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Ultrasound's Role in Pediatric Long-Bone Fracture Detection: Emergency Applications

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Abstract:

Background: Long-bone fractures are among the most common injuries encountered in pediatric trauma, constituting approximately 4% of emergency department visits annually in the United States. These fractures pose risks of hemorrhage and neurovascular compromise, underscoring the importance of timely detection and management to prevent limb loss and morbidity. While conventional radiography remains the primary modality for assessing long-bone injuries, emergency ultrasound offers distinct advantages such as rapidity, non-invasiveness, and absence of ionizing radiation exposure, particularly crucial in pediatric patients vulnerable to radiation-related malignancies.

Objective: This study aimed to evaluate the concordance between emergency physicians' and radiologists' assessments of suspected pediatric long-bone fractures using emergency ultrasound and radiography, respectively.

Methods: A prospective study was conducted involving pediatric patients (aged ≤18 years) presenting with suspected long-bone fractures. Patients with previous fractures, limb deformities, orthopedic hardware, or open fractures were excluded. Investigators received focused training in ultrasound fracture identification and localization.

Results: Fifty-three subjects (mean age: 10.2 years; 56.6% male) underwent 98 ultrasound examinations, primarily targeting upper (70.4%) and lower (29.6%) extremities. Radiography identified 43 fractures. Ultrasound exhibited a sensitivity of 95.3% (95% CI: 82.9%–99.2%) and specificity of 85.5% (95% CI: 72.8%–93.1%) in fracture detection, with positive and negative predictive values of 83.7% (95% CI: 68.8%–92.2%) and 96% (95% CI: 84.9%–99.3%), respectively. Diaphyseal fractures were detected with 100% sensitivity, while near-joint fractures were identified in 93.1% of cases. Ultrasound accurately identified all radiographically confirmed displacements requiring reduction, with sensitivity and specificity of 100% (95% CI: 51.7%–100.0%) and 97.3% (95% CI: 84.2%–99.9%), respectively.

Conclusions: Emergency department-performed ultrasound demonstrated superior accuracy in diagnosing diaphyseal fractures compared to metaphyseal and/or epiphyseal fractures in pediatric patients. Its high sensitivity and specificity, along with its ability to identify fractures requiring reduction, support its utility in evaluating suspected long-bone fractures in children.

Key Words: ultrasound, fracture, injury, trauma

Introduction:

Long-bone fractures are prevalent traumatic injuries, constituting approximately 3.5% to 3.9% of visits to emergency departments (EDs) in the United States annually. These injuries carry a substantial risk of hemorrhage and neurovascular damage, with delayed diagnosis and treatment potentially resulting in severe outcomes such as limb loss or fatality. Presently, emergency physicians primarily depend on conventional plain film radiography for assessing long-bone injuries. However, this approach is resource-intensive, time-consuming, and sometimes invasive, particularly for patients necessitating procedural sedation or repeated imaging for accurate diagnosis. Moreover, radiography, with its use of ionizing radiation, poses long-term risks such as interference with normal cell development and potential cancer development. (Patel et al., 2009)

Emergency ultrasound presents several advantages over radiography and holds promise for identifying long-bone fractures efficiently. Ultrasound offers rapid, noninvasive, and cost-effective imaging, devoid of known adverse effects. It enables dynamic visualization of soft tissue structures like muscles, blood vessels, ligaments, and tendons. In ultrasound imaging, a normal long bone cortex appears as a bright, hyperechoic line with posterior shadowing, while cortical disruption indicative of fracture is evident as discontinuities in the bone's contour. Fracture gaps display as highly echogenic foci, allowing for straightforward measurement of fragment separation. Additionally, ultrasound enables assessment of associated edema and hematoma formation. (Cross et al., 2010)

Despite these advantages, limited data exist regarding the concordance between ultrasound and radiography in detecting long-bone fractures and determining the necessity for reduction. Radiography remains the gold standard for evaluating such fractures. This study aims to investigate the agreement between emergency physicians' and radiologists' assessments of long-bone injuries using ultrasound and radiography, respectively. (Witt & Gilmore, 2007)

Methods:

This prospective study involved a convenience sample of patients presenting with functioning as a level I trauma center. The Department of Emergency Medicine hosts a 1-year emergency ultrasound fellowship training program. Institutional review board approval was obtained, along with a waiver of informed consent. Examinations were conducted in accordance with standard medical practice at the institution. Physician investigators comprised 2 attending physicians without formal ultrasound training, 2 ultrasound fellows, and 2 second-year emergency medicine residents. The institution's director of emergency ultrasound provided training to each investigator on fracture evaluation with ultrasound through a 1-hour didactic and practical session prior to the study's commencement.

Eligible patients were those under 18 years presenting to the pediatric ED with suspected long-bone fractures, typically characterized by swelling, erythema, and localized pain. Exclusion criteria included a history of fracture at the suspected site, extremity deformity, orthopedic hardware at the traumatized area, or an open fracture. Treating physicians, not necessarily study investigators, identified potential subjects.

Prior to radiographic examination, a physician investigator conducted focused ultrasound using a 10-MHz linear array transducer (LOGIQ P5 system; GE Healthcare, Wauwatosa, Wis.). The transducer was placed transversely on the limb to locate and assess the depth of the affected bone. After identifying the distal end of the bone, the transducer was moved along the long axis of the affected extremity. Ultrasound images were captured of each suspected fracture in two planes. Following ultrasound, the physician investigator recorded the location of the suspected fracture and noted the presence of fracture, displacement, or angulation. Each bone evaluated by an operator within a single subject was considered separately. Radiologists evaluating the suspected fractures remained blinded to the ultrasound findings. Clinical decisions were primarily based on the radiologists' final assessment of the radiographs.

