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Review Article

A Review of Current Imaging Modalities In Detecting Bony Fractures In Young Children Suspected of Maltreatment

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Abstract

Child abuse is a critical public health issue that can cause significant harm to the child's physical and emotional well-being. Early detection of maltreatment can be challenging. A missed diagnosis of abuse could result in continued abuse and severe negative outcomes for the child. To ensure the optimal evaluation of suspected child abuse cases, a multidisciplinary team approach is necessary. Pediatricians lead the assessment, relying on radiologists to analyze the images of the suspected cases. Therefore, radiologists play a crucial role in detecting evidence of non-accidental injuries (NAI) and differentiating these findings from other causes. Fractures are the second most common NAI after cutaneous lesions such as bruises. Classic metaphyseal lesions (CMLs) and rib fractures are types of injuries that may indicate physical abuse in young children. Skeletal surveys are the standard screening tool for detecting CMLs, while ultrasound provides better visualization of the knee metaphysis. Chest X-rays are the primary modality for rib assessment, while CT scans are more effective in detecting rib fractures and costochondral junction fractures. An interdisciplinary team utilizing vigilant and systematic imaging techniques and evaluation is essential in identifying child abuse and protecting vulnerable children.

Keywords: child abuse; imaging; bony fractures; review

Introduction

Child maltreatment is a critical public health issue that can cause significant harm to the child's physical and emotional well-being. An estimation of 1 in 4 children in the United States are victims of child maltreatment. Many of them suffer from fractures that require medical evaluation.1 It is also noteworthy that child maltreatment can be a tremendous economic burden for society, which accounts for $124 billion in costs in the United States every year.1 According to World Health Organization (WHO), "child maltreatment is the abuse and neglect that occurs to children under 18 years of age. It includes all types of physical and/or emotional ill-treatment, sexual abuse, neglect, negligence, and commercial or other exploitation, which results in actual or potential harm to the child's health, survival, development, or dignity in the context of a relationship of responsibility, trust or power."2 Early detection of maltreatment can be challenging. A missed diagnosis of abuse could result in continued abuse and severe negative outcomes for the child.

Child abuse is often difficult to detect, despite its high prevalence. To ensure the optimal evaluation of suspected child abuse cases, a multidisciplinary team approach is necessary, where pediatricians lead the assessment, relying on radiologists to analyze the images of the suspected cases. One of the main challenges is to distinguish between accidental and non-accidental injuries (NAI). Therefore, radiologists play a crucial role in detecting evidence of NAI and differentiating these findings from other causes such as falls, and collisions. NAIs are intentionally inflicted by another person to harm the child. Fractures are the second most common NAI after cutaneous lesions such as bruises.3 Classic metaphyseal lesions (CMLs) and rib fractures are types of injuries that may indicate physical abuse in young children.

Radiological imaging is a vital tool for detecting NAI and diagnosing child abuse. Skeletal surveys are the standard screening tool for detecting CMLs, while ultrasound provides better visualization of the knee metaphysis. Chest X-rays are the primary modality for rib assessment, while CT scans are more effective in detecting rib fractures and costochondral junction fractures. An interdisciplinary team utilizing vigilant and systematic imaging techniques and evaluation is essential in identifying child abuse and protecting vulnerable children.

Despite the continuing research on child maltreatment, there is still a limitation in our current knowledge that needs to be addressed. The purpose of this article is to review the current literature about different imaging modalities to detect child maltreatment. Their roles and limitations in

detecting fractures will also be discussed, providing an evidence-based approach for pediatricians, radiologists, and other healthcare professionals to evaluate suspected child abuse.

Discussion

Diagnosis of physical abuse

Child abuse is a significant issue that can cause physical harm to children and unfortunately, is a common problem, especially involving fractures which is one of the most severe forms of child abuse. Upon inspection of a child who has experienced a fracture, it is essential for interprofessional teams to be capable of differentiating between fractures caused by violence and those that have occurred accidentally, as suitable mediation and legal action require correct identification.

When determining child abuse as a main source of fractures, medical care teams must consider several influential causes such as the mechanism that produced the fracture, the type and location, the age of the child, the history of the injury, and the existence of other injuries while contemplating feasible causes4. Trepidations of potential abuse should be contemplated when there are inconsistencies between the history given and the description of the fracture6. To illustrate, if the type of fracture is uncommon for the history given and the nature of the fracture, healthcare providers must contemplate the probability of abuse.

