefore, only suggests when it is safe not to order chest imaging. Having one or more of the criteria does not mandate that physicians should order chest imaging—if misapplied in this manner, it could paradoxically lead to more test ordering as has been seen with other DIs.10

Differences in the ordering of imaging at the study sites could result in spectrum bias, resulting in a study population that does not represent blunt trauma patients in general. For example, if clinicians at one or more of the sites ordered chest radiography only for patients with the most impressive presentations, most who would have at least one of the risk criteria, this might falsely elevate the sensitivity and lower the specificity of the instrument. The converse, of course, may also have occurred, making it difficult to analyze the direction of potential bias in our measurements. To assess the direction and magnitude of this and other types of bias, we are currently evaluating a group of blunt trauma patients at one site regardless of whether they are imaged or not.

DISCUSSION

Although chest imaging is the most common radiography in blunt trauma patients, and it is associated with low yield, substantial cost, and potential health risk, there is no established guideline for its use. In this prospective study, we have derived a highly sensitive DI that, if validated, may result in resource savings.

Although a clinical decision rule has been proposed for pediatric trauma patients,11 the literature for CXR ordering in adults with blunt trauma—beyond our own pilot study1—was limited to two studies. The first was a prospective evaluation of physical examination sensitivity for hemopneumothorax. In this study, Bokhari et al.12 reported that auscultation was 100% sensitive and 99.8% specific for the detection of hemopneumothorax. The major limitations of this study include (1) beyond hemopneumothorax, no other intrathoracic injuries that are diagnosed by CXR were evaluated; (2) only seven patients (6.3%) had the positive finding of hemopneumothorax; and (3) CIIs, which, given the low number of positive findings, would likely be very wide, were not reported. Abnormal auscultation had poor screening performance for significant injury in our study with a sensitivity of 20% (95% CI, 15–25).

The second study examined selective chest radiography guided by trauma surgeon judgment in patients with both penetrating and blunt trauma mechanisms.2 Sears et al.2 found that this method resulted in 100% sensitivity for injuries in the 105 victims of penetrating trauma but only 95.1% sensitivity for injuries in the 667 patients with blunt trauma. The primary limitation of this study was the use of senior trauma surgeons as the deliberators of need for CXR, which severely limits the external applicability of their findings. Most low-acuity trauma patients (those in whom CXR decision rule is most useful) are evaluated by emergency physicians. DIs must use criteria that can be assessed in a consistent and repeatable manner between different clinicians, and therefore, subjective physician judgment is a poor choice for a widely applicable rule.13,14 Finally, the sensitivity of 95% may be too low to allow for selective imaging in serious cases of trauma injury; we think that a cutoff sensitivity of ~99% is required to safely change current imaging practice.

Experience with other DIs, especially cervical spine and head CT guidelines, has shown that ease of use and clarity of definitions play important roles in their ultimate utilization and implementation. Our criteria definitions, including that of rapid deceleration, are simple, and we found excellent interrater reliability. We defined three of our criteria (abnormal alertness, intoxication, and distracting injury) in the same manner as they are defined in the NEXUS cervical spine DI, making our guideline ideally suited for use in conjunction with this widely used blunt trauma DI.

CONCLUSIONS

A DI consisting of chest pain, distracting injury, chest wall tenderness, intoxication, age > 60 years, rapid deceleration, and abnormal alertness/mental status identified SITI in blunt trauma patients with extremely high sensitivity. If validated with similar performance, this instrument will allow for safe, selective chest imaging with potential resource savings.

APPENDIX: CANDIDATE CRITERIA

DEFINITIONS

Abnormal auscultation refers to any abnormality noted on auscultation of the chest with a stethoscope including decreased breath sounds, wheezing, etc.

Chest pain refers simply to the patient’s answer to the question “Do you have any chest pain?” No distinction will be made between pleuritic, positional, or other qualities of the pain. If the patient is unable to answer this question, it will be noted as unknown.

Chest wall tenderness to palpation is tenderness to palpation of any part of the chest wall or torso (boundaries defined as the upper and lower costal margins circumferentially). The physician should palpate the anterior, posterior, and axillary portions of the torso. Isolated clavicular tenderness does not qualify as chest wall tenderness to palpation, but isolated sternal pain does meet this criterion.

Distracting painful injury is defined in the same manner as in the NEXUS cervical spine DI as any condition thought by the clinician to be producing sufficient pain to distract the patient from a second (intrathoracic) injury. Examples may include but are not limited to the following: (1) long bone fractures, (2) visceral injuries requiring surgical consultation, (3) large lacerations, degloving injuries, or crush injuries, (4) large burns, and (5) any other injury producing acute functional impairment. Physicians may also classify any injury as distracting if it is thought to have the potential to impair the patient’s ability to appreciate other injuries.

Ecchymosis is discoloration or bruising, as noted by the clinician on visual inspection of the chest wall.

Evidence of intoxication is defined in the same manner as in the NEXUS cervical spine DI. This includes a history of intoxication or recent intoxicating ingestion is provided by a patient or observer; (b) test of bodily secretions.
(blood, urine, saliva, breath, etc.) is positive for drugs or alcohol; (c) patient has 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.

Hypoxia in this study is defined as a sustained pulse oximetry saturation of <95% at any point during the ED stay (regardless of administered oxygen). Sustained in this case means lasting for >2 minutes.

Pain on lateral chest wall compression means pain noted when the examiner compresses on the chest by pressing on both lateral sides (along the midaxillary line) of the chest wall.

Rapid deceleration mechanism refers to mechanism of blunt trauma that exerts rapid deceleration force on the patient; specifically (1) fall from a height >20 feet and (2) motor vehicle crash at a speed of >40 mph.

Shortness of breath refers simply to the patient’s answer to the patient’s question “Are you short of breath?” If the patient is unable to answer this question, it will be noted as unknown.

Visible chest wall injury is assessed by visual inspection by the physician and includes ecchymosis, abrasions, and lacerations. A seat belt sign on the chest would qualify as visible chest injury.

REFERENCES


