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Review

The challenges of accurately estimating time of long bone injury in children

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ABSTRACT

The ability to determine the time an injury occurred can be of crucial significance in forensic medicine and holds special relevance to the investigation of child abuse. However, dating paediatric long bone injury, including fractures, is nuanced by complexities specific to the paediatric population. These challenges include the ability to identify bone injury in a growing or only partially-calcified skeleton, different injury patterns seen within the spectrum of the paediatric population, the effects of bone growth on healing as a separate entity from injury, differential healing rates seen at different ages, and the relative scarcity of information regarding healing rates in children, especially the very young. The challenges posed by these factors are compounded by a lack of consistency in defining and categorizing healing parameters.

This paper sets out the primary limitations of existing knowledge regarding estimating timing of paediatric bone injury. Consideration and understanding of the multitude of factors affecting bone injury and healing in children will assist those providing opinion in the medical-legal forum.

1. Introduction

There are few absolutes in medicine. In the medical-legal realm, determination of timing of injury, death, or an inciting event may be a central and contentious issue of paramount forensic and legal importance, and yet can be difficult if not impossible to establish without corroborating evidence. Those receiving information, such as the jury within the court setting, may expect information from health professionals to be provided in black-and-white terms, but defining an answer to a process that is reliant on a multitude of variables can be challenging and categorical answers may not always be possible.

With respect to estimating time of bone injury, the best information can only be given in respect to a time range, with clear delineation of the limitations. Systematic study, research, and expanding knowledge of physiology and pathophysiology have permitted some refinement of the process — defining the spectrum of time over which an injury may have occurred has narrowed as our understanding of injury, mechanism and healing processes has increased. However, estimation of time of injury still remains imprecise.

Estimating the timing of bone injury, particularly in children, is especially difficult for a number of reasons: Detecting a “bone injury” can be problematic since identification of injury is dependent on methods used for diagnosis and may necessitate different radiologic investigations to substantiate injury. Since acute bone injury may be difficult to detect in some cases, it follows that radiologic features of bone healing such as periosteal new bone formation have become indirect indicators of injury. Further to timing of injury, physiological and pathophysiological processes both within and between individuals effect injury and differential rates of healing, complicating comparison between groups. The ability to narrow estimation of time of bone injury decreases as time progresses, reflecting natural variability in an individual's healing processes. The influences of force and mechanism on producing a bone injury may affect healing rate, especially in non-accidental trauma. Finally, there are nuances specific to bone injury and healing in the paediatric population and within subgroups of children such as the very young that necessitates distinct and separate consideration from bone injuries in older teens and adults.

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The limitations of each of these factors and the effect on estimating time of bone injury will be discussed in turn. Unless otherwise specified, discussion relates to long bone injuries in living children, and not skull fractures, other trauma, or in the setting of metabolic bone disease.

2. Defining and detecting “bone injury”

What constitutes a “bone injury” is open to interpretation and controversy: the classical and most typical injury that comes to mind is that of a fracture seen on x-ray, however, more subtle injury may be inferred from other diagnostic modalities. A fracture is a laceration of bone, caused when a force exceeds the ability of the bone to deform. Skeletal pliability in childhood accounts for different fracture patterns (for example, greenstick fracture, bowing deformity) from those characteristically seen in adults. For the most part, fractures are readily diagnosed by x-ray, and radiological diagnosis of fractures has been used clinically since the late 1800's.[1]

Radiation exposure notwithstanding, conventional radiography has become the most commonly utilized method for diagnosis of fractures: X-rays are widely accessible and provide high-resolution images. Consequently, classification of long bone fracture patterns, recognition of normal variants, and an understanding of causal mechanisms to explain specific fracture patterns have evolved. Radiographic diagnosis of some fractures, physeal plate trauma and non-calcified bony injury can be subtle and challenging.[2] Non-specific injury may be inferred by some radiographic findings such as haemarthrosis, sometimes necessitating subsequent diagnostic confirmation by other means.

