Chest x-ray as a screening tool for blunt thoracic trauma in children

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BACKGROUND: With the increasing use of thoracic computed tomography (CT) to screen for injuries in pediatric blunt thoracic trauma (BTT), we determined whether chest x-ray (CXR) and other clinical and epidemiologic variables could be used to predict significant thoracic injuries, to inform the selective use of CT in pediatric BTT. We further queried if these were discrepant from factors associated with the decision to obtain a thoracic CT.

METHODS: This retrospective cohort study included cases of BTT from three Level I pediatric trauma centers between April 1999 and March 2008. Pre-CT epidemiologic, clinical, and radiologic variables associated with CT findings of any thoracic injury or a significant thoracic injury as well as the decision to obtain a thoracic CT were determined using logistic regression.

RESULTS: Of 425 patients, 40% patients had a significant thoracic injury, 49% had nonsignificant thoracic injury, and 11% had no thoracic injury at all. Presence of hydrothorax and/or pneumothorax on CXR significantly increased the likelihood of significant chest injury visualized by CT (adjusted odds ratio 10.8; 95% confidence interval, 6.5–18), as did the presence of isolated subcutaneous emphysema (adjusted odds ratio, 19.8; 95% confidence interval, 2.3–168). Although a normal CXR finding was not statistically associated with a reduced risk of significant thoracic injury, 8 of the 9 cases with normal CXR findings and significant injuries involved occult pneumothoraces or hemothoraces not requiring intervention. Converse to features suggesting increased risk of significant injury, the decision to obtain a thoracic CT was only associated with later period in the study and obtaining a CT scan of another body region.

CONCLUSION: CXR can be used to screen for significant thoracic injuries and direct the selective use of thoracic CT in pediatric BTT. Prospective studies are needed to validate these findings and develop guidelines that include CXR to define indications for thoracic CT in pediatric BTT. (J Trauma Acute Care Surg. 2013;75: 613–619. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Prognostic study, level III.

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The value of computed tomography (CT) scanning in detecting head and abdominal injuries in pediatric trauma is well established in the literature. However, the role of CT in the detection of injuries in blunt thoracic trauma (BTT) in children has not yet been adequately defined, and its use remains contentious. There are no known guidelines regarding the indications for CT in BTT in children. Previous studies have endorsed a routine and primary role for thoracic CT and even pan-CT scans in the evaluation of adult trauma patients, possibly taking the place of the chest x-ray (CXR). Few studies have examined the utility of thoracic CT as the primary investigation in pediatric trauma. Manson et al. concluded that CXR is insufficient in the context of clinically significant BTT and that CT is required. A retrospective review by Renton et al., however, concluded that liberal CT use may be cost-ineffective and resulted in only minimal diagnostic improvement; their conclusion was that thoracic CT should not replace the CXR as the primary investigation in pediatric trauma. Other recent studies have similarly concluded that the liberal use of thoracic CT yields little clinical benefit and should be reserved for selected cases.

Children have an increased lifetime risk for developing fatal radiation-induced cancers from CT scanning. Principles such as ALARA (“As Low As Reasonably Achievable”) have been developed for imaging in children. Ultimately, in the context of evaluating BTT, the risks of missing a life-threatening injury must be weighed against the risks of exposure to radiation. As CT use in children increases, the question of how best to determine when it is truly needed to identify clinically significant BTT injuries in children remains to be answered. A number of studies have examined the roles of CXR and CT in evaluating BTT in children, although the clarity of these roles remain unresolved.

The aim of this study was to determine which CXR findings (in addition to other epidemiologic and clinical variables from initial assessment) were associated with significant thoracic injuries that might warrant thoracic CT in pediatric BTT patients. This extended to evaluating whether a normal
CXR finding could rule out the presence of significant thoracic injury, as a means to guide decision making to forgo need for a thoracic CT. A secondary aim was to evaluate epidemiologic, radiologic, and clinical variables in pediatric patients undergoing a thoracic CT, to better determine what drives clinicians to order thoracic CT.

