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Abstract

Recognising the skeletal manifestations of inflicted injury (II) in infants and young children is of crucial importance. There are specific fracture patterns highly suspicious of II and common differential diagnoses with which radiologists should be familiar. Our objective is to provide a non-exhaustive review of the important factors relevant to the imaging and reporting of II as a platform for further learning. Part two encompasses fracture patterns of the appendicular skeleton and important differential diagnoses.

Imaging and reporting considerations for suspected physical abuse (non-accidental injury) in infants and young children. Part 2: Axial skeleton and differential diagnoses

Introduction

Part 1 discussed important initial considerations of imaging inflicted injury (II) and specific fracture patterns of the appendicular skeleton. Fractures of the axial skeleton can be subtle and have a strong association with II. In this second article of a two-part series, we review the important fracture patterns of the axial skeleton, including rib and skull fractures, in addition to examining the important differential diagnoses of II.

Specific fracture patterns of the axial skeleton in inflicted injury

The axial skeleton forms the longitudinal axis of the body and comprises the thoracic cage, the vertebral column and the skull[1].

Rib fractures

Given the degree of plastic deformity tolerated by the normal paediatric chest wall, rib fractures due to natural events and normal handling are uncommon.

Posterior rib fractures are highly specific for abuse and result from substantial squeezing forces generated by adult hands applied to the paediatric chest wall causing 'hyperextension of the posterior rib ends over the transverse processes, with fracture of the ventral cortex'[2]. Highly suspicious features include: rib fractures in children aged less than 18 months[3], and in particular less than 12 months; fractures of the first rib which require considerable energy[4,5]; and posteromedial location of the fracture[3,6-8] (Fig 1).

Anterior rib arc and costochondral fractures result from direct blunt forces to the chest wall[6,7,9,10]; the latter may be associated with minimal healing callus. Anterior/costochondral fractures of the lower ribs are associated with major intra-abdominal injury[10]. Those infants and children with abusive rib fractures tend to have more rib fractures and have fewer concurrent intrathoracic injuries than those with confirmed/witnessed accidental injury[11].

Radiography has a low sensitivity for the detection of acute rib fractures because they are often incomplete and usually minimally displaced[2,10] (Fig 2). In one series concerning sudden unexpected death in infancy (SUDI), nearly 80% of acute rib fractures confirmed on postmortem were undetectable on chest radiographs, even in retrospect[12]. Computed tomography has an increasing role in clinical practice as a problem solver in live children when rib fractures are suspected[13,14].

Pending publication of revised national guidelines, thoracic imaging should consist of an anteroposterior (AP) projection including the clavicles, in addition to oblique views of both sides of the chest to show the ribs ('left and right oblique') on the initial SS[15]. Due to the strong correlation of rib fractures with II[16-19], particularly when multiple[6,7,9,11,17], and given that rib fractures are more easily identified as healing callus develops, follow-up chest radiography should be performed in all cases of suspected abuse[15,16,20] (Fig 1). Oblique views have a higher specificity for identifying posterior rib fractures[21]. Reference to the initial SS is essential.

Rib fractures secondary to cardiopulmonary resuscitation (CPR) have been reported in the literature and remain a contentious issue. Even with forceful cardiopulmonary resuscitation (CPR), rib fractures are rare[12,22,23], even when prolonged[23], implying that significant force is required to produce a rib fracture: thus, any unexplained rib fracture in an infant is highly suspicious. Rib fractures secondary to CPR are usually anterior costochondral in location[12,24,25]. It has been postulated that the change from AP sternal compression to circumferential chest compression for infant CPR may result in an increase in the occurrence rate of rib fractures[24,26,27]: further research in this area is warranted[28].

Skull fractures

Distinguishing between accidental and abusive head trauma can pose a diagnostic dilemma given that age of the child is not necessarily a reliable marker of injury aetiology. The proffered history, clinical findings and congruence of the described mechanism in conjunction with the radiological findings are key to determining the true causation (i.e. whether accidental or inflicted). In particular, knowledge of the height, angle and object from which the child has fallen (caregiver's arms, work surface, cot etc.) will dictate the likelihood of sustaining the identified fracture/intracranial injury through the stated mechanism[29].

Skull fractures secondary to accidental injury are relatively common. The hairline linear parietal skull fracture is the commonest skull fracture found in both accidental and II[30-34]: it is only the history (or lack thereof) that is able to differentiate between the two. Sometimes one carer may have an accident that they are unwilling to reveal and the other carer takes the infant to the hospital with scalp swelling.

Given the findings from an animal study[35], it is likely that the more complex fracture (bilateral, widened, branching[36] or crossing suture lines) implies higher levels of energy (force) that are uncommonly found in accidental domestic events. Furthermore, domestic incidents and falls from heights less than 1 metre are very unlikely to cause fracture[37]. Given that complex fractures are more likely to be associated with abuse when compared to linear fractures[32,36,38], and are more commonly found in abused infants[32,39], it is likely that complex fractures result from a high energy impact force.

"Alice band" skull fractures result from an injury to the vertex (a direct impact to the infant/child on the top of the head) to produce fractures through the left and right parietal bones which usually meet at the sagittal suture (roughly within 1-2 cm of each other) radiating from ear-to-ear giving the appearance of a girl's hair band ("Alice band"). There is a specific mechanism (often accidental) for simple bilateral fractures provided the history of impact is given: the same fracture, if unexplained, is as suspicious as other unexplained skull fractures.

Multiple injuries (both intra- and extra-cranial e.g. fractures) are much more likely to be present when secondary to abuse[32-34]. Table 1[40] outlines the specific features on skull radiographs that are highly suspicious for II, with an example in Fig 3.

NICE guidelines for the investigation of head injury in children recommend that computed tomography (CT) be performed if there is a 'suspicion of non-accidental injury'[41]. The skull radiograph, which forms part of the forensic skeletal survey (SS), is not part of the immediate investigation of acute head injury. That being said, if brain CT with good quality 3D reconstruction is available the need for skull radiographs is debated[42] (Fig 4).

Neuroradiological assessment may be performed by a different set of radiologists to those reporting the SS. Injuries to both areas may co-exist and may be clinically occult[43,44]; in particular, fractures of the first rib with concurrent neurological injury have been described[45]. Therefore, an infant with a suspicious/unexplained head injury mandates a full SS to detect occult skeletal injury and vice versa[46-48]: close collaboration/communication is required between all specialists.

Abusive head trauma is not included in this review but readers should be aware of its presentation, implications and investigation, particularly with regard to the appropriate use and timing of CT and magnetic resonance imaging (MRI)[49]. The national guidelines provide an excellent summary and schedule for neuroimaging[15]. There are excellent reviews that compliment this article which are strongly recommended for further reading[2,46,49]. Although radiation dose is an important consideration in paediatric imaging, in many hospitals CT is more easily accessible for initial assessment than sedated MRI[50].

Vertebral fractures

Although uncommon, isolated vertebral fractures may be the only manifestation of physical abuse, emphasising the need to include lateral spine imaging as part of the routine SS in children under the age of two years when inflicted injury is suspected[51-54].

Although extremely rare in all age groups (except in the context of major trauma), given the disproportionate weight and size of their heads, infants and young children are more susceptible to cervical spine injuries than older children[55]. Injury can occur at any level in the cervical spine[56-60] with a possible predilection for the upper levels[61,62]. Where cervical fractures are sustained, there is a high incidence of ligamentous[63,64] and co-existing intracranial injury[56,57,59,62] which may extend into the spine, e.g. subdural haematoma[58,65,66].

Reported clinical manifestations of thoracolumbar fractures include visible swelling and neurological deficit below the level of injury[67]. Abusive vertebral compression fractures (Fig 5), often at multiple levels[51,54,62] may present with spinal cord compression and injury[54,58,65,66]. Subluxation and dislocation may also be encountered[54,68-71], in addition to ligamentous injury[62], although to a less frequent extent than cervical fractures. Moreover, concurrent intracranial injury alongside abusive fractures of the thoracolumbar region may also be identified[54,62,65]. Sacral fractures have also been reported[51].

Given the association between vertebral fractures and occult intracranial and spinal injury, cross-sectional MRI of the brain and spine must always be performed[54]. In the early literature prior to MRI, the only spinal injuries that were identified were those that were clinically symptomatic: given that access to advanced cross-sectional imaging is now readily available, clinically occult vertebral fractures are now also being identified. Ligamentous injury may be identified when reporting MRI of the neuraxis undertaken for suspected II, which again, may be reported by a different set of radiologists to those reporting the SS. There is developing subspecialisation of radiologists into those reporting skeletal, and those reporting neuroimaging, in suspected II – it is imperative that paediatricians, paediatric radiologists, paediatric neuroradiologists and wider child protection multidisciplinary team maintain close liaison.

The inclusion of full lateral spinal imaging in the SS and dedicated spinal MRI as part of the assessment of head injury should lead to a greater detection of vertebral fractures and spinal injury. If evidence of abusive injury is not sought, it will be missed.

Dating of fractures

Whilst fracture dating is difficult, there are recognised stages of fracture healing[72,73]. There is an element of subjectivity in dating, even between experienced experts and as such, the non-expert radiologist may wish to limit their report to whether the fracture shows soft tissue swelling or any evidence of healing. All radiologists involved in the investigation of suspected II should be aware of the broad time frames discussed below[74]. An important caveat is that imaging in a cast can limit interpretation and reliability of dating[75]. The information below is summarised in Table 3.

Acute diaphyseal and rib arc fractures

If a fractured long bone or rib arc shows no periosteal reaction with or without soft tissue swelling, it is likely to have been sustained in the preceding 10 (but up to 14) days. Rarely, periosteal reaction may be identified as early as 4 days[76]. Healing patterns in ribs and long bones can be considered similarly given their tubular morphology[77].

Healing diaphyseal and rib arc fractures

If a fractured long bone or rib arc shows some periosteal reaction but little or no soft tissue swelling, it is likely to be over 2 weeks old (the inference being that any soft tissue swelling will have resolved after 14 days following an acute injury). Rib and shaft fractures typically heal in a predictable fashion and will have healed completely by 3 months[78].

