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Original article

Ultrasound-guided diagnosis of fractures of the distal forearm in children

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ABSTRACT

Purpose: Distal radius and forearm fractures are injuries that are frequently seen in trauma surgery outpatient clinics. Usually, the wrist is X-rayed in 2 planes as standard diagnostic procedure. In contrast, we evaluate in our study the accuracy of ultrasonography (US) in diagnosing these fractures.
Methods: This prospective study includes the patients who presented at two trauma surgery clinics with a presumptive diagnosis of distal radius or forearm fracture between January and December 2012. After a clinical examination, US imaging of the distal forearm was first carried out on 6 standardized planes followed by radiographs of the wrist made in two planes. The age limit was set at the end of 11 years.
Results: In total, 201 patients between 4 and 11 years of age were recruited with an average age of 9.5 years at the time of the trauma. There were 104 (51.7%) fractures distributed as follows: 89 (85.9%) injuries of the distal radius, 9 (8.7%) injuries of the distal ulna, and 6 (5.8%) combined injuries (radius and ulna). Sixty-five greenstick fractures were detected. Surgery was necessary in 34 cases. Specificity and sensitivity of ultrasound diagnosis were 99.5%.
Conclusion: Ultrasound imaging is suitable to demonstrate fractures of the distal forearm. It is a highly sensitive procedure in detecting distal forearm fractures. In our opinion, a negative result in ultrasound may reduce the need for further radiographs in children with distal forearm lesions. But in any doubtful situation the need for conventional radiographs remains.
Level of evidence: Level III. Prospective study.

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1. Introduction

In recent years, due to higher physical activity and/or higher body weight, an increasing incidence of fractures of the distal forearm has been reported in children [1,2]. Today, the incidence for fractures of the distal radius is approximately 20–36% [3]. Thus, fractures in the area of the distal forearm belong to the most common types of fracture in children [4]. Conventional radiographs of the wrist in 2 planes are considered the gold standard. But in children, the risk of injury from exposure to X-rays is up to 10 times higher than in adults [5,6]. Although for radiographs of the extremities only small amounts of radiation are applied, but radiation effects are cumulative and may cause increased risks over lifetime period. Thus it seems reasonable to search for alternative diagnostic procedures. In literature, some studies have shown that ultrasound-guided diagnosis is reliable in detecting fractures of the distal forearm [7–10]. In children, the periosteal sleeve is thick and protects the cortical bone. In contrast to adults the bone is softer and more flexile. Thus, there is a wide range of fracture types that is uniquely seen in children: torus fracture (buckle), greenstick fracture, complete fractures and fractures of the epiphyseal plate [11].

Joshi et al. described that it is possible to detect an axis deviation by using ultrasonography (US) [12]. It is known, that the potential for spontaneous correction of post-traumatic deformities is enormous up to 11 years, particularly after fractures of the distal radius [13,14]. Van Laer et al. describes a correction potential up to 40 degrees [11]. But in each particular case, it must be asked whether the child can be reasonably expected to put up for months with the unsightly bayonet deformity, a question that must be discussed with patient and relatives.

The aim of our study was to evaluate the accuracy of US in diagnosing a fracture performed by residents in traumatology

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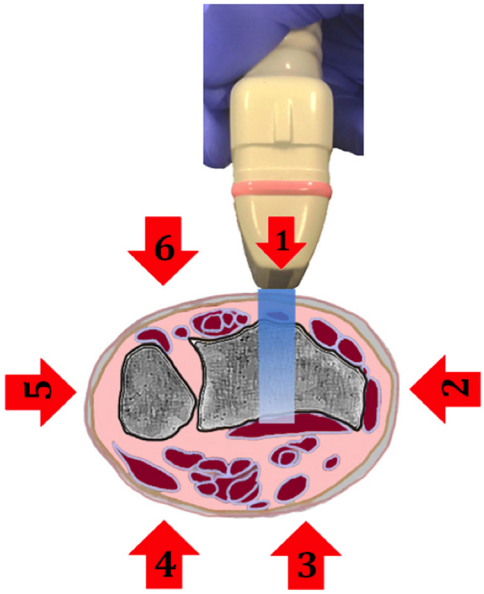

Fig. 1. Ultrasound of the distal forearm: 1: dorsoradial; 2: radial; 3: palmar-radial; 4: palmar-ulnar; 5: ulnar; 6: dorsoulnar

compared to conventional radiographs. Also we assessed and measured an axis deviation diagnosed by US compared to standard radiographs.