**PATIENTS AND METHODS**

Patients presenting to one of three Level I pediatric trauma centers between April 1, 1999, and March 31, 2008, after experiencing BTT or having a thoracic CT were included in the study. The trauma centers included the Children’s Hospital of Eastern Ontario (CHEO), Ottawa Ontario; the IWK Health Centre (IWK), Halifax, Nova Scotia; and the Royal Children’s Hospital (RCH), Melbourne, Australia. Patients transferred to a trauma center from a referring hospital beyond the first 24 hours after injury were excluded from the study, as were patients with an Injury Severity Score (ISS) of less than 12.

Cases were identified using the trauma registry in each hospital. These data were augmented by chart review. Epidemiologic, radiologic, and clinical factors identifiable in the emergency department (ED) of the trauma center were extracted. These included clinical signs/symptoms of thoracic pathology (pain/tenderness, respiratory distress, decreased air entry by auscultation), abnormal findings of CXR (bony, parenchymal, and/or hydrothorax/pneumothorax) at a referral or trauma center, results of CT scans performed at a referral center (if performed), intubation in the trauma center ED or before arrival, chest tube insertion in the ED or before arrival, performance of CT scan (thoracic, abdominal, and/or head) during the initial resuscitation at the trauma center, post-ED destination, final outcome (alive or death), ISS, and injuries sustained. Specifically, we identified discharge diagnoses of thoracic injury if present (Abbreviated Injury Scale [AIS] 90 predot codes 411000–450899) as well as identification in the ED of a femur fracture because this injury type has been found to be associated with other major blunt injury patterns, representing a proxy measurement for high-energy trauma mechanism.

Injuries were grouped into three categories: no thoracic injury, “any” thoracic injury (including bony fractures or pulmonary contusions), and “significant” thoracic injury, defined as hemothorax and/or pneumothorax as well as flail chest, mediastinal, or vascular injuries. We included pneumothoraces that were visualized on CT scan but not on CXR as “significant” based on the fact that knowledge of their presence may prompt specific action (thoracostomy) in case of hemodynamic instability should surgery be required in the emergent period.

Patient charts, initial CXR, and CT scan reports were reviewed. Data collected from the chart review included CXR findings: presence of fluid (hydrothorax), air (pneumothorax, pneumomediastinum), widened mediastinum, parenchyma injury (contusion), subcutaneous emphysema, scapula fracture, spinal injury, clavicle fracture, and rib fractures.

In cases where the CXR report was missing, the ED physician notes reporting the findings were used. When referral hospital CXR findings were not available and a chest tube was inserted at that center, the presence of hemothorax or pneumothorax was assumed, dependent on description of chest tube drainage.

Descriptive statistics and univariate analyses to determine associations between pre-CT variables and outcomes of interest (presence of a thoracic injury [“any” or “significant”] and undergoing a thoracic CT at the trauma center) were performed. Continuous variables (age, ISS) were dichotomized at the level of the upper quartile. Unadjusted odds ratios (ORs) of associations were determined using χ² analyses. Backward stepwise logistic regression was then applied, using all variables reaching a $p < 0.20$ to determine the adjusted ORs, with 95% confidence intervals not spanning 1.0, and $p > 0.05$ was ultimately considered statistically significant. All statistical analyses were performed using SAS statistical software version 8.2, (Cary, NC). This study was approved by the research ethics board of each center in the study.

**RESULTS**

**Patient Population**

A total of 425 patients were included in the study, 71 from IWK, 136 from CHEO, and 218 from RCH. The average age was 12 years (range, 1–18 years), with 64% of the population male. The median ISS was 26 (range, 12–75; interquartile range, 18–35). By far, the most common cause of injury was motor vehicle collision (MVC) as occupant (41%), followed by MVC pedestrian/cyclist (29%) and off-road vehicle incidents (14%) (Table 1). These mechanisms were thus independently studied for association with the presence of a thoracic injury. Few significant differences were seen between the three trauma centers with regard to patient demographics or incidence of the three most common mechanisms of injury (Table 1). Chart documentation of thoracic clinical findings (normal or abnormal) was found for only 120 cases, rendering this variable insufficient to include in the statistical analyses. Other clinical features as well as final ISS was available for all patients and are shown in Table 2.

