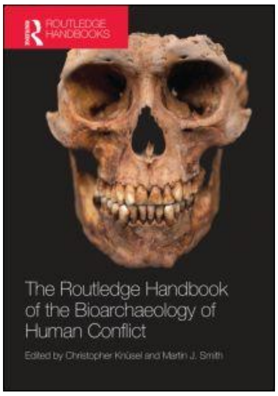

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Sticks and Stones

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STICKS AND STONES

Exploring the nature and significance of child trauma in the past

Mary E. Lewis

Introduction

The identification of trauma in non-adult skeletons (aged less than 17 years) is limited compared with the rates recorded in adult samples. One of the reasons for this is that fractures behave differently in children. It is not that children did not suffer injury in the past, but the nature of immature bone and rapid repair can mask the subtle changes, meaning rates of non-adult trauma are almost certainly an underestimate. The most common forms of injury in the child today are due to motor vehicle accidents, falls (5–10-year-olds), intentional abuse (infants) and recreational sports injuries (adolescents) (Wilber and Thompson 1998). In the past, play, occupation, warfare and physical abuse all exposed children to trauma. Although the causes behind skeletal injuries may have changed over time, the nature of paediatric bone and its reaction to trauma has not. An examination of the type and distribution of trauma in children from past societies may help us to identify the nature of activity in which these children were engaged. Some cases of physical injury in the child documented in the past will be invisible to the osteologist; these include drowning, burns, ingestion of a foreign object or choking. Glencross (2011) emphasizes the importance of examining trauma patterns from a life course perspective, matching social age with cultural agency that dictates when certain activities take place. The biological and social development of the child will also influence the types of trauma to which they will be exposed. Between birth and two years, children are almost entirely dependent on adults for their well-being and can suffer from abuse and neglect; as they develop physically and become more independent, the child's social and cultural involvement increases. Therefore, today, long bone fractures in children before the age of two years are suspicious of abuse, whereas in children aged between two and three years fractures may occur as part of the process of learning to walk and climb (Brown and Fisher 2004).

Trauma is also culturally defined and types of injury may vary considerably across populations due to socio-economic conditions, the levels of urbanization, subsistence strategies, technological advances, cultural practice and other population characteristics (Cheng and Shen 1993). This can render broad comparisons across sites and time periods meaningless. Most of the information we can gather about the incidence, type and pattern of fractures is derived from modern clinical literature and tends to be the result of child recreational activity that did not exist in the past, so male to female ratios and age at which fractures occurred may not be relevant. It is a necessity that we glean what we can from reported cases of child trauma in the archaeological literature, while being aware that these may only represent a snapshot of the factors that surrounded the trauma, and in many cases are isolated events. Given the paucity of data for child trauma in the past, we need to be cautious about how we interpret the lack of evidence. For example, Glencross (2011) takes the absence of fractures in the infants from the Indian Knoll in Kentucky as highlighting the importance of family responsibility and social care of the child. This may be the case, but in order to make such statements, we need first to be sure that we are adequately equipped to identify trauma in such tiny remains. We should also be aware that overreliance on the most obvious cases of child fracture, due to our inability to identify milder forms, may misrepresent those most at risk from trauma, or highlight more extreme accidents over everyday injuries (Glencross and Stuart-Macadam 2001). This chapter will first outline the mechanics behind child trauma before reviewing what can be gleaned from data compiled from a survey of published and unpublished injuries from across the world. By taking a more holistic view of the data, an attempt will be made to explore what the types and rates of child trauma reveal about how they were raised, the dangers to which they were exposed, when they were put to work and if, or at what age, they became engaged in warfare.

Principles of paediatric trauma

Differences in the pattern and nature of paediatric trauma arise from factors associated with the child's size, anatomy and continuous growth. For example, a small child hit by a moving vehicle is in much greater danger of serious injury than an older child or adult. First, they are lighter and more likely to become a projectile, sustaining further injury when they hit the ground (Wilber and Thompson 1998). The ribs of a young child do not cover the liver, spleen or intestines, and the bladder is distended. When an adult falls, they tend to land on their feet, causing fractures of the lower extremities, but a disproportionately large and heavy cranium means that a child is more likely to land head-first (Wilber and Thompson 1998). In toddlers, their upper limbs are too short to protect their heads on impact, resulting in a higher prevalence of cranial fractures. In older children, landing onto an outstretched hand accounts for the larger number of radial fractures as the result of falls (Johnston and Foster 2001). Injury to a child from a fall or collision is much more likely to cause fatal soft tissue injuries and peri-mortem fractures that are much more difficult to identify. Children's bones are highly cartilaginous and more plastic than the relatively brittle bones of an adult (Resnick and Kransdorf 2005), meaning that greater force is needed to produce a complete fracture. When fractures do occur they usually heal quickly without deformity, making them difficult to detect (Currey and Butler 1975). The periosteum in a child is also thicker, stronger and more biologically active than an adult's due to the need for constant remodelling during growth (Wilber and Thompson 1998). Although the periosteum is firmly attached to the ends of the bone (metaphyses) through a dense network of fibres (zone of Ranvier), it is more loosely attached to the shaft (diaphysis). This has an influence on the nature of paediatric trauma, as the periosteum is less likely to rupture during a fracture but instead separates from the bone more easily, remaining intact on the compressed side of the break. This lessens the extent of deformity and allows tissue continuity that bridges the fracture gap and provides stability for healing (Johnston and Foster 2001: 29).

The most common forms of fracture in children are:

- greenstick fractures, a partial fracture with bowing of the compressed side and fracture of the tensile side;
- plastic deformation, causing unusual bowing without fracture;

- torus or buckle fractures, resulting in a bulge of the metaphysis as it fails under compression; and
- chondral and osteochondral fractures of the growth plate.

