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ORIGINAL ARTICLE

Ultrasound evaluation of elbow fractures in children

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Abstract

Purpose Elbow fractures are a common pathology in any pediatric emergency unit. X-ray of the elbow is the standard diagnostic procedure. Previous studies have shown that fractures can also be visualized by ultrasound (US). The aim of our study was to evaluate the diagnostic accuracy of US in comparison to X-rays in diagnosing pediatric elbow fractures.

Methods Sixty-seven patients aged 1–13 years with clinically suspected elbow fracture were first examined by US followed by standard two-plane radiographs. US examination was done with a 12-MHz linear probe from seven longitudinal positions across the distal humerus and additionally from longitudinal positions across the radial head and olecranon. The sonographic and radiological findings were compared in a contingency table, and sensitivity, specificity, and positive and negative predictive values of the US diagnostic procedure were calculated.

Results With X-ray, we found 48 patients with an elbow fracture and 19 patients with no fracture. With US, we found 46 patients with an elbow fracture and 21 patients with no fracture. In comparison to X-ray diagnosis, we calculated for US diagnosis a sensitivity of 97.9 %, a specificity of 95 %, a negative predictive value of 95 %, and a positive predictive value of 97.9 %.

Conclusion Typical elbow fractures in children could also be visualized by US. A positive fat pad sign, in particular, serves as a strong indicator for elbow joint fractures and can be identified very sensitively by US. We confirm US as a valuable primary screening tool for elbow injuries in children. In the absence of US signs of fracture and in sonographically confirmed non-displaced fractures, standard X-rays are dispensable, thereby minimizing the X-ray burden in children without loss of diagnostic safety.

Keywords Ultrasound · Elbow · Supracondylar fracture · Children

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Introduction

Elbow injuries are a common cause for presentation in pediatric emergency units. Among these, supracondylar fracture of the humerus is a characteristic injury in children [1].

In clinically suspected elbow fractures, X-ray is still the imaging procedure of choice [2]. However, due to age-dependent incomplete epiphyseal ossification and often non-exact two-plane radiographs in uncooperative children, radiological assessment of the elbow can be difficult [3, 4]. In the absence of direct fracture signs, the so-called positive fat pad sign indicates an occult elbow fracture [5]. The positive fat pad sign becomes visible in lateral radiographs as a consequence of joint effusion, which lifts up the dorsal and ventral fat pad of the joint capsule. Even if a positive ventral fat pad sign is visible in heavy elbow distorsions or contusions, the dorsal fat pad sign is suggested to be a strong indicator of elbow joint fractures [5, 6].

Since clinical examination of injured and consequently anxious children is often difficult, the indication for X-rays is still made generously so as not to miss a fracture. This results in a significant discrepancy between the number of X-rays taken and the number of fractures thus detected. However, due to the increased radiation risk for children, the indication for X-ray application should be subject to strict review in every single case [7, 8]. Therefore, it seems reasonable to establish alternative imaging methods to minimize unnecessary radiographs in children.

Osteosonography is still not used routinely in diagnosing limb fractures, but numerous studies have shown that US is not only comparable to X-rays in detecting fractures but also is equivalent in assessment of fracture type and displacement. Various authors already recommend US as the primary diagnostic procedure [9–13]. In particular, US diagnosis of distal forearm fractures in children has already been well studied, demonstrating that X-rays could be avoided in cases of non-displaced bulging fractures [14–17].

The normal US anatomy of the elbow in infants and adults is known in detail [18–26]. Sonographic depiction of the positive fat pad sign was first described by Miles and Lamont [27], and it has been shown that ultrasound is superior to X-rays in detecting elbow joint effusions [28]. If a positive fat pad sign can be excluded by US, an elbow joint fracture is quite unlikely, whereas evidence of a positive fat pad sign, especially a dorsal, strongly indicates a fracture, which justifies further examination [29–31]. The sonographic morphology of supracondylar fractures of the humerus in children has already been described [32–35].

The aim of our study was to evaluate the diagnostic accuracy of US in comparison to X-rays in diagnosing pediatric elbow fractures.

