Article:
Paddock, M., Sprigg, A. and Offiah, A.C. orcid.org/0000-0001-8991-5036 (2017) Imaging and reporting considerations for suspected physical abuse (non-accidental injury) in infants and young children. Part 1: Initial considerations and appendicular skeleton. Clinical Radiology, 72 (3). pp. 179-188. ISSN 0009-9260

https://doi.org/10.1016/j.crad.2016.11.016

Imaging and reporting considerations for suspected physical abuse (non-accidental injury) in infants and young children. Part 1: Initial considerations and appendicular skeleton

Introduction

Child abuse in all its forms (physical, emotional, sexual, neglect) is relatively common with 1 in 14 children in the United Kingdom having been physically abused[1]. The Royal College of Radiologists (RCR) echoes the results of a UK survey[2] that general radiologists who may not have received appropriate training may be uncomfortable in reporting imaging for non-accidental injury (NAI)[3]. Recognising the radiological manifestations of inflicted injury (II) is paramount for any radiologist involved in reporting paediatric imaging. II has diverse presentations and its identification is the responsibility of all radiologists reporting paediatric radiographs given that they may be the first person to raise the suspicion of abuse.

There is abundant literature on the imaging and reporting of non-accidental/inflicted injury. This two-part article seeks to condense relevant information into an accessible format for radiology trainees during their paediatric attachment to form a solid foundation upon which further learning can be built. These articles also serve as a comprehensive refresher for general radiologists who report paediatric radiographs, aiming to stimulate teaching and further reading.

Part 1 encompasses important initial considerations, initial and follow-up skeletal survey (SS) and suspicious fracture patterns of the appendicular skeleton. Suspicious fracture patterns of the axial skeleton (including rib and skull fractures), the dating of fractures and relevant differential diagnoses for II are discussed in Part 2.

Initial considerations

Paediatric bone

The composition and biomechanics of maturing bone result in distinctive patterns of fracture and healing in children when compared to adults. Paediatric bone permits a greater absorption of energy and application of strain before fracturing, secondary to the lower modulus of elasticity and bending strength, respectively. Their decreased density but increased porosity restricts fracture propagation, resulting in decreased rates of comminution[4]. Understanding the interplay between the underlying complex processes that determine 'bone strength' is vital to understanding why paediatric bones fracture[5].

Non-accidental injury versus inflicted injury

The term NAI is ubiquitous in the scientific literature. However, 'inflicted injury' may be more accurate because it does not necessarily exclude accidental harm. Consider the busy time-pressured caregiver who shoos and pushes a small ambulant child out of the way who then sustains an injury from the fall. Although the underlying action was not intended to cause injury, it was consequent upon the caregiver's actions. Similarly, the crying infant whose overtired parent forcefully abducts her legs in order to change her nappy may have done so to move the legs out of the way, not with the intent of fracturing the femur. The legal distinction between accidental injury and NAI is difficult: II is more accurate when describing the causal mechanism of injuries in abusive trauma. The term 'suspected physical abuse' is also used synonymously with NAI and II.

Child mobility

Throughout this article, the authors refer to the pre-ambulant infant or child. This implies that the child is of an age where they are not yet independently mobile and encompasses the wide variation in developmental ability and progress. The term non-ambulant may be used when referring to a child with a permanent physical disability who will never be able to walk.

Imaging findings suggestive of II must be considered within the context of the child's mobility and contemporaneous developmental milestones. Reviewing images / discussing imaging findings with the child protection team and paediatricians who have examined the child are of paramount importance to determine how the radiological findings should be interpreted. Whilst the national guidance (discussed in detail below) states that the radiological report forms the basis of communication between radiologists and clinicians[6], the need for close collaboration and face-to-face discussion between the various teams involved in the care of children with suspected II cannot be overstated.

Role of the radiologist

All imaging performed for the investigation of suspected II should be assessed for diagnostic quality by the radiologists involved in the subsequent reporting, and if suboptimal should be repeated. Considering the long bones, two orthogonal radiographic views must be obtained of the initial site of clinical concern and other suspicious sites, particularly for suspected or suspicious metaphyseal fractures[7], diagnosis of which may require coned views of the involved joint(s). In the case of rib fractures, an AP of the chest including the clavicles, in addition to oblique views to show both sides of the chest should be performed. More commonly, these views of the thorax will be obtained as part of a formal skeletal survey (SS), as outlined in Table 3.

Physical abuse is insidious and may not present in a predictable fashion. There are specific risk factors for physical abuse that, once identified, should alert the reporting radiologist to the possibility of occult II (Table 1). Relevant information available to the radiologist at the time of reporting may only be limited to the clinical request. Additional clinical features that raise the suspicion of II are displayed in Table 2[8]. Any discrepancy between the history and the mechanism of injury, severity or age of identified fractures should raise the suspicion of II and be communicated to the requestor or lead clinician involved in the child's care by the reporting radiologist. In infants presenting with an acute life-threatening

event (ALTE), collapse, apnoeic or 'blue' episode, II should be considered as a possible cause[9]. Radiologists should raise the possibility of II when clinically unsuspected fractures are identified, for example, rib fractures on a chest radiograph taken for other reasons (Fig 1).

Once a fracture has been identified, the very next questions the reporting radiologist must ask themselves are: "is there another fracture?" and "is this in keeping with inflicted injury?". Abusive fractures are characteristically sustained over a period of time and demonstrate different stages of healing[10]. Moreover, given that abusive fractures are more likely to be multiple when identified on imaging[11-13], 'satisfaction of search' must be avoided. Children are at high risk of repeated, potentially fatal abuse if the diagnosis of II is not considered and subsequently missed[14,15]. The reporting radiologist may detect findings suggestive of physical abuse whilst differentiating from other underlying pathologies, normal variants[16] and relevant differential diagnoses (discussed in part 2).

Radiological findings alone do not necessarily confirm or refute the diagnosis but are considered alongside the clinical history, examination and biochemical investigations. Hence communication with the clinical teams is vital; not only to ensure that the evidence indicates II before making the diagnosis (and the subsequent profound impact this will have on the child and their carers) but to raise an alert if abuse was not already suspected and recommend further radiological investigations as appropriate.

Which children should be imaged?

In pre-ambulant infants, any fracture may be suspicious for physical abuse if the history is inappropriate. Due attention and consideration should be given to the mechanism of injury and whether the proposed history correlates with the radiological findings: if not considered, the radiological findings of physical abuse can be missed. Additionally, there are specific patterns of fractures that are particularly suspicious and are discussed in more detail below.

The age of the patient is a key consideration. It is important to remember that in the absence of trauma, the likelihood of physical abuse is higher the younger the age of the

child[16,17]. In general, abusive fractures are more common in children aged less than 12 months than those older than two years[11,12] given that pre-ambulant children are dependent upon their caregivers. Over half of all fractures identified in children under the age of one are attributable to abuse[9,12,18,19] and children under the age of 4 months have the highest incidence of abusive fractures[9,12]. In contrast, accidental fractures are more commonly seen in children over the age of 5 years[10].

