Introduction

Paul K. Kleinman

Definition of child abuse

There is a wide range of views among professionals as to what is an acceptable definition of child abuse. The lack of universally accepted terminology to characterize the fundamental elements of this condition illustrates the difficulty in developing a precise definition. The battered child syndrome seemed to be an apt characterization of the injuries described in early reports; however, the term implies that an infant or child is hit with a fist, foot, or blunt object (1). Some injuries are inflicted in this manner, but most occur by indirect forces that develop as the child is grabbed by the trunk or an extremity, is shaken, slammed, or thrown.

Although assailants may be unaware of the ultimate consequences of their actions, the abusive event generally implies a willful assault on a child at the hands of a person entrusted with their care. The term "nonaccidental injury" characterizes the condition by what it is not, rather than by what it is. It requires a reliable definition of what constitutes an accident and implies that if an injury is not due to an accident, it is due to abuse. Some authors link abuse to intentionality (2–4). Intent is often included in legal standards; the notion is a complex one and is not easily applied to the clinical setting by most physicians dealing with traumatic injuries. On occasion, euphemisms and confusing terms such as "trauma-X" are employed to hide the diagnosis from the victim's family or other caretakers, and such terminology may actually hinder initial contacts with these parties as well as undermine the trust that must be established for optimal intervention and treatment.

What constitutes an abusive act is best understood in terms of behavior patterns that are generally exhibited by reasonable and prudent caretakers (5, 6). Although definitions of abuse built upon this type of standard may create difficulties for state authorities in developing child abuse legislation (4), understanding injuries in terms of the types of forces customarily employed in child rearing is fundamental to assessing the significance of an injury in an actual case.

A number of definitions have been offered to characterize child maltreatment – none are perfect and universally applicable to this complex disorder. The Child Abuse Prevention and Treatment Act (CAPTA), (42 U.S.C. §5101), as amended by the CAPTA Reauthorization Act of 2010, retained the existing definition of child abuse and neglect as, at a minimum:

> Any recent act or failure to act on the part of a parent or caretaker which results in death, serious physical or emotional harm, sexual abuse or exploitation; or an act or failure to act, which presents an imminent risk of serious harm (7, 8).

In June 2005, the American Board of Pediatrics accepted a petition to begin a new pediatric subspecialty, certified by the Board (9, 10). Although the leaders of the field who succeeded in winning formal recognition of this discipline acknowledged that there is no perfect term to characterize the condition, the name Child Abuse Pediatrics was chosen for the subspecialty. Although alternative terms will likely persist, particularly outside of North America, "child abuse" and "child maltreatment" are the preferred terms used throughout this text.

Incidence and demographics

There is a vast literature on the epidemiology of the global issue of child maltreatment, and the increasing awareness of this public health problem, particularly in developing nations, is encouraging (11, 12). This review will be limited to the epidemiology of the problem in the United States.

Based on mandated reports, the US Department of Health and Human Services estimates that 686,000 children were victims of maltreatment in 2012 (13). A 2014 study found that annual rates of confirmed child maltreatment dramatically understate the cumulative number of children confirmed to be maltreated during childhood (14). Forty-nine states reported a total of 1593 child maltreatment fatalities. Fatalities are concentrated in infants with a death rate for children aged less than 1 year of 18.83 per 100,000, falling relatively rapidly to a rate of 0.98 per 100,000 at age 5 years (13).

The National Child Abuse and Neglect Data System (NCANDS) defines "child fatality" as the death of a child caused by an injury resulting from abuse or neglect or where abuse or neglect was a contributing factor. Based on their data, an estimated 1570 children died from abuse and neglect nationally in 2011. This translated to a rate of 2.10 children per 100,000 children in the general population and an average

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of *4 children dying every day from abuse or neglect* (15, 16). Children less than than 1 year of age accounted for 42.4% of fatalities; children less than 4 years of age accounted for four-fifths (81.6%) of fatalities. Childbearing at an early age is strongly associated with infant homicide (17).

It is widely acknowledged that there is significant underreporting of child abuse in general and specifically for child abuse fatalities, and that the actual incidence of abuse and neglect is higher than the official statistics indicate (18–22). The International Classification of Diseases and coding on death certificates are particularly unreliable (19, 23–26).

The Fourth National Incidence Study of child abuse and neglect (NIS-4) is the single most comprehensive source of information about the current incidence of child maltreatment in the United States (27). The National Incidence Study (NIS) is a congressionally mandated, periodic effort of the US Department of Health and Human Services. The Keeping Children and Families Safe Act of 2003 (P.L. 108–36) mandated the NIS-4, which collected data in 2005 and 2006. The NIS not only includes children who were investigated by Child Protective Service (CPS) agencies, it also obtains data on other children who were not reported to CPS or who were screened out by CPS without investigation. These additional children were recognized as maltreated by community professionals. Thus, the NIS estimates include both abused and neglected children who are in the official CPS statistics and those who are not.

