ORIGINAL ARTICLE

Pediatric chest CT after trauma: impact on surgical and clinical management

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Abstract

Background Chest CT after pediatric trauma is frequently performed but its clinical impact, particularly with respect to surgical intervention, has not been adequately evaluated.
Objective To assess the impact of chest CT compared with chest radiography on pediatric trauma management.
Materials and methods Two hundred thirty-five consecutive pediatric trauma patients who had both chest CT and radiography were identified. Images were reviewed and findings were categorized and correlated with subsequent chest interventions, blinded to final outcome and management.
Results Of the 235 children, 38.3% (90/235) had an abnormal chest radiograph and 63.8% (150/235) had an abnormal chest CT ($P<0.0001$). Chest interventions followed in 4.7% (11/235); of these, the findings could be made 1 cm above the dome of the liver in 91% (10/11). Findings requiring chest intervention included pneumothorax (PTX) and vertebral fractures. PTX was found on 2.1% (5/235) of chest radio-graphs and 20.0% (47/235) of chest CTs ($P<0.0001$); 1.7% (4/235) of the children received a chest tube for PTX, 0.85% (2/235) seen on chest CT only. Vertebral fractures were present in 3.8% of the children (9/235) and 66.7% (6/9) of those cases were treated with spinal fusion or brace. There were no instances of mediastinal vascular injury.
Conclusion Most intrathoracic findings requiring surgical management in our population were identified in the lower chest and would be included in routine abdominopelvic CT exams; this information needs to be taken into consideration in the diagnostic algorithm of pediatric trauma patients.

Keywords Chest · Trauma · CT · Chest radiography · Children

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Introduction

Trauma is the number one cause of death in children older than 1 year [1]. Pediatric trauma patients with multisystem injuries are frequently evaluated with radiographs or CT [2]. In children with head or abdominal trauma, CT evaluation is well accepted and has been shown to improve patient care by precisely identifying clinically significant injuries that may require emergent surgical referral [3, 4]. The identification of abnormal chest CT findings in pediatric trauma and its impact on patient care, however, is not as well understood.

In the adult population, chest CT in blunt chest trauma is particularly important in the assessment of aortic injury and facilitates prompt surgical referral [5, 6]. In children, however, aortic and other mediastinal injuries are uncommon. In one review of 10,886 children with blunt injury, 7 patients (0.06%) were found to have an aortic injury [7].

The more common thoracic injuries in pediatric trauma patients include pulmonary parenchymal injuries, rib fractures, and pneumothoraces [8]. Although CT is useful in elucidating the extent of these injuries, many of these injuries can also be found on chest radiography. For example, chest CT is more sensitive at detecting pneumothorax and in assessing the extent of an injury [9], but these additional findings do not frequently result in change in management [10]. Furthermore, it is not clear whether or how chest CT findings would affect patient management or patient outcome beyond identification of vascular injury.

At our institution, children with multiple injuries referred for abdominopelvic CT might also undergo chest CT, based on the clinical judgment and concerns of the treating physician. The purpose of this study is to assess the clinical impact of chest CT compared with chest radiography in the management of pediatric trauma, with emphasis on surgical intervention, and the impact of chest CT findings on clinical care in patients without vascular injury in the chest.

Materials and methods

Patient selection and demographics

Our institutional review board approved this retrospective study with waiver of informed consent. Between September 2006 and March 2008, 1,097 patients were admitted to our level 1 trauma center at a free-standing urban tertiary care children's hospital. Patients were included in the study if they met the following criteria: (a) age ≤18 years, (b) referred for full trauma CT (chest, abdomen and pelvis) and (c) had chest radiography performed within 24 h of the chest CT. The referral for chest radiography and CT was based upon the clinical judgment of the requesting physician, typically a pediatric trauma surgeon working in conjunction with a pediatric ED physician. Based on these clinical criteria, 365 children had chest CT in conjunction with abdominal and pelvic CT, and a total of 251 also had chest radiography within 24 h of the CT examinations. Sixteen children were excluded because they had received a chest-related intervention for treatment of a clinically evident thoracic injury prior to imaging, or based on outside, unavailable imaging. The final study population of 235 children included 141 boys and 94 girls, stratified as 25.1% (59/235) preschool age (0–4 years old), 42.5% (100/235) school age (5–12 years old), and 32.3% (76/235) adolescents (13–18 years old). For each child the mechanism of injury, standardized severity injury level assigned by the admitting service, and length of stay were recorded. The standardized severity injury level classification (level 1–3: 1 most severe, 3 least severe) is the trauma injury classification system used by our institution's trauma