There are a number of risk factors and environmental stressors that predispose infants and young children to abuse. Children with underlying chronic disease, such as osteogenesis imperfecta (OI) or a neurological disorder, such as cerebral palsy, are at increased risk of abuse[20]. As there is an increased incidence of II in twins, any co-twin and sibling below 2 years of age should also be clinically assessed and considered for SS[21,22]. Children with abusive burns may also have occult skeletal injuries and should be considered for SS[23,24].

Skeletal survey

Initial imaging

The SS is the radiological investigation of choice when II is suspected, diagnosing the majority of bony injuries[6,25,26]. A SS can detect occult bony injuries[27], aid in the dating of fractures (discussed in Part 2) or identify a predisposing medical condition (metabolic disorder or skeletal dysplasia). Whilst other imaging modalities (CT, ultrasound, radionuclide imaging) can be used for specific indications, further evaluation of their utility is required: SS remains the gold standard[6,16].

The decision to perform a complete SS is age dependent. A full SS should always be performed where physical abuse is suspected in children under the age of two years[6]. In older children, the decision will be guided by the index of suspicion, taking into account clinical and social history, examination findings and the recent NICE guidelines for the investigation of head injury[28].

Given that evidence obtained from the SS may be used as part of court proceedings[6], fully trained paediatric radiographers are fundamental in providing high-quality diagnostic radiographs by adhering to standardised imaging protocols[16,29]. The SS should be conducted during normal working hours with a consultant radiologist available to review the images prior to the child leaving the department to determine if additional views are needed. Coned views may also provide further information, particularly when evaluating metaphyseal fractures[7] (Fig 2). Table 3 outlines the views required for a complete initial SS[6]. Note that a whole limb is not imaged in a single radiograph: when imaging the upper limb, separate radiographs of the humerus, radius and ulna, and hand are obtained (the same applies to lower limb radiographs). Although extra holding is required during acquisition, this allows for better-centered radiographs with appropriate exposures.

Reporting SS for suspected II is regarded as a core competence for specialist paediatric radiologists, in addition to those undertaking paediatric radiology as a special interest in a general department[6]. Whilst the national guidance does not mandate double reporting of SS, it is generally considered best practice; not only to further training and experience but to serve as an added layer of protection for the radiologist, and more importantly, for the child.

Standards and guidelines

The utility of certain projections such as the spine, hands and feet as part of the routine SS and limiting radiographs performed for the follow-up SS are topics of debate[30-32]. Until further evidence is available to the contrary, it is strongly recommended that all radiologists involved in reporting paediatric imaging refer to the 'Standards for radiological investigations of suspected non-accidental injury', a document jointly produced by the RCR and the Royal College of Paediatrics and Child Health (RCPCH) which contains comprehensive information regarding the radiological investigation of II and is freely available to download from the RCR website[6]. This document has been endorsed by the European Society for Paediatric Radiology (ESPR) as the European gold standard for performing the SS[33]. Every radiology department

involved in imaging infants and young children for suspected II should work towards the standards outlined in the above document.

Follow-up imaging

Follow-up imaging approximately 11 to 14 days after the initial SS allows identification of fractures not previously seen due to interval healing (Fig 1) and assists in dating injuries[34]. The national guidance advocates that a repeat SS should be performed two weeks after the initial survey[6]. Recent literature debates the utility of repeating a full lateral spine and pelvis unless there are specific concerns[35]. Locally, the authors routinely perform a limited follow-up SS which compared to the initial SS excludes projections of the skull, spine, pelvis, hands and feet. The need for additional follow-up views (e.g. of hands or feet) are decided on a case-by-case basis, depending on radiological findings/suspicions on the initial SS. As a minimum, follow-up chest radiography (AP and both left and right oblique projections) should be performed in addition to repeat views of equivocal areas identified on the initial SS to assess for bone healing[6]. When reporting the follow-up SS, reference to the initial SS is essential. Where there are ongoing clinical concerns and a firm diagnosis has not been reached/abuse is suspected clinically[36], a full repeat SS with the exclusion of the skull may be warranted[6].

The (radiation) risk versus benefit ratio of initial and follow-up SS in the context of suspected physical abuse is outside the scope of this article but has been discussed in detail elsewhere[37], with debate around whether the low positive fracture yield of SS indicates that children are being over-investigated[38,39]. It is clear that further evaluation of the value of a full follow-up SS is needed, not only in ascertaining the number of additional fractures identified but also for the additional forensic benefit for the child versus the radiation exposure.

Although improving the sensitivity of the initial SS[40,41], follow-up imaging may further delay the definitive diagnosis and have a significant impact on the child's management – this may be further complicated if the child does not re-attend for follow-up imaging. Robust

mechanisms must be in place to deal with such eventualities[6]. At the time of writing this article, revised national guidelines are being prepared which will hopefully provide a unified approach to the projections that should be obtained as part of follow-up imaging.

Specific fracture patterns of inflicted injury in the appendicular skeleton

The appendicular skeleton comprises the bones of the upper and lower limbs, and the pectoral and pelvic girdles[11].

Metaphyseal fractures

Also known as the classic metaphyseal lesion (CML), in the correct clinical context, the metaphyseal fracture is considered to be pathognomonic of II, being the most specific radiographic injury of suspected physical abuse[42,43] regardless of the history in an otherwise normal child. The mechanism is that of a shearing or torsional force across the metaphysis resulting in cumulative microfractures of immature bone[44]. Given this mechanism and the extreme nature of the force required to produce CMLs, it is rare that they occur during 'normal' handling of an otherwise healthy infant. Examples are shown in Figs 2 and 3. The terms ‘corner’ and ‘bucket handle’ describe the fracture appearance obtained from tangential and angled radiographic views, respectively[42]. CMLs may heal with (if the periosteum has been simultaneously stripped from the underlying bone) or without (causing difficulties in dating) periosteal reaction (Fig 2). CMLs are rarely encountered in the older, ambulant child[45] where the Salter-Harris classification of injury is more commonly encountered.

The distal femur, proximal and distal tibia, and proximal humeri are the commonest locations for metaphyseal fractures[42]. The mean age of children under the age of 1 year with metaphyseal fractures is 4 months[27] which, as mentioned above, correlates with this group having the highest incidence of abusive fractures[9,12]. There is a strong association with the presence of CMLs and further abusive fractures identified on SS[27]. It is said that in fatally abused children, bilateral asymmetrical tibial CMLs are the commonest abusive fracture[46].

An additional theory proposes that CMLs may occur during forceful shaking, where the limbs flail around an infant being held by the trunk with a resultant shearing force to the limbs[44]. This may be seen in children who are 'small enough to be shaken violently' who 'cannot protect their limbs'[47]. This mechanism is debated given the evidence that CMLs are not more prevalent in infants with shaken impact injuries compared to those without[48].

Lower limb fractures

As discussed previously, the proffered history and mechanism must be compared with the age and developmental level of the child given the wide variation in the achievement of walking related developmental milestones (cruising, standing alone, walking unaided).