Hard callus and early remodelling can usually be identified at 8 weeks[79]. The remodelling process may continue for a further 3 or more months, therefore the more acute a fracture, the more precisely it can be dated. It has been proposed that the amount of callus formation/thickness of a rib fracture is proportionate to the degree of healing and therefore to the age of the fracture[79]. Alternatively, the degree/thickness of subsequent callus may relate to the amount of initial displacement of a fracture. However, no precise cut-offs are available.

Factors that influence the rate of healing and volume of callus may include: the age of the child (widely stated but no published supporting evidence[78]) ; the type of fracture; displacement and size of bone (a displaced femoral fracture may not heal as rapidly as an undisplaced fracture of a smaller bone); and (lack of) immobilisation of the fractured limb. Visualisation of an acute or early healing fracture will be affected by radiographic technical quality (including patient positioning and presence of cast), further emphasising the need for fully trained paediatric radiographers to obtain high-quality diagnostic radiographs.

Metaphyseal, costochondral, vertebral and skull fractures

Isolated metaphyseal and skull fractures heal without periosteal reaction so different considerations to those summarised above apply.

Metaphyseal and costochondral fractures do not heal by the same process as diaphyseal and rib arc fractures: when identified they are usually less than four weeks of age and heal completely by 4 to 6 weeks[80,81]. The majority of metaphyseal fractures do not heal with periosteal reaction but slowly reabsorb onto bone by about 6 weeks post-event. When there is associated subperiosteal bleeding, the maturity of periosteal reaction assists in dating metaphyseal fractures.

Vertebral and skull fractures cannot be reliably dated, although soft tissue (scalp) swelling over a skull fracture suggests a recent injury (less than 2 weeks). Once present, skull fractures will fade over several months.

Mechanism of injury

The precise amount of force required to produce a fracture in any individual infant is unknown. Biomechanical studies give some information but these tend to be either mechanical or animal models, or are based on dead human bones. In the live child, it is probably not just the amount of force but also the speed of application of that force that causes the bone to fracture. Understanding the interplay between the underlying complex processes that determine 'bone strength' is fundamental to understanding why paediatric bones fracture[82]. As a generalisation, the amount of force required to cause a fracture is considered to be well outside that used in the normal reasonable handling of an otherwise healthy child.

Metaphyseal fractures – traction, or shaking back and forth

Metaphyseal fractures are caused by twisting, gripping and pulling (traction) forces[82] at the site of the fracture. They have also been said to be due to the limbs flailing whilst the infant is shaken back and forth with force[83]. Whilst shaking may represent a potential further mechanism, metaphyseal fractures commonly occur without head/intracranial injury and so shaking cannot be the sole explanation for metaphyseal fractures[84].

Spiral/oblique fractures

Result from a torsional (twisting) force.

Transverse/angulated fractures

Result from either: direct blows and levering forces; indirectly from falls or being thrown and depending upon how the child lands.

Rib fractures

Result from compressive forces. See above section on rib fractures.

Skull fractures

Result from an impaction force either due to the head hitting something hard or something hard hitting the head. Falling at an angle from a significant height may result in a rapid angular deceleration when the head hits the floor which may explain concurrent intracranial injury from a high-energy impact. This may be associated with a ‘shake and throw’ injury or occasionally due to the baby being thrown or swung onto a hard surface. A ‘stamping’ injury where a carer stamps on the head of a baby on the floor is, fortunately, uncommon. See above section on skull fractures.

Differential diagnoses

A wide range of differential diagnoses must be considered (including normal variants[85]) before diagnosing II. If misreported, the consequences for the child and family can be devastating. As such, as much information as possible should be obtained when reporting imaging undertaken for suspected II, including clinical history, index of suspicion and results of appropriate biochemical investigations.

The radiologist may be able to detect an underlying predisposition to easy fracturing such as an underlying bone dysplasia, although conventional radiographs are relatively insensitive to lower levels of demineralisation. The two conditions that most commonly cause diagnostic dilemmas are osteogenesis imperfecta (brittle bone disease) and rickets (metabolic bone disease). If a baby was born extremely prematurely, then metabolic bone disease of prematurity (osteopathy of prematurity) should be considered (based on history, biochemical records and radiographic features).

Birth trauma

Difficulty can arise when the presentation is delayed given that some birth injuries may not be identified immediately on the initial neonatal clinical examination.

Although infrequent, posterior rib fractures have been ascribed to complicated deliveries and may be seen secondary to birth trauma in large babies following difficult deliveries[4,5,86,87], such as shoulder dystocia[88] secondary to macrosomia[4,86]. These are usually posterior, in the upper ribs and may be associated with clavicular fractures (the commonest birth injury) or brachial plexus injury.

Very rarely, birth related leg or arm injuries have been reported including classical metaphyseal lesions[89] and proximal spiral fractures[90] after Caesarean section. Linear and depressed skull fractures have also been reported[91]. Correlation with the mode of delivery and whether ventouse (vacuum assisted vaginal delivery) and/or forceps were employed during delivery is paramount in these instances.

It is important to consider the clinical and birth history in an infant younger than 3 months old that presents with unexplained injury (Fig 6 and 7). Beyond 3 months, any birth related injury should have healed.

Rickets

Results from undermineralisation of bone with resultant growth plate abnormalities in vitamin D deficient children. It may be hereditary or secondary to prematurity and lack of dietary vitamin D and/or sun exposure. Radiographic features (Fig 8) are most prominent at the growth plates and include widening and irregularity of the metaphyses with cupping, flaring and fraying[92,93]. It is important that metaphyseal fragmentation is not mistaken for fracture[94].

Bowing of the legs is seen secondary to bone softening. The bulbous appearance of the anterior rib ends (expansion of the costochondral junctions) is known as the “rachitic rosary” (Fig 9) and should not be mistaken for healing rib fractures. Note that in an infant with unexplained fractures, a low vitamin D level in the absence of other biochemical and radiological signs of rickets, does not account for the fractures[95].

Osteogenesis imperfecta

A group of congenital disorders of collagen type 1 production affecting bone and connective tissue. There is wide variation in phenotype but characteristic features include osteoporosis, bone and dental fragility, easy bruising, short stature, abnormal coloration of the sclera, hearing impairment and joint laxity/hypermobility[96]. The full classification of the subtypes and corresponding clinical characteristics is extensive[97]. Common radiographic features include gracile, osteoporotic bones with cortical thinning, multiple long bone, rib and vertebral fractures, Wormian bones and 'popcorn calcification' (scalloped metaphyseal and/or epiphyseal lucencies with surrounding sclerotic margins). Hyperplastic callus formation during fracture healing is characteristic of OI type V. Examples are given in Fig 10.

II may be erroneously diagnosed in children with OI who are at increased risk of fractures, particularly in those children with forms of the disease demonstrating a relatively high fracture incidence within the first years of life without Wormian bones or scleral discoloration[98]. In OI, there may be a (biological) family history of fracturing with minimal trauma and clinical or radiographic features that assist in establishing the diagnosis. Up to 25% of cases are due to new autosomal dominant mutations and not all cases of OI have osteoporosis, vertebral fractures or an excessive number of Wormian bones to help establish the diagnosis. Apart from congenital insensitivity to pain, fractures are still painful even with an underlying predisposition.

Normal variants

There are numerous normal variants that may simulate II. A detailed discussion of all possible normal variants is beyond the scope of this article and further reading is strongly recommended[85]. Two common variants with which the non-expert radiologist should be familiar are discussed below.

Wormian bones

Wormian bones are small, irregularly shaped bones found at cranial sutures which vary between individuals in size, shape and number[99] and (when relatively few in number) may be mistaken for skull fracture, particularly in the occipital bone[100]. Less than ten Wormian bones in an individual represents an anatomical variant occurring most frequently in the lambdoid suture[101]. It has been proposed that a good quality CT 3D reconstruction of the skull can augment the differentiation of normal variants, such as Wormian bones and accessory sutures[102], and fracture[100].

Multiple Wormian bones occur in several disorders, including OI (Fig 11). A helpful mnemonic to remember the conditions associated with Wormian bones is detailed in Table 2[103]. Note that a skull fracture may co-exist in a child with multiple Wormian bones and/or OI and that even in these cases, a history of impact will be required.

Sternal ossification centres

It is important that sternal segments (ossification centres) are not mistaken for healing rib fractures on oblique chest projections (Fig 1c)[104].

What to do once abuse is suspected

Radiologists play a key role in the detection of II. However, this becomes redundant if any suspicions or concerns are not appropriately and speedily communicated to the relevant clinical team. Failure to instigate child protection measures may result in an infant being exposed to further (potentially fatal) injury if allowed to remain in an abusive environment. An infant may be removed to a place of safety whilst full investigations are conducted.

In the context of suspected II, independent double reporting of imaging is advised. Each department should have well-defined pathways and protocols in place for the double reporting of SS and contact details for a more experienced opinion if required. Most regional paediatric units provide an advisory and review service to colleagues. Good prompt communication with the general paediatric and child protection teams is vital to ensure that the safety of the child remains paramount at all times.

Conclusion

The two articles provide an overview of the key radiographic features related to the diagnosis of II in infants and young children. The radiologist who identifies an injury which is out of context with the clinical history provided, for example, an ‘incidental’ rib fracture in an infant, provides a diagnosis that is as important as spotting the lung cancer in an adult: they are both potentially lethal.

The diagnosis of child abuse is complex and imaging plays a large and important role. The consequences of missing II may be dire, if not fatal, but there are significant emotional sequelae if II is erroneously diagnosed. This is a difficult balance to achieve, and multidisciplinary team working is essential. It is important to remember that child abuse can take many forms and whilst physical abuse may manifest as inflicted skeletal injury, the absence of a fracture does not imply the absence of abuse.

