Orthopaedic aspects of paediatric non-accidental injury

P. Jayakumar, M. Barry, M. Ramachandran

From Barts and The London NHS Trust, London, England

Non-accidental injury (NAI) in children includes orthopaedic trauma throughout the skeleton. Fractures with soft-tissue injuries constitute the majority of manifestations of physical abuse in children. Fracture and injury patterns vary with age and development, and NAI is intrinsically related to the mobility of the child. No fracture in isolation is pathognomonic of NAI, but specific abuse-related injuries include multiple fractures, particularly at various stages of healing, metaphyseal corner and bucket-handle fractures and fractures of ribs. Isolated or multiple rib fractures, irrespective of location, have the highest specificity for NAI. Other fractures with a high specificity for abuse include those of the scapula, lateral end of the clavicle, vertebral and complex skull fractures.

Injuries caused by NAI constitute a relatively small proportion of childhood fractures. They may be associated with significant physical and psychological morbidity, with wide-ranging effects from deviations in normal developmental progression to death.

Orthopaedic surgeons must systematically assess, recognise and act on the indicators for NAI in conjunction with the paediatric multidisciplinary team.

The concept of inflicted injury in children was first introduced by Caffey in 1946.1 Non-accidental injury (NAI) affects children from all cultural and socioeconomic backgrounds worldwide. Physical abuse in children is largely manifested by fractures and soft-tissue injuries such as bruises, bites and burns.2-4 Fractures in children are primarily due to falls, road traffic accidents, sport and other forms of accidental trauma. Although fractures caused by NAI constitute a relatively small proportion of all childhood fractures, they are an important diagnostic challenge for clinicians and, if missed, lead to serious physical, psychological and social implications. The aspects of development include physical, intellectual, emotional, behavioural and social. Paediatric NAI is stated to involve acts of commission or omission which directly or indirectly cause harm to the child, with wide-ranging negative effects on normal development progression to serious injury and death.4 Unfortunately, NAI is probably under-diagnosed in clinical practice.5

Orthopaedic surgeons eventually review up to a third of abused children and approximately a third investigated for suspected abuse are diagnosed with fractures. These are often occult due to the nature of presentation and the limitations of obtaining histories from children.3,6-8 Therefore, it is essential to recognise the musculoskeletal manifestations of NAI, begin appropriate treatment and initiate formal child protection procedures. It is necessary to undertake a thorough assessment, a clinical and psychosocial history, examination and investigation. General and specific factors must be recognised at each stage. Ultimately, undiagnosed or unrecognised children with NAI are at greater risk of further abuse and death.

Clinical history

The general aspects of a history with suspected NAI include a vague, inconsistent, inexplicable or unwitnessed mechanism of injury in relation to the clinical findings or developmental age. Significant delays before seeking medical attention may occur alongside evasive, aggressive or unusual parental responses. Features of outright neglect may be apparent. A birth and past medical history, including details of gestation, delivery and birth trauma, developmental milestones, medical conditions and treatment, such as coagulopathies, leukaemia or connective tissue disorders, are essential. A past injury and social history, including details of attendance at emergency departments and previous concerns for health or social care, must also be obtained. Lower socioeconomic status and unplanned pregnancy are known risk factors for non-
accidental fractures. Twins, pre-term children or those with special needs are also at increased risk.

Specific aspects of the history include the developmental stage, the mechanism of injury, fracture-related factors and the differential diagnosis. In general, the younger the child, the greater the likelihood of abuse. The majority of fractures in NAI occur in children under two years of age, and 25% to 56% in children under the age of one. In particular, infants younger than four months with fractures are more likely to have been abused. Comparative studies with normal paediatric populations are limited. One such showed that 80% of children sustaining non-accidental fractures were less than 18 months old, whereas 85% of genuine accidental fractures occurred in children over five years of age. In terms of motor developmental, abuse-related fractures are less likely in the toddler and more common in those who have not yet walked, unless other features of abuse are present.