In the absence of an appropriate history e.g. of a significant high energy impact/injury such as a road traffic accident, the presence of a lower limb long bone fracture in a pre-ambulant infant is always suspicious of II[49,50]. In particular, a diaphyseal spiral/oblique fracture of the femur is significantly associated with physical abuse[29,50] and, as the commonest abusive femoral fracture[10], implies a significant torsional force which is uncommon in the pre-ambulant infant unless inflicted[51] (Fig 4).

In the older child, a 'toddler's fracture' is a common accidental injury typified by an undisplaced spiral fracture of the tibia in the ambulant child/toddler (i.e. who is known to 'toddle') (Fig 5). If present in isolation in the appropriate age group and supported by a confirmed/witnessed accidental history, then it is not suggestive of physical abuse (particularly if there is no concomitant fibula fracture in a boy aged less than 2.5 years[52]). However, a toddler's fracture is not always witnessed and the absence of a history does not necessarily imply abuse; children may be presented to the Emergency Department by a concerned caregiver because they are 'not moving their leg/refusing to walk/bear weight' with pain on attempted movement, often with no memorable history of injury. Thus, given the appropriate clinical setting, this should not always be regarded as suspicious. Conversely, the same fracture in a pre-ambulant infant is highly suggestive of II and further evidence of physical abuse should be

sought, underpinning the importance of receiving a comprehensive history from referring clinical colleagues.

Upper limb fractures

A humeral fracture identified in a child less than 18 months of age with a suspicious history is highly suggestive of an abusive etiology[53,54], even more so in children aged less than 15 months[55]. Spiral and oblique fractures of the humeral shaft are strongly associated with abuse[53-56] in this age group.

Supracondylar fractures are a common accidental injury[13,53,55] that usually presents with a typical history of a fall from a height (bunk bed, playground equipment) onto a hyperextended elbow with peak age between 5 and 7 years[22] (Fig 6).

Correlation with the age, history and mechanism of injury is key in differentiating accidental injury from II. Should this information not be available at the time of reporting, it must be sought to ensure that the radiological report accurately reflects concerns or suspicions regarding II.

Fractures of the hands and feet

Metacarpal and metatarsal fractures are uncommon and may be clinically occult (i.e. not suspected when examining the child) (Fig 7), reinforcing the need to perform dedicated imaging of these areas as part of the SS[30,57]. Furthermore, these usually transverse or 'buckle' type fractures rarely present in isolation with further abusive fractures found on SS[27]. Infants with abusive fractures of the hands and feet are usually aged less than two years of age[27,58], mean age of hand and foot fractures 14 and 10 months, respectively[30]. Fractures in the hand and foot are thought to result from indirect twisting and bending (hyperextension and hyperflexion) forces as opposed to direct impact in infants[59].

Fractures in unusual locations

Suspicious fractures in unusual locations specific for physical abuse can be best remembered by the use of the helpful aide-memoire, 'the 3 **S**'s': **s**capula, **s**ternum and **s**pinous process fractures.

Scapulae fractures (Fig 8) are uncommon but highly suspicious of II given the significant force (high energy) required for their causation.

Pelvic fractures in the setting of II are rare and are more commonly encountered in the setting of polytrauma (e.g. road traffic accident); in the setting of II, the most common site of injury is the ischio/pubic ramus[54,57,60]. Abusive pelvic fractures may be clinically unsuspected and identified incidentally[61], although when identified, they are usually associated with multiple injuries. An association with sexual abuse has been described in a 4-year-old female[54,62].

Conclusion

The radiological diagnosis of physical abuse in infants and young children can present a diagnostic challenge. When the history and mechanism of injury are presented alongside discordant imaging findings in a pre-ambulant child, the suspicion of II must be raised and discussed with the referring clinical team contemporaneously. A multidisciplinary approach is adopted in the investigation of suspected II and the decision to undertake SS is made in concert with the clinical and child protection teams. The SS is the first line and gold standard imaging investigation in suspected II, diagnosing both clinically suspected and occult bony injuries. The fracture patterns specific and highly suspicious for II are ones with which all radiologists must be familiar.

Figure legends

Figure 1 Acute rib fractures: the value of oblique views and follow-up radiographs. 6-week-old with subdural haemorrhage. (a) Acute rib fractures are not always detectable on AP chest radiographs: however, note the acute posterior fracture of the left 8th rib (arrow). (b and c). Cropped oblique views obtained as part of the same SS more readily demonstrate the acute rib fractures. (b) Right oblique radiograph shows right 7th acute rib fracture (arrow) and (c) left oblique radiograph shows left 7th and 8th acute rib fractures (arrows). (d) AP chest radiograph 14 days after (a) confirms the full extent of healing rib fractures (arrows).

IMPORTANT: Images (b) and (c) have been cropped for the purposes of this article; optimal oblique chest radiographs are demonstrated in Part 2 Figure 2.

Figure 2 Metaphyseal fractures: the value of coned views. Neonate with unexplained leg swelling. (a) An obvious transverse femoral shaft fracture with loss of definition of the fat-muscle plane and no periosteal reaction. This fracture is less than 14 days old. Note the subtle tibial metaphyseal fracture. (b) Coned view of the proximal tibia of the same neonate demonstrates the classic metaphyseal lesion ('bucket handle' fracture) more clearly, highlighting the need for dedicated views of suspicious areas (arrows). (c) Healing metaphyseal fractures in a different child (red arrows). Note the subperiosteal reaction around the tibia due to stripping of the periosteum, but not the fibula (white arrows).

Figure 3 Healing shaft fractures on a skeletal survey for suspected inflicted injury. 15-month-old female presenting with multiple unexplained bruises. (a) DP left humerus demonstrated a healing spiral fracture (white arrow), for which there was no explanation. Notice also the 'corner' fracture configuration of the healing proximal humeral metaphyseal fracture (red arrow). (b) Healing shaft fractures of the left radius in the same child (arrow).

Figure 4 Acute limb fracture in an infant. 9-month-old 'not moving their right leg'. AP radiograph right femur shows an unexplained acute spiral fracture.

Figure 5 *Toddler's fracture*. 13-month-old male with a limp. AP right tibia and fibula radiograph demonstrates an acute spiral 'toddler's fracture' of the tibia.

Figure 6 Supracondylar fracture. (a) AP and (b) lateral left elbow radiographs of a 20-month-old male not using his arm 'since playing with Mum'. Imaging findings can be subtle and often, as in these images, no fracture line is identified. As such, secondary signs are crucial to making the diagnosis. Note the elevation of both the anterior and posterior fat pads indicating a joint effusion (arrows). Additionally, the anterior humeral line is disrupted (red dashed line): normal alignment is demonstrated when this line intersects the long axis of the middle third of the capitellum.

Figure 7 Unexplained recent metatarsal fracture. Pre-ambulant infant with a swollen foot. Radiography revealed an unexplained metatarsal fracture (arrow). SS showed other injuries. Fractures of the hands and feet of a pre-ambulant infant have a strong association with II.

Figure 8 Fractures in an unusual location. Male infant who was found to have healing rib fractures on a pre-operative chest radiograph. (a) AP chest radiograph illustrates bilateral acromion fractures, right (red arrow) more displaced than the left (white arrow) on this initial radiograph at the age of 3 months (arrows), therefore showing less advanced healing on the 8-week follow-up radiograph in (b) (right acromion=red arrow; left acromion=white arrow).

