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Comparison of computed tomography and chest radiography in the detection of rib fractures in abused infants

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ABSTRACT

Purpose: Chest radiographs (CXR) are the standard method for evaluating rib fractures in abused infants. Computed tomography (CT) is a sensitive method to detect rib fractures. The purpose of this study was to compare CT and CXR in the evaluation of rib fractures in abused infants.
Methods: This retrospective study included all 12 abused infants identified from 1999 to 2004 who had rib fractures and both CXR and CT (8 abdomen CTs, 4 chest CTs). CT exams had been performed for clinical indications, and were obtained within one day of the CXR. Studies were reviewed by two pediatric radiologists to determine the number, locations, and approximate ages of the rib fractures. A total of 225 ribs were completely (192) or partially (33) seen by CT, and the matched ribs on CXR were used for the analysis.
Results: The mean patient age was 2.5 months (1.2–5.6), with seven females and five males. While 131 fractures were visualized by CT, only 79 were seen by CXR ($p < .001$). One patient had fractures only seen by CT. There were significantly ($p < .05$) more early subacute (24 vs. 4), subacute (47 vs. 26), and old fractures (4 vs. 0) seen by CT than by CXR. Anterior (42 vs. 11), anterolateral (21 vs. 12), posterolateral (9 vs. 3) and posterior (39 vs. 24) fractures were better seen by CT than by CXR ($p < .01$). Bilateral fractures were detected more often by CT (11) than by CXR (6).
Conclusions: While this study group is small, these findings suggest that CT is better than CXR in visualizing rib fractures in abused infants.

Introduction

Rib fractures are relatively uncommon in infants and children under 3 years of age (Barsness et al., 2003) and may result from either direct trauma to the chest, from anterior-posterior compression of the thorax, or from bone fragility states (Bulloch et al., 2000). Because of the plasticity of the pediatric skeleton, rib fractures are unusual even in severe accidental trauma and are rare after vigorous cardiopulmonary resuscitation (Bush, Jones, Cohle, & Johnson, 1996; Feldman & Brewer, 1984; Maguire et al., 2006; Spevak, Kleinman, Belanger, Primack, & Richmond, 1994). In fact, most rib fractures in infants are caused by non-accidental trauma. Several recent studies (Barsness et al., 2003; Bulloch et al., 2000; Cadzow & Armstrong, 2000) have reported that rib fractures in infants resulted from child abuse in more than 80% of cases.

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Currently, the standard imaging method for evaluating rib fractures in abused infants is the chest radiograph (CXR) (Kemp et al., 2006; Sane et al., 2000; Slovis et al., 2000). As rib fractures may be incomplete, non-displaced, superimposed over other bony structures or oriented obliquely with respect to the X-ray beam, they may be difficult to see (Kleinman, Marks, Adams, & Blackbourne, 1988). To increase detection of these fractures, oblique views (Ingram, Connell, Hay, Strain, & Mackenzie, 2000), bone scintigraphy (Mandelstam, Cook, Fitzgerald, & Ditchfield, 2003; Smith, Gilday, Ash, & Green, 1980) or follow-up chest radiographs after 2 weeks (Kleinman, Nimkin et al., 1996; Zimmerman, Makoroff, Care, Thomas, & Shapiro, 2005) have been suggested.

Chest computed tomography (CT) is known to be accurate in the diagnosis of rib fractures in trauma in adults (Alkadhi, Wildermuth, Marincek, & Boehm, 2004; Chan & Hiorns, 1996,) and children (Renton, Kincaid, & Ehrlich, 2003). However, to date, no studies have been reported comparing chest radiography and computed tomography in the diagnosis of rib fractures in abused infants. The purpose of this study was to compare CXR and chest CT in the diagnosis of rib fractures in abused infants less than 1 year of age. Our hypothesis is that chest CT would be more sensitive than CXR in the diagnosis of rib fractures in abused infants.