A "greenstick" fracture describes a partial fracture that penetrates the cortex but ceases within the medullary cavity. These are the most common form of fracture seen in children, and result from the lower elastic but higher plastic threshold of paediatric bone, causing it to break more easily and with less force than mature bone. The porous nature of the cortex means that some of the force is deflected from the surface of the bone, increasing the amount of pressure needed to cause a fracture (Currey and Butler 1975). However, this load is still not enough to force the fracture through the entire shaft and instead the force is dissipated through transverse cleavage cracks, limiting its progression through the bone (Currey and Butler 1975). The loose attachment of the periosteum to the cortex will often result in a widespread hematoma and large callus formation along the shaft, with limited evidence of a fracture line (Wilber and Thompson 1998). In modern cases, greenstick fractures are common at the proximal metaphysis or diaphysis of the tibia, or the middle third of the radius and ulna (Resnick and Kransdorf 2005). The porous nature of the metaphyseal ends, together with a thinner cortical layer, makes this area of the bone particularly susceptible to trauma (Currey and Butler 1975). Greenstick fractures are rarely recorded in non-adult archaeological remains and this is due to their lack of deformation and ability to heal quickly. One possible sign of an underlying greenstick fracture may be the presence of a sheath of sub-periosteal new bone (Figure 3.1), but, as in clinical medicine, these large deposits are more likely to be interpreted as infection, vitamin C deficiency (scurvy) or bone tumours (Adams and Hamblen 1991; John et al. 1997).

Described as the "greenest of greenstick fractures" (Stuart-Macadam et al. 1998: 260), plastic deformation or traumatic bowing of the long bones in children can occur without the subsequent formation of sub-periosteal new bone (Borden 1974; John et al. 1997). Acute plastic deformation results from excessive vertical compression force along the shaft of the bone causing it to react in an elastic manner, bowing under the force. If the force is removed, the bone returns to normal, but if it persists the bone will either remain bowed (plastic deformation) with numerous micro-fractures occurring along the convex aspect, or the bone will suffer partial or complete fracture (Borden 1974). Resnick (1995) reports that the magnitude of force required to produce plastic deformation in children can be as much as 100–150% of the child's own body weight. Plastic deformation usually occurs in one of the paired bones (i.e. radius and ulna or tibia and fibula) with lateral and antero-posterior bending of the bone, but is most common in the ulna (Resnick and Kransdorf 2005; Stuart-Macadam et al. 1998). These injuries cause many clinical challenges, for example, in the leg, plastic deformation of the fibula occurs when the force penetrating the tibia is absorbed by the interosseous membrane. This permanent bowing deformity often limits attempts to reduce full tibial fractures (John et al. 1997), producing a long-term angular deformity. Permanent deformation of a paired bone may also prevent relocation of a dislocation (Resnick and Kransdorf 2005: 809). In young children, rapid remodelling will correct the deformity, but in children who sustain injuries after ten years of age the deformity may persist, causing a reduction in pronation and supination of the forearm and angular deformity (Borden 1974). Archaeological cases of plastic deformation are rare and require comparison with the unaffected side and consideration of numerous differential diagnoses. These include vitamin D deficiency (rickets), neonatal bowing, osteogenesis imperfecta and post-mortem deformation (Stuart-Macadam et al. 1998).

Figure 3.1 Extensive active sub-periosteal new bone formation on the lateral aspects of the femora in a three- to six-year-old child (Sk136) from St Oswald's Priory, Gloucester, UK. Such deposits may overlie subtle greenstick fractures and should be considered where new bone occurs in unusual skeletal locations such as this.

Torus (buckle) fractures are caused when there is an insufficient impaction or compression force to cause a complete fracture, but instead the cortex "buckles" (Resnick and Kransdorf 2005). These types of trauma usually occur at long bone metaphyses and might be identified macroscopically as a slight bulging of the cortex (Figure 3.2). It is likely that such subtle changes are also missed in clinical radiographs, meaning that modern incidence rates may present an underestimate of how common these injuries actually are. Combined compression and angulation forces may cause a "lead pipe fracture", where one side of the bone buckles, while the other suffers a greenstick fracture (Resnick and Kransdorf 2005: 803).

The most obvious difference between adult and non-adult bone is the presence of the cartilaginous growth plate (or physis) at both ends of the long bones, and at one end of the short tubular bones. It is estimated that 6–15% of all injuries in children under 16 years of age involve the growth plate (Resnick and Kransdorf 2005). Injuries that would normally result in dislocations in adults tend to cause fractures in children as the joint capsule and ligaments are two to five times stronger than the cartilage growth plate (Adams and Hamblen 1991; Resnick and Kransdorf 2005). Transchondral fractures involve the cartilage (chondral) or the bone and cartilage (osteochondral) within a joint. Fractures can occur at the metaphyseal end with partial detachment of the metaphysis away from the diaphysis (e.g. bucket handle or corner fractures), or avulsion of the epiphysis. Shearing and avulsion forces cause 80% of injuries, whereas compression forces cause 20% of metaphyseal fractures (Resnick and Kransdorf 2005). With growth plate injuries, deformities may occur in 25–30% cases, and in 10% this is significant,

Figure 3.2 Clinical radiograph of a torus (buckle) fracture of the radius. The external surface of the cortex is only mildly disrupted and may heal without a trace (from Waters 2001: 409, reproduced with kind permission of Lippincott Williams & Wilkins).

particularly in the youngest individuals (Resnick and Kransdorf 2005). In undisplaced epiphyseal fractures, however, rapid remodelling can cause any residual sign of deformity to be lost and full strength and function of the growth plate can return after just ten days. Nevertheless, minimal unilateral periosteal stripping and subsequent new bone formation may be evident for a brief period (O'Connor and Cohen 1987). Trauma to the growth plate in archaeological material is usually identified by shortening of the long bones in adult skeletal remains (Lewis 2007: 173).

Fracture patterns

Clinical literature on the location and frequency of fractures can provide the palaeopathologist with a general view of the type of fractures that may have existed in the past, but they should be used with caution. The majority of articles are written to allow clinicians to distinguish between accidental and non-accidental injuries, or are based only on children admitted to hospital. Many of the recreational activities that predispose children of different ages to trauma today (e.g. rugby, skiing, roller-skating, trampolining) would not have been a feature in the past, and cannot be expected to reflect the most common injuries that we may observe in archaeological samples. However, the physical development of a child will determine some characteristics of trauma prevalence. It is not the aim of this chapter to discuss trauma associated with physical abuse in any great detail (instead, see Lewis 2007), but rather this will be referred to in general.