service. Level 1 injuries include but are not limited to penetrating trauma to the chest, head or neck, vehicular ejection, major chest wall injury, and major crush injuries. Level 2 injuries include vehicular accident with death in same vehicle, and fall greater than 10 ft. Level 3 injuries include children who are ambulatory at the scene without immediately obvious significant injury.

Image protocols

Chest CT examinations were performed on either a 40-row Philips Brilliance multidetector CT (Philips Medical Systems, Eindhoven, the Netherlands) or a 16-row Philips MX8000 IDT multidetector CT (Philips Medical Systems) with the administration of intravenous contrast material, Optiray 320 (Mallinckrodt Inc., Hazelwood, MO, USA), 2 cc/kg, max 150 cc, via power injector in older children or rapid hand-injected bolus in infants, toddlers and some younger children, dependent on available IV size and site. All axial images were reviewed at 3-mm collimation, and bone algorithm reconstructions were reviewed as sagittal and coronal MIP images in addition to the axial plane. Chest radiographs were performed on an emergent basis and consisted of single-view AP supine chest images.

Radiation dose information was available in 83% of children (194/235). KVp was 120 for all patients, and mAs was determined on a weight basis, with a mean of 137 (min 60, max 300). Based on Monte Carlo estimates, the average radiation dose for the chest examination was 3.2 mSv (min 1.3, max 7.8).

Image analysis

A CAQ-certified pediatric radiologist with 4 additional years of experience reviewed the chest CT and chest radiograph images for all children at separate interpretation sessions, without knowledge of the findings of the other imaging modality. The radiologist was given the original report for all cases before reviewing the images but was blinded to patient outcome and management. If the reviewing radiologist's report conflicted with the original interpretation, the former was used for purposes of this research study. For each study, the radiologist determined whether the whole study was negative or positive for trauma-related findings, subcategorized in the following groups: mediastinal vascular injury, non-vascular mediastinal injury, pneumo- or hemothorax, consolidation, vertebral fracture, other osseous fracture, and extrathoracic soft-tissue injury. Consolidation is defined as any intrapulmonary airspace opacity with mass effect. Extrathoracic soft-tissue injury is defined as any injury-related abnormality within the subcutaneous fat or muscle of the chest wall. The number of patients

with a particular finding on chest CT was compared to the number with the respective category of finding on chest radiography.

When pneumothorax was identified by CT, the radiologist determined whether the pneumothorax could be seen within 1 cm above the dome of the liver, similar to the scan field of a dedicated abdominopelvic CT. When vertebral fractures were present, number and location were determined. When available at the time of initial presentation, dedicated radiographs of the thoracic spine were also reviewed to determine whether vertebral fractures seen on CT could also be identified on the radiographs. These were available in 6/9 children with thoracic spine injury.

Review of patient management and data review

The medical record of every child was evaluated for information on patient management and outcome. Interventions were categorized as either "chest-related intervention" or "non-chest-related intervention." Children with chest-related intervention were further categorized by management type: chest thoracoscopy, thoracotomy, orthopedic surgery, non-surgical orthopedic (e.g., brace for treatment of stable thoracic vertebra compression fracture), or removal of foreign body. Cervical or lumbar spine interventions were classified as orthopedic interventions. Non-chest-related intervention patients were categorized as abdominal intervention, neurologic intervention, orthopedic intervention, and other. "Other" included any soft-tissue injury, extremity vascular repair, or extremity reattachment.

Each child's outcome was categorized by status at discharge: death due to chest trauma, death due to other cause, discharge at baseline health, or discharge below baseline health. Discharge below baseline health includes any follow-up for surgical procedure or need for rehabilitation.