Figure legends

Figure 1 Healing rib fractures. 3-month-old female whose twin brother died from inflicted head injury associated with skull and metaphyseal fractures. The co-twin had an acute event, whereas this twin had old rib injuries proving II at different times. (a) AP chest radiograph (arrows), (b) right oblique (arrows) and (c) left oblique (red arrows) show healing fractures of the posterior arcs of the left 8th and 9th ribs and anterior arcs of the right 2nd to 4th ribs. **Do not mistake the sternal segments (white arrows) seen in (c) for the healing rib fractures (red arrows).**

Figure 2 Acute rib fractures. 6-week-old with subdural haemorrhage. (a) Acute rib fractures are not always detectable on AP chest radiographs: however, note the left posterior 8th acute rib fracture (arrow). This was confirmed by healing callus on radiography 2 weeks later.

Figure 3 Skull fractures. 9-month-old female who presented with an unexplained right-sided boggy swelling. Although felt to have been inflicted, compare this simple linear right parietal skull fracture (arrows) seen on the lateral skull radiograph (a) with the wide, branching right parietal fracture seen on the AP (white arrows) (b) and lateral (black arrows) (c) skull radiographs of an 11-week old male who also presented with unexplained boggy swelling (dashed red line). Both skull fractures were inflicted. Branching, wide fractures are complex fractures and imply greater energy than a simple linear parietal fracture[35] and are therefore more suspicious of II in the absence of a confirmed/witnessed accidental history of a high energy impact.

Figure 4 3D reconstruction of brain CT. 8-week-old male whose head impacted the corner of a shelf whilst being held in father's arms. (a) Selected axial slice from an unenhanced CT brain (bone windows) reveals a minimally displaced fracture of the right parietal bone with an overlying subgaleal haematoma (arrow). No intracranial injury. (b) Anterolateral, (c) lateral and (d) posterolateral 3D reconstructions better demonstrate the extent of the fracture that extends from the superior sagittal suture to the right lambdoid suture. The anterior part of the right parietal bone is minimally depressed relative to the posterior fragment. Note that the fracture branches out from a point of impact in keeping with the proffered history and mechanism.

Figure 5 Vertebral fractures. 21-month old female who "fell" from a window; circumstances suggested that she was pushed/thrown. The lateral spine radiograph demonstrates a subtle depression of the superior endplate of T5 (arrow) in keeping with fracture, and also possibly of T4 and T6 (numbered). No rib fracture. The patient also had a concurrent parietal skull fracture. (Wiring crosses L1.) This child died and no further imaging investigations were performed.

Figure 6 Differential diagnosis: Birth injury. Male infant who was delivered by emergency Caesarean section at 30-weeks due to flexed breech position. (a) Radiograph after delivery (day 0) is suspicious for a probable right proximal humeral classic metaphyseal lesion (CML, arrows). (b) Follow-up radiograph on day 19 demonstrates healing bilateral proximal humeral CMLs confirming birth injury (arrows).

Figure 7 Differential diagnosis: Clavicle fracture secondary to birth injury. 8-day-old who presented with poor right arm movements and clavicle swelling and after a difficult vaginal delivery. The injury was not noted at birth however neonatal bony injury is often overlooked on clinical examination. (a) Radiograph reveals displaced fracture of the right midshaft clavicle. Whilst a more recent II is not excluded, the clinical history was consistent with fracture secondary to delivery. (b) Follow-up radiograph taken 3 weeks later confirmed healing injury (arrow). (c) Palpable swelling over the left clavicle two weeks following a difficult delivery in a different patient. The fracture was not noted on postnatal clinical examination. The radiograph taken on day 14 of life reveals periosteal reaction/healing callus. A comprehensive birth history is imperative to ascertain the aetiology of the injury.

Figure 8 Differential diagnosis: Metabolic bone disease. AP both knees in a 1-year old boy with severe rickets. The bones are osteopenic with flayed irregular metaphyses and widened zones of provisional calcification. Note the distal femoral metaphyseal spurs (white arrows) and possible metadiaphyseal fracture of the left proximal tibia (red arrow).

Figure 9 Rickets. 2-year-old male who presented with failure to thrive and irritability. (a) AP chest radiograph done as part of investigation for infection revealed incidental “rachitic rosary” (red arrows) and features of rickets at the left shoulder (white arrow). It is important that “rachitic rosary” is not mistaken for healing rib fractures.

Figure 10 Differential diagnosis: Skeletal dysplasia. (a) AP chest, (b) left upper limb (c) and right lower limb radiographs performed in a neonate aged 1-day. Note the slender ribs, multiple fractures (sustained in utero) and bowing of the long bones. The broad femur is a consequence of multiple healed in utero fractures. (d) AP left femur shows hyperplastic callus at the site of healing fracture with 'popcorn calcification' in a different child with OI type V. Note the 'zebra lines' in keeping with cyclical bisphosphonate therapy and the intramedullary nail.

Figure 11 Wormian bones in OI. (a) Lateral skull radiograph showing multiple Wormian bones in the occipital bone in a 1-day old child with OI type III – the same child as Figure 10 (a-c). Note also the thin skull. (b) AP skull radiograph showing Wormian bones in a different child with OI type III.

Tables

Table 1

Features of skull fractures that are highly suspicious of inflicted injury[40].

- Non-parietal skull fractures (parietal skull fractures are more in keeping with accidental injury, although can be seen in II)
- Sutural diastasis
- Fractures crossing suture lines, thereby involving multiple bones
- Depressed fracture with a break in the cortex (compare with the "ping pong" fracture in which there is deformation but no cortical disruption)
- Bilateral fractures (have a higher association with II but this does not exclude high energy accidental trauma)

These features all imply significant force (equivalent to a fall from a height greater than 5 feet/1.5 metres).

Table 2

Conditions associated with Wormian bones best remembered by the mnemonic PORKCHOPS[103].

- P – pyknodysostosis
- O – osteogenesis imperfecta
- R – rickets
- K – kinky hairy syndrome (also known as Menkes disease)
- C – cleidocranial dysplasia
- H – hypothyroidism, hypophosphatasia
- O – otopalatodigital syndrome
- P – primary acro-osteolysis (also known as Hajdu-Cheney), pachydermoperiostosis
- S – syndrome of Downs (trisomy 21)

Table 3

Summary table of fracture dating.

Site of fracture	**Nature**	**Periosteal reaction**	**Soft tissue swelling**	**Notes**
Diaphyseal	Acute	-	+ or -	If there is periosteal reaction, it was likely
Rib				

				sustained in the preceding 10-14 days Soft tissue swelling overlying the long bones (not the ribs) develops within the first 24 hours
Diaphyseal Rib	Healing	+	-	Periosteal reaction usually present around day 7-10 (rarely by day 4, always by day 14) Heal completely by 3 months
Metaphyseal	Acute/Healing	- + (If associated with shaft injury, – SPNBF)	-	Difficult to date Usually heal by 4 weeks and always by 6 weeks
Skull	Acute	-	If +	Recent injury <2 weeks, will fade over several months
		-	If -	Could be chronic or acute (less likely)

+ = present. - = absent. SPNBF = subperiosteal new bone formation

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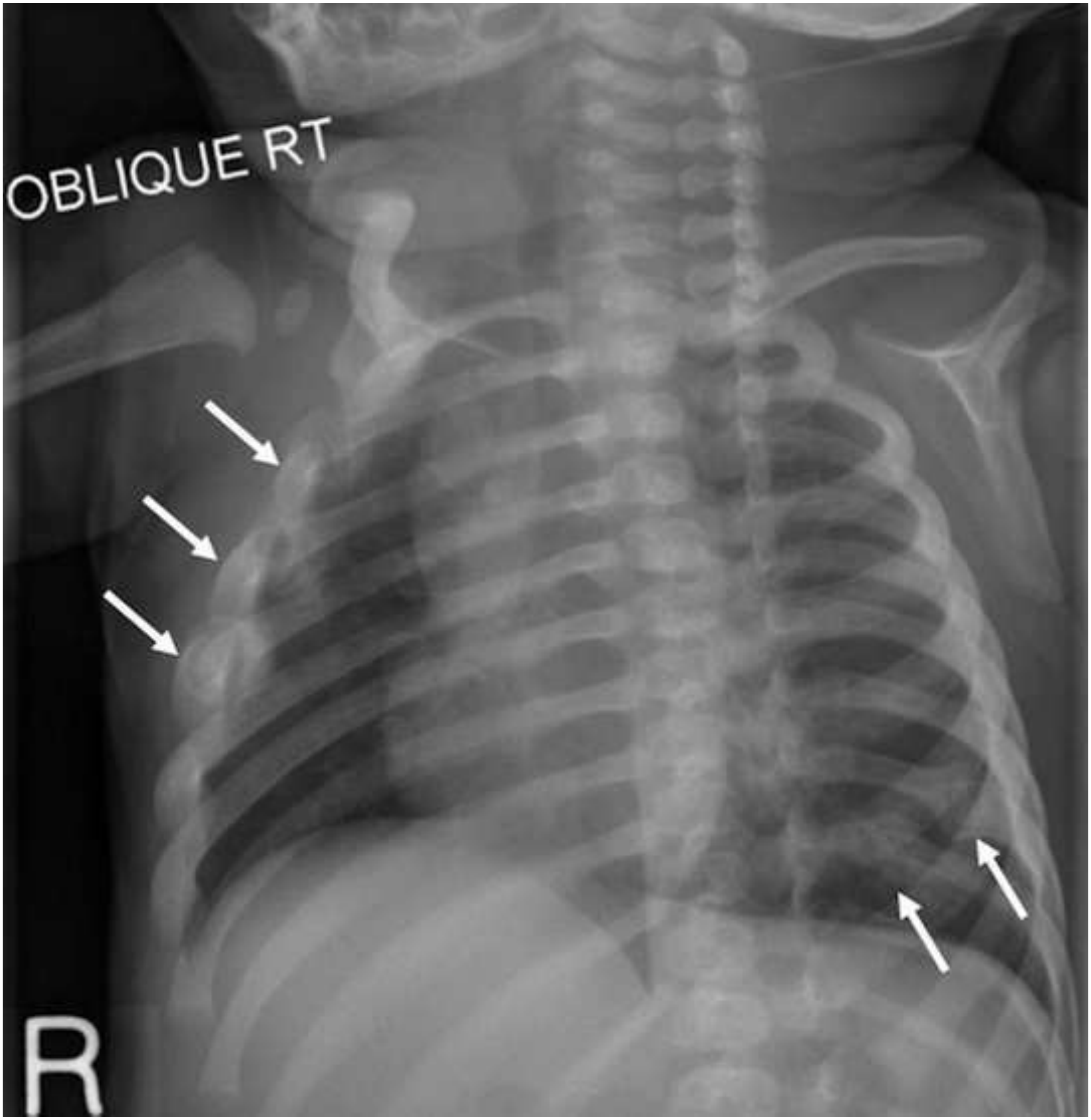
Fig 1a