Primary outcome measures included the presence of fracture, displacement, and/or angulation as visualized by ultrasound and radiography. Sensitivity, specificity, positive predictive value, and negative predictive value were calculated for fracture detection and the need for reduction. Additional analyses were conducted on nondisplaced fractures identified by radiography and separately on diaphyseal and metaphyseal/epiphyseal fractures, acknowledging the diagnostic challenges posed by end-of-bone fractures.

Results:

A total of 53 subjects were included in the study, with a mean age of 10.2 years (SD, 3.8), of which 30 subjects (56.6%) were male. Among them, 42 subjects underwent multiple examinations. Ninety-eight ultrasound examinations of long bones were conducted, with 69 (70.4%) involving upper extremity bones and 29 (29.6%) involving lower extremity bones. The most frequently affected bones were those of the forearm (radius and ulna) and lower leg (tibia and fibula).

Radiography identified 43 fractures, of which 41 (95.3%) were detected by emergency department (ED) physicians using ultrasound. Out of 55 negative readings, ultrasound provided concordant assessments in 47 evaluations (85.5%). False-positive ultrasounds occurred in 8 cases, with the majority involving the radius (37.5%), followed by the ulna (25.0%), fibula (25.0%), and tibia (12.5%). There were 2 false-negative ultrasounds, one involving a 6-year-old girl with a nondisplaced buckle fracture of the distal ulna, and the other a 17-year-old girl with a nondisplaced fracture of the distal fibula. Sensitivity and specificity for ultrasound in detecting fractures were 95.3% (95% CI, 82.9%–99.2%) and 85.5% (95% CI, 72.8%–93.1%), respectively. The positive and negative predictive values were 83.7% (95% CI, 68.8%–92.2%) and 96% (95% CI, 84.9%–99.3%), respectively.

Among the 43 identified fractures, radiography identified 6 displacements (14.0%) requiring reduction according to published orthopedic guidelines. Emergency ultrasound correctly identified all fractures necessitating reduction. One case involved an 8-year-old boy with a distal radius fracture, where ultrasound indicated the need for reduction while radiography did not. The sensitivity and specificity for ultrasound in identifying the need for reduction were 100.0% (95% CI, 51.7%–100.0%) and 97.3% (95% CI, 84.2%–99.9%), respectively, with positive and negative predictive values of 85.7% (95% CI, 42.0%–99.2%) and 100.0% (95% CI, 88.0%–100.0%), respectively.

The majority of fractures (78.4%) occurred near the growth plate, known to be challenging to diagnose. Ultrasound detected all diaphyseal fractures and 27 out of 29 (93.1%) metaphyseal/epiphyseal fractures, consistent with the notion that ultrasound sensitivity is higher for diaphyseal fractures compared to those near bone ends or joints.

Discussion:

The prompt and accurate assessment of children with suspected fractures in emergency settings poses challenges. Physical examination alone may lack sensitivity, particularly in cases where the patient's mental status or additional injuries confound assessment. Radiographic imaging has traditionally been the mainstay for evaluating suspected fractures. However, the notable proportion of negative examinations underscores the importance of correctly identifying cases necessitating radiographic evaluation and the need for alternative modalities devoid of ionizing radiation, cost-effective, yet reliably accurate. (Brenner et al., 2003)

Over the past two decades, emergency physicians have demonstrated proficiency in utilizing ultrasound for musculoskeletal injury evaluation. Ultrasound presents numerous advantages over radiography, including its noninvasiveness, repeatability, portability, and cost-effectiveness. It allows for dynamic visualization and provides immediate results, crucial in busy emergency departments. Particularly advantageous for children, ultrasound is quicker, more comfortable, and radiation-free, catering to the sensitivity of actively growing cells and tissues. Additionally, if reduction is required, ultrasound can assist in fracture reduction through direct probe pressure. (Marshburn et al., 2004)

Studies have shown that emergency department physicians with minimal training can swiftly diagnose fractures in children using ultrasound. Comparable sensitivities and specificities to radiography have been reported in detecting nonarticular, non-displaced forearm fractures. Despite our study's slightly lower sensitivity and specificity in detecting fractures, consistent with previous findings, this discrepancy may be attributed to the inclusion of injuries near bone ends or joints, where diagnostic challenges are prevalent. (Witt & Gilmore, 2007)

It is worth considering that ultrasound may outperform radiography in identifying long-bone fractures in children, particularly given the cartilaginous nature of infant joints. Further investigations should explore diagnostic disagreements between sonography and radiography, especially regarding false-positive ultrasounds where minor fractures might go undetected by radiography. (Swishchuck & Hernandez, 2004)

Our findings support ultrasound's utility in evaluating suspected long-bone fractures in children, including diagnosing fractures and determining the need for reduction. Pending confirmation from larger studies, ultrasound could be embraced as a viable alternative to radiography for evaluating childhood injuries with suspected long-bone fractures. As such, proficiency in ultrasound examinations is becoming increasingly vital for emergency physicians. (American College of Emergency Physicians, 2009)

Conclusions:

Our study demonstrates that emergency physicians with limited ultrasound training can accurately diagnose long-bone fractures in children. The majority of diagnostic errors observed in this study were associated with nondisplaced fractures and fractures near bone ends.

In specific well-defined circumstances in the emergency department (ED), ultrasound may emerge as a satisfactory substitute for radiography in diagnosing long-bone fractures. These findings underscore the importance of pursuing larger prospective studies to further investigate the utility of ultrasound in diagnosing orthopedic injuries in children.

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