Sonographic Fracture Diagnosis in Children and Adolescents

Sonografische Frakturdiagnostik im Kindes- und Jugendalter

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Key words
ultrasound, bones, children, injuries, infants, injuries, trauma

received 28.12.2022
accepted 24.01.2023
published online 26.04.2023

Bibliography
Fortschr Röntgenstr 2023; 195: 790–796
DOI 10.1055/a-2042-2161
ISSN 1438-9029

Georg Thieme Verlag KG, Rüdigerstraße 14,
70469 Stuttgart, Germany

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ABSTRACT

Background Clinical examination after trauma, especially in young children, often proves difficult. As a result, the majority of images show unremarkable findings in the imaging workup of trauma by radiography. Sonography represents an imaging technique without the use of X-rays. As the quality of ultrasound equipment has increased over the past 20 years, numerous studies have demonstrated that fractures in children and adolescents can be detected with very high sensitivity and specificity by sonography.

Method This paper reviews the results obtained so far in the literature. Based on these findings, the importance of sonographic fracture diagnosis in childhood and adolescence for the most important locations is demonstrated.

Results When examining with a high-frequency linear transducer, sensitivities and specificities of more than 90 % can be achieved for the detection of fractures. Dislocations are also reliably detected. In contrast to X-ray examination, sonography allows the diagnosis of cartilage and soft-tissue injuries. Sonography reveals callus formation earlier than radiographs. The examination causes less pain than X-ray examination. If sonographic clarification is limited purely to fracture detection or exclusion, less time is required compared to X-ray diagnosis. The procedure can be learned quickly. If the documentation follows a defined standard examination procedure, the results can also be reproduced by non-examiners.

Conclusion So far, sonography has only been an additive procedure in fracture diagnosis. However, there are now initial recommendations for sonographic fracture diagnosis alone, such as in skull, clavicle and non-displaced distal forearm fractures.

Key Points:
- Sonography can be used to detect or rule out fractures very sensitively.
- Sonographic examination causes less pain than X-ray examination.
- Sonography is usually an additive procedure in fracture diagnosis.
- In the meantime, sonography alone may be sufficient for diagnosing individual fractures.

Zitierweise
- Moritz JD. Sonografische Frakturdiagnostik im Kindes- und Jugendalter. Fortschr Röntgenstr 2023; 195: 790–796

ZUSAMMENFASSUNG

Hintergrund Die klinische Untersuchung nach Trauma insbesondere von Kleinkindern erweist sich häufig als schwierig. Dies hat zur Folge, dass in der bildgebenden Abklärung von Traumata durch Röntgenaufnahmen die Mehrzahl der Aufnahmen einen unauffälligen Befund zeigt. Mit der Sonografie steht ein bildgebendes Verfahren ohne Röntgenstrahlen zur Verfügung. Mit zunehmender Qualität der Ultraschallgeräte konnten in den letzten 20 Jahren zahlreiche Studien zeigen, dass Frakturen im Kindes- und Jugendalter mit sehr hoher Sensitivität und Spezifität durch die Sonografie detektiert werden können.

Methode Diese Arbeit gibt einen Überblick über die bisher erzielten Ergebnisse in der Literatur. Anhand dieser Erkenntnisse wird der Stellenwert der sonografischen Frakturdiagnostik im Kindes- und Jugendalter für die wichtigsten Lokalisationen aufgezeigt.

Ergebnisse Bei Untersuchung mit einem hochfrequenten Linearschallkopf können Sensitivitäten und Spezifitäten von mehr als 90 % im Nachweis von Frakturen erzielt werden. Auch Dislokationen werden sicher erfasst. Im Gegensatz zur

Röntgenuntersuchung erlaubt die Sonografie die Diagnostik von Knorpel- und Weichteilverletzungen. Die Sonografie zeigt Kallusbildung früher als Röntgenaufnahmen. Die Untersuchung verursacht weniger Schmerzen als die Röntgenuntersuchung. Bei Beschränkung der sonografischen Abklärung auf den reinen Frakturnachweis bzw. -ausschluss wird weniger Zeit im Vergleich zur Röntgendiagnostik benötigt. Das Verfahren kann schnell erlernt werden. Erfolgt die Dokumentation nach einem definierten Standard-Untersuchungsgang, können die Ergebnisse auch von Nichtuntersuchern nachvollzogen werden.