The relationships between a positive chest CT or chest radiograph and multiple demographic data points (length of stay, level of trauma, and patient outcome) were also calculated.

Statistical analysis

This is a descriptive study. Proportions of children with the study endpoints such as abnormal CT or chest radiograph are calculated. Proportions between groups are compared using exact chi-square test or Fisher exact test as appropriate depending on the number of events for the endpoints. Mean and range are reported for continuous endpoints such as age and length of hospital stay. P values less than 0.05 are considered statistically significant. All tests are two-tailed. Statistical analyses are performed using the statistical package SAS for Windows (Version 9, Cary, NC, USA) and statistical analysis package R.

Results

Patient demographics

The study patient population is described in Table 1. The average length of stay was 6.4 days (range 1–70 days). Most (66.8%, 157/235) patients included in the study were classified as level 1 injury. Level 2 was assigned to 27.2% (64/235), and 6.0% (14/235) were assigned level 3.

Imaging findings

Chest CT scans were more likely to have a positive finding than chest radiograph (Table 2). Although 63.8 % (150/235) of chest CT scans had at least one positive finding, only 38.3% (90/235) of chest radiographs were positive ($P<0.0001$). When chest radiography was normal

Table 1 Demographic data, mechanism of injury, level of injury, and patient outcome

Parameter	Study Group n=235 (%)
Sex	
Male	141 (60.0)
Female	94 (40.0)
Age (years)	
<1 to 4	59 (25.1)
5 to 12	100 (42.5)
13 to 18	76 (32.3)
Mechanism of injury	
Motor vehicle accident	127 (54.0)
Pedestrian versus motor vehicle	26 (11.1)
Fall	22 (9.4)
All-terrain vehicle accident	22 (9.4)
Non-accidental trauma	9 (3.8)
Other	29 (12.3)
Level of injury	
Level 1	157 (66.8)
Level 2	64 (27.2)
Level 3	14 (6.0)
Length of stay (days)	
Median	4
Range	1–70
Status at discharge	
Baseline	139 (59.1)
Not at baseline	81 (34.5)
Death	15 (6.4)

Table 2 Prevalence of abnormalities on chest CT and chest radiography and ability of radiologist to predict need for chest-related intervention

Finding	Chest radiography n=235 (%)	Chest CT n=235 (%)	P value
Normal	145 (61.7)	85 (36.2)	<0.0001
Abnormal	90 (38.3)	150 (63.8)	<0.0001
Mediastinal vascular	0 (0)	0 (0)	–
Mediastinal nonvascular	1 (0.4)	8 (3.4)[a]	0.0373
PTX/HTX[b]	5 (2.1)	47 (20.0)	<0.0001
Consolidation	62 (26.4)	109 (46.3)	<0.0001
All Bone	23 (9.8)	47 (20.0)	0.0019
Other bony fracture	23 (9.8)	38 (16.2)	0.0395
Vertebral fracture	0 (0)	9 (3.8)	0.0036
Extrathoracic soft tissue	3 (1.3)	3 (1.3)	–

[a] Findings were of pneumomediastinum (described as small to moderate)

[b] Pneumothorax/hemothorax

(n=145), the chest CT was abnormal in 47.6% (69 patients). When chest radiography was abnormal (n=90), the chest CT was abnormal in 82/90 (91.0%). Of the eight children with abnormal chest radiography and normal chest CT, radiographic findings of consolidation (5) likely represented resolving atelectasis between CT and radiography. Additional cases of abnormal chest radiography and normal chest CT include change in support devices (2) and a distal clavicular fracture, which was obvious on the chest radiograph but quite subtle in retrospect on the axial CT images [1].

No mediastinal vascular injuries were identified on either chest CT or radiograph. The most common findings on chest CT were pulmonary consolidation (46.3%, 109/235)) (Fig. 1), pneumothorax/hemothorax (20.0%, 47/235)) (Figs. 1 and 2) and bone fractures (20.0%, 47/235), of which 19.1% (9/47) involved the thoracic vertebrae. Of the 47 pneumothoraces identified by chest CT, 30 (64%) could be identified within 1 cm of the dome of the liver.

