Post-mortem CT examinations and the discovery of occult rib fractures

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Purpose

It is well recognised that acute rib fractures are easily missed on chest radiographs, but that those which are healing are more easily detected. Accepted UK policy for imaging in suspected non-accidental injury (NAI) includes follow-up 3-view chest radiographs two weeks after the initial skeletal survey, to aid detection of any rib fractures. If follow-up radiographs are not obtained, for example in infants who present to the hospital already dead or who die in the two week interval period following an initial skeletal survey, then there is a risk, that rib fractures may be missed and NAI may go undetected.

The purpose of this study was to estimate the proportion of children who have rib fractures, which are diagnosed on CT examinations, but are missed on a skeletal survey performed at the same time.

Methods and Materials

This was a prospective study. Between September 2008 and October 2010, 26 children underwent initial skeletal survey imaging per the recommendations of the 2008 joint RCR/RCPCH working group document, for either alleged or suspected NAI. Included in the study group were children classified initially as “sudden unexpected death of an infant” (SUDI), as it is policy within the Province of Northern Ireland to manage the latter group of patients as suspected NAI victims until pathology proves otherwise. All of the children either presented to hospital dead or died in the two week interval period before follow up chest radiographs could be obtained to look for healing rib fractures.

In addition to the standard imaging protocol, all children had a post-mortem CT chest examination to look for both acute and healing rib fractures. The CT examinations were reviewed in the axial plane, with multiplanar reformatted (MPR) images being constructed for all patients, and 3D-volume rendered (3D VR) images being constructed for those patients in whom fractures were identified.

All of the imaging investigations were reviewed by a single experienced paediatric radiologist and the results were conveyed to the pathology department. The reporting radiologist was not blinded to the clinical information available on the radiology request forms. Abnormal ribs were resected at autopsy and examined microscopically.

The results of the autopsies were cross-referenced with both the radiographic and CT examination results.
Results

There were 16 male and 10 female children. Age range was 1 day - 4 years. None of the children included in the study population had any clinical or radiographic evidence of a bone dysplasia or metabolic abnormality. No other fractures were seen on the skeletal surveys. Five children (19%) were found to have rib fractures on the CT images, that could not be seen on chest radiographs. The number of fractures detected by CT varied from 5 - 20.

Individual case histories where rib fractures were detected on the CT examinations:

1. Index case. 14-week-old male infant transferred to the paediatric intensive care unit (PICU) from a local district general hospital (DGH). On admission he was cold and unresponsive, and had visible bruising over his trunk and extremities. An initial CT brain in the DGH showed sub-dural and sub-arachnoid haemorrhage, contusions and evidence of hypoxia. Repeat imaging on transfer included CT of the chest, abdomen and pelvis to assess for suspected internal injuries (none identified). He died from his brain injuries less than 48 hours after his admission to hospital, when a skeletal survey was performed (Figures 1-6). Final cause of death: NAI

2. 5-month-old male infant found lifeless in the parental bed one morning. He had been sleeping with both his parents and was found lying beneath his father's legs. He underwent prolonged and extensive resuscitation (Figures 7-9). Final cause of death: unascertained SUDI. Rib fractures attributed to CPR

3. Male infant found dead in his cot one morning. He underwent prolonged and extensive resuscitation. No further history available (Figures 10-11). Autopsy result awaited. Rib fractures presumed due to CPR

4. 4-year-old girl. Complex medical history including a recent diagnosis of autism. Fell down a flight of stairs 5 days prior to admission. Well initially, though had a bruise on her right temple. Became withdrawn, refused to eat and developed diarrhoea. Presented moribund to her local DGH, where she was resuscitated. Initial imaging showed a sub-dural haematoma, left-sided rib fractures and a left lower lobe pneumonia. Her serum sodium was recorded at 177mmol/l. She had previously been on the "at risk" register for bilateral leg fractures, with her father listed as the perpetrator, though he was abroad at the time of the current events. Despite maximal therapy after transfer to the PICU, she died 5 days after admission (Figures 12-13). Despite her age, this patient was managed as a potential NAI victim, given her past medical history and several unexplained aspects of her final illness. The case remains under police investigation. Rib fractures in keeping with the documented fall prior to admission
5. 15-month-old female infant transferred to the PICU from her local DGH. She was unconscious at the time of transfer, with fixed and dilated pupils. Physical examination revealed multiple bruises over her body. CT brain showed bilateral sub-dural haematomas and evidence of hypoxic-ischaemic injury. Body CT demonstrated abnormalities consistent with the hypoperfusion complex, along with extensive soft tissue swelling and oedema around the vagina and rectum. She underwent extensive but ultimately unsuccessful resuscitation (Figures 14-17). Final cause of death: NAI