Schlussfolgerungen Bisher ist die Sonografie in der Frakturdiagnostik nur ein additives Verfahren. Mittlerweile gibt es aber erste Empfehlungen zur alleinigen sonografischen Frakturdiagnostik wie bei Schädel-, Klavikula- und nicht dislozierten distalen Unterarmfrakturen.

Examination after trauma, especially in young children, often proves difficult. Young children are not yet capable of communicating the exact location of their pain. Symptoms are also often nonspecific. The entire extremity is typically spared, and the physical examination also does not provide a definitive result. These patients tend to cry regardless of where pressure is applied. Determining the location of maximum pain under these conditions requires both ample experience and intuition.

The standard procedure in trauma diagnostics is to acquire radiographs of the affected body region on 2 planes with the possible addition of special images. In situations in which it cannot be clinically clarified which area of the skeleton is injured, multiple regions of the skeleton may need to be examined with radiography. No fractures are found in the majority of cases primarily in young children [1]. With the increasing quality of ultrasound equipment, numerous studies regarding sonographic fracture diagnosis have been conducted in the last 20 years. It was able to be shown that fractures can be detected by ultrasound with sensitivity (92.9–94 %) and specificity (92–99.5 %) comparable to that of radiography [1, 2]. Similarly good results were also seen in a meta-analysis of point-of-care ultrasound and examinations performed in the emergency department in the case of fractures of the long bones with a sensitivity of 64.7–100 % and specificity of 79.2–100 % [3–5]. This study addresses the value of ultrasound for the workup of fractures in children and adolescents based on the current literature.

Due to the wide range of impedance of soft tissue (muscle 1.66×10^6 Ns/m^3) and bone (6.0×10^6 Ns/m^3), 50 % of sound waves are reflected by bone. In addition, there is very high acoustic absorption within bone (99.7 % at 3.5 MHz and 100 % at 7.0 MHz at a depth of 1 cm). As a result, only the surface of the bone can be seen as a hyperechoic line on ultrasound, while the structures within the bone remain hidden on ultrasound. However, using high-frequency linear probes of at least 9–15 MHz, the bone surface can be examined with high resolution.

A fracture line is seen on ultrasound as a disruption of the cortex. Due to the linear course, it can be differentiated from a vascular channel. A dislocatio ad latus results in a cortical step on the ultrasound image, while a pediatric buckle fracture results in a typical cortical bulge. A dislocatio ad axim results in buckling of the cortex. In the case of a large fracture gap, ultrasound can be used to view deep into the bone. Care is required when imaging the ends of the metaphyses. Small steps that cannot be confused with fractures are usually seen here on ultrasound (▶ **Fig. 1**). In cases of doubt, the opposite side can be easily examined with ultrasound.

Associated injuries can also be reliably detected with ultrasound. The hematoma that is typically present in the surrounding soft tissue is seen as a diffuse increase in echogenicity in the surrounding soft tissue. Large hematomas can present like a hypoechoic soft-tissue tumor around the fracture in the acute stage. The hemarthrosis that always accompanies intraarticular fractures results in an effusion in the affected joint that is not anechoic on ultrasound.

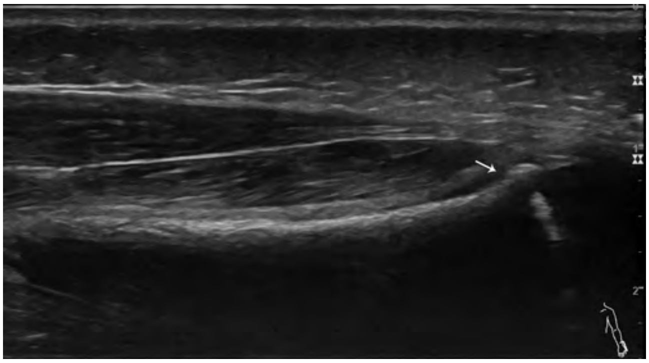
In the sonographic workup of fractures, careful application of the transducer must be ensured. Tilting of the probe can simulate disruptions of the cortex or buckling of the cortex and thus fractures. Injuries to cartilage structures, e. g. rib cartilage, or cartilaginous segments of epiphyses and apophyses in children are missed by radiography. In contrast, cartilage injuries can be detected on ultrasound as reliably as bone injuries.

