European Review for Medical and Pharmacological Sciences 2022; 26: 7949-7954

Advances in the application of ultrasound for fracture diagnosis and treatment

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Abstract. – Fractures are commonly encountered in clinical practice. Early diagnosis and individualized treatment are the basis for achieving high-quality fracture healing and functional recovery. Radiographic examinations play an important role in the diagnosis and treatment of fractures. In recent years, with the innovation in ultrasonic examination technology and equipment, its application in the diagnosis and treatment of fractures has greatly increased. Long bone, rib, radius and ulnar, metacarpal, cartilage, nasal bone, and occult are common fracture types. Ultrasound has long been used in fracture diagnosis and treatment. This narrative review summarizes and discusses the application of ultrasound in the diagnosis and treatment of fractures.

Key Words:
Ultrasound, Fracture, Diagnosis, Treatment.

Introduction

A fracture, the interruption of bone integrity and continuity, is usually caused by trauma. The main clinical features are fracture-end deformity, reverse movement, and bone friction. Severe fractures can cause shock or even death if not treated quickly[1,2]. Fractures can be divided into closed and open types according to whether they pierce the skin and into complete or incomplete according to whether bone integrity is destroyed. Based on the stability of the fracture end, fractures can be divided into stable and unstable fractures[3,4]. For patients with severe local pain and deformity after trauma, the possibility of fracture should be considered, and simple and reliable examination methods should be used to obtain accurate information to inform treatment plans. Radiology computed tomography (CT), and other imaging examination methods are the first choice for fractures, but there are some shortcomings, such as poor radiation and mobility. In recent years, the rapid development of ultrasound technology has led to its application in fracture diagnosis and treatment; for some special fracture types, it has even become the preferred examination method. This article reviews the application of ultrasound in fracture diagnosis and treatment, summarizes its advancements to date, and proposes a new direction for its follow-up application.

Ultrasound Origin and Development

Ultrasonic diagnosis was introduced in the 1940s. First, A-mode ultrasound technology was applied in clinical practice; B-mode, M-mode, and D-mode ultrasound were then performed sequentially. Ultrasound examination has the advantages of being non-invasive, simple, repeatable, instant, and relatively inexpensive. Once published, it was welcomed by doctors and patients[5,6]. The clinical application of color ultrasound makes sonograms of the human arteriovenous vessels, heart, biliary tract, and other organs more intuitive and realistic. In the past 10 years, ultrasonic diagnosis technology has been vigorously developed. With the

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continuous innovation of ultrasonic equipment, the use of body cavity and intraoperative probes has continuously expanded the scope of clinical diagnosis and treatment and improved diagnosis and treatment.

High-frequency and gray-scale ultrasound are currently widely used in clinical practice. High-frequency ultrasound refers to a radio wave with a frequency band of 3-30 MHz. With the increase in frequency, the image resolution displayed by ultrasound examination is also improved to more clearly present lesion characteristics and assist clinicians reach a scientific diagnosis[7]. Gray-scale ultrasound reflects the gray scale using different amplitudes of echo and black-and-white levels corresponding to the sonogram. If the echo amplitude is large and the echo intensity is high, it is called a strong echo; otherwise, it is called a weak echo. To date, it has been successfully applied in the diagnosis and differential diagnosis of diseases, such as mass differentiation and postpartum placenta implantation[8].

Ultrasound Application in Fracture Diagnosis

Direct or indirect violence can interrupt the integrity and continuity of the bone trabecula, leading to displacement, dislocation, and surrounding soft tissue damage of the fracture end. The surface of the normal bone showed a strong reflective interface, which hindered the further observation of the posterior structure. However, when the periosteum undergoes destruction or thinning, fracture, and lesions, ultrasound can be used to observe subperiosteal lesions.

High-frequency ultrasound mostly selects an 8-12 MHz high-frequency probe to observe the continuity of the bone cortex in the areas of pain and swelling, which can clearly show the integrity and continuity of swelling soft tissue and related bones. If local continuity interruption is found, multi-angle and all-round scanning shall be carried out with this as the center until a ladder-like or scattered fragment-like uplift is identified. Relevant studies[9,10] have shown that some fractures are undetected on X-ray examinations due to evident swelling of the soft tissue or avulsion of the fracture block <6 mm. At this time, the fracture can be identified on high-frequency ultrasonic examination, which compensates for the deficiency of the X-ray examination.