2. Materials and methods

In our 2-centre prospective study, children who presented with a presumptive diagnosis of a distal radius or forearm fracture after an accident were examined in a 1-year period between January and December 2012. Before starting the study, all participating residents in their 2nd to 6th year of education in traumatology underwent a short 30-minute training to learn the basics of how to use US to detect fractures of the distal forearm. Furthermore a method was presented to standardize US. For that, a short reference manual including instructions and images was available.

Inclusion criterion was pain in the forearm area following an adequate trauma such as fall on the arm, direct impact or distortion. Exclusion criteria were open wounds in the area of the distal part of the forearm, peripheral disorders of sensitivity and/or circulation, axis deviations that required immediate reduction or pre-existing deformities of the forearm. According to the literature, age limit was set at the end of 11 years [11].

The children and also their parents or caregivers were asked to describe the accident, and were subjected to a clinical examination, including external inspection, palpation and neurovascular assessment. Before obtaining radiographs, focused ultrasound of the distal forearm was performed according to a standardized method (Fig. 1). It was carried out with a 7.5-MHz-linear transducer (Siemens AG, Region West, Franz-Geuer-Str. 10, 50823 Cologne, Germany), with the patient in a supine position. The arm to be examined was placed on an arm table in a pronated position. The gel on the transducer was placed over the distal forearm, with the transducer in contact to the gel but not to the underlying skin. According to this, the distal forarm was examined in 6 standardized planes. First, the radius was visualized in longitudinal section from a dorsal, radial and palmar view, and then the ulna from a palmar, ulnar and dorsal perspective. Ultrasound fracture diagnosis was stated by the presence of cortical gap, cortical bulging, cortical deviation or a positive hematoma covering the corticalis in all views.

A goniometer was placed on the printouts of the ultrasound to measure an eventual axis deviation. The axis point was placed precisely above the visualised cortical interruption, allowing to measure the axis deviation on the degree circle.

Following the ultrasound diagnosis, conventional radiographs of the wrist were made in 2 planes (dorsopalmar and lateral) in the usual manner–for the dorsopalmar image, the child patient lies on, or sits next to, the examination table. The forearm lies flat on the table with elbow and wrist level. The hand is placed on the table in pronated position, 2–5 fingers were slightly bent, with the thumb spread out.

For processing a lateral view, the child patient sits next to the examination table. The elbow is bent 90 degrees, so that forearm, wrist and hand are aligned in an axis. The arm is positioned at the side of the table top. The wrist is placed exactly laterally and in the middle of the cassette, the fingers are stretched, the thumb pointing upwards.

Then the ultrasonographic and radiographic findings, and any eventual axis deviation were separately evaluated; consequences for treatment, axis deviation, patient age and gender were documented separately. The residents who did the evaluation of ultrasound were not blinded to any information about the child. Attending experts in radiography interpreted radiological findings being blinded to the US results.

There was at least one parent who accompanies the child during the entire examination. The child and their parents or caregivers were informed about the examination and the study, and gave their consent to the use of data in an anonymous manner.

Table 1
Demographic distribution.

Number of patients	201
Girls	69 (34.3%)
Boys	132 (65.7%)
Fractures	104 (51.2%)
Radius fractures	89
Ulna fractures	9
Radius and ulna	6
Greenstick fractures	65

3. Results

Between January and December 2012, a total of 201 children aged between 4 and 11 years were examined (Table 1). One hundred and four fractures (51.7%) were found.

The great majority were distal radius fractures (85.9%), 9 (8,7%) were distal ulna fractures and 6 distal forearm fractures (5.8%) (Fig. 2). Greenstick fractures were found in 65 cases (62,5%) (Fig. 3). All 89 fractures of the distal radius found on the radiographs were confirmed by US. Diagnosis of fractures of the distal ulna (isolated or combined) was recognized as correct in the positive or correct in the negative in 14 cases. In 1 case, US showed no fracture of the distal ulna, while radiographs showed cortical swelling similar

Table 2
Results of US and radiographic diagnosis in comparison.