Fig 1b



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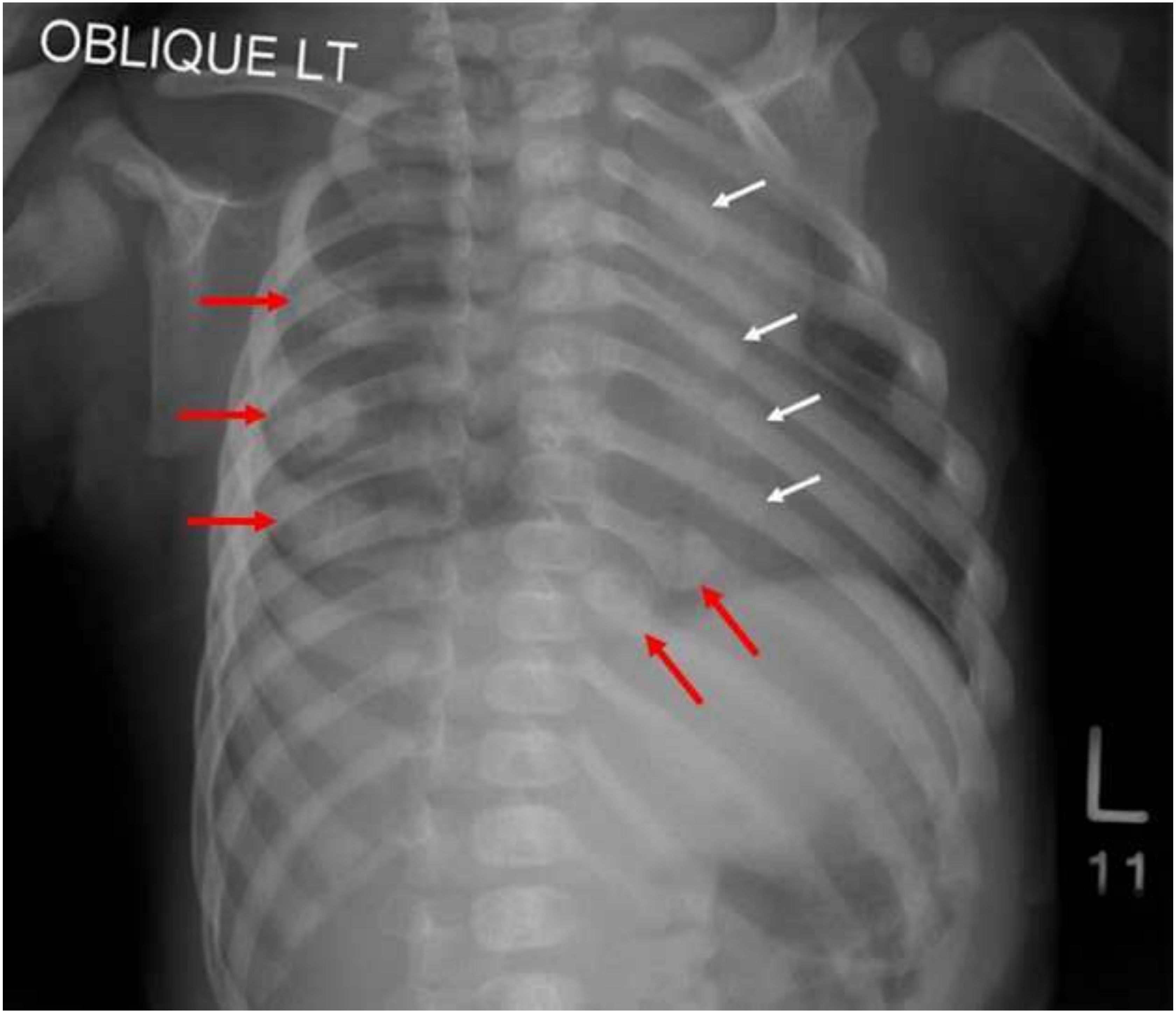

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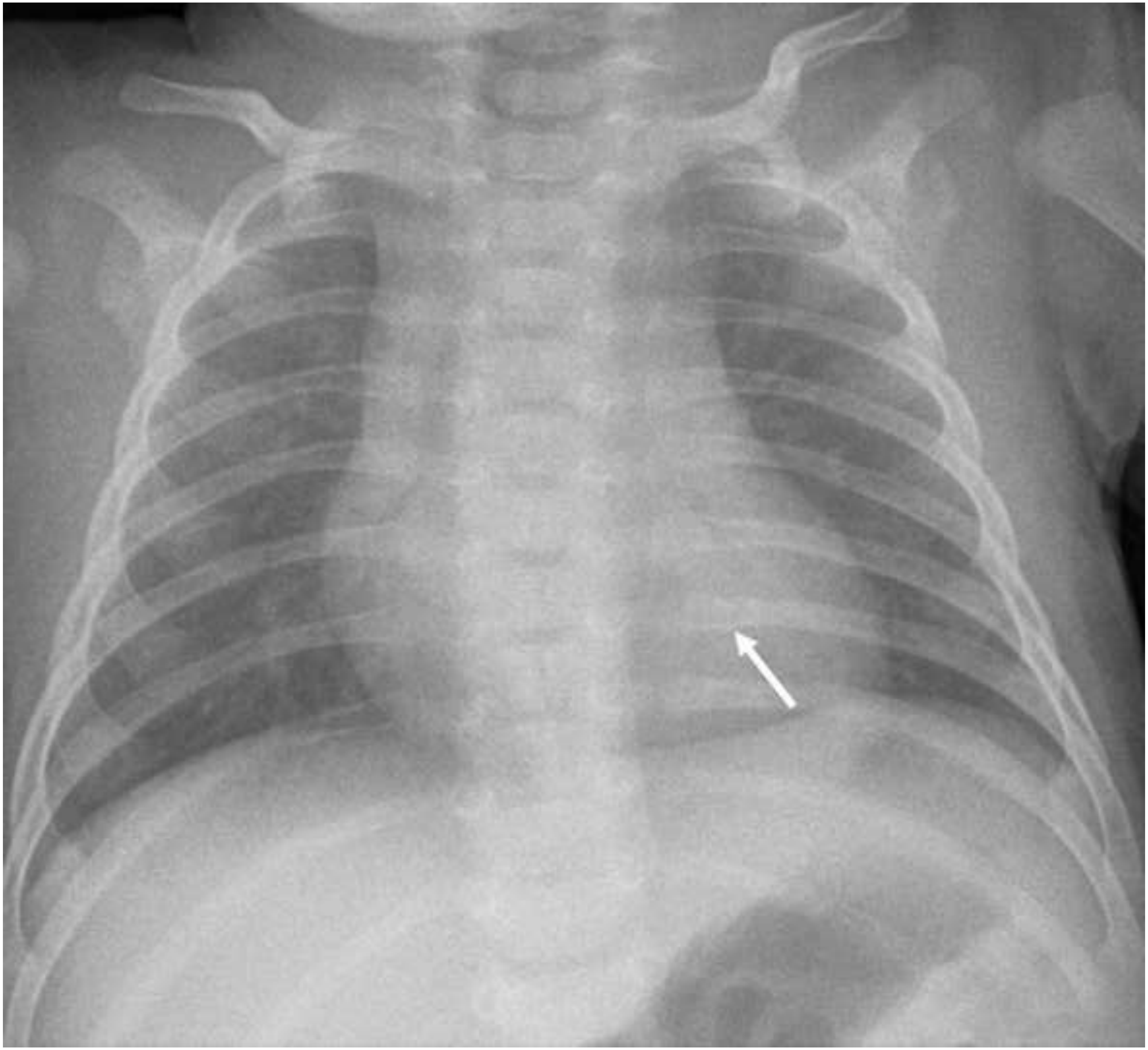