**Patient Outcomes**

A total of 170 patients (40.0%) had a discharge diagnosis of significant thoracic injury, 210 (49.4%) had nonsignificant thoracic injury, and 45 (10.6%) had no injury at all (Table 1). From the ED, 267 (63.0%) went to the intensive care unit, 107 (25.2%) went to an inpatient ward, 33 (7.8%) went to the operating room, 13 (3.1%) died in the ED, 3 (0.7%) were transferred to another hospital, and 1 (0.2%) went home (discharge disposition was unknown for one patient). One hundred thirteen patients (26.6%) were intubated either before or in the ED of either the referring hospital or trauma center; a chest tube was placed in 43 (10.1) patients. Overall, 87.1% of patients were discharged alive.

**Imaging**

Three hundred ninety-six patients had documentation of an initial CXR at admission to the trauma center or referral hospital, with findings as documented in Table 2. Of the entire study population, 174 (41%) had a thoracic CT. Of 13 patients who did not undergo an initial CXR, 2 had a thoracic CT at the referral hospital before transfer, and 1 had a thoracic CT at the...
trauma center. In 16 patients, pre-CT CXR status could not be determined from the medical records; of these, 7 underwent a thoracic CT.

ASSOCIATIONS OF PRE-CT FEATURES WITH DIAGNOSIS OF THORACIC INJURIES

Univariate associations between pre-CT epidemiologic, clinical, and radiologic variables and final diagnosis of any thoracic injury are shown in Table 3. Associations with significant thoracic injuries are shown in Table 4. After controlling for covariates, only older patient age (>14 years) and CXR findings of rib fractures, hydrothorax and/or pneumothorax, and parenchymal opacities suggesting pulmonary contusion remained significantly associated with the ultimate diagnosis of any thoracic injury (Table 3). When considering significant injuries only, age was no longer an associated risk factor, while sustaining trauma from an off-road vehicle incident had an increased risk. Presence of a hydrothorax and/or pneumothorax or isolated presence of subcutaneous emphysema on CXR remained significantly associated with the ultimate diagnosis of any thoracic injury (Table 3). When considering significant injuries only, age was no longer an associated risk factor, while sustaining trauma from an off-road vehicle incident had an increased risk. Presence of a hydrothorax and/or pneumothorax or isolated presence of subcutaneous emphysema on CXR remained significantly associated with the ultimate diagnosis of any thoracic injury (Table 3). More notable was that CXR findings reported as “normal” were not associated with or without the ultimate diagnosis of a significant thoracic injury. However, as shown in Table 5, the vast majority of the significant injuries identified in cases of unremarkable CXRs were occult pneumothoraces seen on CT (usually of the abdomen), which did not require intervention (e.g., insertion of a chest tube).

ASSOCIATIONS OF PRE-CT FEATURES WITH UNDERGOING A THORACIC CT AT THE TRAUMA CENTER

Of the 116 patients undergoing thoracic CT at a trauma center, 43 (37.1%) were performed early in the study period between 1996 and 2003, inclusive, compared with 73 (62.9%) between 2004 and 2008 (OR, 2.2; 95% confidence interval, 1.4–3.4). This as well as other variables associated with having a thoracic CT are shown in Table 6. After controlling for all covariates, cases occurring in the latter half of the study period as well as those also undergoing a CT abdomen and/or head at the trauma center were associated with a greater risk of having undergone a thoracic CT. Patients receiving thoracic CT at the referring hospitals were significantly less likely to