Specific varieties of fractures such as fractures in infants and toddlers, multiple fractures at different stages of healing, or fractures that are bilateral or in unusual locations are more likely to occur due to child abuse5. When compared with other age groups, children under 36 months have a higher hospitalization frequency for abusive fractures3. Furthermore, when spiral or metaphyseal fractures are seen, the mechanism for the damage may point to abuse due to the nature of these injuries4.

There are additional physical and psychological signs of abuse that healthcare providers should be attentive to when examining a child with a suspected abusive fracture. Bruising in uncommon areas, burn and bite marks are all possible signs of abuse4. Children who have experienced and been a victim of abuse may also display emotional and behavioral changes, such as depression, anxiety, and aggression6.

Furthermore, there are careful considerations to be determined when identifying child abuse as the cause of fractures and there are several factors to look for, involving, the location and type of fracture, the mechanism of injury, the age of the child, the history of the injury, and the presence of other physical or psychological signs of abuse. When there are discrepancies in the history provided and the nature of the fracture there should always be a high level of suspicion, or when other signs of abuse are present. Interdisciplinary teams can help protect vulnerable children from the harmful effects of child abuse by using vigilant and systematic imaging techniques and evaluation.

Role of radiology in the evaluation of occult bony fractures

Occult bony fractures are fractures that are not visible on conventional radiographs, either due to lack of displacement or limitations of the imaging technique. They typically occur as a result of high-energy trauma or insufficiency of the bone.7 Occult bony fractures are a challenge and may have serious implications, especially in cases of suspected child abuse. Radiology plays an important role in the detection and characterization of these types of fractures.

Various imaging modalities can be used to evaluate occult bony fractures in pediatric patients, depending on the clinical scenario and the availability of resources. According to the American College of Radiology (ACR) and the Society for Pediatric Radiology (SPR), skeletal surveys are recommended for children who are suspected of NAI.8 Skeletal surveys are a series of plain radiographs covering the entire skeleton that aims to accurately identify focal and diffuse abnormalities, including acute and healing fractures, differentiating them from normal anatomical variants.

There remain challenges to diagnose occult fractures in children with plain radiographs. CT, MRI, and ultrasound, on the other hand, are more sensitive in detecting occult bony fractures in pediatric patients. Despite the high costs, limited availability, and long duration of the exam, MRI has a 99% sensitivity in detecting occult fractures on account of its high resolution.9 CT, as a more readily available imaging modality, compared to MRI, can generate an accurate description of subtle fracture lines and articulations and evaluation of bone loss.10 Ultrasound is also an effective tool for detecting occult fractures in children that is readily available, radiation-free, and inexpensive.11

Detection of fractures

Often, the site of injury can provide substantial evidence for the mechanism through which it occurs. Long bones are highly prone to fracture when a child's arms or legs are twisted or pulled, which creates inertial forces as a result of the shearing forces. This is referred to as a classic metaphyseal lesion (CML) and is highly indicative of physical abuse.12 These bones typically include the distal or proximal tibia, proximal humerus, and distal femur.13 A rib fracture due to accidental causes is uncommon, since young children have highly cartilaginous rib cages that usually do not break unless an intentional external force has been applied to the chest.14 On the other hand, injuries to the vertebrae (especially spinous processes), scapula, and sternum are unlikely to be caused by physical abuse and are rather more suggestive of motor vehicle accidents (MVAs).14 A skull fracture can indicate an accidental fall or a form of physical abuse, which requires further investigation to determine the cause.

Classic Metaphyseal Lesion (CML)

A standard modality for detecting CMLs is radiographic imaging. A skeletal survey (SS) is the standard screening tool recommended by the American Academy of Pediatrics to see all forms of child abuse, including CMLs.15 It involves a series of radiographs, usually 20, that allows for a comprehensive assessment of the axial and appendicular skeleton. According to a retrospective study conducted on children < 24 months of age at multiple children's hospitals in the United States, SSs revealed occult fractures in up to 34% of children that were evaluated due to concern for abuse.16 In another study, 58% of the subjects with positive SSs results were diagnosed with a form of child abuse.15 SSs are considered a safe form of an assessment tool for physical abuse due to their low radiation exposure (0.2 mSv; Monte Carlo simulation).17

On the other hand, CT imaging requires about 100 times the radiation dose of a skull radiograph for children under 2 years of age.18 For this reason, it has rarely been used in the detection of CMLs in children. Nevertheless, technological advancements and better protocol implementation have taken place in order to utilize this form of imaging in child abuse detection.19