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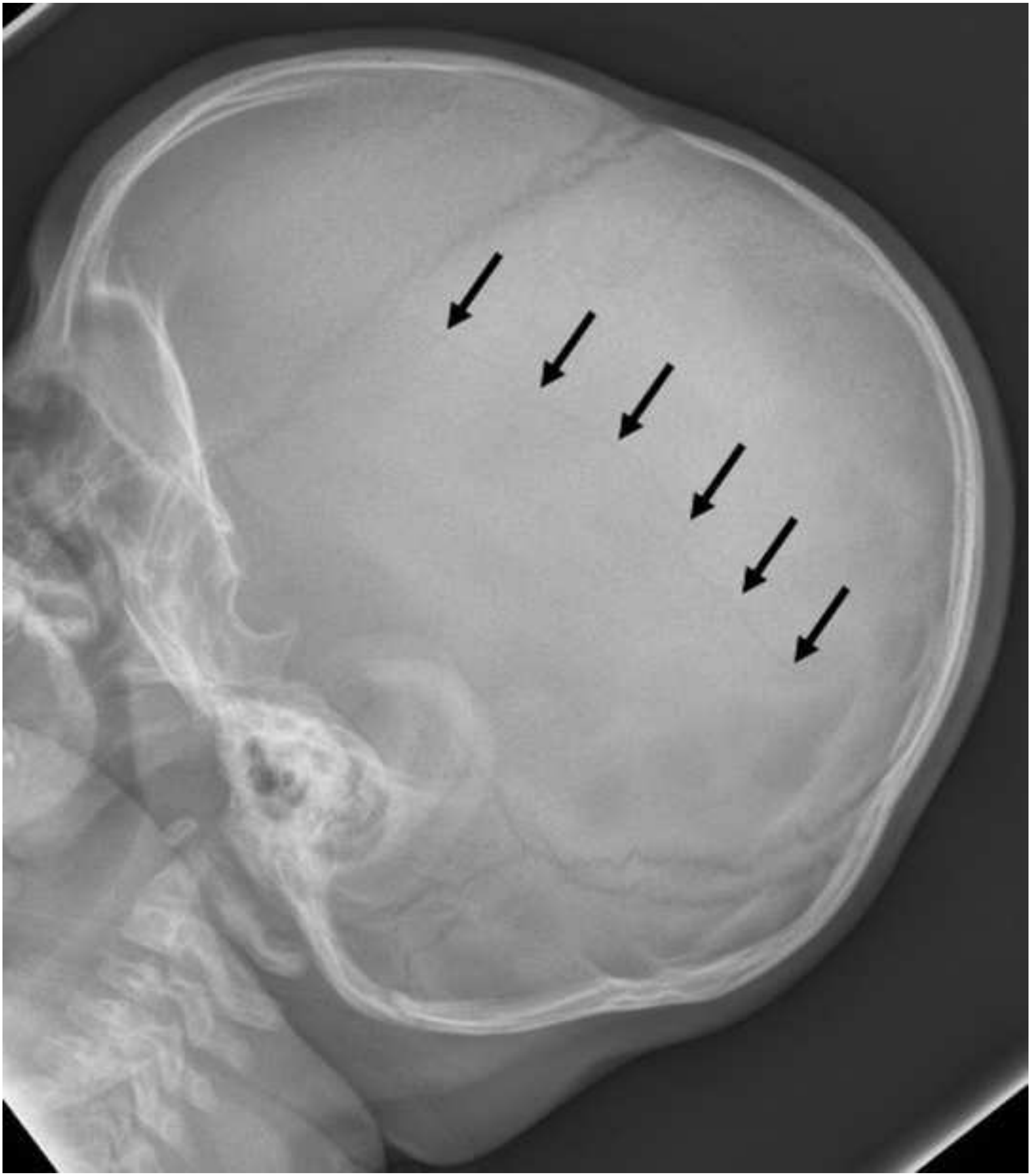

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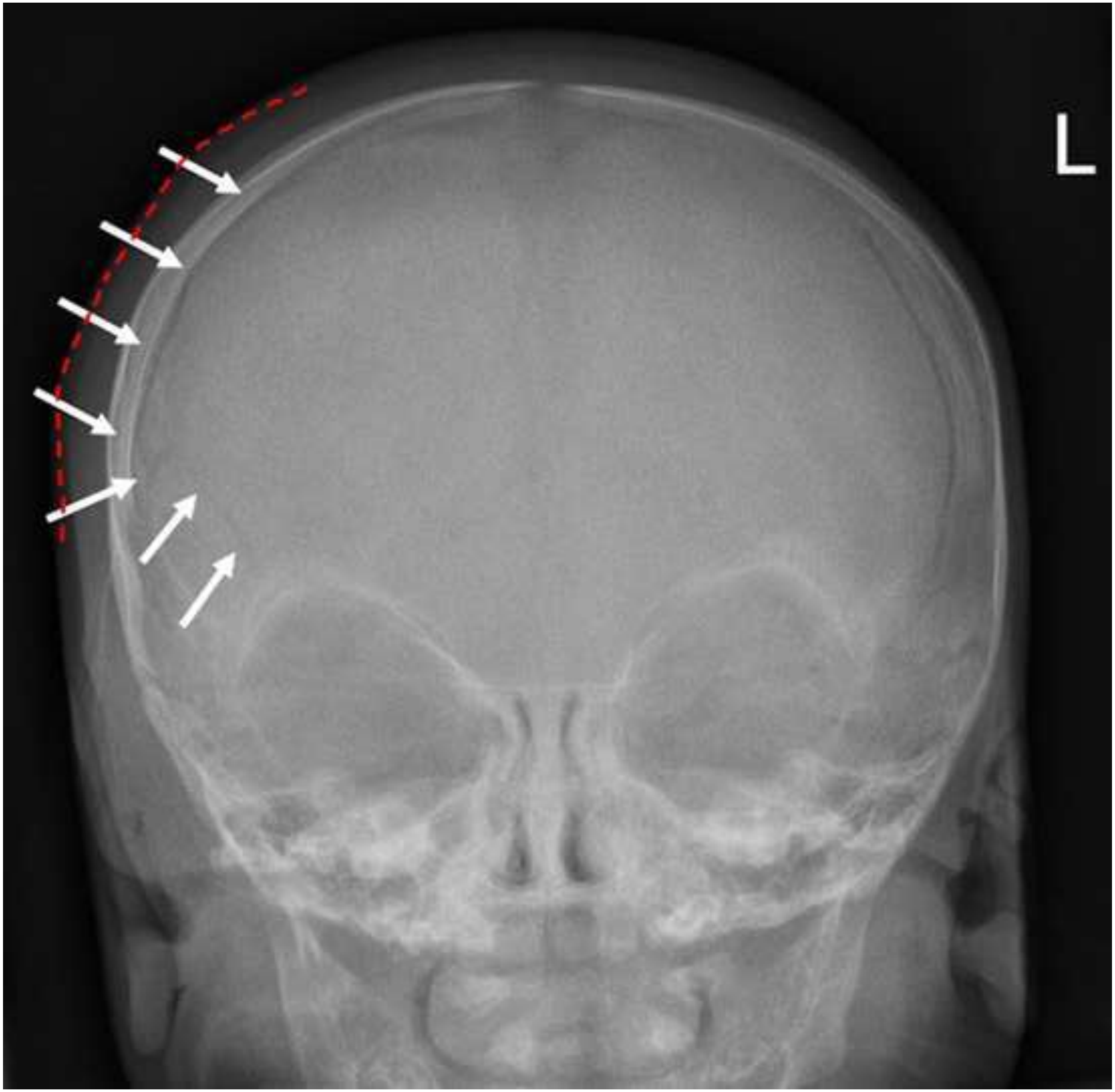

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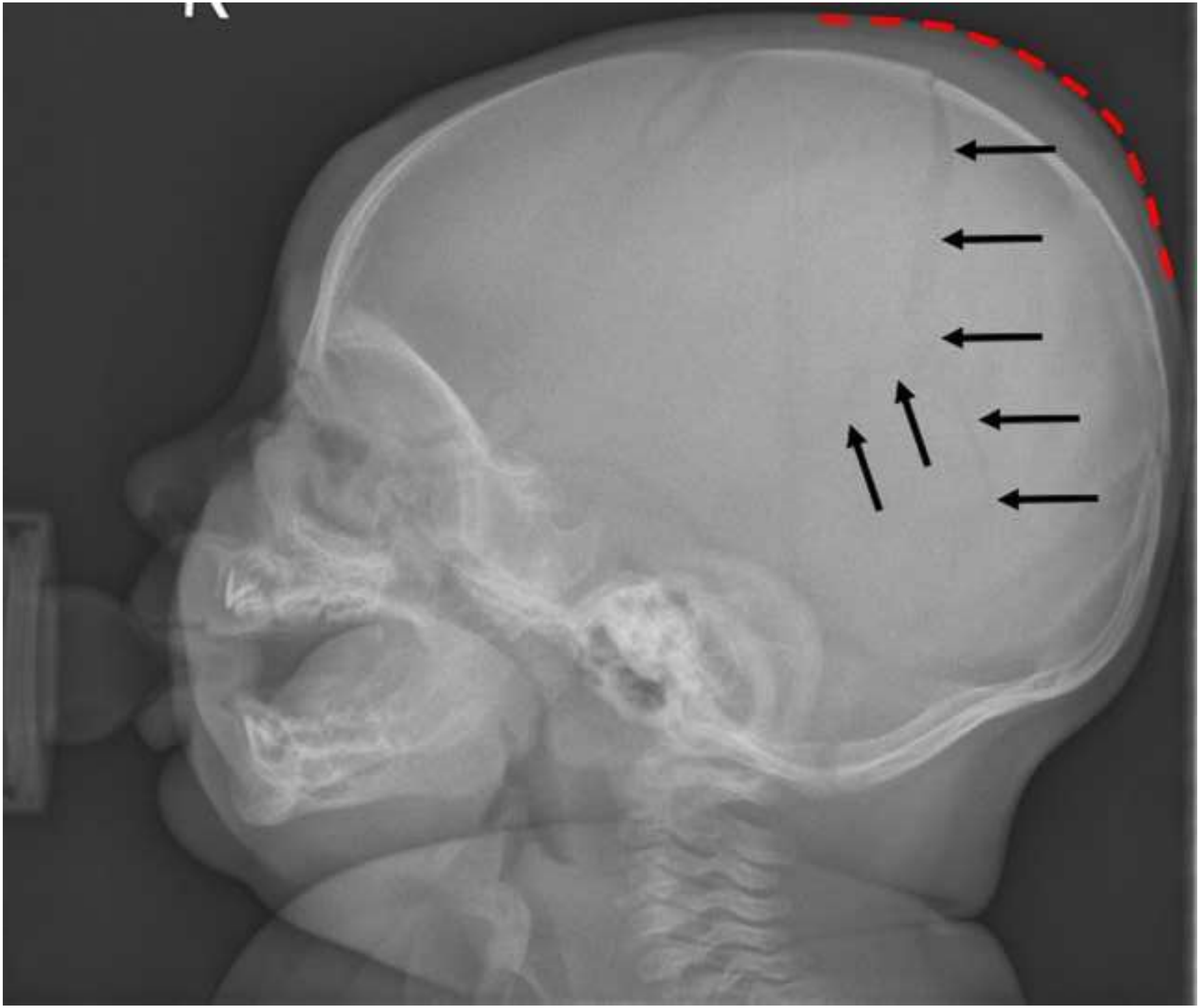