The long bone to be examined is ideally examined sonographically from the four possible directions – ventral, dorsal, medial, and lateral. Using this approach, fractures can be detected or ruled out with high sensitivity and highly reliable conclusions about fracture type and fracture position can also be made [6].

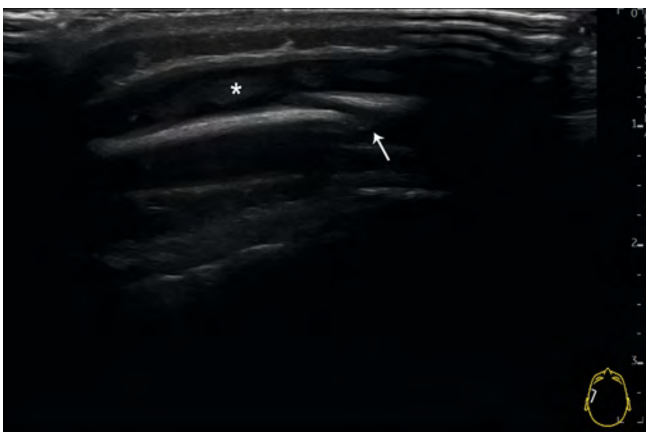
Skull fractures (▶ **Fig. 2**): In the workup of skull fractures, sufficient ultrasound gel must be used particularly in the case of a significant presence of hair. Ultrasound examination must extend beyond the edge of the fracture hematoma since gravity can cause hematomas to sag caudally. Moreover, the examination must be performed in various sound directions. If the sound plane runs parallel to the fracture line, fissures can go undetected. Moreover, the examiner requires knowledge of the position and course of the sutures to avoid confusion with fracture lines.

Under consideration of these principles, ultrasound achieves a very high sensitivity of 91 % and specificity of 96 % in the detection of skull fractures [7, 8]. For the workup of uncomplicated skull fractures without therapeutic consequences, sonographic examination alone is sufficient [9]. Radiography of the skull for detecting fractures is obsolete except in the case of suspicion of child abuse [10]. Complex skull fractures and depression fractures can also be reliably detected on ultrasound and a CT examination can then be conducted [11]. Supraorbital fractures and fractures of the base of the skull are not sufficiently accessible for sonographic examination and are diagnosed with greater sensitivity on CT [9].

Clavicle fractures (▶ **Fig. 3**): Sonographic examination of the clavicle includes ventral and cranial views and possibly also a ventrocranial view. Occasionally, an additional cross-sectional scan of



▶ **Fig. 1** Sonographic longitudinal section – volar view of the radius showing small metaphyseal step (arrow) that should not be confused with a fracture.

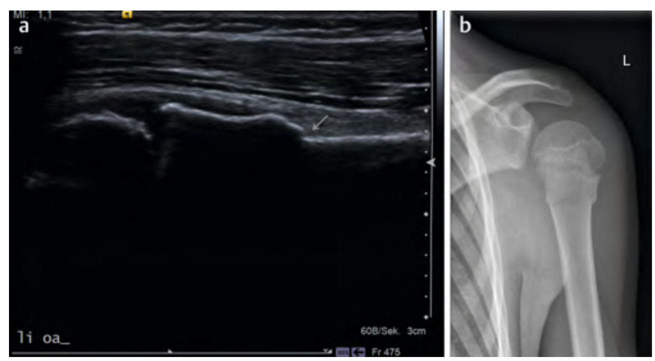


▶ **Fig. 2** Right parietal skull fracture on ultrasound with loss of cortical continuity and minimal step (arrow); large hypoechoic galeal hematoma visible above it (*).

the clavicle can be helpful. Using this approach, ultrasound is superior to radiography for detecting fractures with a sensitivity of 91 % (radiography 77 %) and a specificity of 93 % (radiography 100 %) [12]. Even in the case of a negative radiological finding and clinical signs, additional sonographic workup is indicated [13]. Since fractures in children have good correction potential, fractures detected on ultrasound do not require radiographic control [14]. Multiple studies were able to show that the sonographic examination does not cause any additional pain [14, 15].

