

CT of the chest in suspected child abuse using submillisievert radiation dose

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Abstract The cornerstone of child abuse imaging is the skeletal survey, but initial imaging with radiographs may not demonstrate acute and non-displaced fractures, especially those involving the ribs. Given the high mortality of undiagnosed non-accidental trauma, timely diagnosis is crucial. CT is more sensitive in assessing rib fractures; however the effective radiation dose of a standard chest CT is high. We retrospectively identified four children (three boys, one girl; age range 1–4 months) admitted between January 2013 and February 2014 with high suspicion for non-accidental trauma from unexplained fractures of the long bones; these children all had CT of the chest when no rib fractures were evident on the skeletal survey. The absorbed radiation dose estimates for organs and tissue from the four-view chest radiographs and subsequent CT were determined using Monte Carlo photon transport software, and the effective dose was calculated using published tissue-weighting factors. In two children, CT showed multiple fractures of the ribs, scapula and vertebral body that were not evident on the initial skeletal survey. The average effective dose for a four-view chest radiograph across the four children was 0.29 mSv and the average effective dose for the chest CT was 0.56 mSv. Therefore the effective dose of a chest CT is on average less than twice that of a four-view chest radiograph. Our protocol thus shows that a reduced-dose

chest CT may be useful in the evaluation of high specificity fractures of non-accidental trauma when the four-view chest radiographs are negative.

Keywords Child abuse · Non-accidental trauma · Rib fractures · Computed tomography · Chest · Ribs · Infants

Introduction

The diagnosis of child abuse bears significant consequences to children and their families, as well as to social and medical personnel. Missed diagnosis can result in further injury and death, whereas wrongful intervention can lead to severe emotional distress for the family. It is therefore essential that the medical team closely evaluate all evidence to make the proper diagnosis.

The cornerstone in the imaging of child abuse is still the appropriately obtained skeletal survey as outlined in American College of Radiology and Society for Pediatric Radiology guidelines [1]. However it has been established that initial imaging with radiographs might not show acute and non-displaced fractures, especially those involving the ribs, and that CT is more sensitive in assessing rib fractures [2]. Because rib fractures are one of the most common and highly specific injuries of child abuse, assessment of this type of injury is important [3].

However, CT has not gained traction for imaging of occult rib fractures primarily because of radiation concerns. A standard chest CT exposes the patient to as much as 18 mSv, roughly equivalent to 900 chest radiographs [4]. Cancer risk from diagnostic radiation may be significant. Recent work suggests that in the United States alone at least 4 million pediatric CT scans are performed annually, potentially leading to 3,500 deaths from cancer [5, 6].

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Concern over radiation exposure has led to extensive research into techniques for decreasing radiation exposure by altering imaging parameters and by modifying computer reconstruction algorithms to decrease image noise. It is now possible to reduce the radiation dose significantly without compromising the diagnostic quality of the images [7]. We have developed a chest CT with a submillisievert radiation dose, and at our institution we recommend that highly suspicious cases of child abuse with negative skeletal radiographs undergo chest CT. This is the first description of a technique for obtaining a reduced-dose chest CT in infants to evaluate the bony thorax for signs of non-accidental injuries.

Description

After our institutional review board approved this study, we retrospectively identified four children (three boys, one girl; age range 1–4 months) admitted between January 2013 and February 2014 with high suspicion for non-accidental trauma from unexplained long-bone fractures and conflicting history from the caregivers. The four-view chest radiographs, as part of the skeletal survey, did not show acute or healing fractures. After consultation with the pediatric radiologists, the clinicians requested a CT scan of the chest in these cases to look for radiographically occult fractures. After clinical evaluation as well as neurology and ophthalmology consults, the chest CT scans were performed within 36 h after the skeletal survey (range 11–36 h). These children were imaged using our reduced-dose chest CT protocol with a 64-row multidetector GE LightSpeed VCT (GE Medical Systems, Waukesha, WI). The following parameters were employed:

1. Images were obtained from the top of the clavicles to the upper abdomen to include all ribs.
2. The following manual settings were used: 80 kVp or 100 kVp, 7.5 mAs, 0.98:1 pitch and 40 mm of collimation.
3. Contiguous axial images with slice thickness of 2.5 mm were obtained and reconstructed at 1.25-mm thickness in a 20-cm display field of view.
4. Post-processing using a 20% blended adaptive statistical iterative reconstruction (ASIR-20) was employed to decrease image noise caused by dose reduction.
5. Images were interpreted after obtaining bone algorithm and evaluated together with sagittal and coronal reformations (5-mm slice thickness at 3-mm increments).