Diagnosis of Long Bone Fractures

Long bone fractures, including the humerus, ulna, radius, tibia, and fibula, are among the most common traumatic fractures. During ultrasonic scan, an ultrasonic gel is first applied to the affected area and a high-frequency linear probe is used along the long axis. After adjustment of the depth and gain, the deepest hyperechoic horizontal line (bone cortex) and its rear sound shadow appear in the image. When a fracture occurs, continuity of the bone cortex line can be observed. Displacement and angulation of the fracture end show inward depression and cortical separation on ultrasonic imaging. It has been stated that ultrasound can significantly increase the early accurate diagnosis rate of long bone fractures. Kiwanuka et al[11] reported that high-frequency color Doppler ultrasound guidance can help surgeons perform accurate fracture reduction. However, for long bone fractures near the joint, the accuracy of ultrasonic diagnosis is significantly reduced; thus, it must be combined with other diagnostic methods.

Diagnosis of Rib Fractures

Rib fractures are most often diagnosed on X-ray examinations. However, due to its low resolution and passive body position during patient examination, the detection and diagnosis rates of costal cartilage, overlapping, and crack fractures are low, and misdiagnosis and missed diagnosis may occur. The appearance of high-frequency color Doppler ultrasound probes has greatly improved the examination resolution of superficial tissues and has great advantages in the detection of occult rib fractures. High-frequency linear ultrasound can be used vertically on the long axis of the rib, scan the area 10 cm around the maximum tenderness point, and distinguish the rib cortex and pleural line through the shadow behind the rib. Rib fracture can be diagnosed when echo continuity interruption, dislocation, rough edge, and other phenomena are found[12]. Lalande et al[13] found that, for adult patients with clinically suspected rib fracture, high-frequency ultrasound is a feasible technique for diagnosing rib fractures in the emergency department. Other research[14] also found that ultrasound has the same value for rib fracture complications including hemopneumothorax and soft tissue hematoma.

Diagnosis of Ulnar and Radial Fractures

Ulnar and radial fractures usually occur in children aged 5-12 years, in whom the bone strength of the congenital epiphyseal line is weak. The radiographic diagnosis of patients with ulnar and radial fractures requires full range of motion of the affected limb, which may cause pain. Ultrasonic exploration can obtain effective information in a relatively static state, reduce the patient's radiation and the pain caused by movement of the affected limb, and achieve ideal diagnostic efficiency. The main signs of ulnar and radial fractures detected by ultrasound are interruption of the strong echo in the bone cortex, bending deformation, subperiosteal hematoma, and/or soft tissue edema. The comparison of X-ray and ultrasound in the application of distal forearm fractures in children aged 0-14 years in the Netherlands revealed that the overall diagnostic rate of ultrasound was 92%, similar to that of X-ray, indicating its accuracy for diagnosing distal forearm fractures in children; moreover, it can be implemented quickly with less pain than radiology[15]. Auten et al[16] reported that the sensitivity and specificity of ultrasound in identifying insufficient reduction of ulnar fractures in children were 100% and 92-93%. Ultrasound is an optional method for diagnosing distal ulnar and radial fractures in children.

Diagnosis of Metacarpal and Cartilage Fractures

The anatomical structure of the human palm is unique. Ultrasound can scan the palm only from the front and back; however, there are obvious defects in the side scan. Ultrasonic examinations should be performed as close as possible to the injured local metacarpal bone and compare it with the healthy side to determine the presence of a fracture. X-rays cannot show cartilage fractures, but ultrasound has unique advantages in this regard. Ultrasonic images in the diagnosis of cartilage fractures mainly show low echo, fuzzy boundary, bone dislocation, an arc-shaped connecting line at the fracture end, and low echo of the surrounding soft tissue hematoma, but they do not show typical manifestations such as continuous interruption of the bone cortex. Storch et al[17] reported that ultrasound is the first choice for evaluating the integrity of the cartilage hinge of humeral lateral condyle fractures in children without evident displacement. Bortolotto et al[18] reported that the effect of muscle bone ultrasound in the diagnosis of costal cartilage fractures is superior to those of digital radiography and multislice spiral CT.

Diagnosing Nasal Bone and Occult Fractures

The fragile nasal bone protrudes from the surface of the human body. If it suffers trauma, it is prone to fractures. In severe cases, nasal congestion and dyspnea may occur. Radiographs are widely used in the diagnosis of nasal bone fractures, but their reliability is controversial. Nasal bone ultrasonography has rapidly developed in recent years. Ultrasonography can detect fractures, interruptions, deflections, or subcutaneous ectopic air in the nasal bone cortex.

An occult fracture is the interruption of the integrity and continuity of the phalanges, but the radiographic manifestations are atypical, which can cause clinical misdiagnosis and missed diagnosis. High-frequency ultrasound could detect microfractures as small as 0.5 cm according to the fracture of the cortical echo zone at the fracture end and callus in the convalescent stage. In a study[19] on X-ray occult fracture of the proximal tibia in pediatric patients, instant ultrasound provided evidence of fracture and had value in the diagnosis of clinical occult fracture.