The mechanisms of physical abuse specific to fractures are direct or indirect and include isolated episodes or combinations of punches, kicks, blows, shaking, twisting, pulling, pushing and throwing. The mechanism of injury must consider heights, forces and surfaces involved. Non-accidental fractures indicate a significant assault on the child, irrespective of the energy level of the injury. Fracture-related factors include normal physiological and anatomical variants of the skeleton, such as periosteal new bone formation and metopic sutures, accidental injury, iatrogenic injury, birth-related fractures and predisposing skeletal pathology, including metabolic disorders such as copper deficiency or rickets, osteopenia of prematurity, chronic illness and failure to thrive, connective tissue disorders such as osteogenesis imperfecta and Caffey’s disease, infective disorders such as osteomyelitis and syphilis and neoplasms. Osteopenia of prematurity and osteogenesis imperfecta are the most commonly recognised causes of bone fragility in infancy, with the former occurring predominantly in the first 24 months. Risk factors for fractures in prematurity include cholestatic jaundice, chronic lung disease, physiotherapy, more than two weeks of diuretic treatment and more than three weeks of intravenous nutrition. However, it is important to be aware that NAI and these differential diagnoses can coexist.

Clinical examination
General findings include an altered level of consciousness, problems with the airway, apnoea or difficulty in breathing, seizures and failure to thrive. Specific orthopaedic features of NAI include soft tissue and skeletal injuries. Assessment of pain, swelling, deformity, reduced range of movement, altered function and ability to weight-bear must be adapted to the age of the child.

Bruising is the most common manifestation of NAI. The frequency of bruises correlates with increased mobility in children. However, features of abuse include bruises away from bony prominences, larger bruises, specific shapes of bruise caused by implements and multiple or clustered configurations of bruising. There may be a positive correlation between bruising and fractures, suggesting that forces capable of fracturing bone result in external, visible soft-tissue injury. Conversely, a lack of bruising in association with a fracture may imply inherently weak bone, increasing the likelihood of metabolic bone or connective tissue diseases such as copper deficiency or osteogenesis imperfecta. However, the majority of children presenting with acute accidental fractures have minimal bruising, if any, near the fracture zone at initial presentation. Bruising has been shown to occur more commonly in fractures of the skull compared to those in ribs or extremities. It is therefore a poorly sensitive, highly variable feature, especially when deep soft-tissue envelopes are involved.

Skeletal injury
Notwithstanding the extensive data on accidental paediatric fractures, comparative studies with abuse-related fractures are limited. The most common accidental fractures in children are in the distal radius and ulna. In general, the incidence of fractures increases with age, particularly in the clavicle, distal humerus, distal radius and metacarpals. The prevalence of non-accidental paediatric fractures is variable and depends on age. Up to a third of children investigated for NAI have a fracture, with prevalence rates ranging between 11% and 56%, . Fractures related to abuse have been classified into those with a high and a low specificity for abuse (Table I). Fracture types associated with a high specificity for abuse include metaphyseal, bilateral and complex skull fractures as well as fractures of different ages in the same patient. The fracture locations with a high specificity for abuse include those of the ribs, scapula, lateral end of the clavicle and vertebrae. In a systematic review using probability scoring and identifying distinguishing characteristics of
non-accidental fractures, ribs were shown to have the highest probability for abuse, followed by humeral, femoral and skull fractures. The long bones most frequently injured in abuse are the femur, tibia and humerus.

Multiple fractures are sustained by only 1.2% of children and there is a strong correlation with NAI. In a comparative series, 74% of abused children sustained two or more fractures compared to 16% in non-abused children. In another retrospective series, 66% of a cohort of abused children sustained multiple fractures, including the skull, metaphyses, ribs and long-bones in order of increasing incidence.

Systematic reviews indicate that rib fractures, particularly if multiple and presenting without a clear history and explanation, have the highest specificity for abuse. Their incidence is between 5% and 27%, with a 100% positive predictive value for NAI when all other causes have been excluded. Whereas cardiopulmonary resuscitation may cause rib fractures, a recent systematic review reported a post-resuscitation rate of less than 2%, most in the anterior chest wall. Anterior and costochondral rib fractures have been shown in 0.5% of resuscitated children, and although associations between anterior and, more commonly, posterolateral rib fractures and NAI have been reported, apart from bilaterality and multiple fracture configurations, there are no other clear correlations between types, locations and abuse.

Skull fractures are common in children under the age of three and are more often reported after non-abusive trauma (Fig. 2). Of abuse-related fractures, 88% occur under the age of one year. Although the probability that skull fractures are related to abuse is lower than with rib and most extremity fractures, victims of these high-energy injuries have a higher mortality rate. In particular, there is a strong association between serious intracranial injury in children and physical abuse, with intracranial haemorrhage being one of the most common causes of death in NAI. Multiple, complex, diastatic, depressed and bilateral fractures crossing suture lines have variably been associated with an increased likelihood of NAI after the exclusion of alternative causes. However, the most conclusive finding is that linear fractures of the parietal bone are the most common type and site in both accidental and non-accidental injury.