Cranial fractures

Adults and adolescents have rigid, unyielding crania that differ significantly in their pattern of injuries compared with those of infants and younger children, whose crania are elastic in nature and consist of flat bones, loosely joined by sutures and fontanelles until around four years of age (Pudenz et al. 1961). As infant crania are soft, they may depress inwards but not fracture as the result of trauma, known as a "ping-pong" injury, or the sutures may separate (diastatic fracture). In both cases, because the *dura mater* is so firmly attached to the inner surface of the cranium in a child, it is often torn directly beneath the fracture line making them more susceptible to subdural hematomas. Linear fractures of the cranial vault usually heal quickly, whereas fractures to the much firmer cranial base often go unnoticed in clinical cases (Pudenz et al. 1961). Today, the presence of a cranial fracture in children under two years is considered highly indicative of abuse (Hobbs 1984), and Meservy et al. (1987) argued that multiple cranial fractures, fractures that crossed sutures and bilateral cranial fractures occurred more commonly in victims of abuse. It is increasingly being recognized, however, that complex cranial fractures can also occur accidentally (Wood et al. 2009). Archaeologically, the problem lies with distinguishing linear or depression fractures, suture separation or bone displacement, from breaks and warping caused post-mortem (Crist et al. 1997). As young crania are very thin and fragile, they are often fragmentary, preventing detailed observations of pathology. In the past, the use of a crochet to extract a child from the womb (Eccles 1982) may have resulted in peri-mortem cutmarks to the orbits and palatine surface of the maxilla, or from the mid-sixteenth century, forceps may have caused crush fractures to the frontal, parietal or occipital bone (Lewis 2007; Rushton 1991). No such injuries have ever been identified archaeologically.

Long bone fractures

The prevalence of fractures to the long bones of children can be divided into several age categories that reflect their growing level of mobility, independence and choice of activity. In young children, this is best illustrated by the study of Agran et al. (2003) who examined causes of injury in a cross-section of 23,173 children aged between birth to three years in California. In children aged from birth to two months, a fall from a height was the leading cause of injury (e.g. being dropped), at three to five months battering resulted in the greatest number of fractures, whereas between six to eight months children tended to fall from furniture, at nine to 11 months they choked on foreign objects, they sustained more burns at 12–17 months, and from two to three and half years most of the injuries were due to mobility; for example falls from furniture, stairs and buildings. The incidence of drowning also increased between the ages of one and two and a half years. Cheng and Shen (1993) examined the pattern of fractures in children from different age categories, this time in 3,350 children from Hong Kong. In their sample, 65% of the fractures were of the forearm and elbow (distal radius, and supracondylar part of the humerus) followed by tibial fractures. Boys sustained more fractures than girls and this divide increased with age, and was especially evident during adolescence, with female fractures dropping slightly and those of males increasing dramatically. Hand fractures increased in the 12–16 years age group, as did fractures of the tibia and ankle.

Toddlers' fractures

Today, the most common single fractured bones in children are of the radius and humerus (Wilkins and Aroojis 2001: 12). In many studies, long bone shaft fractures are considered indicative of abuse in a child younger than 18 months who is not yet mobile (Brown and Fisher 2004; Coffey et al. 2005; Strait et al. 1995). For example, Coffey et al. (2005) reported that 75% of children in their study with lower extremity injuries were victims of physical abuse. However, the pattern for shaft and distal humerus fractures is less clear cut, with Strait et al. (1995) finding fractures as the result of abuse in only 36% of children under 15 months, and Shaw and Bohrer (1979) advise caution when diagnosing abuse based on age or fracture patterning. After two years of age, children are learning to walk and climb and are more likely to sustain fractures accidentally. A typical fracture of this period commonly occurs at the distal tibia and is known as the "toddler's fracture". Children generally present with a "spontaneous" limp and pain without any obvious traumatic event. A classic toddler's fracture is a subtle hairline non-displaced oblique or spiral fracture caused by twisting or rotational force of the foot, often missed on the initial radiograph (Heinrich 2001; John et al. 1997). Today, these are often caused by a child tripping or catching their foot in the bars of their playpen (John et al. 1997). They tend to occur at the distal end of the tibia, but may also be seen on the fibula, femur and first metatarsal (Resnick and Kransdorf 2005).

Fractures of the foot, typically buckle fractures of the first metatarsal, are caused when the child falls or jumps from a height. Today, these are known as the "bunk-bed fractures" (John et al. 1997). A fall from height may cause multiple fractures at the base of the metatarsals as the result of vertical loading and compression forces. Compression fractures of the cuboid may occur when it is forced between the calcaneus and metatarsals after a fall (John et al. 1997). Again, the only sign for the palaeopathologist may be new bone formation overlying the site. Although fractures of the talus and calcaneus have been noted in toddlers, they are rare and extremely subtle (John et al. 1997). Owen et al. (1995) describe fracture of the first metatarsal as being the most common in children under five years old (73% in their sample), and suggest susceptibility to compression forces is the result of their lack of a foot arch.

Birth trauma

Birth injury is defined as any condition that adversely affects the foetus during delivery (Gresham 1975). Trauma may result from compression and traction forces during the birth process, abnormal intra-uterine position, difficult prolonged labour, large foetal size and caesarean sections. Significant trauma results in around 2% of neonatal deaths and stillbirths in the United States, with an average of six to eight injuries per 1,000 live births (Gresham 1975). Although any bone may be injured during birth, the most typical fractures occur in the clavicle, humerus, proximal femur and cranium (Brill and Winchester 1987; Caffey 1978; Resnick and Goergen 2002). The use of forceps may result in linear fractures to the parietals and occipital bones, resulting in a haematoma (Sorantin et al. 2006). Spinal injuries causing death, transient or permanent paralysis occur most often in breech births (Gresham 1975), whereas neurological damage to the brachial plexus during childbirth can cause paralysis and atrophy of the arm (Erb's palsy). Caffey (1978) suggests that a callus may be visible between eight and nine days after birth, but for palaeopathologists, diaphyseal new bone formation is difficult to differentiate from new bone laid down during the normal growth process (Lewis 2007).