The NIS-4 employed a sentinel survey methodology in which community professionals or "sentinels" represent all staff of agencies from 122 counties that have contact with children and families (27). The participating sentinels in the NIS-4 were 10,791 professionals in 1094 sentinel agencies. They submitted data forms on any children they encountered who were maltreated during the study data period. The NIS-4 collected 6208 completed data forms from sentinels and 10,667 completed forms on the investigation outcomes and the abuse and neglect involved in cases sampled at participating CPS agencies. The NIS applies definitional standards that include not only those children who have been harmed, but also those whom the reporting sentinel felt were "endangered."

The number of children who experienced Harm Standard physical abuse in the year spanning 2005–2006 was estimated at 323,000 in the NIS-4 compared to an estimated 381,700 from the 1993 NIS-3 data (a 15% decrease in number and a 23% decline in the rate). The number of physically abused children based on the endangerment standard was estimated at 476,600, compared to an estimated 614,100 children in NIS-3 (a 22% decrease in number, a 29% decline in the rate). The significance of this apparent fall in the incidence of physical abuse has been the subject of considerable interest (28, 29). One multicenter study actually shows an increase in pediatric admissions for physical abuse and high-risk traumatic brain injury and has tied them to recent macroeconomic trends (30), while another has shown little effect of the recent recession on the rates of abuse and neglect (31). As with the earlier studies, the NIS-4 found that rates of maltreatment for black children were significantly higher than those for white and Hispanic children; racial, ethnic, and socioeconomic disparities in the reporting and incidence of child abuse are a subject of ongoing interest and study (27, 30, 32–38).

It is evident that infants and young children are at substantial risk for serious physical harm from abusive acts, and they constitute the majority of children who die from their inflicted injuries. Skeletal injuries are present in most infant abuse fatalities and the great majority of these fractures are in a healing phase at the time of death (39). Young children may sustain significant skeletal, abdominal, and central nervous system injuries without clinical findings to indicate abuse, and abuse is often not considered, even when clinical features are present to suggest this diagnosis. The prevalence of injuries that have the highest specificity for abuse is greatest in infants and young children (39–43). It is clear from the literature that diagnostic imaging plays a central role in the evaluation of suspected physical abuse in infants and young children.

Diagnostic imaging of child abuse: past, present, and future

Skeletal injury has been a component of child maltreatment with documented cases as early as Ancient Egypt (44). The modern medical concept of child abuse has its origins with Caffey's seminal description of long bone fractures associated with subdural hematomas (SDHs) (45). He formulated his early concepts regarding the association and the mechanisms of injury of SDHs and inflicted skeletal injury from earlier reports by Snedecor and others (46, 47) and by Ingraham and associates (48, 49).

Although his initial report made only a brief mention of the possibility of "intentional ill treatment" of the victims, Caffey expressed the clear conviction in conferences, lectures, and personal communications that the findings which he noted were manifestations of maltreatment by custodians (45, 50, 51). Notably, as early as 1957 he expressed strong opinions regarding the nature of the skeletal findings he characterized as traumatic lesions:

> The diagnosis of traumatic injury to infants and children is of more than academic interest, especially when the injuries are repeated and when the traumatic origin is denied by parents or other caretakers. The correct early diagnosis of injury may be the only means by which the abused youngsters can be removed from their traumatic environment and their wrongdoers punished. Correct early diagnosis of injury by the radiologist may be lifesaving to some of these otherwise helpless youngsters, or it may prevent permanent crippling injuries to others.

Interestingly, he added:

> Early diagnosis may also prevent or stop unwarranted expensive medical investigations which ultimately prove embarrassing to the attending physician, when the true story of simple trauma becomes known (52).

Silverman played a crucial role in developing the concept of "unrecognized trauma in infants" and acknowledged the important contribution of Ambroise Tardieu in the Rigler lecture of 1971 (50, 53). Ambroise Tardieu, a French physician described the clinical manifestations of inflicted injuries in children in 1860, well before the discovery of x-rays. Silverman advocated the use of the "Syndrome of Ambroise Tardieu" to describe the modern concept of the entity. The contributions of these two authors are embodied in the "Syndrome de Silverman–Ambroise Tardieu," terminology that was used by some authors as recently as 1994 (54).

