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ORIGINAL ARTICLE

Frequency of intrathoracic injuries in children younger than 3 years with rib fractures

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Abstract
Background Research documents that among children admitted to trauma intensive care units the number of rib fractures sustained indicates the child's likelihood of having and severity of intrathoracic injury. This has been misused in court to argue that children with multiple rib fractures who lack intrathoracic injury have abnormal bone fragility rather than inflicted injury.
Objective To determine frequency of intrathoracic injuries in children younger than 3 years with rib fractures in cases of child abuse and accidental trauma.
Materials and methods We conducted a retrospective review of rib fractures caused by documented abuse or accidents from 2003 to 2010 in children treated at Seattle Children's Hospital and Harborview Medical Center. A senior pediatric radiologist and radiology fellow independently reviewed the imaging. Children with bone demineralization were excluded. Descriptive and simple comparative statistics were used.
Results Seventy-two percent (47/65) of infants and toddlers with rib fractures were abused. Abused children had more rib fractures than accidentally injured children (5.55 vs. 3.11, $P=0.012$). However intrathoracic injuries as a whole (55.6% vs. 12.8%, $P<0.001$) and individual types of intrathoracic injuries were more common with accidents. Rates of other thoracic cage injuries did not differ substantially (27.8% accidents vs. 12.8% abuse, $P=0.064$). Intracranial and intra-abdominal injuries and skull fractures were equally frequent, but other extrathoracic fractures were more common with abuse (70.2% vs. 16.7%, $P<0.001$).
Conclusions Abused infants and toddlers have fewer intrathoracic injuries but more rib fractures than accidentally injured peers. This likely reflects different injury mechanics. Lack of intrathoracic injuries in abused children with rib fractures does not imply bone fragility.

Keywords Rib fractures · Intrathoracic trauma · Child abuse · Accidental trauma · Computed tomography · Radiography · Infant · Child

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Introduction

Rib fractures in infants commonly result from child abuse but can also result from overt accidental blunt trauma [1–4]. They can also result from lesser, or even normal, trauma in children with abnormal bones [1–3]. Rib fractures in children younger than 1 year old are thought to be highly associated with child abuse [1, 2, 4, 5]. In abused children, rib fractures have infrequently been reported to be associated with significant intrathoracic injuries, such as hemo- or chylo-thorax or pulmonary or cardiac contusions. These injuries have been infrequent enough that they are the subject of isolated case reports rather than incidence data from case series [6].

Garcia et al. [3] and Peclet et al. [7] have reported that among pediatric patients ages 0–14 years old admitted to a trauma intensive care unit (ICU), rib fractures are commonly associated with intrathoracic injuries and that the number of rib fractures is related to the incidence of such injuries and the overall severity and mortality of the children's injuries. These older papers, both of which appear to evaluate nearly the same patient panel, have been used to argue in court that when intrathoracic injuries do not accompany rib fractures in a child, the child has a problem of bony fragility, decreasing the likelihood of child abuse. Although we have no way of knowing how often this argument has been used in legal defense, we have both participated in cases in which it has been utilized. We have been concerned that this is a miss-application of logic in that (1) bone strength was not studied in these cases and (2) patients admitted to trauma intensive care units are not representative of infants and toddlers seen in pediatric emergency departments or hospitalized on the full range of inpatient services. As a result we undertook the current study to identify the frequency of intrathoracic injuries caused by accidents and abuse in the full hospital scope of infants and toddlers who were recognized to have rib fractures by radiographs.

Materials and methods

The study was approved by the institutional review boards at the participating institutions as an exempt study utilizing existing records.

We searched for children younger than 3 years who had rib fractures through a keyword search of radiology reports during a 7-year period from 2003 to 2010. The subjects had received care at either Seattle Children's Hospital, a tertiary care children's hospital serving the northwest United States, or the regional level 1 pediatric trauma center at Harborview Medical Center. Children evaluated through the inpatient units and emergency departments at both hospitals were studied.