Healing

Rapid healing in the child often causes fractures to go unnoticed, as fracture lines, callus formation and deformity are remodelled to retain the normal dimensions of the growing bone (Adams and Hamblen 1991). Malunion, where the fragments are healed in the wrong position, may be temporary in a child, and disappear during growth (Resnick and Kransdorf 2005: 794). Although angular deformities are remodelled in children under ten years, after that age they may contribute to a shortened limb (Stephens et al. 1989). An unusual complication of shaft fractures of children is overgrowth of the affected bone. This feature is thought to result from increased vascularity of the bone associated with healing at the site of fracture, and subsequent stimulation of the growth plate (Stephens et al. 1989; Stilli et al. 2008). Overgrowth is greater in femoral fractures (Stilli et al. 2008), and may result in a discrepancy in the length of the affected and unaffected side by up to as much as 4cm (Clement and Colton 1986). In fractures that occur between five and 13 years of age, overgrowth may continue for up to four years after fracture, and in 9% of cases continues up to skeletal maturity (Stephens et al. 1989; Stilli et al. 2008). No overgrowth is seen in fractures that occur after the age of 13 years (Stephens et al. 1989). Stilli et al. (2008) suggest that overgrowth may be greater in fractures where there is considerable separation of the periosteum from the cortex.

The time it takes for healing to occur and the callus to be removed depends on the type and severity of the fracture, the nutritional status of the individual, their age, alignment of fractured ends, the presence of infection or secondary pathological conditions and the type of bone fractured (Roberts 2000). Caffey (1978) noted that callus ossification takes place within two weeks for infants and three weeks for older children, and that some bones heal without a callus ever forming (e.g. terminal phalanges, humeral tuberosity, tibial malleous). Several authors have produced references for time-since-trauma based on radiographic estimates, but they vary widely and this is not considered an exact science (see Chapman 1992; Islam et al. 2000; Klotzbach et al. 2003; O'Connor and Cohen 1987). In general, although too variable to accurately predict, it is considered that in adults, cortical bone takes three to five months to heal depending on the size of the bone (Adams and Hamblen 1991), and cancellous bone around six weeks (Ortner 2003). The final stage, where the callus is finally removed, can take many years (Roberts and Manchester 2005). The period of fracture healing in children, and especially infants, is greatly reduced. Salter (1980) illustrates the rapidity of the healing process in a child, related to age. If a femoral fracture occurs at birth, complete healing can take place within three weeks, in a child of eight years this process could take eight weeks, 12 weeks in a 12-year-old child, and 20 weeks in a 20-year-old individual. In the abused child, constant trauma to an area will prevent bony callus formation, and may result in layers of periosteal new bone, with neglect and malnutrition further delaying the healing process (O'Connor and Cohen 1987).

Child trauma in the archaeological record

The study of trauma in past skeletal populations provides information on occupation, personal relationships, mortuary behaviour, accidents, subsistence and trauma treatment. Children were involved in many aspects of life within a community, and preformed many subsistence and occupational activities. Evidence for trauma in their remains helps to unravel many questions such as occupational activity, child abuse, involvement in warfare, parental care, the home environment and, in the case of peri-mortem cuts during autopsy, the development of paediatrics. Despite the wealth of evidence for trauma in adult individuals in the archaeological record, the evidence for trauma in non-adults is very limited and is probably due to both the difficulties in identifying these lesions in the child and, until recently, our failure to even examine non-adults for such pathology. For example, the identification of trauma in children in British samples was considered as rare as not to warrant tabulation in the data collated by Roberts and Cox (2003) for the later medieval and post-medieval periods. Lovejoy and Heiple (1981) argued that the low rate of non-adult fractures in their sample of Amerindians from the Indian Knoll site (Kentucky, USA) was due to the fact that children who sustained fractures during their growing years survived into adulthood without obvious deformity. In addition, they argued that adults had a longer time to sustain fractures, demonstrated by the increase in the prevalence of fractures in the older age categories. Studies of accidental deaths from medieval coroners' inquests (Towner and Towner 2000) and miracle texts (Gordon 1991) also indicate that fractures sustained in childhood were rare. In the medieval period at least, the greatest cause of death for children under the age of five years was drowning, although this was followed by falls and collisions with road traffic (horse and cart). In the miracle texts, Gordon (1991) only found four (2.9%) cases of child fractures in the 134 records she examined.

A survey of published and unpublished cases of trauma in non-adults from archaeological sites from across the world was carried out for this chapter. This resulted in the identification of 31 cases of cranial trauma (Tables 3.1 and 3.2) and 53 cases of post-cranial trauma (Tables 3.3 and 3.4). This includes evidence for craniotomies, trepanations (Table 3.5), projectile injuries and long bone shaft fractures. Admittedly, these data are heavily biased towards European and North American samples, and the nature of the material means that we are often only provided with snapshots of individual trauma, rather than being able to provide a detailed overview of the pattern and prevalence of non-adult trauma through time and across continents. Nevertheless, these data do reveal the potential for trauma identification in child samples, and provide insight into the types of trauma currently being recognized by palaeopathologists. The data are split into broad time periods and divided into European and non-European samples in an attempt to account for any major cultural differences. Cases of cranial modification, osteochondritis dissecans and spondylolysis are not included here, although they are identified in child remains (e.g. Mays 2007a; Özbek 2001; Šlaus et al. 2010a), and should also be considered within the trauma spectrum.

For non-surgical cranial trauma, 17 cases are reported from Europe and 15 from non-European sites. The majority are depressed fractures and 59% (n = 19) are in children aged between three and ten years. That children were involved in warfare and massacres comes from the inclusion of infants and children from mass grave sites in Neolithic Germany (Whittle 1996: 170), the Epi-palaeolithic Sudan and Neolithic Bavaria (Thorpe 2003). In 2003, Dawson et al. reported three peri-mortem depressed fractures and chipped teeth in the skull of a 13–14-year-old child (reportedly male) from a pit in Chalcolithic Israel (4500–3200 BC). The authors argue the child received the blows during face-to-face combat, suggesting that male children in this society became warriors in their teens. Two cases of head trauma in children from Neolithic Eulau in Germany suggest they were caught up in a raid (Meyer et al. 2009) with lethal consequences. In South Africa, the discovery of three badly wounded crania of children in the same grave at the Modder River (dated to around 2600 BP) suggests they experienced a violent death with a penetrating weapon. The reasons behind such injuries are not known, but isotopic evidence suggests they may have been members of the same family, or at least sharing a very similar diet (Pfeiffer and Van der Merwe 2004). A quartz projectile was found embedded in the vertebral column of an adolescent from the Neolithic site of Maderas Enco, Chile (Standen and Arriaza 2000), and another possible case in a 9–12-year-old from Mouse Creek, Tennessee (Smith 2003). A blade injury was also identified on the mandible of a 4–6-year-old from Romano-British Lankhills, Winchester (Hampshire, UK). Brødholt and Holck (2010) describe an adolescent with a penetrating leg injury and two cranial injuries in children from medieval Oslo, thought to be associated with a civil war of the twelfth to thirteenth centuries. Stab wounds to the posterior surface of the scapulae of two children, and the humerus of another at Čepin, Croatia, suggest children were victims of a

Table 3.1 Reported cranial trauma in European non-adult remains.