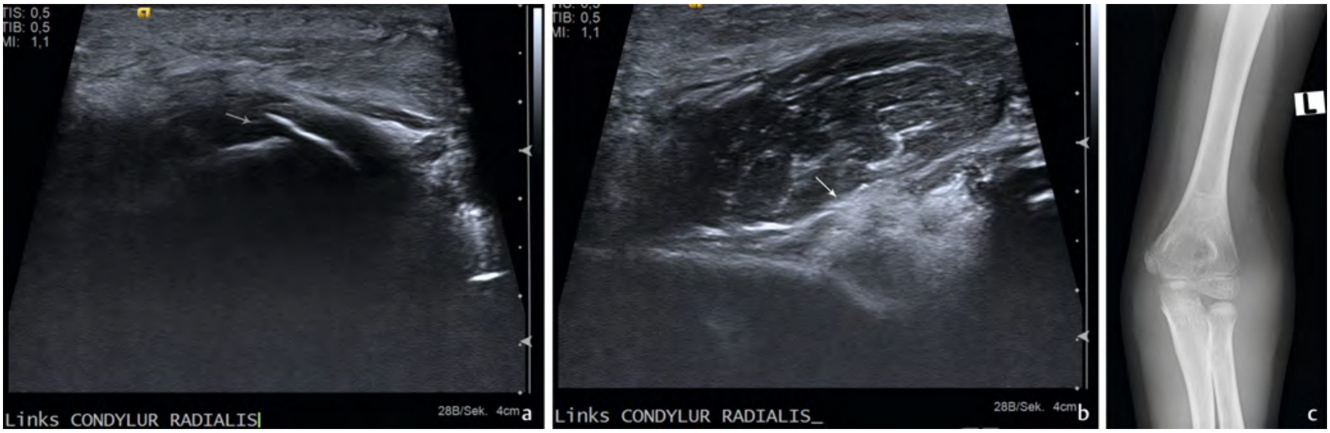
Proximal humerus fractures: A standardized ultrasound examination of the proximal humerus is performed in longitudinal sections in ventral, lateral, and dorsal views with the arm attached and internally rotated and additionally in a ventral view with the arm attached and in neutral position (forearm in ventral orientation) [16, 17]. It must be ensured that the cortex is visualized on the entire width of the image and the epiphyseal cartilage is also visualized (▶ **Fig. 4**). Sonography also achieves a very high sensitivity of 94 % and specificity of 100 % for the diagnosis of proximal humerus fractures [18–20]. Studies have shown that the axial deviation can be determined more precisely with ultrasound than radiography [19, 20]. If a fracture can be diagnosed on ultrasound, radiographs are then needed to rule out a pathological fracture [16, 17, 19, 20]. If a fracture can be ruled out on ultrasound, radiographs are not necessary [16, 17]. Due to possible intraarticular fractures, ultrasound is only suitable as a supplementary method in children over the age of 12 [18].

▶ **Fig. 3** Clavicle fracture on ultrasound with distinct step (arrow), diffuse hyperechoic hematoma in the surrounding soft tissue.



▶ **Fig. 4** **a** Proximal fracture of the humeral shaft on ultrasound **a** with small step (arrow) and adjacent diffuse, hyperechoic hematoma. **b** Radiograph of the fracture (**b**).