During this study period, children with concerns for child abuse were evaluated by the same three child abuse specialists and their diagnosis of abuse was made with the assistance and consensus of the child abuse team. Children who were found by either Child Protective Services or the courts to have been abused were also included as abused. The diagnosis of abuse was based on the sum of all available clinical and investigative information and was not based solely on the presence of rib fractures in any patient. Only children with a confirmed diagnosis of abuse or accidental injury were studied; indeterminate cases were excluded.

All radiology images of the subjects were reviewed independently on the picture archiving and communication system (PACS) by a senior pediatric radiologist with 29 years of practice specializing in genetic and metabolic bone diseases and abusive skeletal injuries and by a pediatric radiology fellow. When available, CT images were used in addition to the plain radiographic images for the study review. The chest CTs had been obtained at the discretion of the treating physicians for significant clinical concerns for intrathoracic injuries. All children with radiologic evidence of bone demineralization or genetic or metabolic bone disease were excluded from the study cohort. These determinations were made clinically from the sum of the radiologic findings, not just the perception of bone density. Films were independently reviewed for the presence of rib fractures and for evidence of intrathoracic trauma. Disagreements were settled by joint review and consensus. The radiology fellow conducted a review of the clinical records. His review included demographic and clinical information, such as the need for intensive care.

For the purpose of analysis we documented the presence of pneumothorax, pleural effusion, pulmonary contusion and pulmonary laceration individually and for the presence of any of these injuries as the presence of "any intrathoracic injury." Atelectasis and pneumonia were documented in combination because it can be difficult to differentiate the two and they may not be the immediate result of trauma. Similarly, injuries of the clavicle, scapula, sternum and thoracic spine were documented individually and as "any thoracic cage injury" other than rib fractures. Individual types of intracranial injuries, excluding retinal hemorrhage and skull fractures, were documented individually and as their sum as "any intracranial injury." Abdominal organ injuries were also documented individually and as the sum of "any intra-abdominal injury."

Analytical methods

Data were collected in tabulated form then converted to Statistical Package for the Social Sciences (SPSS v. 20.0; IBM, Armonk, NY) for analyses that employed parametric (T score was computed for continuous variables by the *t*-test) and non-parametric (Z value was computed for categorical variables by the Mann–Whitney test) methods.

Results

During the study period 106 children (about 15 per year) were initially identified as having rib fractures. Of them, 65 children met the full study criteria of having a documented cause of injury, no underlying bony abnormality and available imaging. Forty-seven children were abused and 18 were accidentally injured (Table 1). Thus 72.3% of children younger than 3 years with rib fractures had injuries caused by abuse. Among the accidentally injured children, 4 (22%) were motor vehicle occupants and 7 (39%) were pedestrians hit by motor vehicles. All but 1 of the motor vehicle–pedestrian injuries included

Table 1 Demographics and morbidity of abused and accidentally injured infants and toddlers with rib fractures

	Abused children *n* (%)	Accidentally injured *n* (%)	Statistics[a]
Total	47	18	
Age in months (mean±1 standard deviation)	4.02+4.03	19.78±10.87	t=8.60, P<0.001
0–6 months old	40 (85.1)	3 (16.7)	
7–12 months old	4 (8.5)	1 (5.6)	
1–2 years old	3 (6.4)	6 (33.3)	
2–3 years old	0 (0.0)	8 (44.4)	
Male gender	27 (57.4)	11 (61.1)	Z=−0.27, P=0.79
Intensive care admission	23 (48.9)	12 (66.7)	Z=−1.27, P=0.20
Mortality	4 (8.5)	2 (11.1)	Z=−0.33, P=0.75

[a] Reflects comparison between abused and accidentally injured children. T score is computed from the *t*-test and Z score from the Mann–Whitney test. Values are significant at 0.05

some roll-over component. Falls from height caused 5 (28%) accidental injuries, including 4 two- to four-story window falls and a fall down stairs in an adult's arms with an associated crush injury. A television fell on one child and a horse kicked the final child. Abused children were younger than children with accidental injuries (mean 4.02±4.03 months vs. 19.78± 10.87 months, P<0.001) (Table 1). Although boys were injured more often than girls, the male-to-female ratio for abused children did not differ from that of the accidentally injured children (P=0.79).