Methods

This observational retrospective study was approved by the University of California, Davis Medical Center (UCDMC) Institutional Review Board. Study subjects were obtained from a comprehensive search of the medical record database for child abuse cases admitted at UCDMC over a 5 year time period from 1999 to 2004. The study group included all infants less than 12 months of age who had confirmed non-accidental trauma and who had both of the following: (1) a two-view (frontal and lateral) chest radiograph (CXR) and a computed tomography (CT) scan of either the abdomen or chest obtained at clinical presentation; and (2) documentation of at least one rib fracture by either method. Both the CXR and CT were performed within 1 day of each other on all patients. The medical records were reviewed for demographic data including gender, age at presentation, and other injuries at admission. Two pediatric radiologists blinded to the patient name separately reviewed the two-view chest radiographs and the CT scans. The result of the CXR was not utilized in the review of the CT, nor vice versa. The following information was determined by consensus between the two radiologists: (1) number of ribs viewed; and for each individual rib (2) the presence or absence of rib fracture(s); (3) the location of rib fracture(s) along the rib (anterior, anterolateral, lateral, posterolateral, or posterior); and (4) the fracture age (acute, early subacute, subacute, late subacute, old (Islam et al., 2000)). Acute fractures were defined as those with sharp margins and no periosteal reaction. Early subacute fractures were defined as those with blurring of the fracture margins, and very early periosteal reaction. Subacute fractures had well-developed periosteal reaction, and/or early callus formation. Late subacute fractures demonstrated well-developed callus and near complete resolution of the fracture line. Old fractures demonstrated mature callus, non-visualization of fracture lines, and bony remodeling.

Statistical analysis

Data were entered into an Access database and analyzed in SPSS (11.0) for Windows. Descriptive statistics were conducted on child demographics, number of ribs visualized, number of ribs fractured, and other child abuse injuries. To determine significant differences in fracture outcome between radiography and CT, χ^2 analysis was conducted.

Results

There were 12 patients in this study: 7 females and 5 males, with a mean age of 2.5 months (range 1.2–5.6) (Table 1). While all 12 children had CXR, CTs were performed based on clinical indication, and included 8 abdominal CTs and 4 chest CTs. A total of 225 ribs were visualized by CT: 192 were seen totally (along their entire arc) and in 33 only a part of the rib

Table 1
Patient demographic data

Patient	Gender	Age (months)	CT type	Other findings (besides rib fractures)
#1	M	2.5	Abdominal	SDH; skull fracture; liver laceration
#2	M	4.8	Abdominal	ICH; cystic encephalomalacia
#3	F	1.6	Abdominal	SDH; bilateral cerebral infarcts
#4	M	1.3	Abdominal	Retinal hemorrhage; SAH; neuro-respiratory failure
#5	F	2.2	Abdominal	Skull fracture; SDH; retinal hemorrhages
#6	F	1.3	Chest	Subconjunctival hemorrhages
#7	M	1.8	Chest	Retinal hemorrhages; ICH; pleural effusion
#8	F	1.9	Abdominal	SDH; retinal hemorrhages; skull fracture
#9	F	4.3	Chest	Skull fracture; cerebral edema; retinal hemorrhages
#10	F	1.2	Abdominal	SDH; ICH; right humerus fracture; left tibial fracture.
#11	F	1.6	Abdominal	SDH; encephalomalacia; left femur fracture; retinal hemorrhages
#12	M	5.6	Chest	None

ICH, intracranial hemorrhage; SAH, subarachnoid hemorrhage; SDH, subdural hematoma.

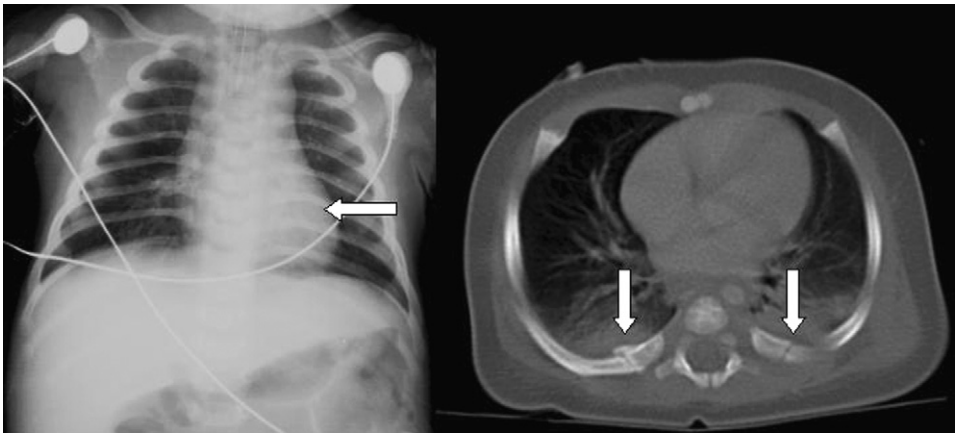

Figure 1. Bilateral posterior rib fractures seen by CT, while only unilateral left 7th rib posterior fracture was detected by CXR.