Elbow fractures: Most studies on the sonographic diagnosis of elbow fractures relate to the detection or exclusion of joint effusion based on a dorsal longitudinal scan of the olecranon fossa. A positive dorsal fat pad sign is seen as a correlate on radiography. Ultrasound has a sensitivity of 97–100 % and a specificity of 90 % here [21, 22]. If a joint effusion is detected, radiography is indicated for fracture classification [16, 17]. If there is no joint effusion, a fracture is unlikely [16, 17, 23]. Therefore, ultrasound is a suitable method for fracture exclusion in the case of low clinical suspicion [24]. However, it must be taken into consideration that there is often no joint effusion in non-displaced proximal radius fractures and Chassaignac subluxation. The epicondylus ulnaris is



▶ **Fig. 5** **a** Fracture of the condylus radialis with distinct step (arrow) on ultrasound **a** and extensive diffuse, hyperechoic soft-tissue hematoma. **b** Consecutive hyperechoic hemarthrosis (arrow) on ultrasound (**b**). **c** Radiograph in the antero-posterior projection (**c**).

also in a partially extraarticular position so that joint effusion is not always present in incomplete fracture [25].

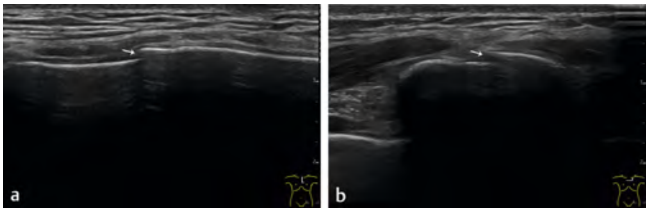
Due to the complex anatomy of the elbow joint, it is very difficult or even impossible to detect the exact type of fracture and the course of the fracture on ultrasound (▶ **Fig. 5**). In particular, extension of the fracture to the joint surface can be missed on ultrasound since the joint surfaces can only be partially visualized on ultrasound. Therefore, radiographs are always needed for patients over the age of 13. However, ultrasound can visualize cartilage but radiography cannot. Therefore, in the case of injuries to the cartilage in the elbow, primarily condyles, epicondyles, and the head of the radius before the emergence of epiphyseal nuclei, ultrasound is superior to radiography. In the case of a minimally displaced fracture of the radial condyle, the stability of the fracture can be determined on transverse ultrasound [26].

Distal forearm fractures: Sonographic diagnosis of distal forearm fractures is documented in scientific studies (▶ **Fig. 6**). Sonographic examination is ideally performed at the radius in volar, radial, and dorsal views, and at the ulna in volar, ulnar, and dorsal views, using the „wrist SAFE algorithm“ [27]. Ultrasound achieves a very high sensitivity of 92–100 % and specificity of 88–100 % for the detection of distal forearm fractures [28–31]. If a sonographically diagnosed distal forearm fracture does not require repositioning or surgery, ultrasound can be performed as the only imaging method [27]. Additional radiographs are needed in all other cases. With this approach, 81 % of radiographs can be avoided. However, starting in the 14th year of life, intraarticular fractures can occur and can no longer be sufficiently diagnosed with ultrasound. Therefore, starting at this age, distal forearm fractures must generally undergo X-ray examination [27].

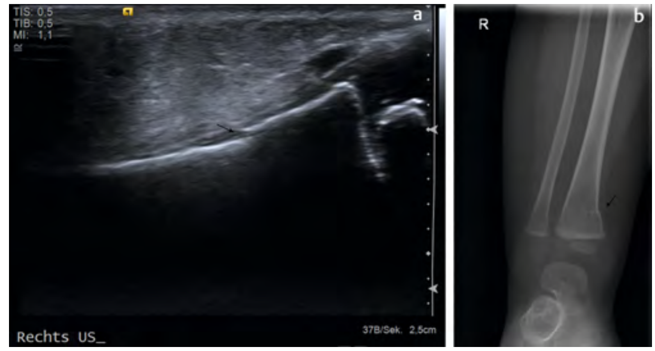
▶ **Fig. 6** **a** Distal forearm fracture. Ulnar view of the ulna on ultrasound showing slight bulging (arrow, **a**) and dorsal view showing loss of cortical continuity and minimal step (arrow, **b**); dorsal view of the radius showing more distinct step (arrow, **c**) and radial view showing impaction and bulging (arrow, **d**). **e** Dorsovolar **e** and lateral **f** radiographs, fractures indicated by arrows.