Period	*Site*	*Country*	*Age (years)*	*Description*	*Reference*
Neolithic (4000–2500 BC)	Belas Knap, Gloucestershire	England	Child	Peri-mortem blunt force trauma of right frontal and parietal	(Smith and Brickley 2009)
	Eulau, Naumberg, Saxony-Anhalt	Germany	4–5	Small depressed healed fracture on frontal	(Meyer et al. 2009)
	Eulau, Naumberg, Saxony-Anhalt	Germany	8–9	Comminuted penetrating fracture of the back of the cranium resulting in triangular lesion	(Meyer et al. 2009)
Roman (AD 43–450)	Ferrybridge Henge, West Yorkshire	England	15–18	Blunt force trauma	(Holst 2003)
	Ilturo, Cabrera de Mar, Barcelona	Spain	38 weeks	Healed fracture above left orbit; suggested birth injury	(Baxarias et al. 2010)
	Lisieux-Michelet, Calvados	France	2	Two depressed fractures on right parietal (physical abuse?)	(Blondiaux et al. 2002)
Early Medieval (AD 450–1066)	Nusplingen	Germany	2–4	Diastatic fracture of the sagittal suture	(Weber et al. 2003)
Later Medieval (AD 1066–1550)	North East Bailey, Norwich Castle, Norwich	England	13–18	Depressed fracture	(Ayers 1985)
	St Helen-on-the-Walls, York	England	10–14	Depressed fracture on right parietal	(Lewis 1999)
	St Mary's Church, Oslo	Norway	5–10	Frontal bone healed injury	(Brødholt and Holck 2010)
	St Mary's Church, Oslo	Norway	10–15	Nasal bone healed injury	(Brødholt and Holck 2010)
	St Peter's Church, Barton-on-Humber	England	2–3	Peri-mortem depressed fracture	(Waldron 2007)
	St Peter's Church, Barton-on-Humber	England	7	Depressed fracture of the parietal	(Waldron 2007)
	Wharram Percy, North Yorkshire	England	>3	Ante-mortem dental fracture of deciduous right maxillary central incisor	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	5–6	Peri-mortem blunt force trauma of parietal	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	6–10	Depressed fracture	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	14–17	Depressed fracture	(Mays 2007b)

Table 3.2 Reported cranial trauma in non-European non-adult remains.

Period	*Site*	*Country*	*Age (years)*	*Description*	*Reference*
10,500–8000 BC	Hayonim Cave	Israel	Child	Depressed fracture on frontal and parietal	(Eshed et al. 2010)
	Shiqmim, northern Negev	Israel	13–14	Three peri-mortem depressed fractures and a chipped teeth	(Dawson et al. 2003)
800 BC–AD 1	Modder River, Western Cape Province	South Africa	12–13	Peri-mortem trauma; six round-edged breaks, three on frontal, one at coronal suture, two on left parietal, one on right parietal; blunt force trauma?	(Pfeiffer and Van der Merwe 2004)
	Modder River, Western Cape Province	South Africa	6–7	Peri-mortem blunt force trauma to left and right parietal; large triangular lesion to top of skull	(Pfeiffer and Van der Merwe 2004)
	Modder River, Western Cape Province	South Africa	1–1.5	Peri-mortem depressed fracture to right aspect of the occipital	(Pfeiffer and Van der Merwe 2004)
	Semna South, Batn el Hajar	Sudan	8	Healed parietal fracture	(Alvrus 1999)
AD 450–1066	Conchopata	Peru	6–8	Cutmarks to mandible, peri-mortem fracture of upper cervical vertebra; sacrifice	(Tung and Knudson 2010)
AD 1066–1550	Grasshopper Pueblo, Arizona	USA	3–4	Depressed fracture on frontal	(Hinkes 1983)
	Grasshopper Pueblo, Arizona	USA	3–4	Depressed fracture on frontal	(Hinkes 1983)
	Grasshopper Pueblo, Arizona	USA	2–3	Depressed fracture at parietal	(Hinkes 1983)
	Grasshopper Pueblo, Arizona	USA	4–6	Depressed fracture on frontal	(Hinkes 1983)
	McDuffee Site, Arkansas	USA	7	Depressed fracture on right parietal	(Ghalib 1999)
	Moundville, Alabama	USA	6–7	Depressed fracture at sagittal suture	(Bridges et al. 2000)
	Moundville, Alabama	USA	17	Fractured mandibular ramus	(Bridges et al. 2000)
	Ocoee, Tennessee	USA	9–11	Blunt force trauma	(Smith 2003)
AD 1550–1950	New York African Burial Ground	USA	13–15	Fracture?	(Wilczak et al. 2004)

Table 3.3 Post-cranial trauma in European samples.