Application of Ultrasound in Fracture Treatment

Fracture Treatment and Localization

Fracture healing is a complex process, and the healing times vary significantly among body parts. Monitoring the fracture healing process is a current focus of clinical research. Ultrasonography is non-invasive, safe, non-radiating, and repeatable, and it has been widely used in fracture treatment, guidance, positioning, and healing. Krishnamurthy et al[20] reported that preoperative ultrasound-assisted fracture end positioning in patients with multiple injuries and rib fractures can improve the accuracy of fracture end positioning, thereby shortening surgical incision length and operation time and reducing the patient's surgical trauma. Among elderly patients undergoing hip fracture surgery, ultrasound-guided trefoil positioning improved the application of lumbar plexus blocks with high safety[10]. Yu et al[21] analyzed patients with femoral fractures and found that ultrasound identified vascular and neural structures around the hip joint, assisting the reduction of difficult to reduce femoral neck fractures and avoiding further disruption of the blood supply to the femoral head. However, there are certain limitations in the positioning of ultrasound therapy. For example, severe hematoma or subcutaneous emphysema at the fracture end can directly affect the clarity of ultrasound imaging, reduce the accuracy of ultrasound positioning, and ultimately affect the treatment effect. Fractures should be visualized with a variety of inspection methods to achieve precise positioning and maximize the treatment effect.

Fracture Localization and Anesthesia

Ultrasonography can flexibly and accurately locate the fracture surgical site so that it can be marked on the body surface and scientifically guide surgical incision position. In rib fracture fixation, ultrasound localization optimized the surgical approach and reduced the incision length and operative time[22]. In patients with closed nasal bone fractures, high-frequency ultrasonography provides accurate localization and facilitates subsequent restorations, with specific results similar to those of nasal bone CT scans[23]. Gu et al[24] found that the ultrasound-guided polynomial block may be an alternative to commonly used anesthesia procedures in elderly patients with hip fracture, providing satisfactory intraoperative pain management and reducing early postoperative cognitive impairment. Ultrasound-guided brachial plexus block anesthesia in patients with upper-extremity fractures has the advantages of short onset time, long block time, and good surgical satisfaction[25].

Fracture Healing, Monitoring, and Treatment

Gray-scale ultrasound can be used to observe the fracture healing process by showing the following processes. (1) Hematoma organization: a semicircular anechoic area with a regular shape at the fracture end followed by a semicircle or slope, hypoechoic fibrous callus with honeycomb-like changes, and atypical honeycomb-like fibrous callus with dense hypoechoic changes in the later stages. (2) Primitive callus formation: the fracture line is blurred under ultrasound, and a semicircular callus is formed that is densely hyperechoic in a radial or irregular arrangement, and X-rays observe this phenomenon later than ultrasound. (3) Remodeling of callus: the fracture line is further blurred or even completely disappears under ultrasound, the bone connection appears at the fracture end, and the callus shows dense radial hyperechoic shadows[19,26]. The display times of X-ray and ultrasound in this period were roughly equal. Nicholson et al[27] found that 3D fracture reconstruction can be established using multiple ultrasound images to assess the presence of bridging bone; this imaging modality has the potential to improve the usability and accuracy of early fracture healing identification. In addition to monitoring fracture healing, low-intensity pulsed ultrasound can promote fracture healing. The specific mechanism involves the regulation of cavitation and mechanical effects on the fracture healing microenvironment. Previous studies[28] confirmed that low-intensity pulsed ultrasound can shorten fracture healing time.

Advantages and Limitations of Ultrasound Applications

High-frequency ultrasound can detect small fracture lines with higher sensitivity for fracture detection than that of X-rays. Therefore, it has greater diagnostic value for small and occult fractures. Ultrasound can be performed in multiple directions and angles, avoiding repeated radiation hazards, and has better safety for sensitive groups such as children and pregnant women. Ultrasonography also has certain limitations in fracture diagnosis: it is easily affected by physical properties, has difficulty visualizing the internal situation of the bone, and features a limited observation field. At the same time, the subjective cognition and technology of the test subject are greatly influenced by the ultrasonic results, which may cause diagnostic errors. Therefore, for some cases with unclear images and difficult diagnoses, other imaging methods, such as X-ray, CT, and MRI, ultrasonic results should be employed as well to further improve the diagnosis result.

Conclusions

Ultrasonography plays an important role in fracture diagnosis and treatment. It is more sensitive than X-rays for some fractures. However, we must not interpret ultrasound findings alone; rather, they must be combined with other examinations and clinical manifestations to improve diagnostic accuracy.

Conflict of Interest

The Authors declare that they have no conflict of interests.

Ethical Approval

As the study did not involve human participants, ethics approval was not required.

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