The rates of intensive care admission (abuse 48.9% vs. accidents 66.7%) and death (abuse 8.5% vs. accidents 11.1%) were not dissimilar between groups (Table 1).

Abused children had significantly more rib fractures per child (5.55±4.24 each, 265 total fractures) than accidentally injured children (3.11±2.52 each, 64 total fractures) (P= 0.025) (Table 2, Fig. 1). Among the abused children, 25.5% had one or more *acute* rib fractures, a lower frequency than the 94.4% of children with accidental injury (Z=−4.93, P<0.001). The situation was reversed for children with one or more *healing* fractures (abused children 89.2%, accidental injury 0%, Z=−6.06, P<0.001). Although only abused children had *concurrent acute and healing* rib fractures (17.0%), this finding did not reach statistical significance (P=0.064). Bilateral fractures were significantly more common in the abused group (43%) than the accidental injury group (5.5%) (Z=2.83, P=0.005).

Intrathoracic injuries were far more common among the accidentally injured children than abused children (abuse 12.8% vs. accident 55.6%, P<0.001) (Table 2). All individual types of intrathoracic injury except pleural effusion also were more common among the accidental injury group. Children who were accidentally injured demonstrated a relationship between the number of rib fractures and the presence of intrathoracic injury (r=0.72, P=0.001, whereas no relationship was observed for the abused group (r=0.21, P=0.15). In those abused children who had intrathoracic injuries, most were found closely adjacent to the chest wall (Table 2) (Fig. 2), whereas accidentally injured children often had associated pulmonary injuries (Table 2) (Fig. 3). Among all abused children with rib fractures, one child had a pneumothorax, four had pleural effusions, two had pulmonary contusions, but none had a pulmonary laceration. Accidentally injured children frequently had pneumothoraxes and or pleural effusions, but nearly half also had pulmonary contusions and two had pulmonary lacerations. The frequency of any

Table 2 Types of thoracic and intrathoracic injuries in abused and accidentally injured infants and toddlers with rib fractures

	Abused children *n* (%)	Accidentally injured children *n* (%)	Statistics
Total	47	18	
Total number of rib fractures per patient	5.55±4.24	3.11±2.52	t=2.29, P=0.025[a]
Any intrathoracic injury[b]	6 (12.8)	10 (55.6)	Z=−3.56, P<0.001[a]
Pneumothorax	1 (2.1)	8 (44.4)	Z=−4.39, P<0.001[a]
Pleural effusion	4 (8.5)	4 (22.2)	Z=−1.49, P=0.14
Pulmonary contusion	2 (4.3)	9 (50.0)	Z=−4.37, P<0.001[a]
Pulmonary laceration	0 (0)	2 (11.1)	Z=−2.30, P=0.021[a]
Any thoracic cage injury (excluding ribs)[c]	6 (12.8)	5 (27.8)	Z=−1.43, P=0.15
Clavicle fracture	5 (10.6)	4 (22.2)	Z=−1.20, P=0.23
Scapula fracture	0 (0)	1 (5.6)	Z=−1.62, P=0.11
Sternal fracture	0 (0)	0 (0)	Z=0.00, P=1.00
Thoracic spinal fracture	1 (2.1)	2 (11.1)	Z=−1.53, P=0.12
Either pneumonia or atelectasis	10 (21.3)	8 (44.4)	Z=−1.85, P=0.64

[a] Reflects comparison between abused and accidentally injured children. T score is computed from the *t*-test and Z score from the Mann–Whitney test. Values are significant at 0.05

[b] Includes pneumothorax, pleural effusion, pulmonary contusion, pulmonary laceration