Period	*Site*	*Country*	*Age (years)*	*Area affected*	*Description*	*Reference*
Bronze Age (2600–800 BC)	Castellón Alto, Galera	Spain		Left clavicle	Fracture at lateral aspect	(Jimenez-Brobeil et al. 2007)
	Castellón Alto, Galera	Spain	6–7	Left femur	Fracture at midshaft with atrophy	(Jimenez-Brobeil et al. 2007)
	Castellón Alto, Galera	Spain	7–8	Right humerus	Fracture at the distal aspect with anterior displacement	(Jimenez-Brobeil et al. 2007)
Roman (AD 43–450)	Bempton Lane, Bridlington	England	2–4 mths	Right femur	Disuse atrophy, breech birth trauma?	(Holst 2004)
	Ferrybridge Henge, West Yorkshire	England	15–17	Tibia	Haematoma	(Holst 2003)
	Herculaneum	Italy	7–8	Right radius and ulna	Oblique fractures at distal aspects of the shafts; good alignment and partial healing suggest a successful reduction shortly before death	(Bisel 1987; Ottini et al. 2001)
	Lankhills, Winchester	England	4–6	Mandible	Blade injury	(Clough and Boyle 2010)
	Lankhills, Winchester	England	13–17	Sacrum, tibia	Fractures (plastic deformation?)	(Clough and Boyle 2010)
	Poundbury Camp, Dorset	England	1	Distal left tibia	Bucket handle, abuse?	(Lewis 2010)
	Poundbury Camp, Dorset	England	2	Ribs	Fracture	(Lewis 2010)
	Poundbury Camp, Dorset	England	Neonate	Ribs	Fracture	(Lewis 2010)
	Poundbury Camp, Dorset	England	7	Ribs	Fracture	(Lewis 2010)

Early Medieval (AD 450–1066)	Cannington, Bridgewater	England	9	Ulna	Greenstick fracture	(Brothwell and Powers 2000)
	Raunds Furnells, Northamptonshire	England	6–10	Clavicles	Bilateral fractures	(Lewis 1999)
	Raunds Furnells, Northamptonshire	England	14–17	Lumbar spine (4–5)	Compression fractures	(Lewis 1999)
Later Medieval (AD 1066–1550)	Čepin	Croatia	4–9	Left scapula	Two peri-mortem sharp force injuries to posterior aspect, one penetrating, one superficial	(Šlaus et al. 2010b)
	Čepin	Croatia	10–15	Right scapula	One peri-mortem sharp force injury to posterior aspect	(Šlaus et al. 2010b)
	Čepin	Croatia	1–4	Left humerus	Two deep penetrating injuries to anterior aspect	(Šlaus et al. 2010b)
	El Burgo de Osma Cathedral, Soria	Spain	7–9 mths	Right femur	Fracture with callus	(Garralda et al. 2002)
	La Madeleine, Orleans	France	6–7.5	Right humerus	Trauma to proximal growth plate resulting in humerus varus; 29mm shorter than left humerus	(Kacki et al. 2011)
	St Helen-on-the-Walls, York	England	6–10	Mandible	Oblique fracture to body	(Lewis 1999)
	St Helen-on-the-Walls, York	England	14–17	Tibia	Fracture with shortening of affected bone	(Lewis 1999)
	Sts James and Mary Magdalene, Chichester, Sussex	England	17	Spine (L4–5) and tibia	Fracture	(Ortner 2003)

(*continued*)

Table 3.3 (continued).

Period	*Site*	*Country*	*Age (years)*	*Area affected*	*Description*	*Reference*
	Sts. James and Mary Magdalene, Chichester, Sussex	England	15–17	Sacrum (S3)	Fracture	(Ortner 2002)
	St Mary's Church, Oslo	Norway	15–20	Tibia	Penetrating injury, peri-mortem	(Brødholt and Holck 2010)
	St Oswald's Priory, Gloucester	England	1–2	Humerus	Fracture with callus, abuse	(Lewis 1999)
	St Peter's Church, Barton-on-Humber	England	17	Humerus, radius, ulna	Dislocated elbow	(Waldron 2007)
	St Peter's Church, Barton-on-Humber	England	10	Tibia	Partially healed sharp injury	(Waldron 2007)
	St Peter's Church, Barton-on-Humber	England	12–13	Femur	Slipped femoral epiphysis	(Waldron 2007)
	Wharram Percy, North Yorkshire	England	14–15	Right clavicle	Fracture	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	1.5	Humerus	Greenstick fracture	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	>3	Dentition	Ante-mortem tooth fracture	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	2–6	Left leg	Disuse atrophy	(Mays 2007b)
	Wharram Percy, North Yorkshire	England	13–15	Femur	Slipped femoral epiphysis	(Mays 2007b)
Post-Medieval (AD 1550–1950)	Christ Church Spitalfields, London	England	14–17	Rib	Fracture	(Lewis 1999)
	Christ Church Spitalfields, London	England	6 mths	Ribs	Fracture	(Lewis 1999)
	Christ Church Spitalfields, London	England	6 mths	Clavicle	Fracture, birth trauma?	(Lewis 1999)
	Christ Church Spitalfields, London	England	10–14	Clavicle and humerus	Fracture with shortening	(Lewis 1999)
	St Mary and St Michael, Whitechapel, London	England	Child	Fibula	Greenstick fracture visible on X-ray	(Walker et al. 2009)
	West Butts Street, Poole, Dorset	England	6–7	Foot	Fracture	(McKinley 2008)
	West Butts Street, Poole, Dorset	England	4–5	Left tibia	Greenstick fracture	(McKinley 2008)

Table 3.4 Post-cranial trauma in non-European samples.

Period	*Site*	*Country*	*Age (years)*	*Area affected*	*Description*	*reference*
10,500–8000 BC	Tochibara, Minami-Saku-Gun	Japan	3	Whole skeleton	Rock fall (no image) "cleft on Ilium"	(Kōhara et al. 1971)
	Tochibara, Minami-Saku-Gun	Japan	5.5	Whole skeleton	Rock fall (no image)	(Kōhara et al. 1971)
4000–2500 BC	Maderas Enco, Chinchorro	Chile	16–17	Spine (L2)	Quartz projectile	(Standen and Arriaza 2000)
800 BC–AD 1	Semna South, Batn el Hajar	Sudan	6	Humerus	Ante-mortem supracondylar fracture	(Alvrus 1999)
AD 43–450	Kellis II, Dakleh Oasis	Egypt	3	Clavicle, humerus, pelvis	Physical abuse (fractures, plastic deformation, new bone)	(Wheeler et al. 2007)
AD 1066–1550	Glen Williams Ossuary, Halton County	Canada	14–17	Left ulna	Plastic deformation	(Stuart-Macadam et al. 1998)
	McDuffee Site, Arkansas	USA	9 mths	Left radius	Greenstick fracture	(Ghalib 1999)
	Mouse Creek, Tennessee	USA	9–12	10th thoracic vertebra	Projectile injury, but bone not recovered during excavation	(Smith 2003)
AD 1550–1950	New York African Burial Ground	USA	Child	Clavicle	Fracture (18 peri-mortem injuries mentioned, but no detail)	(Wilczak et al. 2004)
	Pecos Pueblo, New Mexico	USA	9	Femur	Fracture and callus	(Ortner 2002)

Table 3.5 Reported surgical procedures.