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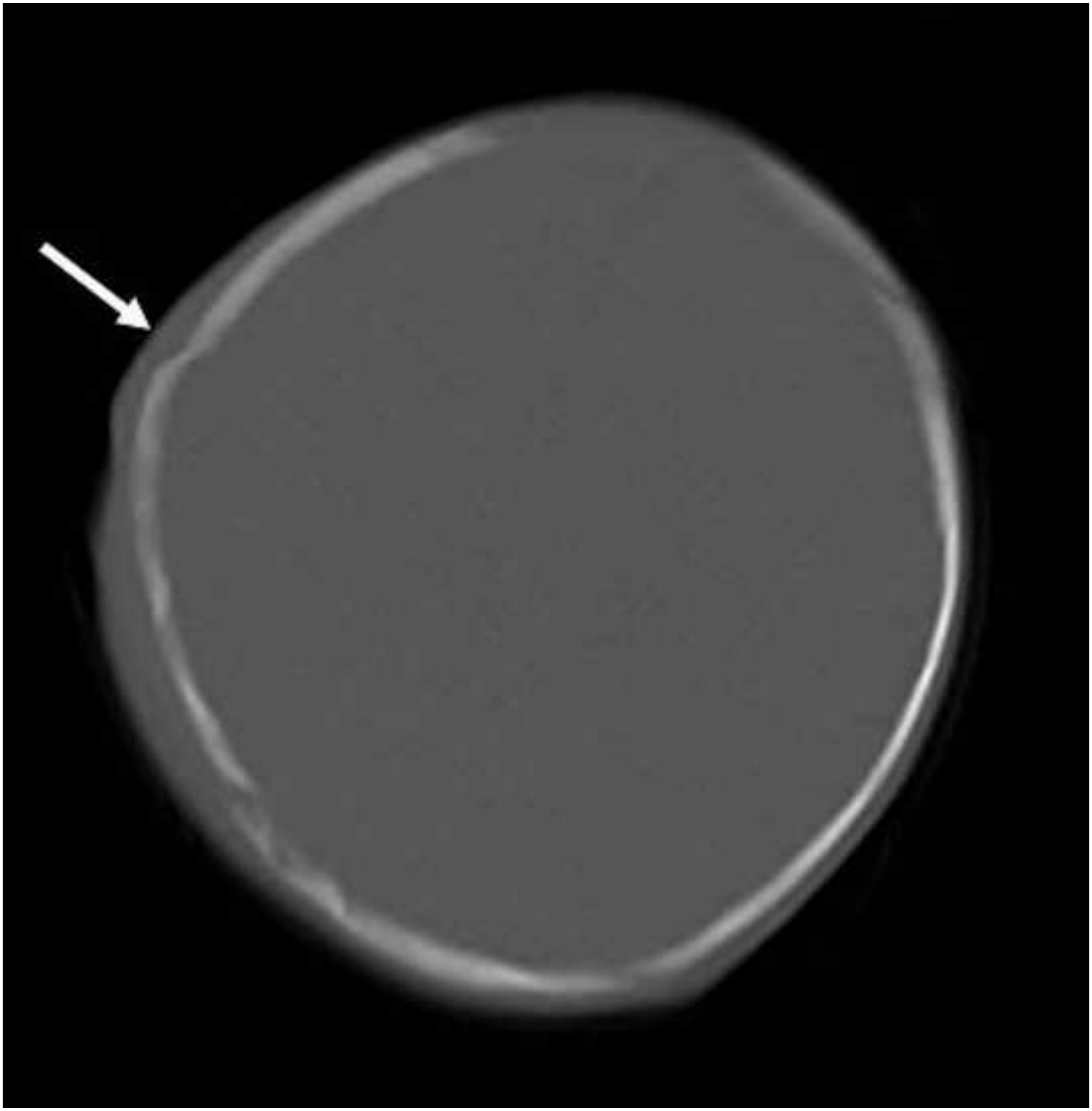

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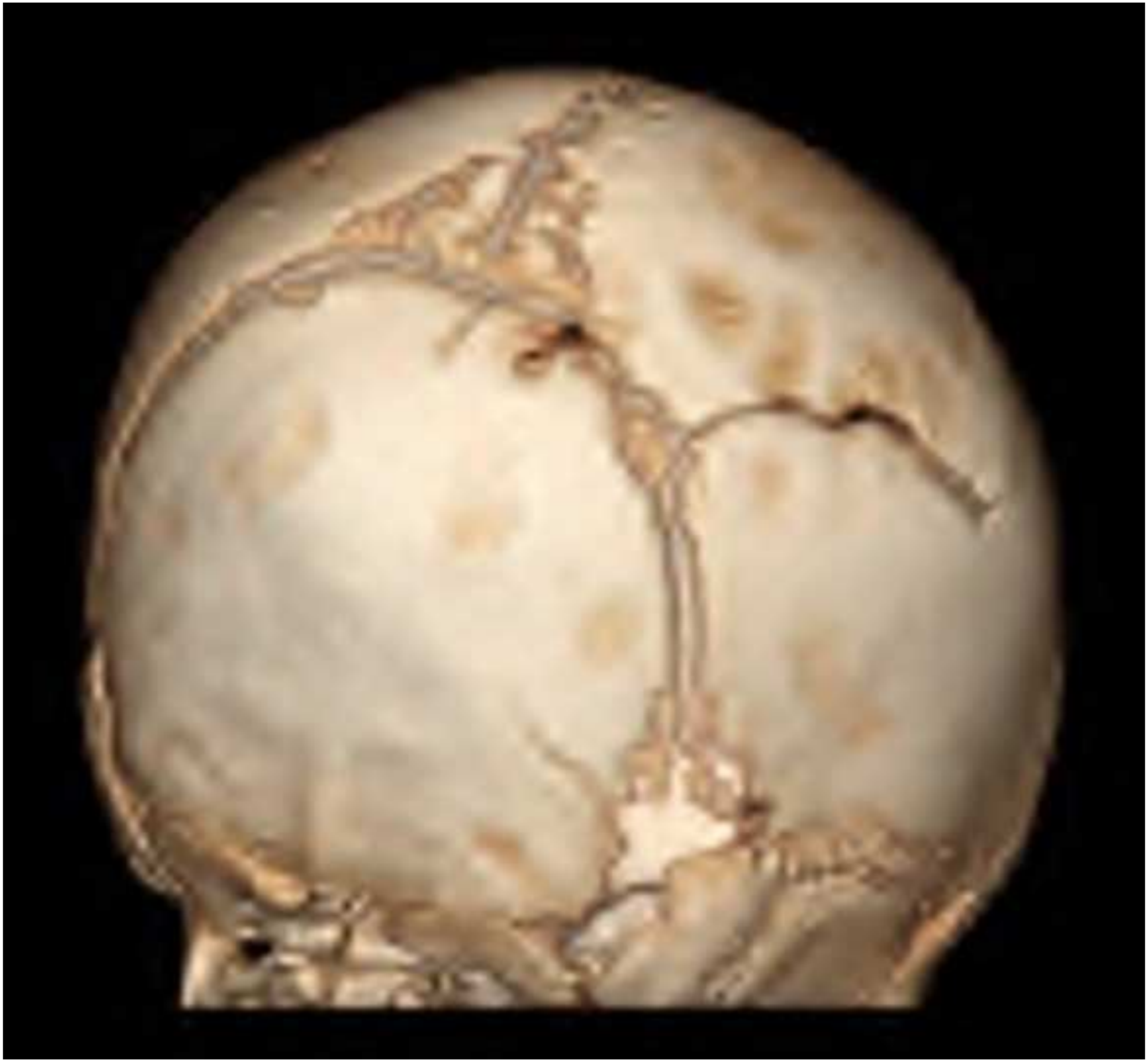

Fig 5

Fig 6a

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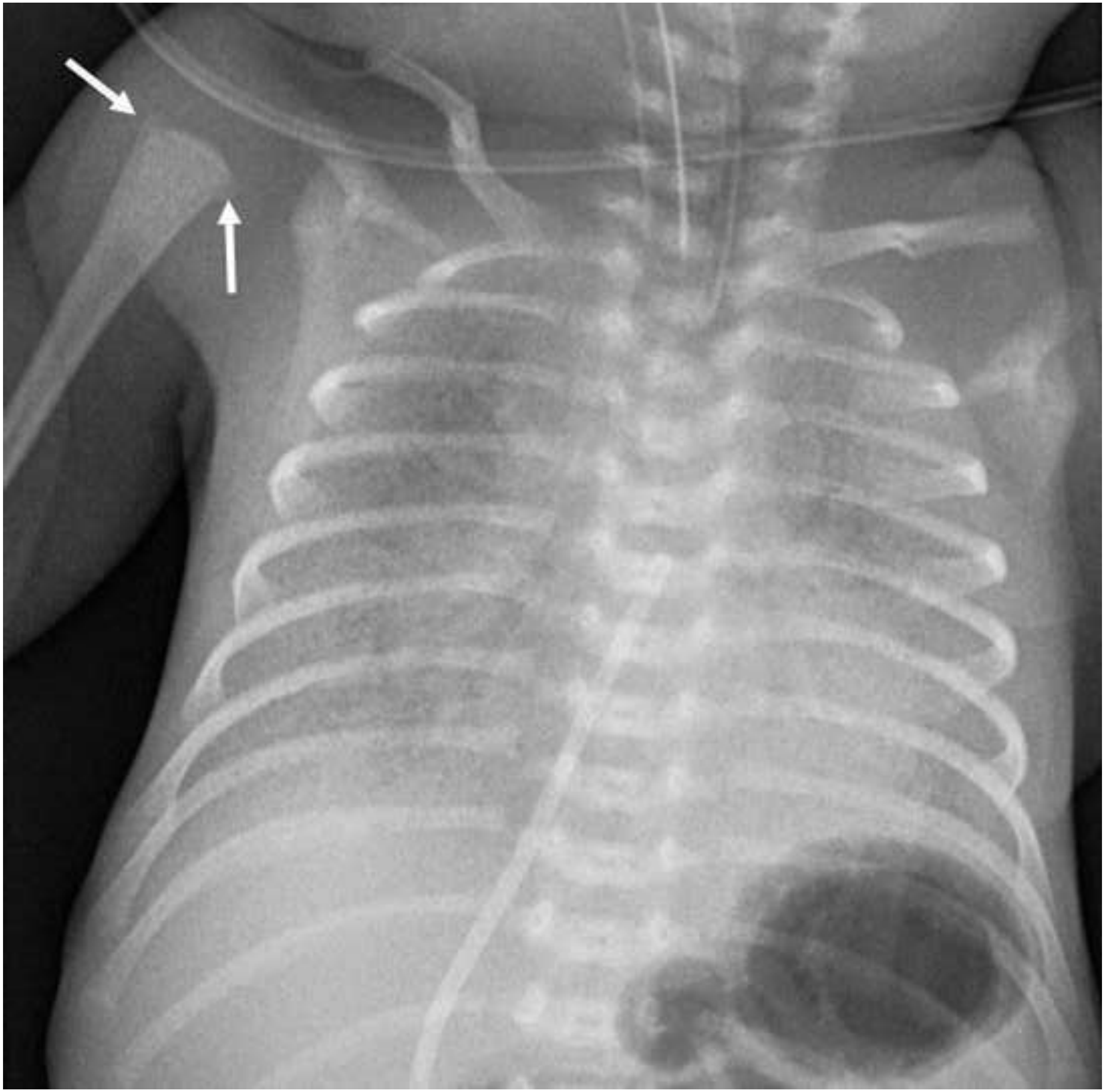