| Table 1. Demographics and Mechanisms of Injury by Trauma Center |
|---------------------------------------------------------------|
| Demographics | IWK Cases (n = 71) | CHEO Cases (n = 136) | RCH Cases (n = 218) | All Cases (n = 425) |
|---------------|--------------------|---------------------|--------------------|--------------------|
| Male sex, %   | 64.8               | 60.3                | 66.5               | 64.2               |
| Age, mean (SD), y | 10.8 (4.6)    | 11.3 (4.6)*          | 9.5 (4.6)*         | 10.3 (4.7)          |
| Older age (>14 y), % | 28.2             | 26.5                | 14.7*              | 20.7               |
| Younger age (<7 y), % | 18.3             | 18.4                | 29.8*              | 24.2               |
| Mechanism of injury | MVC occupant, % | 47.9                | 41.1                | 39.5               |
| MVC-pedestrian/cyclist, % | 29.6   | 24.3                | 31.7                | 28.9               |
| Off-road vehicle, ** % | 14.1          | 14.7                | 12.8                | 13.7               |
| Fall from height, % | 4.2             | 11.8*               | 5.1                 | 7.1                |
| Struck by object, % | 0*              | 5.2                 | 6.4                 | 4.9                |
| Non-MVC cyclist, % | 4.2             | 2.2                 | 2.8                 | 2.8                |
| Other, % | 0                  | 0.7                 | 1.8                 | 1.2                |
| Thoracic injury sustained | Any     | 85.9                | 91.9                | 89.0               |
| Significant | 31.0               | 45.6                | 39.5                | 40.0               |
| Injury severity | ISS > 26†       | 61.1*               | 50.7                | 40.8*              |
| ISS > 36† | 31.9*               | 25.0                | 17.9*               | 22.5               |

* <p < 0.05 when compared with other two hospitals, combined. χ² for discrete variables; Student’s t test for continuous variables.
** Off-road vehicle includes all terrain vehicles, dirtbikes, motorcross bikes, motorcycles.
† ISS of greater than 26 represents cases above the median ISS value for the entire study group. ISS of greater than 36 represents those greater than the upper quartile of the range of ISS of the entire study group.

| Table 2. Clinical and Radiologic Findings |
|------------------------------------------|
| Pre-CT Findings (Total n = 425) | Percentage of Patients |
| Clinical findings | Clinical findings suggestive of chest pathology (n = 120) | 47.4 |
| Intubated in ED or pre-ED | 26.6 |
| Chest tube inserted (either center) | 10.1 |
| Femur fracture | 11.5 |
| CT chest performed at referral center | 14.1 |
| Thoracic center CT | Head | 40.9 |
| Abdomen | 46.4 |
| Hydrothorax and/or pneumothorax | 31.7 |
| Subcutaneous emphysema (without evident hydro/pneumothorax) | 2.8 |
| Parenchymal opacities | 52.9 |
| Widened mediastium | 6.1 |
| Rib fracture(s) | 20.1 |
| Clavicle fracture(s) | 13.4 |
| Scapula fracture(s) | 1.5 |
| Thoracic spine fracture(s) | 5.3 |
| Unremarkable | 23.2 |
| ISS | ISS > 26* | 47.3 |
| ISS > 36* | 22.6 |

*ISS is calculated after patient discharge and not in the ED.
receive thoracic CT at the trauma center. Sex and presence of clavicular, scapular, and/or spinal fractures on pre-CT CXR did not reach significance level of association to be included in the multivariate model (data not shown).

**DISCUSSION**

Approximately 11% of all CT scans are performed in children each year in the United States, totaling nearly seven million pediatric studies.12 The frequency of CT imaging is increasing each year, largely owing to increasing accessibility, speed, and resolution. Despite its many benefits in terms of diagnosis and effect on management, this imaging modality has been suggested to expose patients to significant amounts of radiation. Children have an increased lifetime risk for fatal cancer; radiation-induced cancers may take decades to manifest.14 Brenner et al.10 estimated the lifetime risk for a 1-year-old child for developing a fatal cancer to be 0.18% for an