The relatively widespread availability and high resolution of conventional x-ray combined with the historical context of use makes radiology commonplace for both diagnosing fractures and chronicling healing processes. However, accurate assessment of timing of fractures diagnosed by x-ray can only be done in the broadest of terms by characterizing healing patterns and are initially non-specific: a fracture between a few minutes and a few days of age may be radiographically indistinguishable. The features of healing patterns of treated fractures in adults have been well-characterized radiographically, but there are challenges specific to paediatrics: diagnosing injury in a skeleton that may not be fully calcified, establishing consistency in defining radiographic nomenclature pertaining to healing, and accelerated fracture healing rates seen within the paediatric population as compared with adults.[3,4]

Radiographic skeletal survey can be used to look for unsuspected fractures in other anatomical locations and unusual fractures (rib, for example).[5] Skeletal survey also provides a useful baseline for comparison should a repeat study be obtained later demonstrating evidence of fracture healing. Both the American College of Radiology and the Royal college of Radiologists/Royal College of Paediatrics and Child Health (United Kingdom) have specific guidelines for the radiologic investigation of child abuse, including indications and suggested views for skeletal survey.[6,7] The UK guidelines have been adopted and endorsed by the European Society for Paediatric Radiology.

Diagnostic modalities other than x-ray have become important in diagnosing bone injury, including ultrasound, MRI, CT and scintigraphy (bone scan).[8–10]

Advanced techniques have refined our ability to diagnose and characterize subtle bone injury, such as bone bruise, physis injury, or cartilaginous damage that could otherwise be missed on x-ray.[11–14] Autopsy histopathologic correlates to MRI findings of “bone bruising” include microfractures of cancellous bone, edema, and bleeding into the marrow. Fragments of hyaline cartilage with fragmented bony trabeculae can also be seen.[15] However, usefulness of these modalities in timing of injury occurrence is limited by selection bias as to availability of the technology and who receives the test. None of the tests other than conventional x-rays are usually considered “first line” for diagnosis of long bone injury in most children. Furthermore, the paucity of data surrounding the use of MRI, ultrasound and nuclear medicine bone scans for children who have long bone injury of known aetiology (e.g., accidental trauma) limits the radiologist's ability to interpret whether findings from these radiological investigations can determine when injury occurred.

Ultrasound utilized by trained emergency physicians has been shown to be useful to demonstrate acute hematoma formation and occult recent fractures in cases where child abuse may not initially have been considered or x-ray findings may have been subtle or overlooked.[16,17] Peri-fracture hematoma formation can be diagnosed by ultrasound within an hour of injury and can be an important diagnostic indicator of injury when other findings such as bruising may be absent.[18] Both hematoma and early fracture callus formation may be visible with ultrasound, and assessment by ultrasound for hematoma localization for anaesthetic infiltration, assessment of fracture, and guided reduction is common practice in adults and children within the ED.[19,20] The expanding role of ultrasound as a first-line diagnostic technique for acute injury may narrow estimation of timing of injury by refining and expediting diagnosis of bone injury, thereby alleviating the delay in awaiting radiographic evidence of healing.[21–24]

MRI is used relatively commonly in the United States for assessment of suspected paediatric physis injury, but availability and timely access to MRI for acute injury may be limited in countries with largely socialized medical systems.[25] MRI may be useful for diagnosing more subtle bone injury such as bone bruising but has limited utility in assessing timing of injury per se because MRI is largely relegated as a second-line test, often obtained weeks or months after x-ray for further assessment (for example, in cases of suspected physis injury that is still painful). Furthermore, bone injury identifiable on MRI may persist for weeks to months, limiting diagnostic utility for dating outside the acute timeframe. Although useful as diagnostic adjuncts, advanced imaging techniques such as MRI are not as sensitive as skeletal survey or bone scanning in diagnosing certain injuries such as classic metaphyseal injuries and rib fractures.[26] Children may require sedation for optimal MRI imaging.

CT scanning may be utilized early in the assessment of fractures and injury in childhood trauma. Three-dimensional CT reconstructions may be useful in delineating occult fractures or subchondral injury if suspected, but increased radiation exposure concerns with CT as compared to x-ray and the necessity for sedation in the very young patient limits utility as a routine diagnostic tool.[27,28]

Bone scintigraphy, or bone scanning, is a functional test that assesses bone metabolism (including normal physis growth) by utilizing radioactive markers and radionuclide scanning. Bone scanning can be useful in assessing severity and extent of injury by characterising areas of increased metabolic activity. Increased activity with occult fractures has been seen within hours of injury, with peak uptake at 10–12 weeks in adults; absence of uptake within 5 days can rule out injury.[29] It has been shown that fracture-related isotope uptake may persist for up to 2 years post injury[30]; although Matin's paper from 1979 looking at long-term fracture uptake only included adults, it serves as a useful reminder that estimating time of injury based upon evidence of healing becomes more difficult as time progresses. In the setting of suspected trauma, bone scan can detect previously unrecognized periosteal reactions and fractures, indicating extent of injury and possibly timing if evidence of multiple fractures are found.