Although considered a standard mode of imaging, radiographic detection of CML can be occult or subtle. Additionally, a skeletal survey can only show subperiosteal new bone growth in only a minority of distal tibia CMLs.20 Ultrasound can provide better visualization of the knee metaphysis, detecting fine details of the new bone growth of the metaphysis.20

Rib Fractures

As briefly mentioned above, rib fractures are uncommon in infants and toddlers due to the highly cartilaginous nature of the bones that exhibit great elasticity. Given this fact, signs of anterior or posterior rib fractures, with varying states of healing process, may be indicative of abuse. It is important to consider other potential causes of rib fractures, such as genetic abnormalities in bone formation (e.g., osteogenesis imperfecta), accidental blunt force injuries as occur during motor vehicle collisions, and previous application of cardio-pulmonary resuscitation on the child.21

In children, chest X-Rays are the primary modality for rib assessment, which is used a lot more frequently than CT scans. However, obtaining signs of rib fractures on radiographs poses an image classification challenge, as it

requires a much higher spatial resolution for fractures.21 This is consistent with the results of another study, which found that chest CT outperforms the conventional X-ray in most aspects of rib fracture detection.22 Specifically, a substantial improvement in sensitivity was observed when using CT as opposed to radiography, with a minor decrease in specificity.

While a fracture due to blunt force trauma can occur at any segment of the rib arch, it is worth paying special attention to a type of fracture unique to the rib, known as the costochondral junction (CCJ) fracture. This junction connects the bone to the cartilage, serving as an important site for the growth and development of the rib during childhood and early adulthood.23 As the rib grows, the cartilage at the costochondral junction also expands and helps to maintain the connection between the rib and the sternum. Viewed under histopathologic imaging, healing injuries on the rib typically exhibit an outgrowth of the proliferating chondrocytes from the growth plate into the end of the rib (primary spongiosa). This, along with the fact that most of the CCJ fractures identified on X-Ray are in the healing phase, raises concerns about the visibility of CCJ fractures on radiographic imaging, including SS. Because of this, other imaging modalities to identify CCJ fractures may lead to a better diagnosis of non-accidental trauma.23

Skull Fractures

Differentiating skull fractures from natural sutures and vascular grooves can be challenging on plain radiographs.24 Compared to the autopsy, 63% of single skull fractures were successfully identified on radiographs, while only 50% of fractures with two or more lesions on the same bone were successfully identified **in** one study.25 Moreover, brain CTs are recommended for the diagnosis of trauma to the brain,26 which have been shown to increase the detection of skull fractures, with 10-30% more identification than plain radiographs.27

Furthermore, black bone MRI imaging is a new imaging technique that uses a partial flip angle to obtain a uniform background by suppressing fat and water to increase the contrast between bone and soft tissue.28 Despite this sequence, about 25% of skull fractures are still overlooked in children around 4 years of age compared to CT.29 Moreover, one study found that ultrasound had a sensitivity of 91% and specificity of 85% in assessing pediatric patients under 2 years of age with NTI.30 However, due to the nature of ultrasound, it will be limited to regions of swelling of soft tissues. The gold standard in diagnosing skull fractures is a CT scan.30

Other Fractures

Other fractures such as spinal and scapular fractures are highly specific for abuse, while they are relatively rare in young children.31 Plain radiographs may not be sensitive enough to detect these types of fractures due to the complexity of the anatomy. Some studies have shown that CT and bone scans may have a higher sensitivity.32 33 Pelvic fracture is also uncommon in NAI and data is limited and with varying results.34 Clavicle fractures are common in NAI as it is the most common fracture during vaginal delivery.35 Both radiographs and ultrasound are sensitive enough for diagnosis.34 35

Conclusion

Pediatric fractures are common and can be indicative of child maltreatment. Diagnostic imaging can be used to accurately assess the bony structures in children of suspected abuse. CT could be a better modality in the cases of rib and skull fractures, while skeletal survey could be better in detecting CML. Radiation-free MRI and ultrasound can be used to confirm the diagnosis. On the other hand, CT would expose children to a higher dose of radiation. The best practice in cases of suspected child abuse is to accurately identify the NAI. It is essential to select the appropriate modality base on the history, physical examination, and radiation dose. Further research investigating strategies to improve prediction in diagnosing child maltreatment is warranted.

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