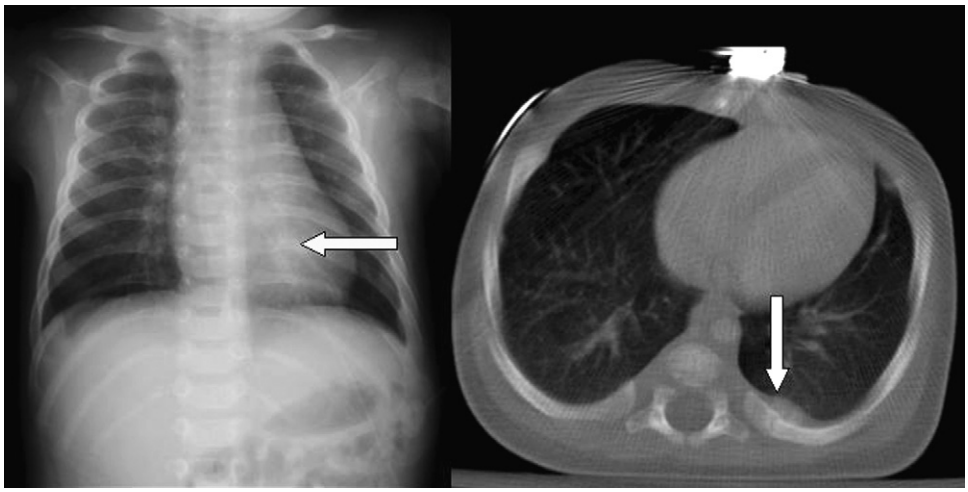

Figure 2. Eighth left acute posterior rib fracture seen by CT but not by CXR. Adjacent subperiosteal hemorrhage is also noted on the CT scan.

(not the entire rib) was visualized as only the lower chest was imaged during abdominal CT scanning. The matched ribs on CXR were used for analysis. The CT scout image was not utilized for rib fracture detection or description in any case.

CT ($n = 131$) detected significantly more rib fractures than did CXR ($n = 79$). Out of the 12 patients in the study, 11 had bilateral rib fractures. All 11 cases of bilateral fractures were detected by CT, but only 6 of the 11 were seen by CXR (Figure 1). More fractures were seen per patient by CT than by CXR, with a mean of 10.9 fractures per patient detected by CT and a mean of 6.6 fractures per patient seen by CXR. In one patient, CXR did not detect any fractures while one rib fracture was viewed on the baby's abdominal CT (Figure 2). No fracture was seen only by CXR but not by CT.

Separating out the four patients who had CXR and chest CT, the CT detected significantly more fractures ($n = 59$) than the CXR ($n = 22$).

Table 2 shows the relative detection of fractures based upon their anatomical position. Fractures in the posterior ($p < .01$), posterolateral ($p < .01$), anterolateral ($p < .01$) and anterior ($p < .01$) portions of the rib were more often seen by CT than by CXR. However, laterally positioned fractures were better seen by CXR than by CT ($p < .01$).

Table 2
Rib fracture detection based upon position

Position	CXR	CT	$p\,(\chi^2)$
Posterior	24	39	<.01
Posterolateral	3	9	<.01
Lateral	26	16	<.01
Anterolateral	12	21	<.01
Anterior	11	42	<.01

Table 3
Rib fracture detection based upon fracture age

Age	CXR	CT	$p\,(\chi^2)$
Acute	14	16	*ns*
Early subacute	4	24	<.05
Subacute	26	47	<.05
Late subacute	32	36	*ns*
Old	0	4	<.05

CT was better in detecting early subacute ($p < .05$), subacute ($p < .05$), and old fractures ($p < .05$) than CXR (Table 3). There was no significant difference between CXR and CT in detecting acute and late subacute fractures.

There were two non-skeletal traumatic findings seen on CT and not on CXR including one pleural effusion and one liver laceration.

Discussion

Detection of rib fractures is important in the evaluation for non-accidental trauma. Rib fractures are the most common skeletal injury in child abuse (Kleinman, Marks, Nimkin, Rayder, & Kessler, 1996; Kleinman, Marks, Richmond, & Blackbourne, 1995), and are strongly associated with child abuse. Feldman and Brewer (1984) found rib fractures in 15% of their series of abused infants. Several recent studies (Barsness et al., 2003; Bulloch et al., 2000; Cadzow & Armstrong, 2000) have shown that rib fractures detected in a child under a year of age result from non-accidental trauma in over 80% of cases. Barsness et al. also noted that in 29% of their abuse cases rib fractures were the only skeletal abnormality. Kleinman, Marks et al. (1996) found rib fractures to be present in 35% of 31 infants who died as a result of child abuse, and that rib fractures accounted for over half of the total number of fractures in these babies.