Pulmonary consolidations and fractures were also the most common findings on chest radiography (26.4% or 62/235, and 9.8% or 23/235, respectively), with pneumothorax/hemothorax being less common (2.1%, 5/235). No vertebral fractures were found on chest radiograph.

The 9 patients who had vertebral fractures identified by CT had a total of 27 vertebral fractures. The distribution of fractures by vertebral level included: T1 (0), T2 (2), T3 (2), T4 (0), T5 (2), T6 (2), T7 (3), T8 (4), T9 (3), T10 (4), T11 (4), T12 (0), and L1 (1). Eight of the nine patients with vertebral fractures had at least one coexisting vertebral fracture involving T9 or below, which would have been included on an abdominopelvic CT. The one child without lower thoracic vertebral fractures had thoracic vertebral fractures isolated at the T2, T3 transverse processes. Although none of the vertebral fractures was visible on chest radiograph, 6/9 children with vertebral fractures also had thoracic plain radiographs at the time of initial work-up. These 6 patients had a total of 20 vertebral fractures based on CT. All 6 had abnormal thoracic spine radiographs, but only 40% of the fractures (8/20) could be confidently identified on the radiographs.

Patient management and outcome

The management of this patient population is described in Table 3. The majority of patients received a non-chest-related intervention (63.4%, 149/235). Only a small percentage of all patients (4.7%, 11/235) received a chest-related intervention. Of these 11 patients, 3 had both a chest intervention and non-chest-related intervention. Of the 11 patients who underwent chest intervention, eight were level 1, two were level 2, and one was level 3.

The most common chest-related intervention was orthopedic management of vertebral fracture (54.5%, 6/11) (Fig. 3). Of this group, three patients underwent operative stabilization and three were managed non-operatively (i.e. with a brace). The one child with isolated T2 and T3 transverse process fractures did not undergo operative stabilization and was managed non-operatively with a brace. The other chest-related interventions included tube thoracostomy for pneumothorax or hemothorax (36.4%, 4/11) and removal of foreign body from lung parenchyma (9.1%, 1/11).

All six vertebral injuries requiring intervention were identified by CT and missed by chest radiograph; however, all six were seen by thoracic spine radiographs, and evidence of spine injury would have been included in the upper images of an abdominopelvic CT in all six. However, abdominopelvic CT and thoracic spine radiographs underestimated the number of thoracic spine fractures, suggesting that when identified on these examinations, chest CT would be indicated. All four pneumothoraces requiring chest tube placement were identified by chest CT. In addition, all four pneumothoraces identified by chest CT requiring chest tube placement were identifiable within 1 cm of the dome of the liver. Chest radiography identified 2/4 (50%) of these pneumothoraces requiring intervention. In the one child requiring intervention for foreign body removal, the foreign body was seen on both chest CT and chest radiography.
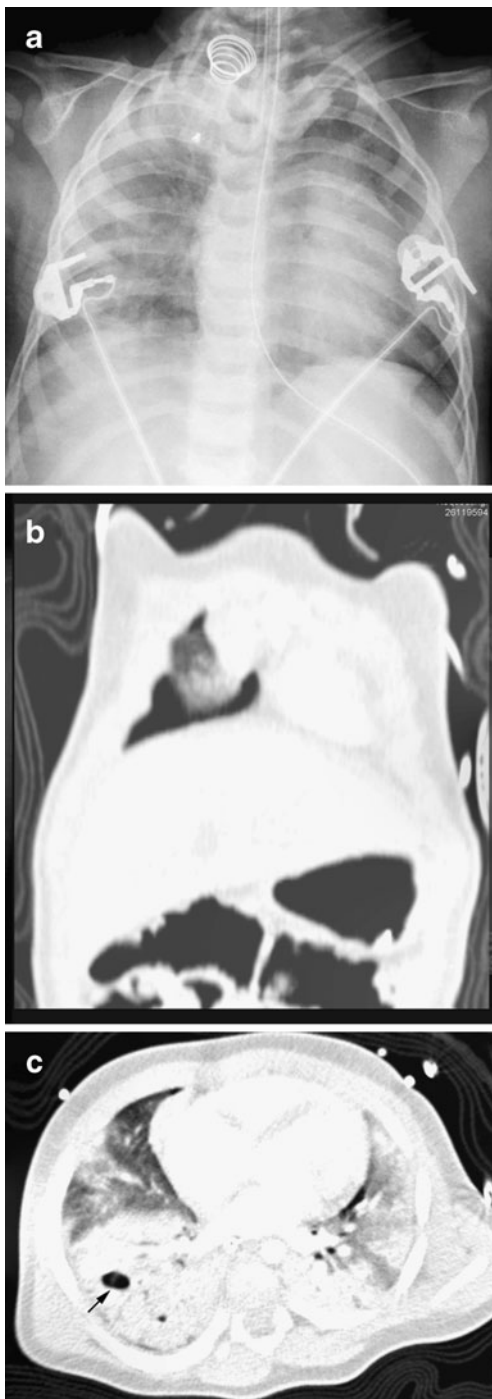
Fig. 1 Images of a 15-month-old child following a motor vehicle accident. **a** Portable chest radiograph shows no evidence of pneumothorax. Chest CT with coronal (**b**) reformatted image shows small pneumothorax, and (**c**) axial image shows pulmonary contusion and traumatic pneumatoceles (*arrow*). The child required chest tube placement