Period	*Site*	*Country*	*Age (years)*	*Area affected*	*Description*	*Reference*
European						
Neolithic (4000–2500 BC)	Makotřasy, Kladno	Czech Republic	4–5	Cranium	Oval aperture at bregma with one to two weeks of healing	(Shbat and Smrčka 2009)
	Makotřasy, Kladno	Czech Republic	4	Cranium	Trepanations at parietal and occipital; no healing Pathological lesions (tumour?) on skull	(Shbat and Smrčka 2009)
Roman (AD 43–450)	Fidenae, Rome	Italy	5–6	Cranium	Trepanation (with hydrocephalus)	(Mariani-Costanitini et al. 2000)
	Poundbury Camp, Dorset	England	Neonate	Whole skeleton	Embryotomy	(Farwell and Molleson 1993)
Later Medieval (AD 1066–1550)	St Oswald's Priory, Gloucester	England	6–10	Cranium	Trepanation?	(Lewis 1999)
Post-Medieval (AD 1550–1950)	Bow Baptiste Church, London	England	Adolescent	Tibia	Amputation	(Miles and Powers 2007)
	Bow Baptiste Church, London	England	13–18	Cranium	Craniotomy	(Miles and Powers 2007)
	Bow Baptiste Church, London	England	13–18	Cranium	Craniotomy	(Miles and Powers 2007)
	Bow Baptiste Church, London	England	>5	Cranium	Craniotomy	(Miles and Powers 2007)
	Bow Baptiste Church, London	England	>5	Cranium	Craniotomy	(Miles and Powers 2007)
	Brading, Isle of Wight	England	12	Distal right radius and ulna	Amputation; crushed appearance of the lesion suggests a peri-mortem accident	(Redfern 2007)

	St Marylebone Church, London	England	4–5	Ribs and cranium	Autopsy	(Miles et al. 2008)
	St Marylebone Church, London	England	4–5	Ribs and cranium	Autopsy	(Miles et al. 2008)
	St Marylebone Church, London	England	5	Cranium	Craniotomy	(Miles et al. 2008)
	St Marylebone Church, London	England	12–17	Cranium	Craniotomy	(Miles et al. 2008)
	Christ Church Spitalfields, London	England	6–10	Ribs and cranium	Autopsy (son of surgeon)	(Molleson and Cox 1993)
	Christ Church Spitalfields, London	England	1	Cranium	Craniotomy	(Molleson and Cox 1993)
	Christ Church Spitalfields, London	England	1	Cranium	Craniotomy	(Molleson and Cox 1993)
	West Butts Street, Poole, Dorset	England	5	Cranium	Craniotomy	(McKinley 2008)
Non-European				Cranium		
800 BC–AD 1	Kazibaba 5, Uzbekistan	Central Asia	2.5–3.5	Cranium	Round aperture, trepanation?	(Blau 2005)
AD 450–1066	Ancon, Lima	Peru	4–5	Cranium	Trepanation; ante-mortem depression to occipital from scraped trepanation, group of five small holes on frontal; possibly as treatment for aural defect	(Kato et al. 2007)
AD 1066–1550	Kuelap, Chachapoya	Peru	7	Cranium	Trepanation on left frontal bone with evidence of healing and periosteal reaction	(Nystrom 2007)

Turkish raid in AD 1441, designed to spread panic throughout the region. The youngest child was under four years of age (Šlaus et al. 2010b). Notably, these were the only cases of peri-mortem trauma found in a review of 659 non-adults from the Balkans (Šlaus et al. 2010b).

In 1923, a study by MacCurdy of trepanations in Peruvian crania revealed no evidence in non-adults, despite a prevalence of trepanations in 17% (47 of 273) of adult crania. Today, five possible cases of trepanation have been reported, two from sites in Peru (Ortner 2003; Shbat and Smrčka 2009). In three cases these are thought to be associated with pathological conditions. A 5–6-year-old child from Fidenae in Rome is reported to have also had hydrocephalus, and in Ancon, Peru, a child with a possible aural defect also had evidence of surgical exploration. An unusual circular lesion was related to the trepanations on the skull of a Neolithic four-year-old from the Czech Republic (Shbat and Smrčka 2009). Evidence for autopsy procedures from transverse cuts to the rib cage and craniotomies are evident in four post-medieval sites in England (McKinley 2008; Miles et al. 2008; Miles and Powers 2007; Molleson and Cox 1993) and correspond to a rise in paediatric interests during this time (Lomax 1996). Two possible amputations, one believed to have occurred as the result of a peri-mortem accident (Miles and Powers 2007; Redfern 2007), have also been reported in children from this period.

Of the 53 post-cranial fractures identified from the literature, the vast majority (n = 41) came from European samples, with 11 from the Americas and two each from Africa and Asia. The most common bones affected were the humerus (n = 10), followed by the tibia (n = 8), clavicle (n = 7) femur (n = 6) and ribs (n = 5). This pattern is similar to that seen in modern cases, with the exception of fractures to the radius. Only three cases were reported in the archaeological literature. The age distribution of lesions roughly followed that for the cranial lesions, with fractures in children between the ages of 2–6 years, 6–10 years and 14–17 years most often reported. Greenstick fractures have been suggested in five cases (Brothwell and Powers 2000; Ghalib 1999; Mays 2007b; McKinley 2008; Walker et al. 2009), and there are three cases of plastic deformation (Clough and Boyle 2010; Stuart-Macadam et al. 1998; Wheeler et al. 2007). Trauma to the growth plates have been recorded at later medieval Chichester, Sussex (Ortner 2003) and Pecos Pueblo in New Mexico (Ortner 2003), post-medieval Christ Church Spitalfields in London (Lewis 2002), early medieval Raunds Furnells in Northamptonshire (Lewis 2002) and medieval La Madeleine, Orléans, France (Kacki et al. 2011). Four post-cranial fractures were found in children living on the steep terraces of the Bronze Age Iberian Peninsula (Jimenez-Brobeil et al. 2007). The authors suggest that hazards due to playing and carrying out chores in such a rugged environment explains the relatively high prevalence of fractures in the children (3.2%).