Two children underwent the reduced-dose chest CT protocol with 100 kVp and two had 80 kVp, which further reduced the effective dose. For each of the children the four-view chest radiographs (as part of the skeletal survey) were acquired on a Philips Digital-

Diagnost flat-panel radiography system (Philips Healthcare, Bothell, WA). Information on each exam was extracted, including the kV, mAs, field dimensions, dose-area-product indicator, and projection view. Effective dose was estimated using a software program, PCXMC (STUK, Helsinki, Finland), a Monte Carlo program for calculating patient doses in medical X-ray examinations. The anthropomorphic phantom dimensions simulating each child were size- and weight-adjusted, and X-ray field areas were matched to the radiographs. Individual organ and tissue doses were determined, and a final effective dose estimate was calculated based on ICRP 103 weighting factors [8].

CT dose was calculated by sending acquired axial data to a dose-calculation software engine, Radimetrics eXposure (Bayer, Toronto, Canada). Information was extracted from the localizer radiograph, axial reconstructed radiographs, radiation dose structured report, and dose protocol page on the scanner for the chest CT scan independent of other scans (e.g., head CT scan). Using a Monte Carlo routine and child-size anthropomorphic phantom for each CT acquisition event, organ doses were determined, from which an effective dose was calculated using tissue-weighting factors as described in ICRP 103 [8].

All four children had initial routine skeletal surveys, three showing long-bone fractures. Rib fractures were not evident on any of the four-view chest radiographs in the four children. High suspicion for non-accidental trauma prompted referral for chest CT, which was performed using the lower-dose protocol described above. Effective-dose calculations for the four children comparing the four-view chest radiographs and the CT are summarized in Table 1. The average effective dose for a four-view chest radiograph across four children was 0.29 mSv, and the average effective dose for the chest CT was 0.56 mSv. Therefore the effective dose of CT was on average less than twice that of a four-view chest radiograph.

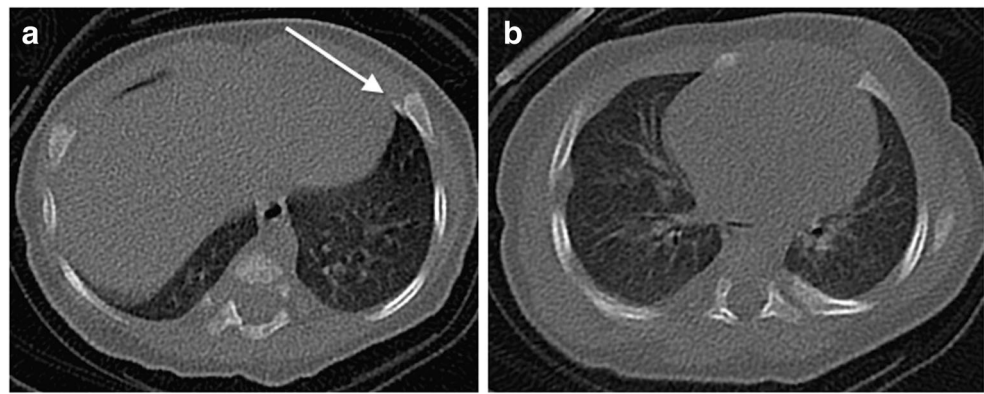
All four submillisievert CT studies were deemed diagnostic by the interpreting pediatric radiologists. In one child who

Table 1 Effective dose comparison for chest radiographs and chest CT

Patient	CT technique factors (kV, mAs)	Effective dose for chest CT (mSv)	Effective dose for the 4-view chest radiographs
1	100 kV, 7.5 mAs	0.72 mSv	0.31 mSv
2	100 kV, 7.5 mAs	1.13 mSv ^a	0.30 mSv
3	80 kV, 7.5 mAs	0.48 mSv	0.35 mSv
4	80 kV, 7.5 mAs	0.45 mSv	0.19 mSv

^a This child had two limited CT scans on the upper and lower boundaries of the main scan because of inadequate coverage of the ribs with some overlaps, explaining the increased effective dose

Fig. 1 Rib fractures in a 6-week-old girl as seen on CT. Radiographs in this infant showed no fractures, but CT was ordered because of high suspicion for non-accidental injury. **a** Axial CT shows a healing costochondral rib fracture (*arrow*) that was not evident on the standard four-view chest radiographs. **b** Adjacent normal costochondral junction for comparison



underwent a chest CT using 100 kVp with an effective dose of 0.72 mSv, healing fractures were seen bilaterally involving the right 3rd costochondral junction and 4th–6th posterior ribs and the left 2nd–3rd and 6th–7th anterior ribs (Figs. 1 and 2) as well as a healing right scapular fracture (Fig. 3) and compression fracture of the T3 vertebral body (Fig. 4). Even in retrospect, the initial radiographs of the chest were normal.