<table>
<thead>
<tr>
<th>Patient No.</th>
<th>CXR findings</th>
<th>CT results</th>
<th>Autopsy results</th>
<th>% agreement between CT and pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Acute #s of Lt R9 and Rt R10 at CVJ</td>
<td>Acute # Lt R9 at CVJ</td>
<td>Confirmed acute #s Lt R8, R9 &amp; R10 at CVJ</td>
<td>Pathology confirmed 11/14 (79%) of rib #s and found 3 additional ones</td>
</tr>
<tr>
<td></td>
<td>Suspected acute # Lt R10 at CVJ</td>
<td>Suspected acute # Lt R8, R9 &amp; R10 at CVJ</td>
<td>Further acute #s B R5, R6, R7, R8, R9 &amp; Lt R9 at CCJ</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Suspected acute #s Lt R9 &amp; Rt R7 at CCJ</td>
<td>Suspected acute #s B R5, R7, R8, R9, R12 at CCJ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>No #s seen</td>
<td>Acute #s B at R5 &amp; R6 CCJ</td>
<td>Acute anterior #s B R3, R4, R5 &amp; R6</td>
<td>Pathology confirmed 8/9 (89%) of rib #s</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Acute buckle #s Rt R2, B R3 &amp; R4 lat to CCJ (internal cortices only)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>No #s seen</td>
<td>Acute buckle #s B R4 &amp; R5, Lt R6 lat to CCJ (internal cortices only)</td>
<td>Awaited</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Healing lateral #s Lt R6-10 inclusive at rib angles</td>
<td>Healing lateral #s Lt R6-10 inclusive at rib angles</td>
<td>Healing #s at angles of Lt R6-10 inclusive</td>
<td>Pathology confirmed 7/7 (100%) of rib #s</td>
</tr>
</tbody>
</table>
Table showing results of chest radiographs, CT chest studies and autopsy

Key to table symbols: # - fracture, B - bilateral, CCJ - costo-chondral junction, CVJ - costo-vertebral junction, Lt - left, MCL - mid-clavicular line, Rt - right, R + number - corresponding rib number

Summary of CT results:

The types of fracture seen on the CT studies varied, depending upon their underlying cause, as determined by autopsy.

- In cases with a final diagnosis of NAI, both acute and healing fractures were seen, fractures occurred in all ribs and at all sites along the rib arch. Posterior rib fractures were not seen in any other circumstances
- In those infants in whom NAI was excluded as a cause of death, and who had undergone extensive resuscitation by paramedical staff at the scene and/or upon arrival at the Emergency Department, fractures were located anteriorly, the majority of which were lateral to the costo-chondral junctions, were bilateral and symmetric, between ribs 3 - 6 inclusive and more typically appeared as buckle fractures on the internal cortices of the ribs
• Traumatic (appropriate history given) fractures were seen at the site of impact and were associated with overlying soft tissue swelling. Buckle fractures on the outer cortices of the ribs opposite to the site of impact were also identified.

Images for this section:

**Fig. 1:** Patient 1. Index case. Cropped view of costo-vertebral junctions (CVJ) of the 9th ribs from CT axial source image. There is a fracture of the left 9th rib with associated soft tissue change on the pleural surface. Soft tissue change adjacent to the right 9th rib is the only visible sign of a fracture at this site.
Fig. 2: Patient 1. Index case. Axial CT source image. Note the irregularity of the ribs anteriorly at the costo-chondral junctons (CCJ), particularly the 'spiking' of the left CCJ. Both of these ribs were fractured at the CCJ. In addition, there is soft tissue reaction on the pleural surface of the left posterior rib at the CVJ; this rib was also fractured.
Fig. 3: Patient 1. Index case. CT axial source image. Further fractures of the CCJs are demonstrated, as manifested by the irregularity and spiking of the anterior ribs.
**Fig. 4:** Patient 1. Index case. Frontal chest radiograph from post-mortem skeletal survey. No definite rib fractures are identified.
Fig. 5: Patient 1. Index case. Specimen radiograph of the resected bony thorax (sternum removed) following autopsy. There are acute fractures of the left 9th and right 10th ribs at the CVJs
Fig. 6: Patient 1. Index case. Photograph of left posterior ribs taken at the forensic autopsy. Arrows indicate callus at the healing left 9th CVJ fracture site
**Fig. 7:** Patient 2. Axial source image from post-mortem CT chest examination. There are fractures of the CCJs bilaterally, seen as irregularity and spiking at these sites. Bilateral airspace disease, possibly due to pneumonia is seen; this may have caused or contributed to this infant's death. Air within the cardiac chambers is a normal post-mortem finding.
Fig. 8: Patient 2. Axial source image from post-mortem CT chest examination. There is a subtle buckle fracture on the inner cortex of the right 2nd rib, along with significant bilateral airspace disease. Pneumonia was queried with the pathologist as having contributed to or caused the patient's death
**Fig. 9:** Patient 2. Axial source image from post-mortem CT chest examination. Subtle contour abnormalities are seen along the inner cortices of the ribs, lateral to the CCJs. These findings are in keeping with bilateral buckle fractures at these sites.
**Fig. 10:** Patient 3. Post-mortem chest radiograph from skeletal survey. No rib fractures are identified. There is extensive air space disease bilaterally, which is out of keeping with a time of death only hours previously. Bronchopneumonia was queried with the pathologists.
**Fig. 11**: Patient 3. Axial source image from post-mortem CT chest examination. There is a subtle buckle fracture on the inner cortex of the left rib, lateral to the CCJ. In addition, there is extensive air space disease in both lungs raising the possibility of pneumonia causing or contributing to the cause of death. Air within the cardiac chambers is an expected post-mortem finding.
Fig. 12: Patient 4. Axial source image from post-mortem CT chest examination. There is a buckle fracture on the outer cortex of the right (5th) rib in close relation to the CCJ. This fracture is on the opposite side of the chest to the through-and-through rib fractures visualised following the documented fall downstairs, and is felt to represent a "contra-coup" injury due to plastic deformation of the bony thorax at the time of impact.
Fig. 13: Patient 4. 3D-VR image reconstruction from post-mortem CT chest examination. The healing through-and-through rib fractures are easily seen on the left side. The "contra-coup" type rib fractures on the outer cortices of right-sided ribs 2 and 5 are seen as vertically orientated lines lying lateral to the CCJs.
**Fig. 14:** Patient 5. Post-mortem chest radiograph from skeletal survey examination. Support apparatus remains in situ. There are fractures of the right 3rd-6th ribs inclusive, the left 7th and 8th ribs and the right 9th rib. All show signs of healing.
Fig. 15: Patient 5. Axial source image from post-mortem CT chest examination. There is a healing fracture of the left 1st rib. Kleinman states that fractures of the first rib are an uncommon finding in NAI cases, and that they require "massive indirect forces" to cause them.
Fig. 16: Patient 5. Axial source image from post-mortem CT chest examination. There is an easily visible healing rib fracture on the right side and a buckle fracture on the inner cortex of the left-sided rib more anteriorly.
Fig. 17: Patient 5. There is a fracture of the CCJ on the left side. Both anatomically and visually, fractures of this region are analogous to the classic metaphyseal fractures of the long bones seen in NAI ("corner" or "bucket handle" fractures), something which is easily appreciated in this instance.
Conclusion

Discussion

The thoracic cage in infants and young children is inherently plastic, meaning rib fractures are uncommon in this age group; it takes significant force to fracture the ribs of a healthy infant skeleton. It is possible to fracture anywhere along the length of the rib arc, as a result of severe accidental (figure 1) or non-accidental trauma, though when present in a child less than 3 years of age, such fractures are highly predictive of NAI. It takes less force to fracture a rib, which is abnormal as a result of an underlying congenital or metabolic disorder. Rib fractures may be single or multiple, uni- or bilateral, depending upon how they have been caused.

CVJ fractures have been shown in both animal models and through case study reports, to occur as a result of compression or deformation of the rib cage in an antero-posterior direction; for example, when the chest of an infant is encircled by an adult's hands (figure 2). In this position, forces are generated, which lever the posterior aspects of the ribs over the adjacent vertebral transverse processes, resulting in fractures in the region of the rib head and neck, close to their articulation with the vertebral body. Similar directional forces can arise if an infant is thrown or slammed face-forwards into a solid surface or object (figure 3), though would be more likely to be associated with visible bruising over the chest and/or face in these circumstances.

Compared with posterior and lateral rib fractures, CCJ fractures are much less common, and reportedly require more force to cause them. They too can result from antero-posterior compression forces, where the sternum and costal cartilages are depressed, leading to maximum tension along the inner aspect of the rib in the region of the CCJ (figure 2), which explains the CT finding of buckle fractures along the anterior inner rib cortices in three of the study patients. CCJ fractures may also occur as a consequence of a direct blow to the adjacent chest wall, in which case they can be associated with intra-thoracic or intra-abdominal organ injuries and visible bruising at the site of impact.