	Correct positive	Correct negative	Correct (overall), *n* (%)	False positive	False negative	False (overall), *n* (%)
Radius (201)	95	106	201 (100)	0	0	0 (0)
Ulna (201)	14	186	200 (99.5)	0	1	1 (0.5)

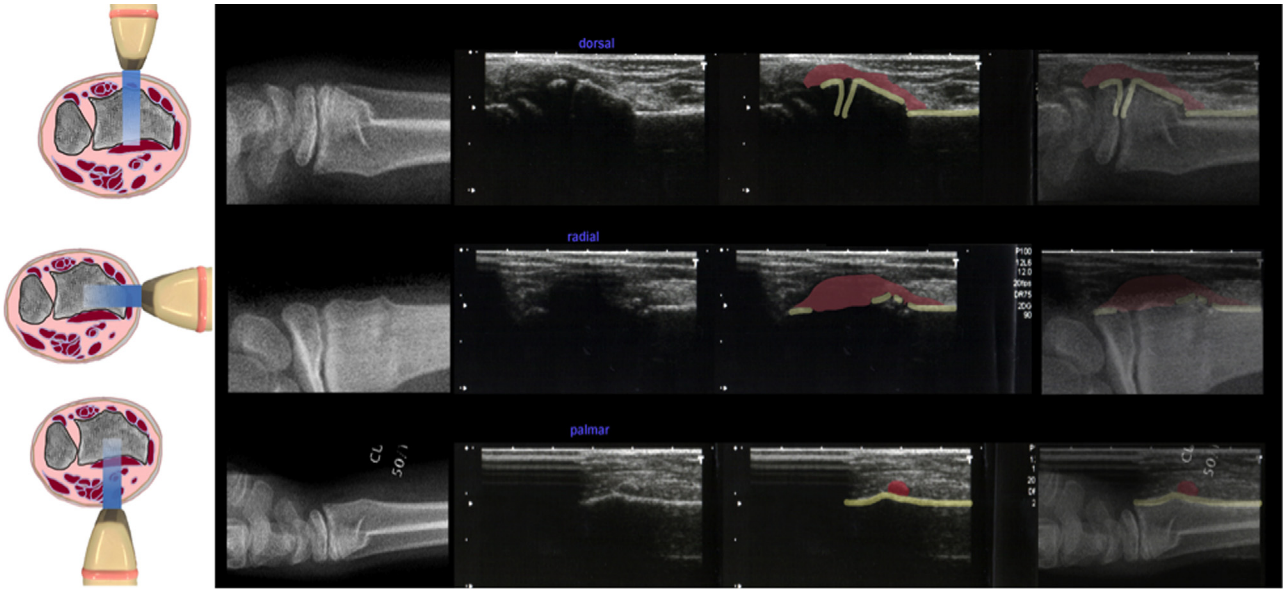

Fig. 2. Conventional radiologic and ultrasonographic diagnosis of closed dislocated distal radius fracture in direct comparison.