[c] Includes clavicle, scapula, sternal and thoracic spine fractures

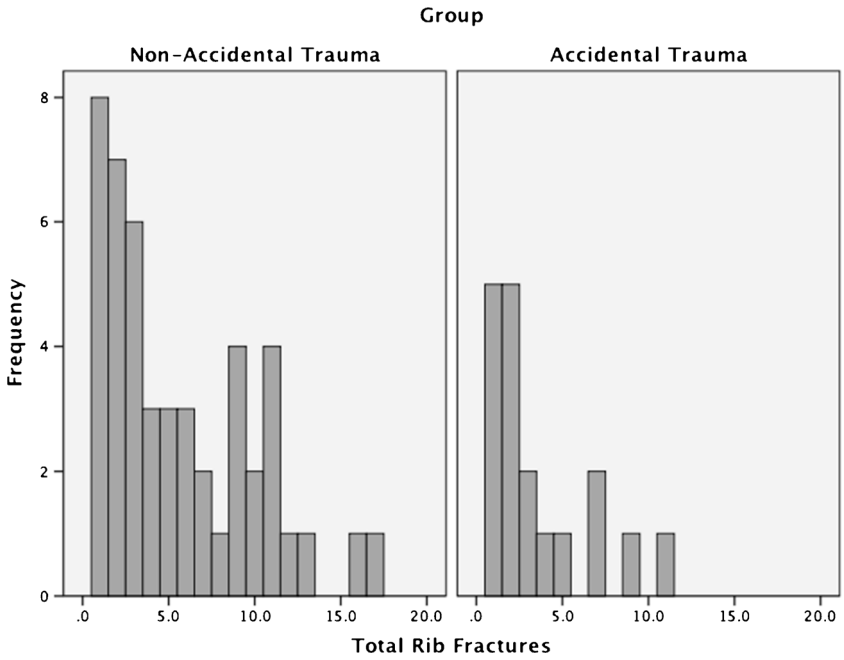

Fig. 1 Graph shows comparison of the number of rib fractures in abused vs. accidentally injured children

thoracic cage injury, excluding rib fractures, was similar between abusively and accidentally injured children (abuse 12.8% vs. accidents 27.8%, P=0.152). Likewise the rates of individual thoracic injuries did not differ.

Because this study was limited to radiology results, the frequency of cardiac trauma was not determined.

Extrathoracic injuries were common in both groups (Table 3). The presence of any intra-abdominal injury occurred at a similar frequency (abuse 14.9% vs. accidents 16.7%, P=0.86). Also, no individual type of abdominal injury neared significance (descriptive data not shown, all P values >0.10). The presence of any intracranial injury also did not differ (abuse 57.4% vs. accidents 38.9%, P=0.18). Likewise, the presence of any individual type of intracranial injury did not differ (descriptive data not shown, all P values >0.10). However retinal hemorrhages were only present in the abused children (abuse 36.2% vs. accidents 0%, P=0.003). The frequency of skull fractures was similar (abuse 23.4% vs. accidents 33.3%, P=0.42). Extrathoracic fractures were seen more commonly in the abuse group (abuse 70.2% vs. accidents 16.7%, P<0.001). This finding was more pronounced for the long bones of both the upper body (abuse 42.6% vs. accidents 0%, P=0.001) and the lower body (abuse 48.9% vs. accidents 11.1%, P=0.005). However, for hands or feet, lumbar spine and pelvis there were no differences (data not shown, all P values were insignificant).

Discussion

Children younger than 3 years old who had been abused had more rib fractures than accidentally injured children but were less likely to sustain associated intrathoracic injuries. Among the children with rib fractures caused by abusive trauma, 12.8% had intrathoracic injuries. This percentage is certainly clinically important but far less than the 55.6% frequency observed among our accidentally injured children.

We are concerned that Garcia et al.'s [3] and Peclet et al.'s [7] data, though appropriately pointing out increased rates of intrathoracic injury, morbidity and mortality among predominately severely accidentally injured children with more rib fractures, has been misused in the legal arena. Our data are similar to theirs [3, 7] in that for accidentally injured children a higher number of rib fractures was associated with a greater likelihood of intrathoracic injury. However, that relationship was not present in the abused children. The other authors also observed greater morbidity [3] and mortality [7] in children who had more rib fractures.