In the years following Caffey's 1946 article, many authors expanded the concept of inflicted skeletal injuries and their association with SDHs in children (52, 53, 55–65). In 1962, Kempe collaborated with Silverman and others in a landmark article that developed the notion of the "battered child syndrome," and brought it to a wide medical audience (1, 66). In the early 1970s, the introduction of the concept of violent shaking greatly enhanced the understanding of the pathology and dynamics of physical assaults on infants (Fig. I.1) (67–69).

With further developments in radiography and the advent of nuclear imaging, sonography, computed tomography (CT), and magnetic resonance imaging (MRI), a vast array of imaging abnormalities due to abuse and neglect were described. These reports have not only served to catalogue the various manifestations of inflicted injury, but correlations with surgical and autopsy findings have provided valuable insights into the mechanisms responsible for these injuries. Currently, radiologists have a wide range of choices of imaging modalities to evaluate cases of suspected abuse. The results of these imaging examinations often form the basis of a diagnosis of abuse and are frequently offered as evidence in legal cases. Furthermore, radiologists may play a role in the activities of child fatality review teams (70).

It is increasingly recognized that society pays a high economic cost in caring for abused children, as well as those at risk for injury (71, 72). A substantial portion of the hospital expenses relates to diagnostic imaging studies (73–75).

The twenty-first century brings with it the hope that a heightened awareness of child maltreatment by professionals and the public at large will spur further interest in defining the entire spectrum of physical alterations and their causal mechanisms. The ultimate reduction in morbidity and mortality from abuse will rest in large part on prevention measures and early detection. An effective public health approach to the problem is predicated on a thorough understanding of the pathologic features and the mechanisms underlying inflicted injuries in infants and children. Diagnostic imaging is fundamental to the acquisition of this knowledge and can play an important role in the formulation of public health policy.

Diagnostic challenges of child abuse

Because most forms of domestic abuse tend to be cyclic, there is a high risk of repetitive injury, particularly in infants and young children. A missed diagnosis carries the risk that a child will be subjected to further assaults (76–82). In infants, these attacks tend to escalate in severity and culminate with life-threatening central nervous system injury (39). Imaging strategies for suspected abuse are, therefore, formulated to minimize the risk of a missed diagnosis. On the other hand, overzealous efforts by professionals who are ill-prepared to differentiate child abuse from other conditions can have a profoundly negative impact on children and their families. To date, general screening programs for physical abuse have had mixed results and efforts to develop valid screening instruments and programs for at-risk children are needed (83).

The fundamental role of diagnostic imaging in cases of suspected abuse is much the same as with other medical conditions. The diagnostic process is characterized by gathering facts through appropriate imaging studies, integrating these findings with clinical and laboratory data, consultation with colleagues, and the formulation of a diagnosis based on knowledge and expertise. This process is predicated on a

Figure I.1 The shaken infant. (Illustrated by Laura Perry MD, based on descriptions by assailants. With permission from Kleinman PK. Diagnostic imaging in infant abuse. Review article. *AJR*. 1990;155:703–12.)

thorough understanding of the varied manifestations of child abuse and its imitators on modern diagnostic imaging studies.

Organization of the book

Skeletal injuries are the most common physical alterations identified on imaging studies in cases of abuse, and certain fractures carry a high diagnostic specificity. The presence of these strong indicators of abuse in cases with nonspecific clinical and imaging findings often provides the level of certainty required to arrive at a secure diagnosis. Section I of this book deals with the imaging features of inflicted skeletal injury, followed by the various differential diagnoses which may be entertained in cases of suspected abuse. The concept of evidence-based medicine (EBM) has been used and *abused* in discussions of the differential diagnosis of child maltreatment, and Dr. Christopher Greeley's chapter on EBM in the context of the abused child seeks to sharpen the reader's focus on how to critically evaluate the relevant literature. The important issue of dating fractures is addressed, providing the parameters of fracture healing with a goal towards defining the strengths and limitations of radiography in the timing of skeletal injury. Current recommended skeletal imaging strategies are provided and the section concludes with a discussion of postmortem skeletal imaging.

Section II addresses the all-important field of abusive head and spinal trauma, the leading cause of maltreatment fatalities in infants and young children. Dr. Gary Hedlund heads a team of experts in the clinical, biomechanical, and neuroimaging aspects of inflicted head and spinal injuries. The differential diagnoses and the imaging strategies are woven into these discussions.

Section III covers the imaging features of inflicted visceral trauma, including the imaging approach to these usually serious injuries. Miscellaneous forms of abuse and neglect have protean manifestations, and because there is considerable overlap with classic visceral injuries, these topics are considered together.