Tables

Table 1

Risk factors associated with child abuse from the perspective of the reporting radiologist.

Risk factor	**How identified**

Prematurity	Previous radiographs obtained on SCBU/NNU/NICU
Age	Date of birth on request card/radiograph
Multiple births	Imaged patient named 'Baby boy one', 'Twin two' on previous radiographs
Physical/developmental problem or disability, e.g. cerebral palsy	Specific radiographic features identifying condition, clinical information provided on the request card

361 SCBU=special care baby unit. NNU=neonatal unit. NICU=neonatal intensive care unit.

362

363 **Table 2**

364 Clinical features which raise the suspicion of inflicted injury[8].

- Injury in non-ambulatory/totally dependent child
- Injury and history/mechanism given are incompatible
- Delay in seeking medical attention
- Multiple fractures (of different ages) with no family history or clinical features of bone disease
- Retinal haemorrhage
- Torn frenulum
- History of household fall resulting in fracture (these falls are common, fractures are not)

365

366 **Table 3**

367 The standard child protection skeletal survey for suspected inflicted injury[6].

Skull	AP and lateral (Towne projection if clinically indicated) Skull radiographs should be taken with the skeletal survey even if a CT scan has been or will be performed
Chest	AP including the clavicles

	Oblique views of both of the sides of the chest to show ribs (left and right oblique)
Abdomen	AP of the abdomen including the pelvis and hips
Spine	Lateral: this may require separate exposures of the cervical, thoracic and thoracolumbar regions If the whole of the spine is not seen in the AP projection on the chest and abdominal radiographs then additional views will be required AP views of the cervical spine are rarely diagnostic at this age and should only be performed at the discretion of the radiologist
Limbs	AP of both upper arms, forearms, femurs and lower legs PA of hands DP of feet

AP=anteroposterior. PA=posteroanterior. DP=dorsoplantar.

Additional supplementary (AP and lateral coned views) or tangential views may be obtained where specific regions are not well visualised such as the metaphyses of long bones to demonstrate injuries in greater detail.

References

1. Radford L, Corral S, Bradley C, et al. Child abuse and neglect in the UK today. London: National Society for the Prevention of Cruelty to Children (NSPCC); 2011.

2. Leung RS, Nwachuckwu C, Pervaiz A, Wallace C, Landes C, Offiah AC. Are UK radiologists satisfied with the training and support received in suspected child abuse? Clinical radiology 2009;64:690-8.

3. Paediatric radiology experts. London: The Royal College of Radiologists. https://www.rcr.ac.uk/sites/default/files/publication/BFCR%2811%299_paedexpert.pdf 2011. Accessed 23 June 2015.

4. Calmar A, Vinci RJ. The anatomy and physiology of bone fracture and healing. Clinical Pediatric Emergency Medicine 2002;3:86-93.

5. Forestier-Zhang L, Bishop N. Bone strength in children: understanding basic bone biomechanics. Archives of disease in childhood Education and practice edition 2016;101:2-7.

6. Standards for Radiological Investigations of Suspected Non-accidental Injury. London: Royal College of Radiologists & Royal College of Paediatrics and Child Health. https://www.rcr.ac.uk/docs/radiology/pdf/RCPCH_RCR_final.pdf 2008. Accessed 23 June 2015.

7. Cosway B, Mathura N, Mott A, et al. Occult Rib Fractures: Defining the Cause. Child Abuse Rev 2015;24:6-15.

8. Knipe H, Bhattacharya B. Non-accidental injuries. Radiopaedia.org. http://radiopaedia.org/articles/non-accidental-injuries 2015. Accessed 23 June 2015.

9. Duffy SO, Squires J, Fromkin JB, Berger RP. Use of skeletal surveys to evaluate for physical abuse: analysis of 703 consecutive skeletal surveys. Pediatrics 2011;127:e47-52.

10. Cohn EJ. Blood: a brief survey of its chemical components and of their natural functions and clinical uses. Blood 2015;126:2531.

11. Marieb EN. The Skeletal System. Eessenitals of Human Anatomy & Physiology. 11th ed. Essex, England, United Kingdom: Peason; 2015:158-204.

12. Rangel EL, Cook BS, Bennett BL, Shebesta K, Ying J, Falcone RA. Eliminating disparity in evaluation for abuse in infants with head injury: use of a screening guideline. Journal of pediatric surgery 2009;44:1229-34; discussion 34-5.

13. Worlock P, Stower M, Barbor P. Patterns of fractures in accidental and non-accidental injury in children: a comparative study. British medical journal 1986;293:100-2.

14. Hobbs C, Childs AM, Wynne J, Livingston J, Seal A. Subdural haematoma and effusion in infancy: an epidemiological study. Archives of disease in childhood 2005;90:952-5.

15. Jenny C, Hymel KP, Ritzen A, Reinert SE, Hay TC. Analysis of missed cases of abusive head trauma. Jama 1999;281:621-6.

16. Offiah A, van Rijn RR, Perez-Rossello JM, Kleinman PK. Skeletal imaging of child abuse (non-accidental injury). Pediatric radiology 2009;39:461-70.

17. Hobbs CJ. Skull fracture and the diagnosis of abuse. Archives of disease in childhood 1984;59:246-52.

18. Prabhu SP, Newton AW, Perez-Rossello JM, Kleinman PK. Three-dimensional skull models as a problem-solving tool in suspected child abuse. Pediatric radiology 2013;43:575-81.

19. Barber I, Kleinman PK. Imaging of skeletal injuries associated with abusive head trauma. Pediatric radiology 2014;44 Suppl 4:S613-20.

20. Runyan D, Wattam C, Ikeda R, Hassan F, Ramiro L. Child abuse and neglect by parents and caregivers. In: Krug E, Dahlberg LL, Mercy JA, Zwi AB, Lozano R, eds. World report on violence and health. Geneva, Switzerland: World Health Organization; 2002:59-86.

21. Wormian bones (mnemonic). 2016. (Accessed 30 March, 2016, at http://radiopaedia.org/articles/wormian-bones-mnemonic.)

22. Supracondylar fracture. 2016. (Accessed 29 March, 2016, at http://radiopaedia.org/articles/supracondylar-fracture.)

23. Pandya NK, Baldwin K, Wolfgruber H, Christian CW, Drummond DS, Hosalkar HS. Child abuse and orthopaedic injury patterns: analysis at a level I pediatric trauma center. Journal of pediatric orthopedics 2009;29:618-25.

24. Barsness KA, Cha ES, Bensard DD, et al. The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. The Journal of trauma 2003;54:1107-10.

25. Kleinman PL, Kleinman PK, Savageau JA. Suspected infant abuse: radiographic skeletal survey practices in pediatric health care facilities. Radiology 2004;233:477-85.

26. Fractures. Which fractures are indicative of abuse? Rib fractures. Results. CORE INFO Cardiff Child Protection Systematic Reviews. 2016. (Accessed 30 March, 2016, at

http://www.core-info.cardiff.ac.uk/reviews/fractures/which-fractures-are-indicative-of-abuse/rib-fractures/results.)