Rib fractures as a consequence of cardio-pulmonary resuscitation (CPR) are much less common in children than in adults (0-2% versus 13-97% respectively). Dolinak's paper from 2007 commented that CPR-related rib fractures in infants are subtle and are likely to be missed even at autopsy, unless the parietal pleura is stripped-back and the internal surface of the thorax examined visually and by palpation. In the 8 children he described with rib fractures secondary to CPR, the fracture types and location mirrored those found in the present study, which were attributed to CPR. That is, the fractures were anterolateral in location, were often bilateral and symmetrical, thereby reflecting the
forces imparted to the mid-sternum by chest compressions, and involved the 2nd-6th ribs. As in the study population, many of the fractures Dolinak describes were of the buckle variety, with little or no associated haemorrhage at the fracture site, and none could be identified on pre-autopsy chest radiographs. A 2009 paper by Weber and colleagues echoed Dolinak's findings, and again stressed the importance of pleural stripping to search for rib fractures during infant autopsies. Neither Dolinak nor Weber described CCJ fractures in association with CPR. A literature review on CPR-related rib fractures in children, published by Maguire in 2006, describes only 3 children with rib fractures (one with CCJ and two with mid-clavicular fractures) in 923 children following CPR, that was performed variably by both trained medical personnel and lay people. In all 3 cases, the fractures were multiple and anterior, but no posterior rib fractures were identified. The outlined work from the literature and the current study support the accepted theories describing the biomechanical forces required to fracture the ribs of a young child: when the infant's back is supported on a firm surface and the chest compressed during CPR (figure 4), the posterior ribs cannot migrate over their transverse processes and therefore, do not fracture at the CVJ. The antero-posterior compressive forces generated can, however, cause anterior fractures. Similarly, if the child is resuscitated on a soft surface such as a bed, the chest as a whole is pressed into the soft surface and rib leverage cannot take place, meaning posterior rib fractures do not occur in these circumstances either.

Only one published study of 12 cases (Wootton-Gorges et al 2008) compares the detection of rib fractures on CT exams to chest radiographs in NAI. However, this study differs from the current one, in that it was retrospective and involved live children, not all of whom had CT chest examinations; children for whom abdomino-pelvic CT studies had been performed were also included. The presence or absence of rib fractures was accepted from the initial imaging studies, and no follow up examinations were performed. Despite these limitations, the authors concluded CT was more sensitive than chest radiography for the detection of rib fractures in NAI, though cautioned it should be used judiciously given the risks of the radiation dose each patient receives. The current study is both prospective and larger, comparing chest radiography from skeletal survey examinations with CT chest studies, using autopsy and histology as the gold standard to detect rib fractures in recently deceased infants, in whom NAI cannot immediately be discounted. Radiation risks are not an issue.

**Conclusion**

The authors recommend post-mortem CT chest examinations be performed alongside skeletal surveys in infants, whether they are alleged victims of NAI or have been classified initially as SUDI. This group of infants includes those who are dead upon arrival at hospital or who die in the two-week period before it is possible to obtain follow-up chest radiographs. NAI is a diagnosis of exclusion. Rib fractures, particularly when
they are multiple and of different ages are highly suggestive of the diagnosis, and CVJ fractures are rarely found in any other circumstances. The conceivable consequences both medico-legally and to any surviving siblings of missing such fractures are huge. Ribs with both definite and suspected fractures should be resected at autopsy to confirm or refute their presence. Moreover, the location and type of any fractures seen on the CT study may help to differentiate between those resulting from trauma - be it accidental or non-accidental, and those occurring subsequent to vigorous CPR.

Acknowledgment: with thanks to Mr Brendan Ellis, Medical Artist, Royal Victoria Hospital, Belfast for providing the diagrams used in producing this poster

Images for this section:

Fig. 1: Diagrammatic representation of the mechanism of injury in patient 4, who was documented to have fallen down the stairs five days prior to her hospital admission. Rib
fractures with soft tissue swelling were seen at the presumed site of impact (against the stair edge or possibly the newel post). Mechanically, if there is enough compression of the chest, then the forces generated could cause deformity and ultimately fracture of the ribs on the side opposite to the impact; the buckle fractures described on the outer cortex of the patient's ribs support this theory.

Fig. 2: Diagrammatic representation of causal mechanism to explain rib fractures in NAI: adult hands encircle the infant's chest and squeeze, eliciting an antero-posterior force. The ribs may fracture anywhere along the arc, including at the CVJs and the CCJs.
Fig. 3: Diagrammatic representation of causal mechanism of injury in NAI leading to posterior rib fractures in the region of the rib neck and head: infant being slammed face-forward into a solid object
Fig. 4: Diagrammatic representation of the forces generated during CPR performed with the patient lying supine on a firm surface: the posterior aspects of the ribs do not lever over their respective transverse processes, with the consequence that CVJ fractures have not been described following CPR, however, the forces generated anteriorly, may on rare occasions, cause fractures of the anterior ribs in the region of the MCL (even less often at the CCJs), which is the site of maximal stress on the rib during this manoeuvre.
References


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