## TABLE 3. Associations of Diagnosis of Any Thoracic Injury With Pre-CT Findings—Unadjusted and Adjusted

|                              | Unadjusted | Adjusted | p-value |
|------------------------------|------------|----------|---------|
| Later period (≥2004)         | 0.5 (0.3–1.0), 0.06* | ns, 0.30 |
| Older age (<14 y)            | 2.2 (0.9–5.8), 0.09* | 3.2 (1.1–9.6), 0.037 |
| Sex, female                  | 1.1 (0.6–2.2), 0.72 |         |         |
| Motor vehicle crash occupant | 1.3 (0.7–2.5), 0.40 |         |         |
| Pedestrian/cyclist—motor vehicle crash | 1.0 (0.5–2.0), 0.99 |         |         |
| Off-road vehicle incident    | 1.0 (0.4–2.6), 0.95 |         |         |
| Presence of femur fracture   | 1.9 (0.6–6.5), 0.28 |         |         |
| Required intubation (pre-ED or in ED) | 0.6 (0.3–1.2), 0.14* | ns, 0.14 |
| CXR findings                 |            |          |         |
| Presence of hydrothorax and/or pneumothorax | 7.1 (2.1–23.4), 0.0002* | 6.0 (1.8–20.1), 0.004* |
| Isolated subcutaneous emphysema | Unable to calculate** 0.24 |         |         |
| Parenchymal opacities        | 4.3 (2.0–9.0), <0.0001* | 4.1 (1.9–8.8), 0.0003 |
| Mediastinal widening         | 0.4 (0.2–1.2), 0.16* | ns, 0.16 |
| Rib fracture(s)              | 12.1 (1.6–89.1), * 0.002 | 10.0 (1.3–75.2), 0.026 |
| Clavicle fracture(s)         | 3.5 (0.8–14.7), 0.076* | ns, 0.65 |
| Scapula fracture(s)          | Unable to calculate** 0.39 |         |         |
| Spine fracture(s)            | 2.5 (0.3–19.2), 0.36 |         |         |
| CXR reported as “unremarkable” | 0.17 (0.09–0.33), * <0.0001 | ns, 0.25 |

*p < 0.20 and entered into the multivariate regression model; results in bold are statistically significant.

**Unable to calculate OR because of cell with null value.

## TABLE 4. Associations of Diagnosis of a Significant Thoracic Injury With Pre-CT Findings—Unadjusted and Adjusted

|                              | Unadjusted | Adjusted | p-value |
|------------------------------|------------|----------|---------|
| Later period (≥2004)         | 0.9 (0.6–1.3), 0.53 |         |         |
| Older age (<14 y)            | 1.1 (0.7–1.8), 0.66 |         |         |
| Sex, female                  | 0.8 (0.6–1.3), 0.43 |         |         |
| Motor vehicle crash occupant | 0.8 (0.6–1.2), 0.38 |         |         |
| Pedestrian/cyclist—motor vehicle crash | 0.8 (0.5–1.2), 0.26 |         |         |
| Off-road vehicle incident    | 2.6 (1.5–4.6), 0.0007* | 2.1 (1.0–4.1), 0.046 |
| Presence of femur fracture   | 1.1 (0.6–2.1), 0.66 |         |         |
| Required intubation (pre-ED or in ED) | 1.1 (0.7–1.8), 0.53 |         |         |
| CXR findings                 |            |          |         |
| Presence of hydrothorax and/or pneumothorax | 10.6 (6.4–17.4), <0.0001* | 10.8 (6.5–18), <0.0001 |
| Isolated subcutaneous emphysema | 15.9 (2.0–126), 0.0006* | 19.8 (2.3–168), 0.0063 |
| Parenchymal opacities        | 1.2 (0.8–1.8), 0.32 |         |         |
| Mediastinal widening         | 1.3 (0.6–2.9), 0.55 |         |         |
| Rib fracture(s)              | 1.6 (1.0–2.6), 0.076* | ns, 0.99 |
| Clavicle fracture(s)         | 1.3 (0.7–2.3), 0.40 |         |         |
| Scapula fracture(s)          | 0.3 (0.03–2.5), 0.24 |         |         |
| Spine fracture(s)            | 1.4 (0.6–3.3), 0.47 |         |         |
| CXR reported as “unremarkable” | 0.24 (0.13–0.43), * <0.0001 | ns, 0.24 |