27. Barber I, Perez-Rossello JM, Wilson CR, Kleinman PK. The yield of high-detail radiographic skeletal surveys in suspected infant abuse. Pediatric radiology 2015;45:69-80.

28. Head injury: Triage, assessment, investigation and early management of head injury in children, young people and adults. National Institute for Health and Care Excellence (NICE). https://www.nice.org.uk/guidance/cg176 2014. Accessed 23 June 2015.

29. Suspected non-accidental injury skeletal survey. London: The Society and College of Radiographers http://www.sor.org/learning/document-library/skeletal-survey-suspected-nai-sids-and-sudi-guidance-radiographers/suspected-nai-skeletal-survey 2015. Accessed 28 June 2015.

30. Kleinman PK, Morris NB, Makris J, Moles RL, Kleinman PL. Yield of radiographic skeletal surveys for detection of hand, foot, and spine fractures in suspected child abuse. AJR American journal of roentgenology 2013;200:641-4.

31. Hoskote AU, Martin K, Hormbrey P, Burns EC. Fractures in infants: one in four is non-accidental. Child Abuse Review 2003;12:384-91.

32. Hui C, Joughin E, Goldstein S, et al. Femoral fractures in children younger than three years: the role of nonaccidental injury. Journal of pediatric orthopedics 2008;28:297-302.

33. Offiah AC, Adamsbaum C, van Rijn RR. ESPR adopts British guidelines for imaging in suspected non-accidental injury as the European standard. Pediatric radiology 2014;44:1338.

34. Maguire S, Cowley L, Mann M, Kemp A. What does the recent literature add to the identification and investigation of fractures in child abuse: an overview of review updates 2005 - 2013. Evidence Based Child Health: A Cochrane Review Journal 2013;8:2044-57.

35. Sonik A, Stein-Wexler R, Rogers KK, Coulter KP, Wootton-Gorges SL. Follow-up skeletal surveys for suspected non-accidental trauma: can a more limited survey be performed without compromising diagnostic information? Child abuse & neglect 2010;34:804-6.

463 36. Cadzow SP, Armstrong KL. Rib fractures in infants: red alert! The clinical features,
464 investigations and child protection outcomes. Journal of paediatrics and child health
465 2000;36:322-6.
466 37. Harlan SR, Nixon GW, Campbell KA, Hansen K, Prince JS. Follow-up skeletal surveys
467 for nonaccidental trauma: can a more limited survey be performed? Pediatric radiology
468 2009;39:962-8.
469 38. The Skeletal Survey in suspected abuse- how necessary is it? 2015. (Accessed 5 April,
470 2016, at http://adc.bmj.com/content/early/2015/04/21/archdischild-2015-308418.full.)
471 39. Re: The Skeletal Survey in suspected abuse- how necessary is it? 2015. (Accessed 5
472 April, 2016, at http://adc.bmj.com/content/early/2015/04/21/archdischild-2015-
473 308418.full.)
474 40. Kellogg ND. American Academy of Pediatrics Committee on Child Abuse and
475 Neglect. Evaluation of suspected child physical abuse. Pediatrics 2007;119:1232-41.
476 41. Kleinman PK, Nimkin K, Spevak MR, et al. Follow-up skeletal surveys in suspected
477 child abuse. AJR American journal of roentgenology 1996;167:893-6.
478 42. Kleinman PK. Problems in the diagnosis of metaphyseal fractures. Pediatric radiology
479 2008;38 Suppl 3:S388-94.
480 43. Kleinman PK, Marks SC, Jr. Relationship of the subperiosteal bone collar to
481 metaphyseal lesions in abused infants. The Journal of bone and joint surgery American volume
482 1995;77:1471-6.
483 44. Kleinman PK, Marks SC, Blackbourne B. The metaphyseal lesion in abused infants: a
484 radiologic-histopathologic study. AJR American journal of roentgenology 1986;146:895-905.
485 45. Cohn A, Johnson A, Ehlke S, Villanti AC. Characterizing substance use and mental
486 health profiles of cigar, blunt, and non-blunt marijuana users from the National Survey of Drug
487 Use and Health. Drug and alcohol dependence 2016;160:105-11.
488 46. Fractures. Which fractures are indicative of abuse? Fatally abused children with
489 metaphyseal fractures. CORE INFO Cardiff Child Protection Systematic Reviews. 2016.

(Accessed 30 March, 2016, at http://www.core-info.cardiff.ac.uk/reviews/fractures/which-fractures-are-indicative-of-abuse/metaphyseal-fractures/fatally-abused-children-with-metaphyseal-fractures.)

47. Lonergan GJ, Baker AM, Morey MK, Boos SC. From the archives of the AFIP. Child abuse: radiologic-pathologic correlation. Radiographics : a review publication of the Radiological Society of North America, Inc 2003;23:811-45.

48. Carty H, Pierce A. Non-accidental injury: a retrospective analysis of a large cohort. European radiology 2002;12:2919-25.

49. Darling SE, Done SL, Friedman SD, Feldman KW. Frequency of intrathoracic injuries in children younger than 3 years with rib fractures. Pediatric radiology 2014;44:1230-6.

50. Hannon E, Williams R, Allan R, Okoye B. UK intussusception audit: a national survey of practice and audit of reduction rates. Clin Radiol 2014;69:344-9.

51. Thomas SA, Rosenfield NS, Leventhal JM, Markowitz RI. Long-bone fractures in young children: distinguishing accidental injuries from child abuse. Pediatrics 1991;88:471-6.

52. Fractures. Which fractures are indicative of abuse? Other useful references. CORE INFO Cardiff Child Protection Systematic Reviews. 2016. (Accessed 30 March, 2016, at http://www.core-info.cardiff.ac.uk/reviews/fractures/which-fractures-are-indicative-of-abuse/other-useful-references.)

53. Ablin DS, Greenspan A, Reinhart M, Grix A. Differentiation of child abuse from osteogenesis imperfecta. AJR American journal of roentgenology 1990;154:1035-46.

54. Ablin DS, Greenspan A, Reinhart MA. Pelvic injuries in child abuse. Pediatric radiology 1992;22:454-7.

55. Ablin DS, Reinhart MA. Esophageal perforation by a tooth in child abuse. Pediatric radiology 1992;22:339-41.

56. Bajaj M, Offiah AC. Imaging in suspected child abuse: necessity or radiation hazard? Archives of disease in childhood 2015;100:1163-8.

57. Barber I, Bixby SD, Morris NB, et al. An electronic tool for systematic reporting of fractures on skeletal surveys in suspected child abuse: prototype development and physician feedback. Pediatric radiology 2014;44:1564-72.

58. Lindberg DM, Harper NS, Laskey AL, Berger RP, Investigators. E. Prevalence of abusive fractures of the hands, feet, spine, or pelvis on skeletal survey: perhaps "uncommon" is more common than suggested. Pediatric emergency care 2013;29:26-9.

59. Nimkin K, Spevak MR, Kleinman PK. Fractures of the hands and feet in child abuse: imaging and pathologic features. Radiology 1997;203:233-6.