A common fallacy in the interpretation of reported research data is to draw conclusions from results that are not specifically studied or discussed. If one is to draw a logical conclusion from a data set, that conclusion must arise from one of the premises or independent study variables. Failure to do this is termed "illicit distribution of an end term" [8]. This issue applies to the common courtroom misuse of the papers by Garcia et al. [3] and Peclet et al. [7] wherein the papers' actual premise and justified conclusion was that rib fractures in infants and children in trauma intensive care units are an indicator of risk for major intrathoracic injury and mortality. The fallacy of drawing the conclusion that infants for whom rib fractures exist but in whom no major intrathoracic injury is found must have had insufficient or fragile bones is that bone quality is nowhere among the variables studied and therefore such a conclusion is not supported by the findings.

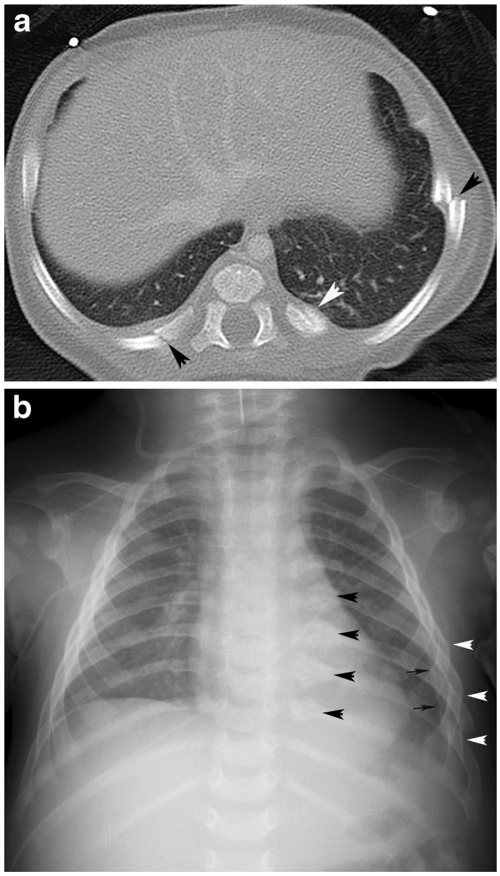

Fig. 2 Imaging in a 6-week-old boy who had become limp and unresponsive found cranial and bilateral posterior thoracic bruising, subdural hemorrhage with decreased gray–white matter distinction, multilayer profuse retinal hemorrhages with bilateral schesis cavities and a healing impacted distal radius fracture. He had a history of scleral hemorrhage and brow bruising. **a** Axial chest CT image on the day of admission shows that left lateral and right posteromedial rib fractures (*black arrowheads*) are acute while left posteromedial rib fracture has soft callus (*white arrowhead*). There is no evidence of pulmonary contusion or other intrathoracic injury except for minimal pleural thickening. **b** Anteroposterior chest radiograph 2 days later shows subacute posteriormedial rib fractures with soft callus (*black arrowheads*). There are acute right-side rib fractures (*white arrowheads*) of differing ages with subjacent pleural thickening or fluid (*small black arrows*). Multiple ages of rib injury and superficial intrathoracic injury are associated with abuse