*p < 0.20 and entered into the multivariate regression model; results in bold are statistically significant. ns, not significant.
abdominal CT and 0.07% for a head CT, which equates to roughly 1 in 500 and 1 in 1,500, respectively. More recently, a retrospective cohort study by Pearce et al. found a small but significant association between childhood CT scans and subsequent risk of leukemia and brain tumors. The lifetime cancer risk from radiation exposure attributable to CT scans in children is not insignificant, and the risks and costs associated with CT must be weighed against the potential benefits.

Recent studies in adult trauma support an expanding role of thoracic CT or pan-CT as the initial evaluation of patients sustaining blunt trauma, in place of the CXR and regardless of clinical status. Trauma management protocols used in children have often been derived from recommendations in the management of adult trauma. However, there are several unique considerations in pediatric BTT mostly owing to anatomic and physiologic differences from adults. First, children experience a different pattern of thoracic trauma to adults. The pediatric chest wall has greater compliance when compared with adults, and this typically causes the ribs to bend rather than break with BTT. This can result in a greater amount of force transferred to underlying lung or thoracic contents. Consequently, major intrathoracic injury can occur even in the absence of rib fractures. Second, blunt thoracic aortic injuries are far less common in children (<16 years) than in adults, occurring in only 0.03% of children admitted for trauma compared with 0.21% of adults (National Trauma Data Bank). This is caused by steering wheel impact and their anatomy, which provides greater tissue elasticity, a lack of atherosclerotic disease, and decreased

### TABLE 5. Cases With Significant Thoracic Injury Yet Reportedly “Normal” CXR Finding

| Case Number | Mechanism/Workup | Injury Sustained |
|-------------|------------------|------------------|
| 4           | MVC occupant. CXR finding reported as “normal.” | Small pneumothorax seen on CT abdomen. No chest tube required. |
| 12          | Struck by object. CXR finding reported as “normal.” | Small pneumothorax seen on CT abdomen. No chest tube required. |
| 30          | Struck by object. CXR finding reported as “normal.” | Small pneumothorax and lower-rib fracture seen on CT abdomen. No chest tube required. |
| 46          | MVC occupant. CXR finding reported as “normal.” | Small hemotorax seen on CT abdomen. No chest tube required. |
| 47          | Fall from height. CXR finding reported as “normal.” | Small pneumothorax seen on CT abdomen. No chest tube required. |
| 59          | Fall from height. CXR finding reported as “normal.” | Small pneumothorax seen on CT chest. No chest tube required. |
| 100         | Struck by object. CXR reported as “normal.” | Atrial disruption with hemopericardium and hemotorax seen on CT chest. No chest tube required. |
| 365         | Motorcycle crash. CXR reported as “normal.” | Small bilateral pneumomoraces and pulmonary contusions seen on CT chest. No chest tubes required. |