Metacarpal fractures: The metacarpal bones are examined sonographically in dorsal and volar views using sufficient ultrasound gel. Fractures can be diagnosed sonographically with a sensitivity of 90–100 % and a specificity of 95 % [32]. Radiologically occult fractures can also be detected. The palmar tilt of the head, the extent of which is decisive for treatment, can be measured more precisely on ultrasound than radiography.

Rib fractures: There are currently only a few studies on this topic. Sonographic examination is performed at the site of the greatest pressure pain in the longitudinal direction of the rib. The adjacent ribs should also be included in the examination. Ultrasound is superior to radiography here with a sensitivity of 97 % compared to 77 % and a specificity of 94 % compared to 100 % [12, 33]. If no fracture is detected on radiography, a fracture can still be detected on ultrasound in 25–40 % of cases [34–36]. Rib cartilage fractures can also be detected on ultrasound in 69 % of cases [37].



▶ **Fig. 7** **a** Longitudinal section **a** and axial section **b** of sternum fracture with visible step (arrows).



▶ **Fig. 8** **a** Distal tibial shaft fracture. Ultrasound examination including medial view **a** in the longitudinal section showing minimal step (arrow) and adjacent diffuse hyperechoic soft-tissue hematoma. **b** Anteroposterior radiograph **b**, fracture indicated by arrow.

Sternum fractures: Only individual studies with a small number of cases are available here. The sternum is examined on ultrasound in the sagittal and transverse directions (▶ **Fig. 7**). Ultrasound achieves a sensitivity of 91 % (radiography 77 %) and a specificity of 93 % (radiography 100 %) [12].

Distal lower leg fractures (▶ **Fig. 8**): The distal tibia and fibula are examined in ventral, dorsal, and medial/lateral views. For the detection of fractures, a sensitivity of 96–100 % and a specificity of 93–97 % are described [38, 39]. However, the fractures cannot be sufficiently classified on ultrasound so that a targeted X-ray examination must be subsequently performed if a fracture is detected [17]. However, if a fracture is ruled out on ultrasound, an X-ray examination is not necessary.

Metatarsal fracture: Some of the studies include only a very small number of cases regarding this region. Comparable to the metacarpal bones, the metatarsal bones are examined in the longitudinal direction in dorsal and plantar views and the first ray and fifth ray are examined in medial and lateral views, respectively, on ultrasound. For fracture detection, a sensitivity of 80–97 % and specificity of 76–100 % are achieved [40].

Fractures of the long bones (▶ **Fig. 9**): The standard is to perform sonographic examinations in the longitudinal direction in ventral, medial, dorsal, and lateral views. Sensitivities of 90–96 % and specificities of 86–100 % are achieved [3, 5].

If the sonographic examination is performed as recommended in ventral, dorsal, medial, and lateral views, a dislocation can also be reliably detected [6]. The need for repositioning can be identified with a sensitivity of 100 % and a specificity of 85–97 % [3, 5]. Adequate repositioning can be confirmed sonographically with a sensitivity of 94–100 % and a specificity of 56–100 % [4, 5]. Inadequate repositioning can be identified with a sensitivity of 100 % and a specificity of 92–93 % [41].

Following long bone fracture, callus formation can be detected sonographically with good sensitivity (▶ **Fig. 10**). Ultrasound scans are able to identify callus formation significantly earlier than radiographs [42]. On ultrasound, the callus has a higher degree of vascularization compared to healthy periosteum. Ultrasound is mentioned as a possible alternative to radiography for examining fracture healing [43]. However, hardly anyone would be comfortable with removing a cast for fracture stabilization based solely on sonographic imaging.

Ultrasound examination in trauma patients can be performed in the most comfortable position for the patient, for example, in the mother's arms. It can be performed in the least painful position and requires only minimal position changes. It is not necessary to apply much pressure to the transducer and a cooling gel can be used. Therefore, it is not surprising that multiple studies have shown that patients experience significantly less pain in ultrasound examinations than X-ray examinations [14, 17, 27, 31]. Since radiography requires exact a. p. and lateral images, highly painful positioning of the patient and unpleasant position changes are often necessary.