Diaphyseal fractures are four times more common than metaphyseal injuries in NAI. Epiphyseal fractures are rare, owing to containment by periosteum. Periosteal reaction itself is a common feature of fracture repair in NAI, and a rough grip may be enough to cause periosteal new bone formation. However, this must be distinguished from the physiological smooth, lamellar, symmetrical periosteal reaction occurring between six weeks and six months, and differential diagnoses such as metabolic bone disease or osteomyelitis should be excluded.

Femoral fractures are traditionally associated with NAI. Systematic reviews suggest that they occur more commonly in abuse than either tibial or fibular fractures, with the midshaft being the commonest site in both acci-
Another study demonstrated a spiral pattern to be the most common abuse-related femoral fracture in children under 15 months. However, there is no reproducible or clearly demonstrable association between specific fracture patterns in the femur and NAI. Femoral fractures in children under the age of one and tibial and fibular fractures in those under 18 months regardless of type are highly suggestive of abuse and intrinsically related to those who are not independently mobile.

In toddlers under 15 months, humeral fractures of all configurations, excluding supracondylar fractures, have a strong association with NAI, after the exclusion of other accidental causes. Linear fractures are recognised as the most common type overall i.e., in accidental and abuse-related fractures. Spiral fractures are generally uncommon and have been strongly linked with abuse, although some studies have indicated that spiral and oblique fractures are more frequent in children under 15 months old. Humeral supracondylar fractures have been reported in abuse, but systematic reviews suggest a weak association with NAI, with prevalence increasing once walking is achieved. Some studies have highlighted a strong incidence of abuse-related forearm fractures, and fractures other than greenstick types in the forearm, for example metaphyseal chips and transverse patterns, are more likely to be due to abuse.

Metaphyseal fractures in infants are relatively rare, but can occur from indirect forces on the limbs, including shear and acceleration-deceleration forces. Their incidence ranges from 11% to 28% and they are often multiple. They have been associated with birth injury, physiotherapy, and casting for talipes in the neonatal period. However, outside this period and under the age of two, metaphyseal fractures are highly specific for NAI and are related to the subperiosteal bone collar. This collar in the metaphysis is a frequent, normal finding in infants and is described as a protective ‘spur’ or ‘step-off’ beyond the physis. In post-mortem radiological and histopathological analysis of fracture specimens in children, a typical morphological pattern of transmetaphyseal fractures occurs through the weak zone of provisional calcification of the physis. Such fracture lines classically extend away from the physeal chondro-osseous junction, approach the cortex and undercut a fragment of bone with a collar that is thicker peripherally than centrally and which includes subperiosteal bone.

Investigations

Investigations to exclude the diagnosis of abusive orthopaedic injury include biochemical testing for bone profiles and metabolic markers of bone disease such as calcium, phosphate, alkaline phosphatase, copper, caeruloplasmin, magnesium, fasting 25-hydroxyvitamin D and parathyroid hormone. Osteogenesis imperfecta is diagnosed by genetic testing (mutation analysis of RNA/DNA) and biochemical
Fig. 4

Femur radiograph showing an oblique diaphyseal fracture in conjunction with a metaphyseal distal femoral bucket-handle fracture (arrow) in a one-year-old following a twisting injury.

Fig. 5

Knee radiograph showing metaphyseal distal femoral and proximal tibial bucket-handle fractures (arrows) in a 14-month-old infant following an unknown injury mechanism.

Fig. 6

Diagrammatic representation of the relationship of the subperiosteal bone collar to a metaphyseal lesion (from Kleinman and Marks). A) A tangential view of the metaphyseal margin, demonstrating a fracture line that extends adjacent to the chondro-osseous junction centrally. Peripherally, the fracture line (arrows) veers away from the growth plate to undermine a larger peripheral fragment incorporating the subperiosteal bone collar. b) When the fracture line (arrows) is projected obliquely, the thicker peripheral fragment, including the subperiosteal bone collar, is projected as a curvilinear fragment or a bucket-handle lesion. c) When the fracture line (arrow) is incomplete (it extends across only a portion of the metaphysis). The appearance suggests a focal, triangularly shaped peripheral fragment encompassing the subperiosteal bone collar. d) When the fracture line (arrow) is tipped obliquely, the peripheral margin of the fragment is projected as a curvilinear density (reprinted with permission from the Journal of Bone and Joint Surgery [Am]).