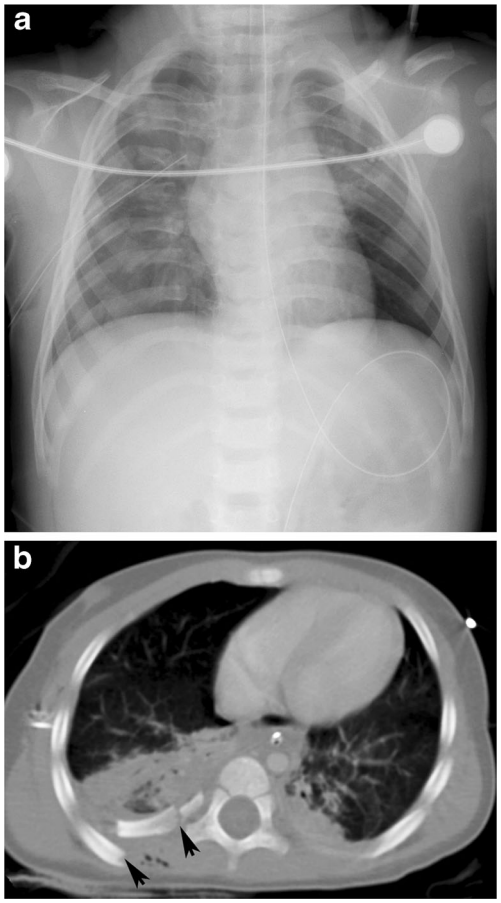

Fig. 3 Imaging in a 14-month-old boy who was unresponsive in the field after he was backed over at low speed by a sport-utility vehicle. He sustained cranial injury with basilar and temporal skull fractures, subdural hemorrhage, right internal carotid occlusion with secondary middle cerebral infarction, left clavicle fracture, atlanto-axial strain and multiple thoracic injuries. **a** Initial anteroposterior chest radiograph shows multiple traumatic injuries including right-side fractures of ribs 2–9 posteriormedially. More laterally, ribs 3–10 have fractures. A moderate pleural effusion layered out posteriorly. There is an acute left clavicular fracture. **b** Axial CT image obtained on the same day shows a right-side segmental rib fracture (*arrowheads*) with air in the extrathoracic soft tissues. Underlying pulmonary contusion and pleural effusion are present. Deep pulmonary injury is more frequent in accidents than in abuse

Another common fallacy in the utilization of Garcia et al.'s [3] and Peclet et al.'s [7] studies is the extrapolation of their results to different populations from their study subjects. Their studies included children ages 0–14 years old but were limited to those who had been admitted to a trauma intensive care unit. Sixty percent [3] and 47% [7] of their subjects with rib fractures were reported to be younger than 5 years. The number of children younger than 3 years, the predominant age of abusive head injuries and fractures and the age of our study population, was not specified in the other studies. However, 20% of Garcia's cohort with rib fractures was reported to be less than 1 year old and he noted that 63% of children younger than 3 years with rib fractures had been abused [3]. This percentage of abuse as a cause rib fractures among younger subjects is in the range of our current data (72%) and other reports [1, 2, 4].

Seven of Garcia et al.'s [3] subjects had been abused, but the number of them with associated intrathoracic injury was not specified. Abused children are often admitted for unclear signs and symptoms because of false or lacking histories; thus, they may not be admitted to trauma intensive care units but instead may be seen and discharged from the emergency department or admitted to general pediatric intensive care units or regular hospital wards. As a result they are likely to have a different injury spectrum than patients admitted to trauma intensive care units. Also, because Garcia et al. [3]

Table 3 Types of extrathoracic injuries in abused and accidentally injured infants and toddlers with rib fractures

	Abused children *n* (%)	Accidentally injured children *n* (%)	Statistics
Total	47	18	
Intra-abdominal injury	7 (14.9)	3 (16.7)	$Z=-0.18$, $P=0.86$
Intracranial injury (excluding retinal hemorrhage and skull fractures)	27 (57.4)	7 (38.9)	$Z=-1.13$, $P=0.18$
Skull fractures	11 (23.4)	6 (33.3)	$Z=-0.81$, $P=0.42$
Retinal hemorrhages	17 (36.2)	0 (0)	$Z=-2.95$, $P=0.003$[a]
Extrathoracic fractures (except skull)	33 (70.2)	3 (16.7)	$Z=-3.86$, $P<0.001$[a]
Upper extremity	20 (42.6)	0 (0)	$Z=-3.30$, $P=0.001$[a]
Lower extremity	23 (48.9)	2 (11.1)	$Z=-2.78$, $P=0.005$[a]

[a] Reflects comparison between abused and accidentally injured children. Z score was computed using the Mann–Whitney test. Value is significant at 0.05

and Peclet et al. [7] did not break down the rate of associated intrathoracic injuries by age, it is inappropriate to extrapolate their data, which included older children, to infants and toddlers. Their overall mortality rate of 42.4% [7] was also considerably higher than the overall rate for our study subjects (9.2%), suggesting their population differed from the general hospital population of infants and toddlers with rib fractures. Further, only 47% of our abused subjects required intensive care. Among their subjects, motor vehicle crash occupants had higher mortality (71.4%) than abused children (42.9%) or pedestrians (37.5%) and all three of their patients who had fallen survived [3, 7]. Similarly, most of our children with rib fractures caused by accidents had been involved in either a motor vehicle occupant even (22%) or motor vehicle–pedestrian event (39%). It is unlikely that those histories would have been confused with abuse.