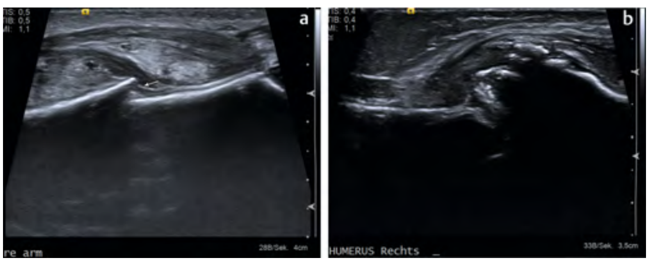
If the ultrasound examination is performed as point-of-care ultrasound (POCUS), the examination is significantly shorter compared to an X-ray examination [14, 24, 27, 31]. The sonographic workup of a distal forearm or elbow fracture requires 2 to a maximum of 5 minutes [24, 27, 31]. However, if the examination goes beyond mere POCUS, the examination can take significantly more time. This is particularly true when the location of the fracture is unclear or the patient is uncooperative. More detailed evaluation of the fracture, e. g. characterization of an elbow fracture, typically requires more time.

Sonographic fracture diagnosis can be learned quickly. In addition to sonographic fracture diagnosis training and experience, knowledge of the examination procedure and documentation must be acquired. Multiple studies were able to demonstrate that forearm fractures can be reliably diagnosed on ultrasound after only a brief training period [27, 30, 44].

The examination region and plane is not clear from the ultrasound image alone. It is essential to provide image documentation after a defined standard examination procedure that can be readily understood by non-examiners. If distal forearm fractures are documented according to the Wrist SAFE algorithm, the image documentation can be reliably reviewed and application by assistant physicians is possible [27]. However, image documentation of complex content is difficult. Radiographs on two perpendicular planes provide three-dimensional information about the fracture. In ultrasound examination, this can only be achieved with real-time examination so that the examination can often only be understood by the examiner. The extent to which this information can be taken from a video loop or a 3 D ultrasound scan must be clarified by future studies.

Ultrasound has several advantages compared to radiography. It allows visualization of bone on various planes without superimposition, while radiographs are always summation images. In cases of doubt, a comparison with the opposite side can be per-

▶ **Fig. 9** **a** Spiral fracture of humeral shaft. Sonographic longitudinal section – lateral view **a** showing distinct step (arrow) and volar view **b** showing distinct step and axial angulation (arrow). **c** Anteroposterior **c** and lateral **d** radiograph.



▶ **Fig. 10** **a** Sonographic longitudinal section of a humeral shaft fracture **a** showing step (arrow), axial angulation, and diffuse hyperechoic soft-tissue hematoma. **b** Significant irregular widening due to callus formation seen on ultrasound **b** 3 weeks later.

formed with ultrasound. It is a dynamic examination performed in real time in which image as well as clinical information, e. g., the detection of the site of maximum pain, can be acquired. Ultrasound provides additional information about soft-tissue injuries, joint effusion, hematomas, and cartilage injuries. The method does not require radiation and can be performed easily on site. Open injuries, apparent defective positions, suspected vascular and nerve involvement, refractures, suspicion of intraarticular and intraosseous lesions, and pathological fractures remain the domain of radiography [17].

Sonographic fracture diagnosis is problematic when the work-up goes beyond basic fracture detection or exclusion. Such cases can result in a more time-intensive examination that ties up medical personnel. This usually exceeds medical capacity and the compensation for services in these cases is inadequate. Depending on the complexity of the fracture, adequate documentation can be difficult or impossible since 3 D information can only be insufficiently recorded in images.

To date, ultrasound has only been used as a supplementary method in fracture diagnosis. However, it is a reliable method for fracture detection and exclusion. Dislocations can also be reliably detected on ultrasound. The examiner needs corresponding expertise and certain equipment requirements must be met. There are now initial recommendations for the sole use of sonographic fracture diagnosis in skull, clavicle, and non-displaced distal forearm fractures.

Conflict of Interest

Coauthor of AWMF Leitlinie Fraktursonographie

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