Fig. 2 Images of a 16-year-old following a motor vehicle accident. **a** Portable chest radiograph shows pneumothorax (*arrows*). **b** Chest CT shows moderate-size pneumothorax. The child required chest tube placement

group included patients who were transferred to a rehabilitation center, had permanent disabilities caused by their injuries, or required further follow-up of their injuries in an outpatient clinic. The mortality rate in our population was

Table 3 Prevalence of major interventions

Type of intervention	n=235 (%)
No intervention	78 (33.2)
Non-chest-related intervention[a]	149 (63.4)
Abdominal intervention	7
Neuro intervention	18
Orthopedic intervention	68
Other[b]	85
Chest-related intervention	11 (4.7)[c]
Chest tube	4
Orthopedic surgical intervention	3
Orthopedic non-surgical intervention	3
Removal of foreign body	1

[a] Patients may have received more than one intervention

[b] The majority were deep soft-tissue injury repairs, followed by extremity vascular repair, and extremity reattachment

[c] Includes 3 patients who required both non-chest- and chest-related intervention

Most children (59.1%, 139/235) had returned to baseline health by discharge from the hospital. However, 34.5% (81/235; 58 level 1 patients, 21 level 2 patients, and 2 level 3 patients) were not at baseline health upon discharge. This
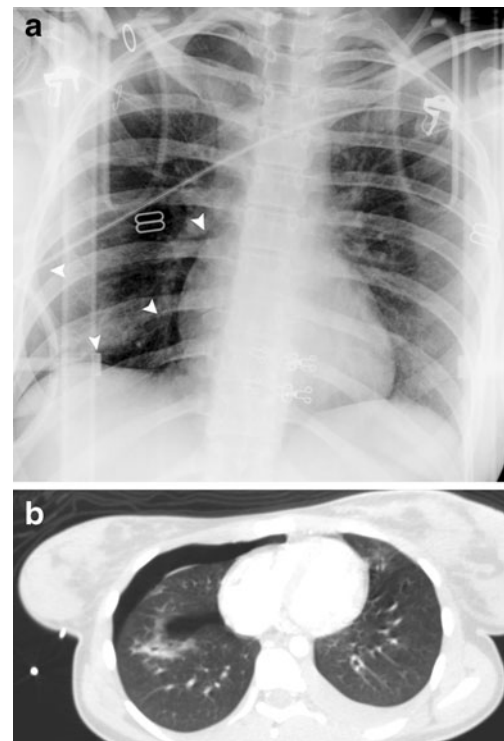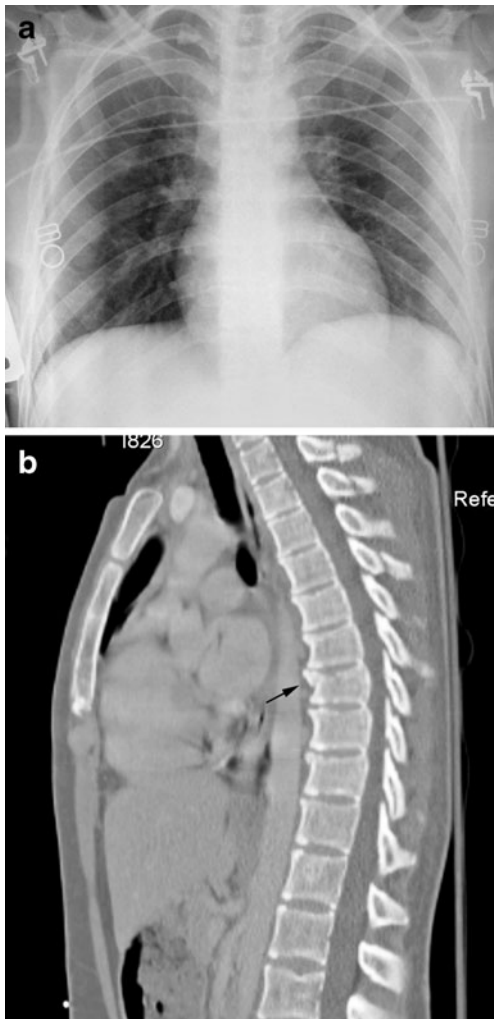
Fig. 3 Images of a 16-year-old following a motor vehicle accident. **a** Portable chest radiograph shows no evidence of thoracic spine injury. **b** Chest CT with sagittal reformations shows thoracic vertebral-body compression fracture (*arrow*). The patient required non-surgical orthopedic intervention (thoracic brace fixation)

6% (15/235; 13 level 1 patients, 0 level 2 patients, and 2 level 3 patients) but none of the deaths was caused by chest-related injury. The cause of death in these 15 children included 13 from central nervous system injury (anoxia, trauma, or herniation), 1 from septic shock, and 1 from cardiopulmonary arrest.

Impact of abnormal image findings on patient management

The majority (72.7%, 8/11) of children who received a chest-related intervention had been classified as a level 1 injury. Among the 15 children who died, only 2 had negative chest CT studies, whereas 7 had negative chest radiograph studies. The average length of stay was longer for those patients with positive findings on chest CT than those with negative studies (7.4 vs. 4.6 days, $P<0.001$).