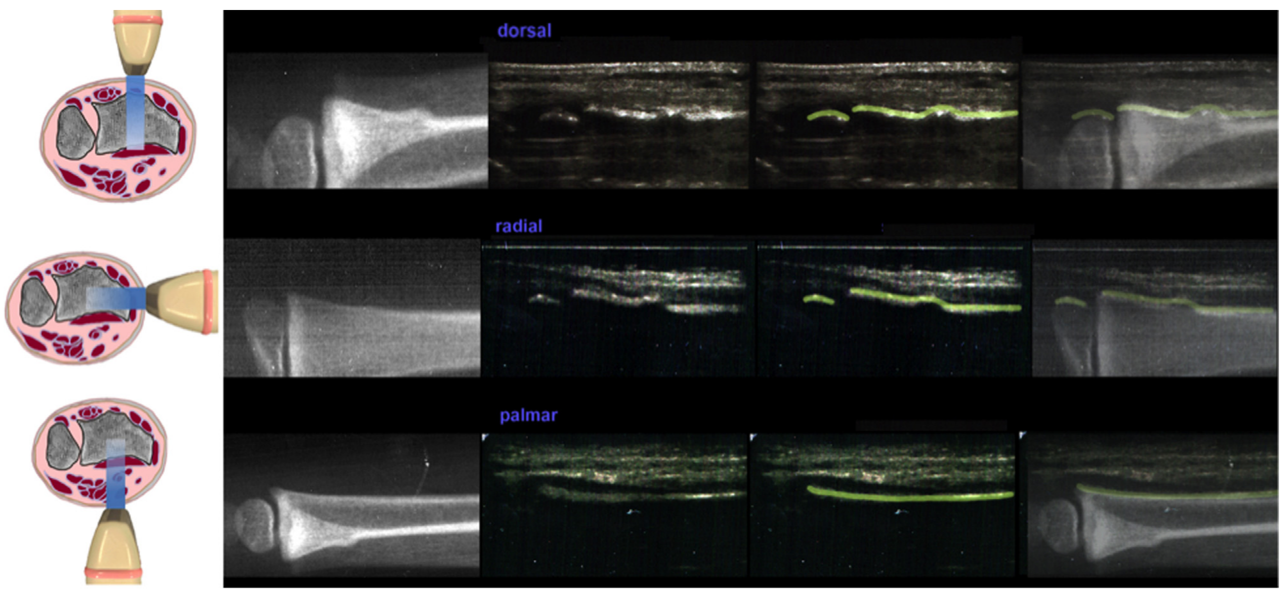

Fig. 3. Conventional radiologic and ultrasonographic diagnosis of a torus fracture of the distal radius in direct comparison.

Table 3
Average axis deviation in the radiographic and US image.

	Number of fractures requiring surgery	Axis deviation (dorsoradial) (°)
Radiology	34	18.4
Ultrasonography	34	18.2

to a torus fracture (Table 2). The axis deviation documented in 34 fractures requiring surgery was in average 18.4° (radiography) and 18.2° (US) (Table 3). In these cases percutaneous K-wire fixation was necessary.

4. Discussion

In our study, we examined the accuracy of US in diagnosing a fracture in comparison to radiography. This technique seems to be an excellent alternative to radiography of the distal forearm. Given to the anatomy of the forearm, US is particularly suitable for this purpose. Combination of thin soft tissue and small distance between the transducer and the bone ensures an excellent image quality. In addition, the 6 planes allow visualizing the bone almost completely on all planes. In contrast to radiography, displaying indirect signs of fracture, such as signs of hematoma or detachment of the periosteum is possible. Unlike radiography, evaluation of soft tissue such as muscle oedema, tendon and joint functions is an advantage of US. Furthermore, US provides a high spatial resolution with multiplanar capability of imaging. It has been known to localize the interposition of soft tissues between fracture fragments preoperatively [15]. Standard radiography will only detect erosions that are in a plane that is tangential to the radiographic beam. Variations in film projection and penetration may further limit the quality of the image, which ultimately relies upon the projection of a three dimensional image on to a two dimensional medium [16,17]. The use of US to detect skeletal fractures has already been described in some studies with different outcomes

[8,18,19]. According to the literature, use of US on the skeleton of adult patients is confined to a few special cases, e.g. rib fractures or fractures in the area of the face (nose, jaw, and cheekbone) [20–24]. In children, US has proved to be particularly accurate in detecting hip dysplasia [25]. US is also commonly used on joints. Moreover, it represents a low-cost and radiation-free alternative to the standardized radiography of fractures [9]. In recent years, because of the multitude of osseous injuries to the distal forearm at young age, the technique has been transferred to this region [7,10]. In 2007, Chen et al. conducted fracture reductions at the distal forearm under US guidance. In agreement with our results, US allowed to accurately measure the axis deviation so that even a fracture reduction was possible under ultrasonographic guidance [15]. According to our study, the axis deviations measured by means of radiography and of US were almost identical, with a difference of 0.2°.

During ultrasound examination, there must be a direct contact between the transducer and the area to be examined. Therefore, the examination can be painful even without great pressure being applied. To avoid any harm to the children, the gel on the transducer was placed over the distal forearm with the transducer in contact to the gel but not to the underlying skin. From our personal experience and appreciation the use of ultrasound gel has the second effect to cool the fracture region; most patients described it as agreeable. Other authors showed that ultrasound examination is not associated with an increase of pain and comparable to taking radiographs [26,27].