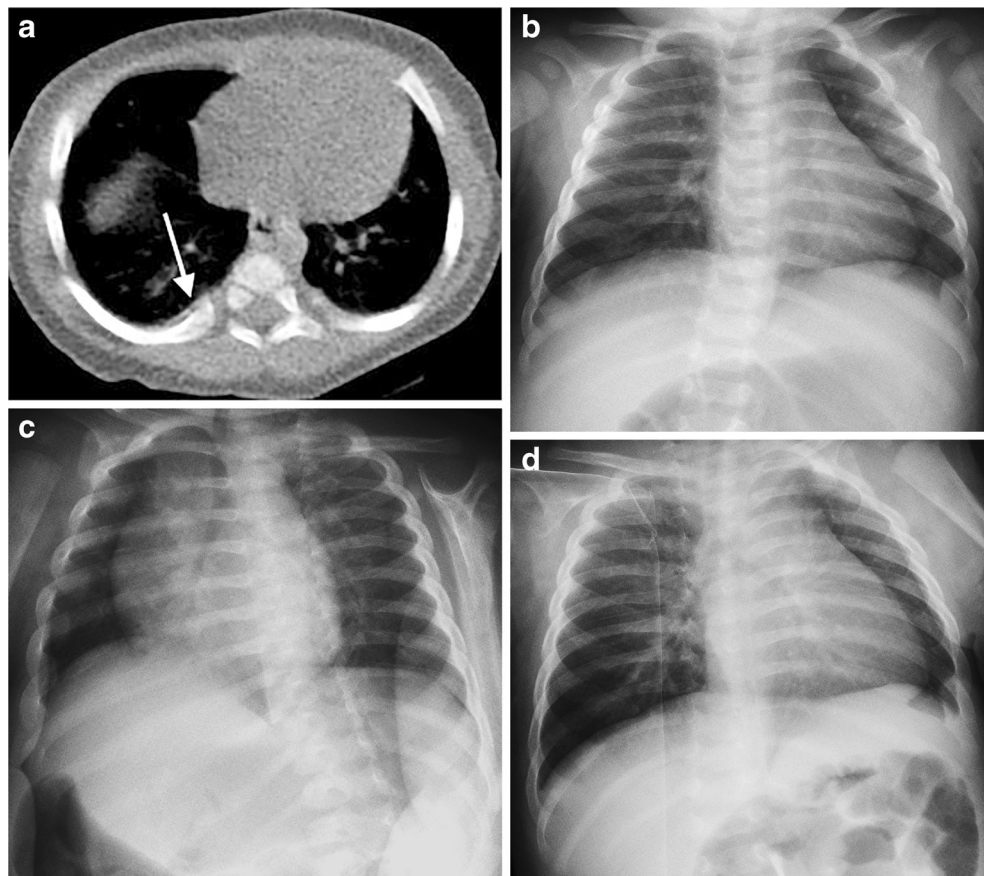
In another child who had a chest CT with 80 kVp and an effective dose of 0.48 mSv, the study showed bilateral fractures of the right 3rd–6th and left 4th–7th anterior ribs. There was also a healing right scapular body fracture and a T8 vertebral body compression. Again, these fractures were not

visualized on the prior plain radiographs. The CT scans of the other two children revealed no rib fractures.