Several authors have identified possible cases of birth trauma. In adults, Roberts (1989) reported a case of Erb's palsy in a young female from Romano-British Kingsholm, and Molto (2000) identified humerus varus deformity in a male and a female from a Roman cemetery in Dakhleh, Egypt, which he interprets as evidence of birth trauma to the proximal epiphysis. In non-adults, a healed fractured clavicle was evident in a four-month-old child from Christ Church Spitalfields, London, that may have occurred during birth (Lewis 2002), and Baxarias et al. (2010) identified a healed linear fracture above the left orbit of a 38-week-old infant, suggesting birth trauma caused the injury. Holst (2004) also identified disuse atrophy in the right femur of a 2–4-month-old child that has been suggested as a case of birth trauma. Perhaps the most famous case of trauma to a perinate comes from Romano-British Poundbury Camp, Dorchester, where extensive peri-mortem cutmarks to a neonate suggest an embryotomy (Farwell and Molleson 1993).

The paucity of evidence for physical child abuse in past populations has been explained by clandestine burials of the victims (Waldron 2000), that swaddling caused a different pattern of injuries (De Mause 1974; Knight 1986), or that social circumstances meant that older children, rather than infants, were the most common victims of abuse in the past (Walker 1997). Blondiaux et al. (2002) were the first to suggest physical abuse in a two-year-old child from Roman Lisieux-Michelet, Normandy, France, who had sustained several head injuries and rib fractures in addition to suffering rickets. Since then, three other possible cases have been identified. Wheeler et al. (2007) reported on a 2–3-year-old child with multiple trauma and widespread periosteal reactions from Kellis 2 in the Dakhleh Oasis. The child had fractures of the humeri, clavicles, ribs and plastic deformation of the right ilium. Given the pattern of trauma with various stages of healing, the authors suggest child abuse is the most probable cause. Also from the Roman period, Lewis (2010) identified a tibial bucket-handle fracture in an infant from Romano-British Poundbury Camp. While the tibial injury may be a toddler's fracture, at 18 months, this injury would be suspected as non-accidental today. Finally, a 1–2-year-old child from St Oswald's Priory in Gloucester, England, had a partially healed mid-shaft fracture of the right humerus (Figure 3.3). While an uncommon accidental injury in children of this age today, it should be noted that this child is also the only one in the non-adult sample (n = 144) with rickets. This underlying pathology may have weakened the bone resulting in a fracture, but the presence of this disease may also signal ongoing neglect.

Figure 3.3 Transverse fracture at the mid-shaft of the right humerus in a one- to two-year-old child (Sk376) from St Oswald's Priory, Gloucester, UK. The fracture callus is made up of fibre bone and has re-broken post-mortem (arrow). The scapula and metaphyseal ends of the humerus show porosity and fraying typical of vitamin D deficiency.

The most frequently recognized evidence we have for childhood fractures in the past is the presence of shortened limbs in adults as a result of trauma and premature fusion of the growth plate (Lewis 2000). How much shortening occurs depends on the age of the individual at the time of the trauma, the epiphysis affected and the amount of longitudinal growth still to occur. For example, in the tibia, 43% of longitudinal growth from the centre of ossification is carried out by the distal growth plate, whereas 57% occurs at the proximal end of the bone (Maresh 1955). Hence, a fracture and fusion of the proximal tibial epiphysis would cause a greater degree of shortening (growth dysplasia) than similar trauma to the distal end. In theory, detailed knowledge of proportional bone growth could provide evidence of the age at which the fracture occurred. These data would, for example, allow us to examine male: female ratios of trauma patterning in the past. Attempts to improve our recognition and recording of such trauma has been carried out by Stuart-Macadam et al. (1998) and Glencross and Stuart-Macadam (2000, 2001), who have identified healed fractures of the humeral epicondyle, supra-condylar buckling and plastic deformation in adults. Accurate identification and recording of these types of injuries would greatly increase what we know about child trauma in the past. As an illustration, at the Indian Knoll site, Glencross (2011) only recorded six (0.27%) fractures in 2,200 complete children's bones, compared with 45% (n = 35) of fractures in the adults believed to have occurred during childhood. There is still a great deal of work to be carried out in this area.

Conclusions

The study of skeletal trauma in the remains of children from past societies is limited, with only a handful of fractures being reported in the literature. The main reason for this deficit is the plastic nature of paediatric bone, which results in incomplete, greenstick fractures that heal rapidly without deformity, and the subtlety of other signatures of trauma such as premature epiphyseal fusion and periosteal lesions. The latter are often described as resulting from infection, and when widespread, assumed to be indicative of scurvy or congenital syphilis. It is clear that, as today, children suffered from epiphyseal fractures, traumatic shortening of the limb and neurological injuries. The age at which these fractures occurred, their type and frequency can provide information on birthing practices, environmental hazards, the age at which children began work and were exposed to trauma. Evidence of physical abuse is hindered by the often subtle and non-specific lesions that are left behind, and problems of differential diagnosis. A survey of archaeological cases of child trauma reveals that plastic deformation and greenstick fractures can be identified through the use of radiography and comparisons with unaffected bones. Cranial and weapon injuries indicate that young children were often victims of raids and by the time they were teenagers, were probably participating in warfare. There is increasing evidence for physical abuse in archaeological material, although interpretations of the lesions remain challenging, and diagnosis made on modern patterns of injury should be treated with caution. We still know very little about the effect of occupation on the skeletons of children, who in some societies may have begun work as apprentices by the age of seven years (Lewis 2002), and children would certainly have been involved with gathering of foodstuffs and household chores from a much earlier age. Further work on identifying childhood trauma in adult populations may help us build a picture of the age at which certain types of epiphyseal injury were sustained, and differences between males and females. We should consider trauma as a possible aetiology in the bones of infants and young children that display sheaths of periosteal new bone formation, and employ multiple view and comparative radiographs and CT scans to help us visualize subtle fracture lines. However, it is the infants that cause the greatest challenges for trauma diagnosis.

Infant remains are often very fragile, fragmentary and are rarely recovered in their entirety. Finally, we need to place our analysis of trauma within a life course structure, taking into account the child's physical development, and the cultural context of the remains.

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