Analysis of collagen conformation by skin biopsy. In 2008, the Royal College of Radiologists and Paediatrics and Child Health published a joint report containing guidelines on skeletal imaging in suspected NAI. Full skeletal surveys are recommended in children under two years to diagnose occult fractures, with optimal detection requiring high-quality radiographs reported by designated paediatric musculoskeletal radiologists. The report clearly states the required views for a standard child protection skeletal survey (Table II). For example, diagnosis in detecting acute and occult fractures can be improved by using oblique projections for ribs and bone scintigraphy. The detection of rib fractures using standard projections may be difficult owing to superimposition of transverse processes over fracture sites, frac-
Skeletal surveys, and there is increasing neuroradiological state that CT head scanning be considered in addition to all. Recent from old. Therefore, the orthopaedic surgeon should reassess each case periodically and be proactive in surveillance, repeating radiographs and skeletal surveys, for example in 11 to 14 days, when calcification not visibly obvious may appear and when bone scans have not been conducted. This is especially pertinent as recent studies suggest a wide variation in the content and standard of skeletal surveys.

NAI and associated musculoskeletal injuries pose a complex problem for the orthopaedic surgeon and paediatric multidisciplinary team. Despite an improved awareness and expanding literature, there are limitations to the evidence base. The large variety of retrospective studies are prone to incomplete datasets and inaccuracy. Publications are heterogeneous, owing to variations in age ranges, fracture descriptions, radiological techniques and, most importantly, geographical and cultural variations. There is ambiguity about whether cases were referred, suspected or classified as abuse in some studies. This has been repeatedly highlighted in contemporary systematic reviews and may have led to an intrinsic bias in the detection of NAI.

Comparative and high-quality prospective epidemiological studies, with standardised collection of clinical and radiological data and multivariate analysis, are necessary to further evaluate the orthopaedic features of NAI. This need is exemplified by metaphyseal fractures which are classed as strong predictors for abuse but which have no comparative studies to substantiate this theory. Future studies must also involve high-risk groups such as children with disabilities. Ultimately, orthopaedic surgeons must form part of a dedicated group of multidisciplinary professionals capable of stratifying risk, diagnosing, and defining a clear and comprehensive clinical and social management plan for each paediatric victim of NAI.

The radiological dating of injuries was thought to have an acceptable level of accuracy. However, this is an imprecise science with orders of precision limited to broad banding of fracture ages (Table III) and distinguishing recent from old. Therefore, the orthopaedic surgeon should reassess each case periodically and be proactive in surveillance, repeating radiographs and skeletal surveys, for example in 11 to 14 days, when calcification not pre

---


<table>
<thead>
<tr>
<th>Skull</th>
<th>Anterior posterior (AP), lateral, and Towne’s view (the latter if clinically indicated). Skull radiographs should be taken with the skeletal survey even if a CT scan has been or will be performed.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chest</td>
<td>AP including the clavicles. Oblique views of both of the sides of the chest to show ribs (‘left and right oblique’).</td>
</tr>
<tr>
<td>Abdomen</td>
<td>AP of abdomen including the pelvis and hips.</td>
</tr>
<tr>
<td>Spine</td>
<td>Lateral: this may require separate exposures of the cervical, thoracic and thoracolumbar regions. If the whole spine is not seen in the AP projection on the chest and abdominal radiographs, 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.</td>
</tr>
<tr>
<td>Limbs</td>
<td>AP of both upper arms. AP of both forearms. AP of both femurs. AP of both lower legs. Posteroanterior view of hands. Dorsoplantar view of feet.</td>
</tr>
</tbody>
</table>

---

**Table III.** Dating fractures (with permission from Springer Science & Business Media: European Radiology, Non-accidental injury: a review of the radiology. 1997;7:1365-76, Carty H)73

<table>
<thead>
<tr>
<th>Band</th>
<th>Peak (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft-tissue resolution (days)</td>
<td>2 to 10</td>
</tr>
<tr>
<td>Early periosteal new bone (days)</td>
<td>4 to 21</td>
</tr>
<tr>
<td>Loss of fracture line definition (days)</td>
<td>10 to 21</td>
</tr>
<tr>
<td>Soft callus (days)</td>
<td>10 to 21</td>
</tr>
<tr>
<td>Hard callus (days)</td>
<td>14 to 90</td>
</tr>
<tr>
<td>Remodelling</td>
<td>3 mths to 2 years</td>
</tr>
</tbody>
</table>

References