60. Garcia VF, Gotschall CS, Eichelberger MR, Bowman LM. Rib fractures in children: a marker of severe trauma. The Journal of trauma 1990;30:695-700.

61. Fagen KE, Shalaby-Rana E, Jackson AM. Frequency of skeletal injuries in children with inflicted burns. Pediatric radiology 2015;45:396-401.

62. Prendergast NC, deRoux SJ, Adsay NV. Non-accidental pediatric pelvic fracture: a case report. Pediatric radiology 1998;28:344-6.

Fig 1a

Click here to download Revised Figure Updated Fig 1a.jpg

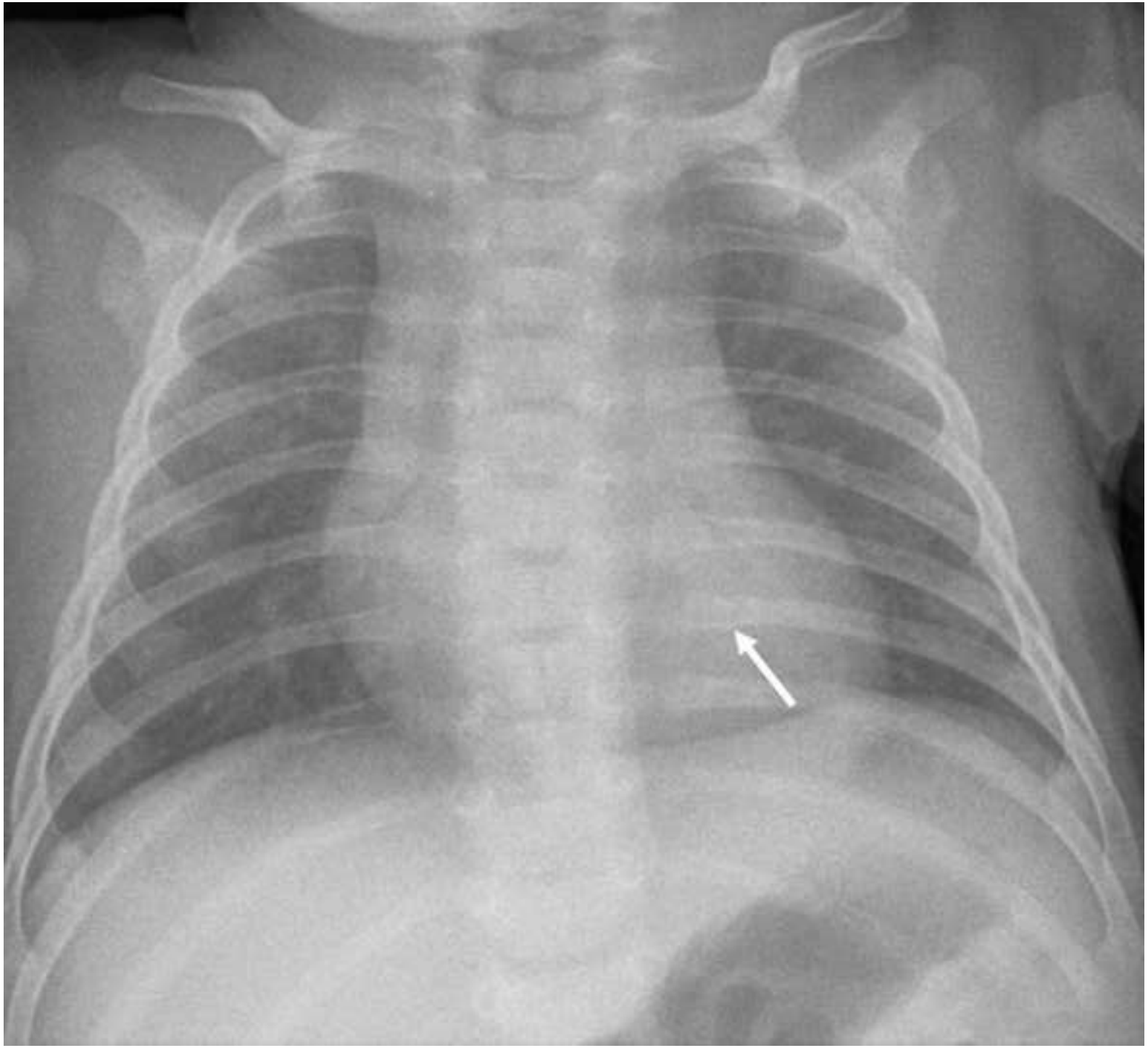

Fig 1b