Discussion

Four-view chest radiographs are often performed as part of a screening skeletal survey in cases of suspected child abuse. If no fractures are identified, a follow-up skeletal survey after 2 weeks is often the next step, because callus formation makes healing fractures more conspicuous. Chest CT has been shown to demonstrate

Fig. 2 Comparison of radiographic and CT findings in the same infant as Fig. 1. **a** Axial CT shows healing posteromedial rib fracture with early periosteal reaction (*arrow*), an injury that is highly specific for child abuse. This fracture most often declares itself only when significant callus forms after several weeks. **b, c, d** Anteroposterior and bilateral oblique radiographs of the same infant taken prior to CT show no fractures



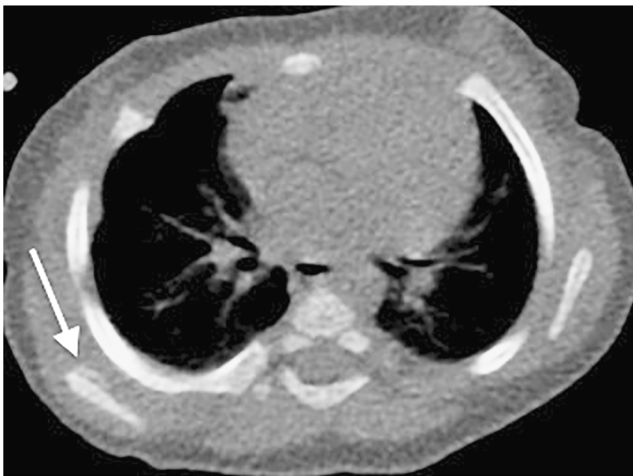


Fig. 3 Scapular fracture in the same infant as in Figs. 1 and 2. Axial CT shows a healing right scapular fracture (*arrow*). This type of injury is highly specific for child abuse but can be very difficult to see on radiographs

rib fractures that are not seen on standard chest radiographs [2], but concern about radiation-induced cancer morbidity and mortality has dampened interest in this modality. We have modified our chest CT scan protocol to produce a study that lowers the dose substantially but still adequately evaluates the bony thorax. At our institution this has become an important addition to conventional radiographic imaging of child abuse, as it occasionally demonstrates additional highly specific fractures that are not apparent on radiographs.

The average effective dose of a chest CT using our protocol outlined above for children 4 months and younger was 0.56 mSv, less than twice the calculated effective dose of a standard four-view chest radiograph, which is 0.29 mSv. This



Fig. 4 Vertebral body compression fracture in the same infant as in Figs. 1, 2 and 3. Sagittal CT reformatted image shows a thoracic vertebral body compression fracture (*arrow*). This injury, also considered moderately specific for abuse, was not evident on radiographs

is far below the effective dose of a standard chest CT, which can expose the patient to as much as 18 mSv [4], more than 30 times the dose of our chest CT. Using a manual setting of 80 kVp, the effective dose nearly approaches that of the four-view chest radiograph (0.48 mSv for the CT vs. 0.35 mSv for the radiographs). Even with 100 kVp, the effective dose for the chest CT for the child who had occult rib fractures on the four-view chest radiograph is only 0.72 mSv and is just over twice the effective dose of the chest radiographs. Furthermore, if the CT demonstrates highly suspicious fractures, a follow-up skeletal survey after 2 weeks may become unnecessary, decreasing the overall radiation burden while expediting patient management and reducing the likelihood of additional injury.

Another advantage of performing a reduced-dose CT is that it can evaluate not only the ribs but also the entire bony thorax, including the spine. Indeed, the two infants with multiple rib fractures also had scapular fractures that are thought to be rare even in the setting of non-accidental trauma. Compression fractures of the spine, which are also considered moderate specificity fractures for child abuse, were also demonstrated in these two patients.

One limitation of our study is the small number of patients. Although both the 100 kVp and 80 kVp settings for the chest CT were able to diagnose the radiographically occult fractures, a more extensive and possibly prospective study needs to be performed to confirm our findings. We recommend further study using the 100-kVp protocol because it produces better images with less noise and only minimally increases the effective radiation dose (Table 2).

In conclusion, if child abuse is highly suspected but the skeletal survey is negative, CT scan of the chest can play an important role in providing optimal patient care. Fractures, especially those that are acute, nondisplaced or obscured by other bony structures on plain radiographs, can be demonstrated on the chest CT scan.

Table 2 Suggested protocol for a submillisievert radiation dose chest CT for infants

Tube voltage	100 kVp
Tube current	15 mA
Rotation time	0.5 s
Pitch	0.98:1
Collimation	40 mm
Field of view (FOV)	20 cm
ASIR	20%
Algorithm	Bone
Slice thickness	2.5-mm contiguous axial
Image reconstructions	1.25-mm axial and 3 × 5-mm coronal and sagittal reformations

ASIR adaptive statistical iterative reconstruction

Conflicts of interest None

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