The average length of stay was longer for those children with positive findings on chest radiography than those with negative studies (8.3 vs. 5.2 days, $P<0.0034$).

Discussion

In children with multiple injuries caused by trauma, CT and chest radiography are frequently the initial diagnostic studies performed. Studies have found that head and abdominal CT scans are beneficial in identifying surgically significant injuries that require emergent intervention [3, 4], and there are well-defined guidelines for evaluation of head and abdominal injury with CT in children [11, 12]. However, the management of chest injury is not as well studied.

Chest CT is the study of choice in the evaluation of traumatic aortic injury and is used in routine adult screening to optimize diagnosis of this emergent condition [13]. In adult trauma patients, great vessel injury, which can be occult or subtle on chest radiography, can be quickly and reliably identified by chest CT [5, 6]. In children, however, aortic injury is very uncommon. In our study there were no cases of aortic injury. In the absence of penetrating chest trauma, the rarity of aortic injury in children [14, 15] calls into question the clinical necessity and cost-effectiveness of routine chest CT. Beyond the question of vascular injury, our study further addresses the utility of chest CT in the pediatric trauma patients without aortic injury.

Earlier research studies encouraged chest CT in the primary evaluation of pediatric trauma [16], while more recent studies with greater awareness of radiation concerns recommend more conservative management [17]. In our study, the majority of children with thoracic vertebral fractures and all children with pneumothoraces requiring chest tube placement were identifiable within the lower chest that typically is imaged during abdominopelvic CT studies. In our study population, if chest CT imaging in hemodynamically stable patients were selectively limited to patients with pneumothoraces or lower thoracic vertebral fractures identified in the trauma abdominopelvic CT scan, 179 (76%) fewer chest CT exams would had been performed, with the attendant savings in radiation exposure and cost.