Click here to download Revised Figure Updated Fig 1b.jpg

Fic 1c

Click here to download Revised Figure Updated Fig 1c.jpg

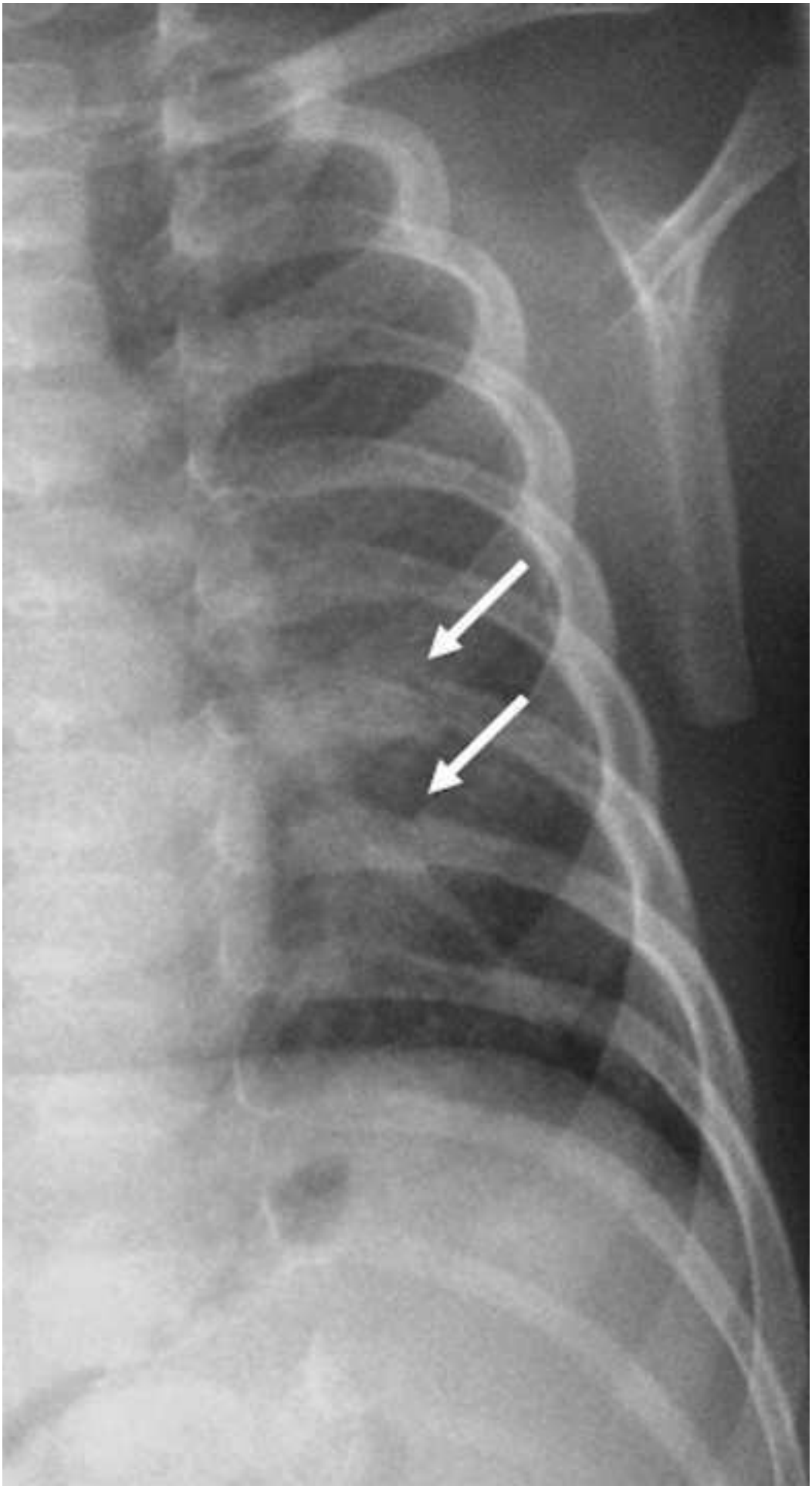

Fig 1d

Click here to download Revised Figure Updated Fig 1d.jpg

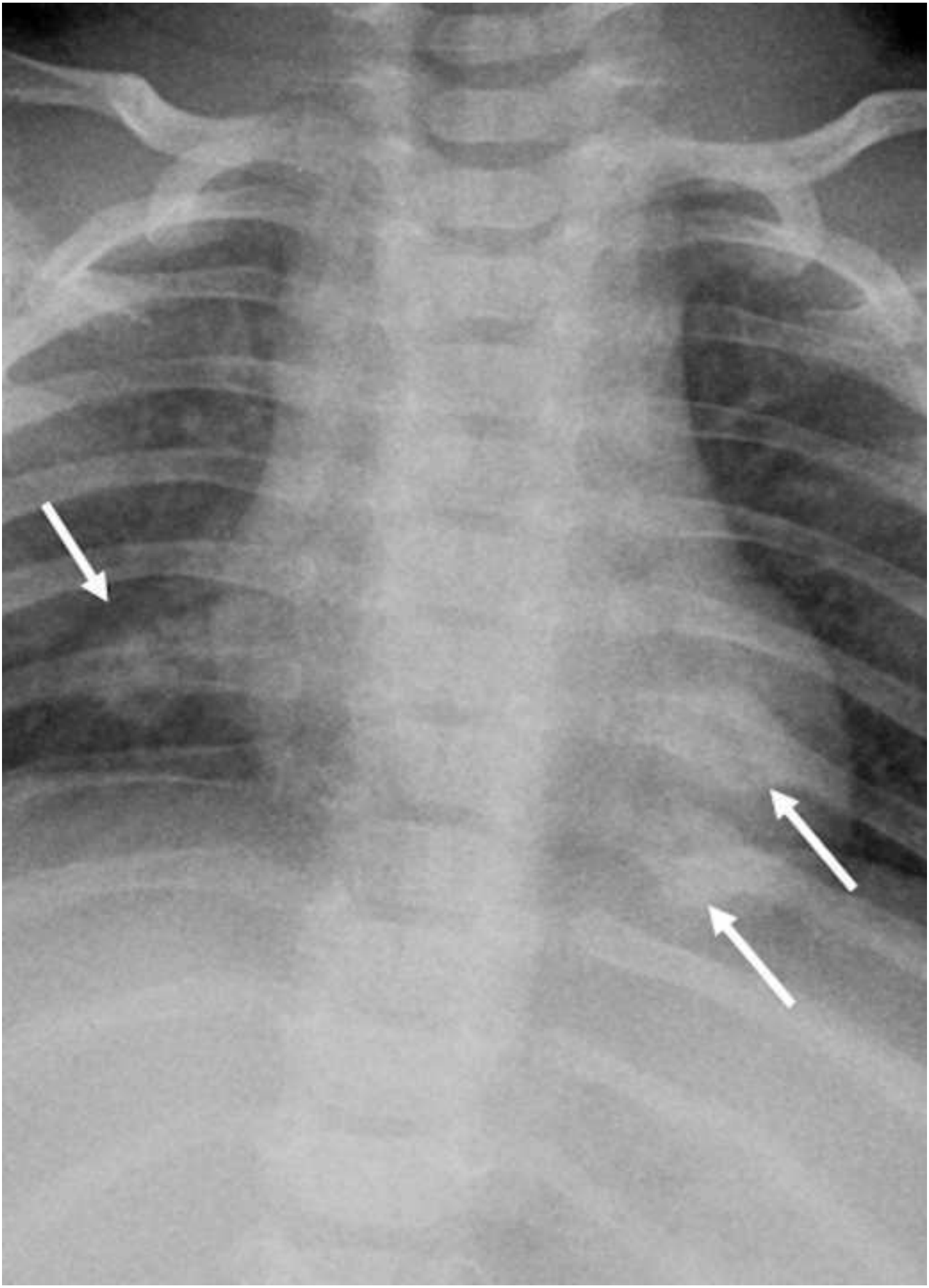

Fig 2a

Click here to download Revised Figure Updated Fig 2a.jpg

Fig 2b

Click here to download Revised Figure Updated Fig 2b.jpg

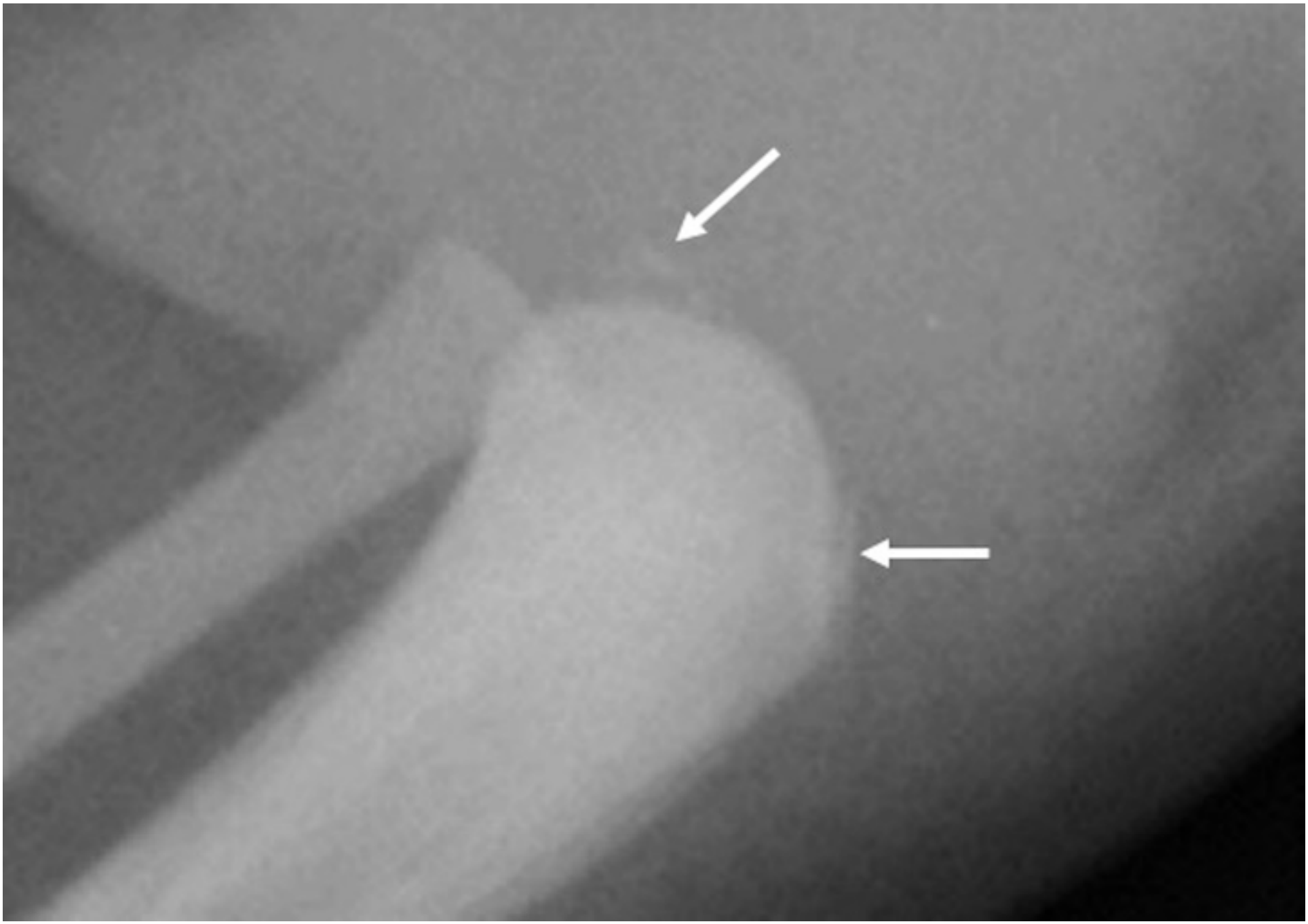

Fig 2c

Click here to download Revised Figure Updated Fig 2c.jpg

Fig 3a

Click here to download Revised Figure Updated Fig 3a.jpg