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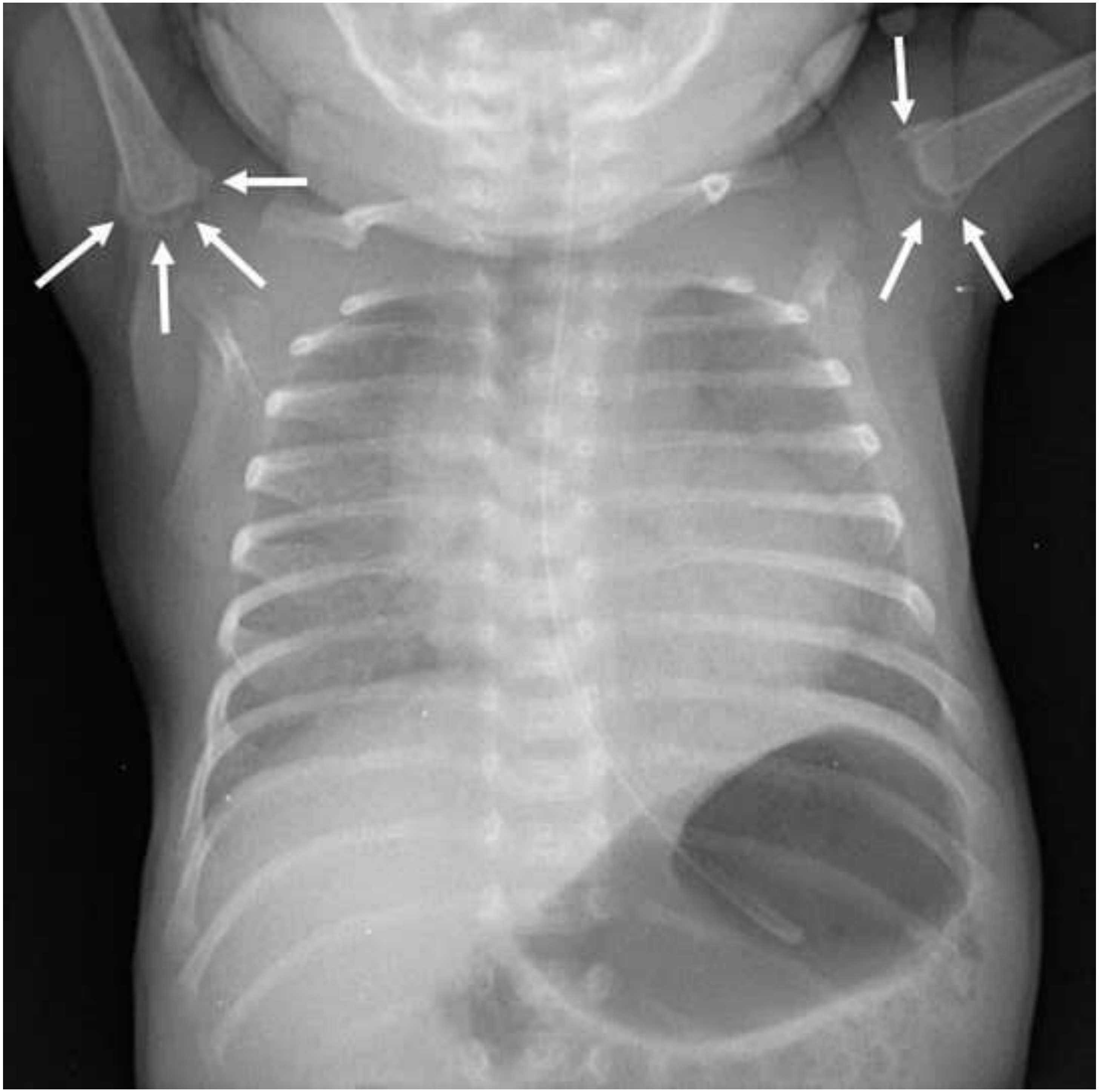

Fig 7a

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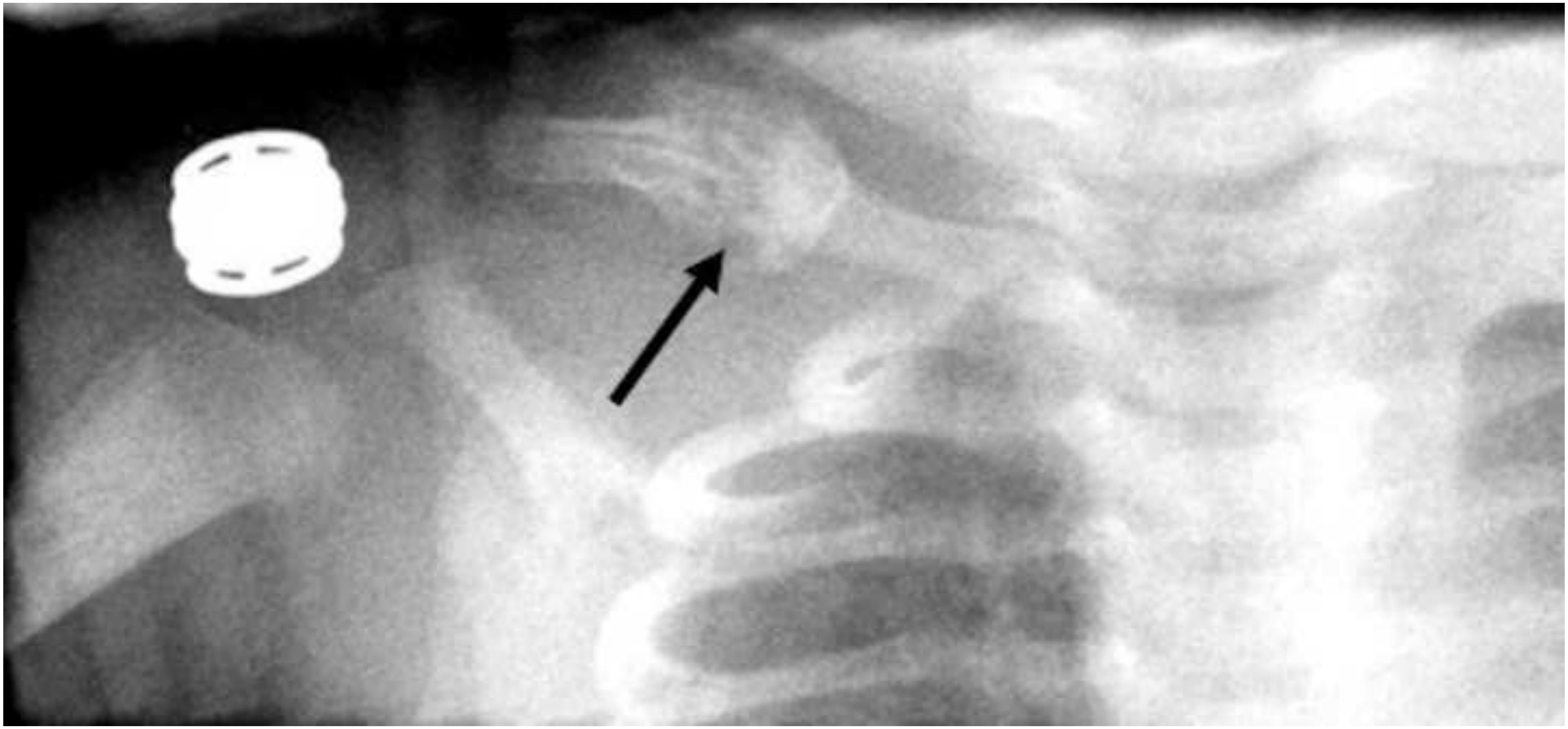