In our study the most common findings were pulmonary consolidations, pneumothorax/hemothorax, and rib fractures. In published reports, the common thoracic injuries found on chest CT in pediatric trauma patients include pulmonary parenchymal injury, pneumothoraces, and hemothoraces [16, 17]. In younger children, rib fractures are not as common but increase in frequency as the rib cage ossifies [18]. There were significantly more abnormal findings on chest CT than chest radiography in our study

(47.6%), similar to a prior study by Sivit et al. [19], who observed that chest radiography missed or underestimated intrathoracic injuries in 37.6% of cases. However, few of the additional findings in our study resulted in a change in surgical management of chest injuries. For example, although 47 pneumo- or hemothoraces were found on chest CT (42 more than were found on chest radiography), only 4 of these children received a chest tube. Of the four children who required chest tube placement, two were identified by chest radiograph and all were identified by CT within 1 cm of the dome of the liver.

Vertebral injury was the one category of findings on chest CT that significantly impacted patient management and represents the only abnormal finding demonstrated exclusively by chest CT. Although published data document a low incidence of spine fractures [20], investigators have found that vertebral fractures were most commonly identified in the thoracic spine in pediatric trauma patients, regardless of mechanism of injury [21]. This type of injury was also not common in our study, and most such injuries found in our study were treated with bracing or underwent operative stabilization. All six children with vertebral fractures requiring intervention could be identified on abdominopelvic CT, allowing redirection of further management. Extra-vertebral findings delineated by CT that resulted in intervention affected only three children: two with pneumothoraces and one with deep soft-tissue foreign body removal; these findings, however, were either visible on chest radiograph or would have been visible 1 cm above the liver dome on abdominopelvic CT.

The findings in our study, in an ALARA environment, suggest that chest CT should not be routinely used to evaluate all pediatric trauma patients. Our findings suggest that chest CT should be reserved for patients in whom the mechanism of injury or cardiovascular status are suggestive of spinal or vascular injury. In children who are hemodynamically stable with low probability of intrathoracic vascular injury, our data suggest that findings leading to a change in surgical management can be made at the lung bases on an abdominopelvic CT examination. Although we did not formally include review and comparison of lateral thoracic spine radiographs with information obtained on CT scan, the availability of the lateral radiograph in 6/9 patients with spinal fractures suggests that thoracic radiographs are useful in screening patients with potential thoracic spine injury who need further workup.

Our investigation has several limitations, including that it is a retrospective study. Our sample did not include certain pathology such as aortic injury, but this can be attributed to the very low incidence of aortic injury in the general pediatric trauma population. Our relatively low detection rate of pneumothoraces by chest radiography is in part related to the fact that all children had undergone portable chest radiography in the supine position. The spectrum of injuries found in our study was in children who were medically stable to undergo chest CT. Therefore, more severe intrathoracic injuries might be underrepresented in our study population, as these children might have died or received emergent surgical intervention prior to chest CT (and therefore were excluded from our study). However, this does not change the significance of the results of our study, as we deal only with the decision tree in those children who are sufficiently stable to have a CT scan performed. An additional limitation of this study is that we limited it to the surgical management of trauma-related chest findings. We did not fully evaluate non-surgical parameters that affect patient care, such as whether the presence of a non-surgically treated pneumothorax seen only by CT, or pulmonary contusion, changes the degree of patient monitoring (ICU versus regular floor bed) or affects the level of anesthesia management during the surgical treatment of non-thoracic injuries.

Conclusion

In this population that did not have intrathoracic vascular injuries, we have found that chest CT was most useful in the detection of occult thoracic spine fractures. Significant intrathoracic injuries requiring intervention were most often found in the lower chest, which is typically included with abdominopelvic CT exams. Therefore, abdominopelvic CT imaging that includes the lower chest might obviate the need for dedicated chest CT imaging when the suspicion for significant intrathoracic injury is low.

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