Fig 3b

Click here to download Revised Figure Updated Fig 3b.jpg

Fig 4

Click here to download Revised Figure Updated Fig 4.jpg

Fig 5

Click here to download Revised Figure Updated Fig 5.jpg

Fig 6a

Click here to download Revised Figure Updated Fig 6a.jpg

Fig 6b

Click here to download Revised Figure Updated Fig 6b.jpg

Fig 7

Click here to download Revised Figure Updated Fig 7.jpg

Fig 8a

Click here to download Revised Figure Updated Fig 8a.jpg

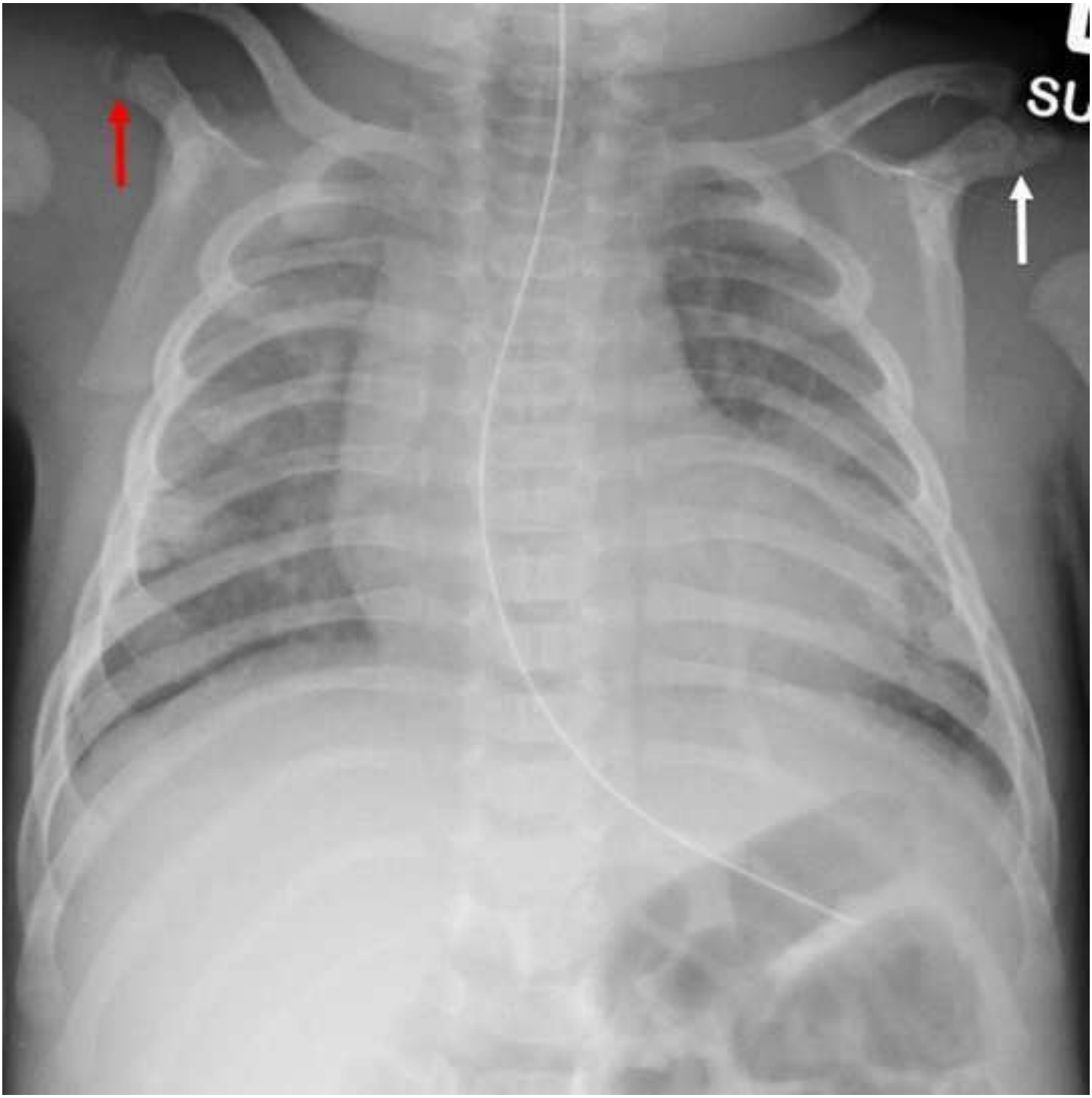

Fig 8b

Click here to download Revised Figure Updated Fig 8b.jpg