Section IV places diagnostic imaging in a societal context. A presentation of the factors at work during the complex and sensitive interactions among imaging professionals, abused children, and their families sets the stage for a discussion of the legal issues that arise once care and protection, or criminal proceedings have begun. The section concludes with the author's perspective on this challenging, and often daunting, subject.

Diagnostic imaging is rooted in basic technical, physical, and biologic principles, which must be fully understood to obtain optimal studies to properly identify and characterize imaging alterations. Section V provides the fundamental principles of diagnostic imaging to professionals who may be unfamiliar with these techniques and addresses risk considerations which accompany studies employing ionizing radiation. This section concludes with a discussion of quality assurance. An imaging department may be equipped with modern and sophisticated imaging modalities and staffed by expert pediatric radiologists, but if the imaging chain is of suboptimal quality, radiologic interpretation may be significantly compromised.

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Section 1

Skeletal trauma

Section I

Skeletal trauma

Chapter 1

The skeleton: structure, growth and development, and basis of skeletal injury

Andrew E. Rosenberg

Introduction

This chapter focuses on the purpose and composition of the skeleton, bones, and bone tissue, and their formation and maturation. Providing the basis for understanding the inherent weaknesses and susceptibility of the immature infant skeleton to physical injury, this information also builds the foundation for comprehending the morphologic expression of the trauma and the body's response to the associated tissue damage.

Skeletal structure and function

The skeletal system is vital to life. It plays an essential role in mineral metabolism, movement, protection of viscera, endocrine regulation of critical biologic processes (energy metabolism, male phenotype and fertility, ion homeostasis), and the storage and nourishment of hematopoietic marrow. To accommodate these demands the skeletal system is complex and composed of 206 organs, namely, the individual bones of the body, and a variety of different cell and tissue types (Fig. 1.1). Bones are intricate living structures that have the unique capacity to undergo constant remodeling throughout life. This special biology forms the foundation of its growth and development, its ability to change its structure, function, and metabolism in response to biomechanic and systemic requirements, and its remarkable proficiency in repairing itself, often completely, in the setting of skeletal injury (1).

Tan-white and smooth-surfaced, bones are the hardest and strongest structures of the body, being as strong as cast iron but one-third of the weight as a result of their adaptive architecture. Comparatively lightweight, rigid but not brittle,

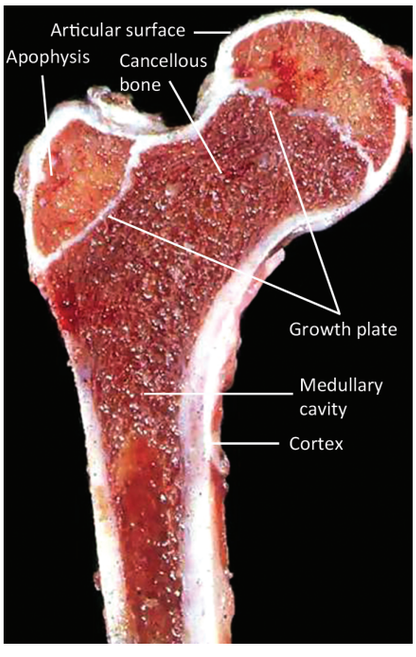

Figure 1.1 Proximal femur from an older child demonstrating the cortex, medullary cavity, growth plates, apophysis, and articular surface.

reinforced, generally asymmetric, and hollow, bones are designed to have a relatively high tensile strength, and maximum strength-to-weight ratio. These characteristics are derived from the substance of bones – all are composed of bone tissue – a specialized type of connective tissue that is a unique biphasic blend of inorganic or mineral component – calcium hydroxyapatite – and organic constituents – the cells and the proteins they synthesize.

Bones vary greatly in size and shape and these features form the basis of the classification of individual bones. The most prominent group of bones are tubular, both long and short (Fig. 1.1), and the other types include flat (bilaminar plates) and cuboid bones. Anatomically, tubular bones are further subdivided into the epiphysis, the metaphysis, and the diaphysis (Fig. 1.2) (2). The epiphysis extends from the base of the articular surface to the beginning point of significant narrowing of the bone. The metaphysis embodies the region of bone that displays a prominent reduction in diameter, and the diaphysis or shaft extends from the base of one metaphysis (the point where decrease in bone diameter ceases) to the base of the opposing metaphysis. During growth and development the metaphysis is composed of the cartilaginous growth plate also known as the physis and the adjacent primary and secondary spongiosa and the surrounding cortex. The medical and forensic determination of skeletal age and the prediction of ultimate size utilize the degree of maturation of the physes, the amount and localization of bone ossification, the formation and dimensions of the secondary ossification centers, and the degree and amount of remodeling (see below).