Currently, chest radiography is the standard method for detection of rib fractures in abuse cases (Kemp et al., 2006; Sane et al., 2000; Slovis et al., 2000). However, acute, incomplete, and non-displaced fractures may be difficult to see (Lonergan, Baker, Morey, & Boos, 2003). Posterior rib fractures, due to their superimposition on the transverse processes of the spine, may also be difficult to see on CXR (Kleinman et al., 1988; Kleinman, Marks, Spevak, & Richmond, 1992; Klotzbach, Delling, Richter, Sperhake, & Puschel, 2003). Oblique views of the ribs may improve detection of rib fractures in child abuse (Ingram et al., 2000), but are not routinely performed at most institutions (Kleinman, Kleinman, & Savageau, 2004). With healing, as callus forms, most rib fractures become more evident. This has led researchers to recommend follow-up CXR several weeks after injury (Kleinman, Nimkin et al., 1996; Zimmerman et al., 2005), or to consider the complementary use of bone scintigraphy (Mandelstam et al., 2003) to improve detection of rib fractures.

CT is a highly sensitive modality for imaging the thorax in the setting of trauma (Omert, Yeaney, & Protetch, 2001; Renton et al., 2003), and is useful in the detection of radiographically occult rib fractures in adults (Chan & Hiorns, 1996; Niitsu & Takeda, 2003). Multiplanar reformatted images from the axial datasets may also prove useful (Alkadhi et al., 2004) in analysis of rib fractures. While authors have suggested the potential utility of chest CT in detecting rib fractures in non-accidental trauma (Kleinman et al., 1992; Lonergan et al., 2003), to date no formal study regarding this has been performed.

This study has demonstrated that, overall, CT is significantly more sensitive than CXR in the detection of rib fractures in child abuse. It is better at detecting fractures at every position along the ribs except for the lateral position. This is somewhat of a surprise, but may be partially explained by the fact that not all of the ribs were fully seen by CT (especially on the abdominal CT exams). When only part of the ribs were imaged by CT (due to the abdominal CT only including the base of the chest) (33), the posterior or anterior portions, but not the lateral, were imaged. However, they were then compared with the corresponding fully visualized rib on CXR. CT was also particularly useful in detection of anterior rib fractures, an area that may be difficult to evaluate on CXR due to the often bulbous normal costochondral junction.

Early subacute, subacute and old fractures were better detected by CT, while CT and CXR were equal in detecting acute and late subacute fractures. The fact that acute fractures were equally detected by CT and CXR is an unexpected outcome from this study, and the authors do not have a definitive explanation for this. Late subacute fractures have the largest amount of callus, so it is not surprising that these were seen by CXR as well as by CT.

Why not, then, perform chest CT on all infants suspected of non-accidental trauma? With current generation CT technology and short scan times the necessity for sedation of infants for CT has markedly decreased. However, a major disadvantage to this technology remains – the significant radiation dose of CT as compared with CXR. Strict attention to ALARA (as low as reasonably achievable) principles (Frush, 2002) minimizes this exposure, but children are known to be more radiosensitive than adults (BEIR V, 1990), and the potential risk of CT-induced malignancy (Brenner, Elliston, Hall, & Berdon, 2001) in the pediatric population has been widely publicized in the lay press. Thus, CT must remain an important but *selective* tool in evaluation of infants for non-accidental trauma. It may be useful, for example, in infants highly suspected of non-accidental trauma in whom the CXR is normal, or in infants in whom the question of intrathoracic or intraabdominal injury exists in addition to the question of rib fracture.

The limitations of this study include (a) the retrospective nature of the study, and (b) the small sample size, and (c) not all patients had CT of the chest to directly compare to the CXR. Further research in this area including prospective evaluation of a larger cohort of patients will help to define the exact utility of CT in the detection of rib fractures in abused infants.

In summary, CT is significantly more sensitive than CXR in the detection of rib fractures in abused infants under 1 year of age, and may be helpful in evaluation of infants with suspected non-accidental trauma, It must, however, be used judiciously as the radiation exposure from CT is significantly higher than from CXR.

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