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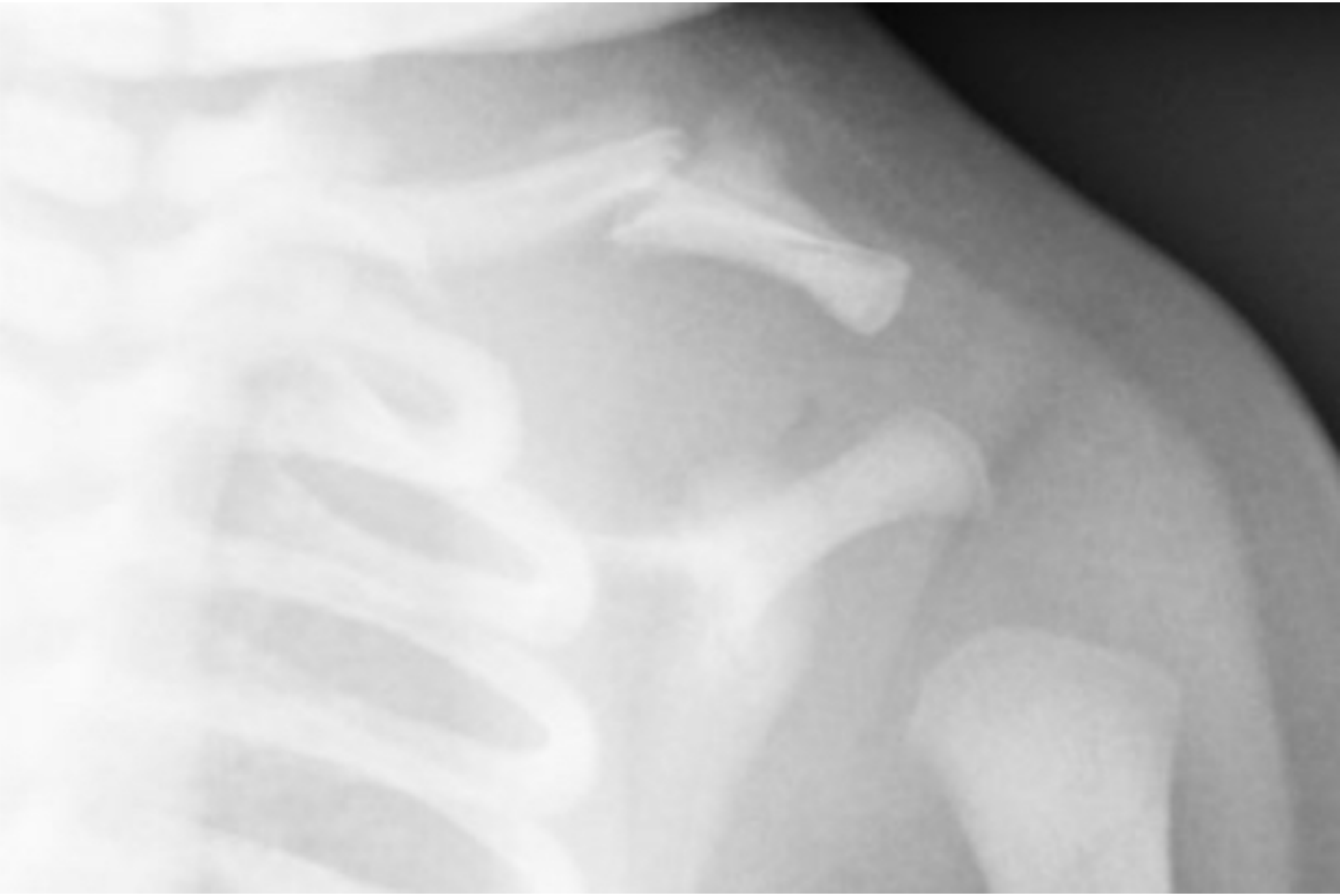

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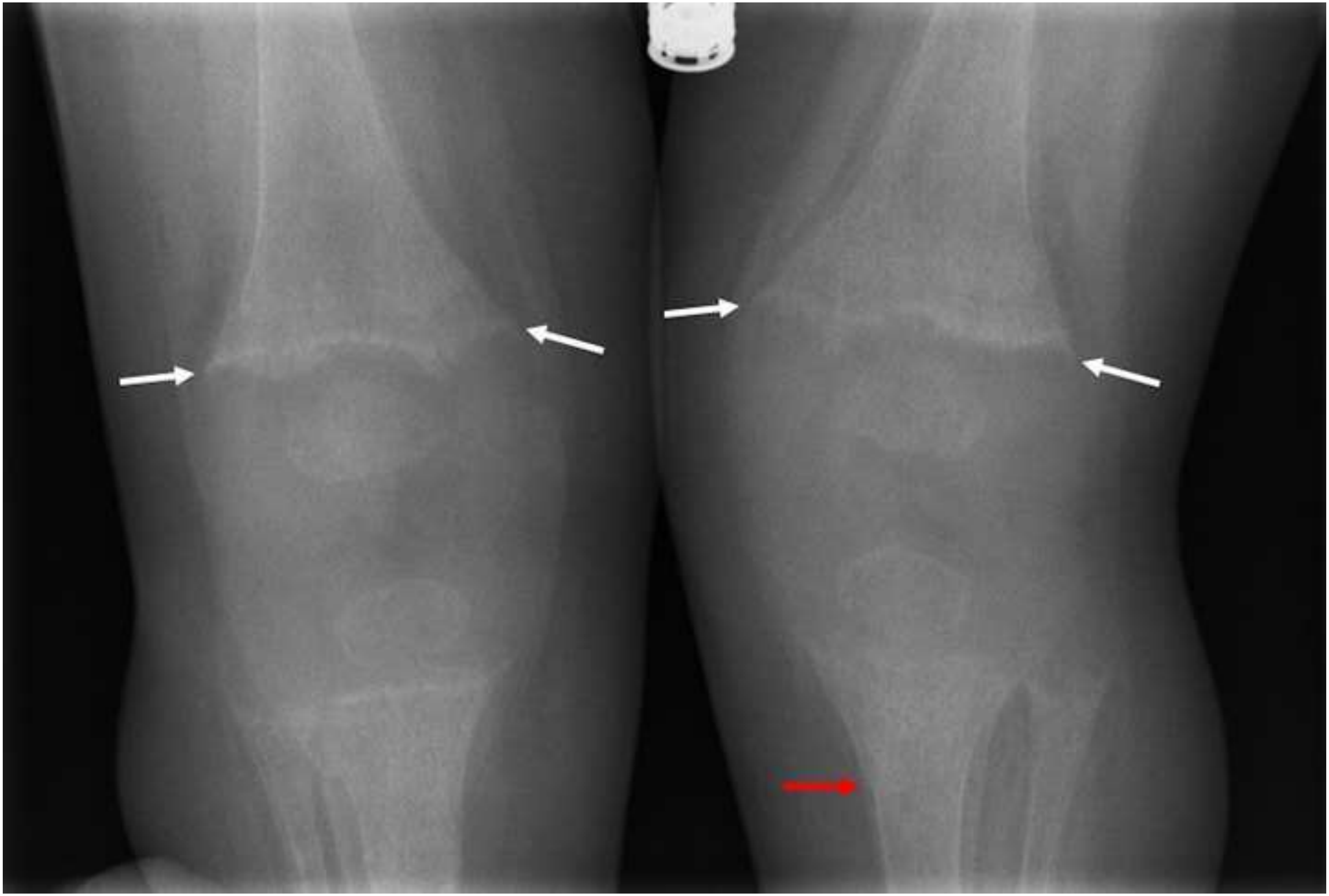

Fig 9

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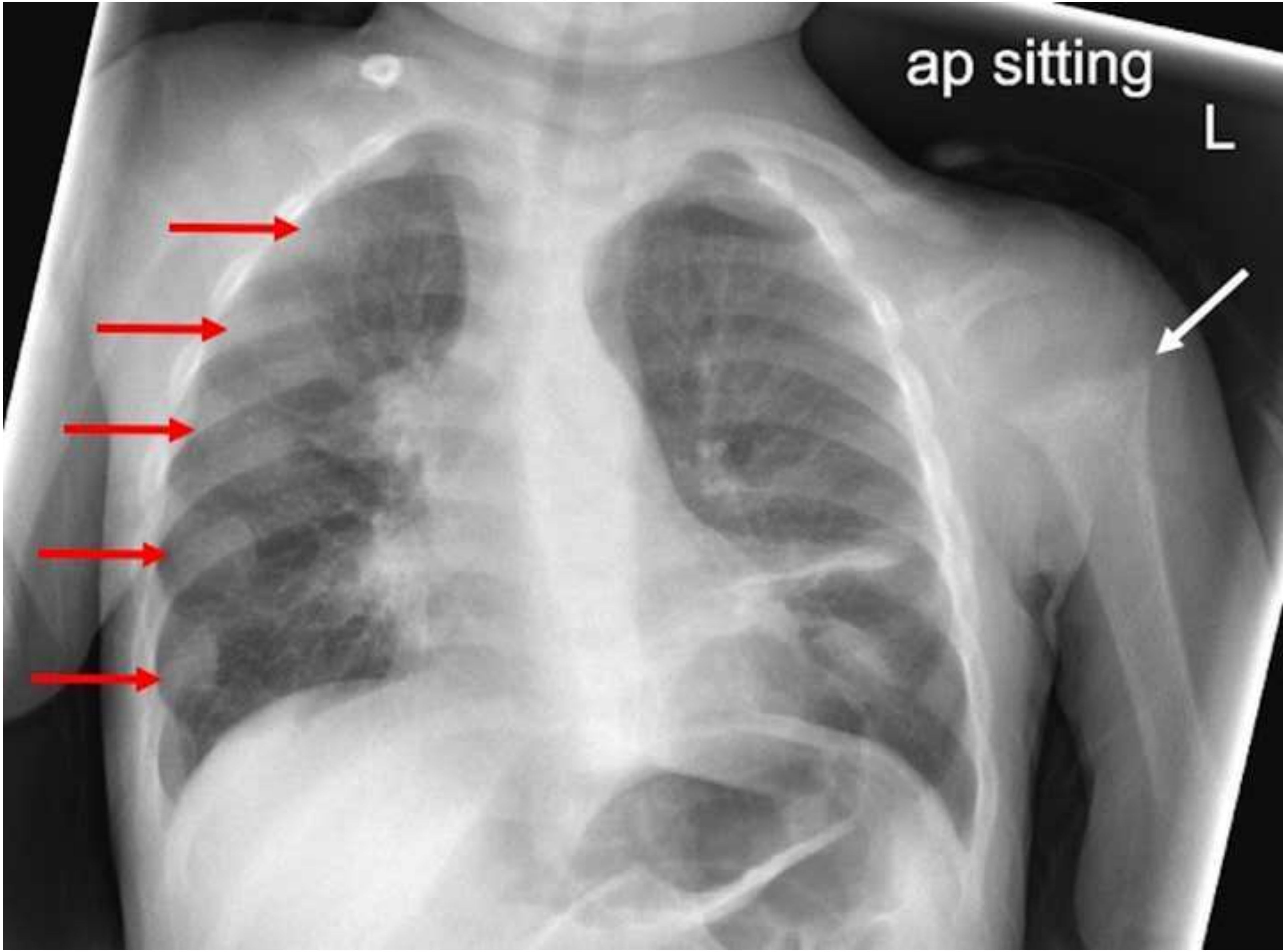

Fig 10a

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Fig 10b

Fig 10c

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Fig 10d

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Fig 11a

Fig 11b

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