Bones are covered externally by a periosteum. The periosteum is anchored to the cortex, which in turn houses the medullary canal that contains variable amounts of cancellous or trabecular bone, fatty and hematopoietic marrow, blood vessels, and nerves. The quantity and arrangement of cortical and cancellous bone is directly related to the biomechanical requirements of each bone. For example, long bones that are exposed to the largest torsional and load-bearing forces and flat bones that serve a protective function, such as the skull, are composed roughly of 80–100 % cortical bone and 0–20 % cancellous bone. In contrast, bones that transmit predominately weight-bearing forces, such as the vertebral bodies, consist of 80 % cancellous bone and 20 % cortical bone. The trabeculae of cancellous bone are arranged according to the lines of stress to which they are exposed.

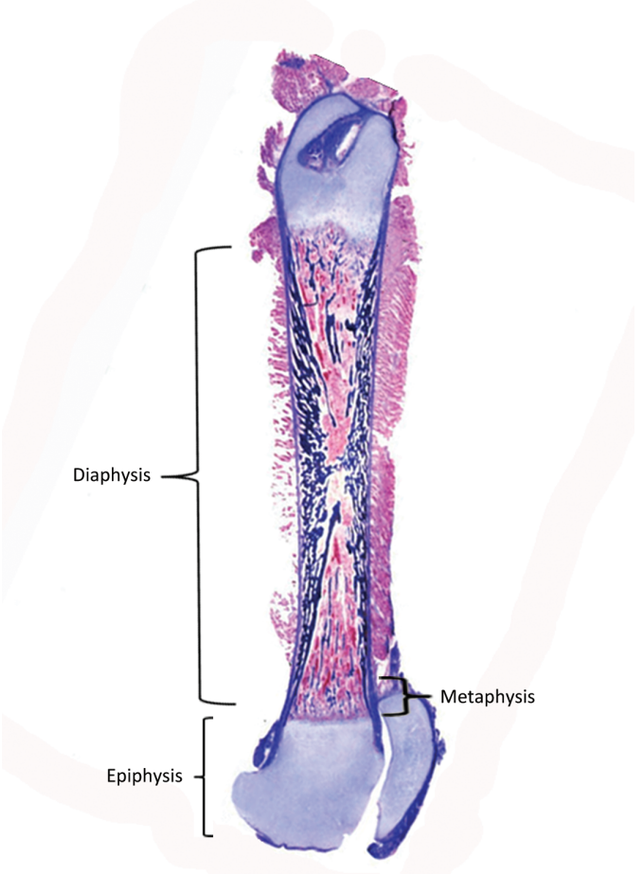

Figure 1.2 Femur from a fetus showing the epiphysis, metaphysis, and diaphysis.

Bone structure

Woven and lamellar bone

Bone tissue is categorized into woven and lamellar types based on the organization of its main structural protein – type I collagen fibers. In woven bone, the collagen fibers are arranged in a seemingly haphazard feltwork, while in lamellar bone they are deposited in parallel arrays (Fig. 1.3).

Woven bone is fabricated during periods of rapid bone growth or formation. It composes parts of the developing

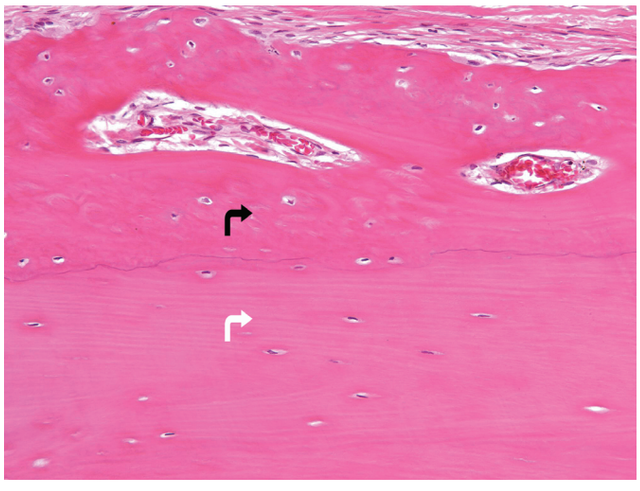

Figure 1.3 Outer portion of cortex composed of lamellar bone (white arrow) that has superiosteal reactive woven bone (black arrow) on its surface. The type I collagen fibers in the woven bone are oriented in a weave, whereas those in the underlying cortex are arranged in parallel array. The osteocytes in the woven bone are more numerous and larger than those in the lamellar bone.