We found that intrathoracic injuries were more likely to be located immediately adjacent to the chest wall in abused children than in accidentally injured children. The differences in the intrathoracic injury rate and location are probably explained by differences in the mechanisms of injury. Most abusive rib fractures are likely to have resulted from forcible chest squeezing — a high-force but low-velocity and superficially focused force mechanism [5, 6, 9]. However most accidental rib fractures, including motor vehicle occupant injuries and motor vehicle–pedestrian injuries, are the result of direct blunt impact including high-velocity and high-impact forces associated with rapid decelerations and large amounts of kinetic energy, which penetrates to deeper structures [3, 4]. The accidentally injured children also frequently experienced motor vehicle–pedestrian roll-over events or other forms of crush injury. These events might partly explain the thoracic cage injuries in accidentally injured children. It is notable that rates of abdominal and cranial injury were similar, but extracranial fractures and retinal hemorrhages were more frequent among abused children.

Maguire et al.'s [6] literature review of visceral injury from child abuse identified case reports of four children who had developed chylothorax from abusive injury. All of those children presented with respiratory distress and had rib fractures. All three of their cases reported to have pulmonary contusions or perforations from abuse also had rib fractures, including one with a flail chest [6]. They also identified one child with traumatic lung bullae and one with subpleural contusions and hemothorax associated with abusive hepatic injury [6]. In addition they found case reports of cardiac lacerations and contusions and great vessel lacerations [6]. Commotio cordis [10] and elevated cardiac enzymes from abusive sternal blows [11] have also been described. Although these individual case reports are in the literature, Maguire et al. [6] failed to identify any studies that discussed their frequency in a series of children with abusive or accidental rib fractures in infants and toddlers, such as ours. Garcia et al. [3] described the frequency of intrathoracic injury associated with rib fractures but did not break down their data to victims of different age groups or injury mechanisms, nor were the specific intrathoracic injuries described. In our series 12.8% of abused children with rib fractures had associated intrathoracic injuries. Commonest were pleural effusions (4). We also saw one pneumothorax and two pulmonary contusions but no lacerations.

Our study is limited by its retrospective design, which might have failed to provide complete and consistent case detail. Although the use of our radiology dictation search should have captured the children with rib fractures, it is possible that some children were missed by this search strategy. There is no gold standard for identifying abuse. It is likely that the presence of rib fractures and other thoracic injuries contributed to our diagnosis of abuse, involving some circularity of judgment. However, judgments of the legal and protective systems and a child abuse team are commonly used child abuse diagnostic standards in the literature [12] and we did not use rib fractures alone to diagnose abuse. Likewise, our exclusion of equivocal or indeterminate cases should increase the validity of the abuse and accident diagnoses of our subjects. We excluded children with decreased bone mineralization and metabolic bone disease. This involved our

radiologists' subjective judgment about images and likely failed to exclude some children with decreased mineralization that was too subtle to identify on radiographs. However, such children are unlikely to sustain insufficiency fractures if bone mineral loss is too minimal to be evident on the plain radiographs [13]. Some of our study numbers were small, reflecting in part the inherent features of the sample. For example we only identified 18 children with rib fractures caused by accidents, an indication of the predominance of child abuse as a cause of rib fractures in infants and toddlers. Likewise the children with each individual type of intrathoracic injury are few, so the incidences of these types of injuries are likely to have wide confidence intervals. A larger series would likely reveal additional pulmonary injuries caused by child abuse.

Conclusion

Although abused children younger than 3 years have more rib fractures than accidentally injured children, they have far fewer intrathoracic injuries. This likely reflects the high-energy and short-duration forces of accidental injury, while abused children sustain injuries from longer duration, manual chest squeezing or crush mechanisms. The increased number of rib fractures in abused children is not caused by underlying bony fragility but is inherent to the process of abuse itself.

Conflicts of interest Drs. Done and Feldman have consulted on child abuse legal cases.

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