The fracture not detected in our study was a greenstick fracture of the distal ulna combined with an injury to the distal radius. With almost 100% specificity and sensitivity, US can be considered as a reliable technique. Fractures involving only cortical swelling can be detected equally well with both methods. Discrete twists without cortical swelling are more difficult to detect with US as with radiography. However, US provides the advantage to detect an additional fracture hematoma with periosteal detachment or involvement of soft tissue. In our case of a missed fracture, it depends on how the investigator interprets the twist or periosteal oedema as pathological or not. In our opinion, in these cases, such a fracture can be undetected using both techniques.

Compared to radiography, the 6 ultrasound printouts or images on the monitor show nothing more than selected image sections; this makes a subsequent assignment more difficult if the documentation is not precise. However, to date it is not clear whether superimposing of the 6 longitudinal ultrasound image sections would be possible to generate a 2-dimensional image by using image processing software. In our opinion, it is not possible to obtain true coronal and sagittal planes of the distal forearm only by the use of 6 US planes. This context should be carried out by further studies.

In contrast, a radiological image allows directly assigning the represented area. If there is a doubt of any further fractures of the adjacent joints during clinical examination, it is easy to get a radiograph of these joints. Radiographs provide the possibility to evaluate the joints proximal and distal of the fracture. By the use of US it is impossible to display more than the represented area. Unlike to radiography, assessment of articular surface, bone penetration or measurement of conventional radiographs such as radial articular inclination or palmar tilt cannot be measured directly by the use of US [28].

According to the literature, US can be used as a screening technique in order to reduce the use of radiographs [29]. In our opinion, if US does not show any evidence of a fracture or a fracture involving nothing more than torus formation or typical cortical swelling, it might reasonable to abstain from further radiographs in children with distal forearm lesions. But we want to emphasize that in cases of any doubt or if detecting a fracture with axis deviation or finding a fracture of the epiphyseal plate or distinctive dislocation, conventional radiography should be carried out as usual to guide treatment planning.

In cases of conservative treated fractures such as greenstick fractures, follow-up monitoring by the use of US is possible. In cases of pre-existing ultrasound images, a radiograph might not be necessary to monitor the further outcome. Dulchalsky et al. stated that fracture healing could also be displayed on US images [20]. In contrast, postoperative US-monitoring is not possible if the forearm is immobilized in a circular plaster cast. While taking off the plaster cast in follow-up visit, there is a risk of secondary fracture dislocation. Whether an immersion US with a plastic cast is possible as monitoring tool is yet to be investigated.

5. Limitations

First, we do not provide a second review of our primary ultrasound findings by an experienced sonologist/radiologist for an objective diagnosis. However, it is more difficult to analyze US images retrospectively by an experienced sonologist/radiologist in cases of doubt, because US is a dynamic procedure even if US views are standardized. In contrast, radiographs can be reviewed in a simple way.

Second, in our study, residents in their 2nd to 6th year of education performed the examination. These physicians weren't experts in ultrasound diagnosis, but they underwent a short training in ultrasound-guided fracture diagnosis. Thus, we can't exclude any inter-observer variability. Already stated in other studies by Ackermann et al. and Chaar-Alvarez et al. a minimal training of some hours is enough to acquire sufficient skills to detect fractures by using US [26,27]. According to these studies we agree in this point. In our study, the residents were able to detect fractures of the distal forearm accurately. This shows that ultrasound-guided diagnosis of fractures can be learned quickly.

Third, we do not provide a true double-blind method for analysis of both procedures. In our study, the residents who did the evaluation of ultrasound findings were not blinded to any information about the child, but attending experts in radiography interpreted radiological findings being blinded to the US results.

6. Conclusion

In summary, we showed that, in principle, US can be used to detect fractures of the distal forearm in children. According to previous studies of Eckert et al. we can give a diagnosis of fractures of the distal forearm even by a positive sign of periosteal hematoma or direct fracture signs such as a cortical gap or bulging. To the best of our knowledge with a collective of 201 patients, our study is one of the largest evaluations of ultrasound diagnosis of distal forearm fractures in children. Our promising results support and reflect previous studies on this field of study.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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