### TABLE 6. Associations of pre-CT Findings With Undergoing Chest CT at the Trauma Center—Unadjusted and Adjusted

| Associations OR (95% Confidence Interval), p | Unadjusted | Adjusted |
|---------------------------------------------|------------|----------|
| Older age (>14 y)                           | 1.2 (0.97-2.0), 0.46 | —         |
| Later period (≥2004)                        | 2.2 (1.4-3.5), 0.0003* | 1.9 (1.2-3.2), 0.011 |
| Motor vehicle crash occupant                | 1.1 (0.7-1.7), 0.57 | —         |
| Pedestrian/cyclist—motor vehicle crash      | 0.9 (0.6-1.4), 0.66 | —         |
| Off-road vehicle incident                   | 0.9 (0.5-1.7), 0.57 | —         |
| Presence of femur fracture                  | 0.8 (0.4-1.7), 0.61 | —         |
| Required intubation (pre-ED or in ED)       | 1.4 (0.9-2.3), 0.12* | ns, 0.48  |
| CXR findings                                |             |          |
| Presence of hydrothorax and/or pneumothorax |             |          |
| Isolated subcutaneous emphysema             | 1.2 (0.8-1.9), 0.41 | —         |
| Parenchymal opacities                       | 1.4 (0.4-4.9), 0.74 | —         |
| Mediastinal widening                        | 1.2 (0.8-1.8), 0.48 | —         |
| Rib fracture(s)                             | 2.2 (1.0-5.0), 0.06* | ns, 0.07  |
| CXR reported as “unremarkable”             | 1.1 (0.6-1.8), 0.82 | —         |
| CT chest performed at referring center      | 0.12 (0.04-0.38), <0.0001* | 0.26 (0.07-0.94), 0.042 |
| CT of any other body system performed at referring center | 0.18 (0.05-0.58), 0.0015* | ns, 0.08  |
| CT abdomen performed at trauma center       | 8.1 (4.9-13.6), <0.0001* | 4.1 (2.3-7.3), <0.0001 |
| CT head performed at trauma center          | 5.5 (3.5-8.8), <0.0001* | 2.7 (1.6-4.5), 0.0003 |

*p < 0.20 and entered into the multivariate regression model; results in bold are statistically significant.
body mass. These all decrease the magnitude of force upon impact.\textsuperscript{21,22} In addition, aortic injuries are associated with significant mortality, with 80% to 90% of cases being fatal at the scene compounding the rarity of their presentation to the ED.\textsuperscript{21,23} Of those who do survive to presentation, the mortality rates range between 4% and 66%.\textsuperscript{21} No doubt, concern of the presence of an aortic injury in a child sustaining BTT is what drives many clinicians to further investigate with thoracic CT. However, while others have demonstrated that in adult cases, distinct findings on CXR (e.g., widened aortic knob) as well as classic injury mechanisms (e.g., older patients, unrestrained drivers, or passengers in MVCs) are present in the vast majority, they can thus be used to direct further imaging, while interpretation of the mediastinal outline on a chest radiograph in younger children in the supine position is complicated by the presence of the thymus.\textsuperscript{22}

Our study suggests that major thoracic injuries that are or have the potential to be of clinical significance, thus warranting further imaging by CT, may be screened for by CXR. Positive findings include hydrothorax/pneumothorax, subcutaneous emphysema, or distortion of the mediastinal shadow, in conjunction with the clinical features of the patient and the injury mechanism. The finding of occult pneumothoraces in 7 (1.8%) of 396 “unremarkable” CXRs raises the question of the negative predictive value of a normal CXR finding in the context of clinical scenarios lacking features that suggest a high risk of occult thoracic injuries. A recent multicenter study has suggested that the vast majority of occult pneumothoraces can be managed without intervention, even in the face of positive-pressure ventilation.\textsuperscript{24} Similar conclusions have been reached by others with regard to occult pulmonary contusions, identified on thoracic CT scanning alone, suggesting that these are of little clinical significance.\textsuperscript{25} Further prospective studies are needed to study this, especially for those patients ultimately requiring positive-pressure ventilation.

It is of note that visualization of a widened mediastinum on CXR was not associated with ultimate diagnosis of a significant injury in this study. This is likely caused by the actual rarity of aortic disruption in pediatric trauma (discussed later) as well as potential to overcall this feature in the setting of blunt trauma due to presence of a thymic shadow in younger children or for fear of missing a potentially devastating injury.\textsuperscript{26}

The discrepancy between pre-CT factors associated with yielding an injury (any or significant) on CT and those associated with the decision to obtaining a thoracic CT at the trauma center is of some concern. The increased use of CT in the latter half of the study period or if the patient was having a CT scan of another body region may reflect a lower threshold for ordering a CT in later years in addition to easier access due to increased availability of this technology.\textsuperscript{10} The perception of “cost” to the patient may also be perceived as lower when already having another region scanned, decreasing the hesitation to ordering this high-radiation imaging modality. Most notable was that the presence of a positive finding on CXR was not associated with having a thoracic CT at the trauma center, an unexpected finding given that several CXR findings were associated with significant thoracic injury. On the contrary, this may reflect sound clinical judgment where the presence of a pneumothorax in the context of a clinically stable patient was sufficient for diagnosis in these cases. All taken, these discrepancies point to the value of a clinical decision rule that includes CXR findings to direct the use of thoracic CT scanning in children and reduce the use of scanning in situations of very low yield of visualizing clinically significant injuries.

An additional finding of note was the negative association between having a thoracic CT at a referral center and having one at the trauma center. There were, however, three cases in which a thoracic CT was performed at both centers, which may represent change in clinical status of the patient or poor communication of initial CT findings to the trauma center. Unnecessary repeat scans are unacceptable when considering the excess exposure to radiation. Clear communication and regional accessibility to images (such as Web-based computer archiving systems) between the referring and trauma centers are also essential to avoid unnecessary radiation exposure in children.

**Limitations**

Limitations to this study are inherent in its retrospective design. First, we were unable to clearly examine effects of systematically collected clinical findings or any changes in clinical management owing to positive CT findings. This would help determine if CT added to CXR in terms of overall management. Indications for CT were not recorded, and so reasons for CT use were not clear in each case. While this study was conducted at three centers, all are Level I trauma centers. Thus, the results may not be generalizable to all pediatric centers. Retrospective designs have a potential for misclassification. For example, cases transferred to the trauma center with a chest tube in place and no indication of having had a pretransfer CXR were assumed to have a hemothorax or pneumothorax and designated as such. However, this only applied to one case, which did not receive any CT scan of the chest. Thus, it would have been excluded from all analyses looking at the association of CXR findings and significant injury.

Finally, a major flaw of any retrospective study with data derived from a chart review is the potential for misclassification bias, especially if case definitions are too narrow and specific. For that reason, we opted to create a broad definition of “major injury” by including all pneumothoraces and hydrothoraces, regardless of size or clinical status (these latter two variables being subject to further misclassification error when abstracting from text from a chart). A prospective study to investigate and validate the role of CXR to screen for the need of a thoracic CT in this patient population is needed.

To the best of our knowledge, this is the only multicenter study examining the role of thoracic CT in the evaluation of pediatric BTT. We have highlighted the CXR as a screening tool for significant injury, which may be used in conjunction with expert clinical judgment to guide the use of thoracic CT. Clear guidelines may reduce the number of negative scan results and the exposure to carcinogenic ionizing radiation. More directed use of CT will also improve efficiency in health care provision, redirect scarce resources, and ensure efficient evaluation of children sustaining BTT.

In conclusion, there may be a value of CXR in the assessment of pediatric BTT and the potential to direct selective use of CT. Moreover, a negative CXR finding may be incorporated into a decision rule for when to forgo performing a
thoracic CT. Such a rule, including the sensitivity and specificity of CXR findings, must ultimately be validated in a separate cohort to develop a decision rule for CT use. Finally, the vast majority of thoracic injuries are hemothoraces/pneumothoraces. Those of clinical significance are generally not occult in that they are obvious on CXR and do not require further imaging with CT and/or do not result in hemodynamic instability. In that light, CT chest is rarely, if ever required to further establish a diagnosis.

AUTHORSHIP
N.L.Y., M.B., and B.S. designed the study. K.W., M.B., C.S.P., M.Z.E., and J.C. conducted the research. N.L.Y. and K.W. performed the analyses. N.L.Y., K.W., C.S.P., M.Z.E., and J.C. wrote the manuscript.

DISCLOSURE
The authors declare no conflicts of interest.

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