Patients and methods

From May 2010 to February 2012 we prospectively examined 68 patients, aged between 1 and 13 years (mean age 6 years; 36 boys, 32 girls). Patients with suspected elbow fracture by historical and clinical examination were included. All patients with an obvious deformity, open injury or suspected vascular or nerve injury were excluded. The injured elbow was first examined by US and then radiographed. US examination was conducted with a 12-MHz linear probe of width 6.5 cm. The distal humerus was depicted from seven standardized longitudinal positions, and the radial head and olecranon were also depicted longitudinally (see below). US results were compared to X-ray diagnoses given by an independent pediatric radiologist (Table 1). The US findings were collected in a contingency table and contrasted with the radiological findings (Table 2). Sensitivity, specificity, and positive and negative predictive value of US (Table 3) were calculated relative to X-ray. The sonographic examination was always performed in the presence of at least one parent after providing a detailed explanation and getting approval. All patients and their parents gave their informed consent to the US examination. Treatment of the elbow injury was conducted only according to the patient's clinical and radiological findings.

Standard ultrasound sections of the elbow and fracture morphology

The US examination can be done in almost any position most comfortable for the patient; thus, a specific positioning is not required. From our experience, most patients spontaneously take a sitting position with the hand of the affected arm lying loose on the thigh and minimally flexed in the elbow joint. The US probe then can be carefully moved around the elbow joint to adjust the standard positions, and even the ventro-radial section can be adjusted sufficiently (see below). A careful abduction of the arm is necessary only for depicting the medial humerus.

There are five standard sections defined to represent the adult elbow joint [18, 19]. However, for US interpretation of the child's elbow, a precise knowledge of the six ossification centers is necessary. Reetz [12] therefore developed a more detailed sonographic description of the infant elbow joint, which takes into account the characteristics of the growing bone with its ossification centers. For adequate assessment of fracture displacement of the supracondylar region, Pistor established two additional sections along the dorso-radial and dorso-ulnar humerus. Using these standardized sections described by Reetz [12] and Pistor [20], supracondylar elbow fractures can be reliably detected and also evaluated in terms of displacement.

In our study, we used seven longitudinal sections across the distal humerus: (1) dorso-median (2) dorso-ulnar, (3) dorso-radial, (4) lateral, (5) medial, (6) ventro-radial, and (7) ventro-ulnar (Fig. 1a, b). To ensure a complete representation of the elbow joint according to X-ray, additional longitudinal sections across the radial head and olecranon were employed.

Figure 2a–j shows the normal sonographic morphology of the elbow joint. The cortex proximal to the US probe appears as a hyperechoic line with complete extinction posteriorly. The cartilaginous portions of the epiphysis appear anechoic to hypoechoic with a hyperechoic epiphyseal core. From our experience, the dorso-median and the ventro-radial sections are most useful for rapidly assessing bony injury of the elbow. In the dorso-median section, a

Table 1 Sonographic findings compared to X-ray findings

Ultrasound diagnosis	X-ray diagnosis
21 × no fracture	19 × no fracture
	1 × non-displaced proximal fracture of the ulna
	1 × Chaissagnac lesion misdiagnosed as an occult supracondylar fracture
9 × occult supracondylar fracture	8 × occult supracondylar fracture
	1 × fracture of the processus coronoideus ulnae
24 × non or minimally displaced supracondylar fractures	23 × non or minimally displaced supracondylar fractures
	1 × no fracture
2 × displaced supracondylar fractures	2 × displaced supracondylar fractures
4 × fracture of the condylus radialis	4 × fracture of the condylus radialis
1 × fracture of the epicondylus ulnaris	1 × fracture of the epicondylus ulnaris
2 × fracture of the olecranon	2 × fracture of the olecranon
2 × bulging fracture of the radial head	2 × bulging fracture of the radial head
3 × displaced fracture of the radial head	3 × displaced fracture of the radial head
68 patients in total	68 patients in total

Table 2 Contingency table

	Ultrasound		
	Positive (fracture)	Negative (no fracture)	Total
X-ray			
Positive (fracture)	46	1	47
Negative (no fracture)	1	19	20
Total	47	20	67

Table 3 Sensitivity, specificity, and negative and positive predictive values of ultrasound fracture diagnosis as compared to X-ray diagnosis

Sensitivity	97.9 %
Specificity	95.0 %
Negative predictive value	95.0 %
Positive predictive value	97.9 %

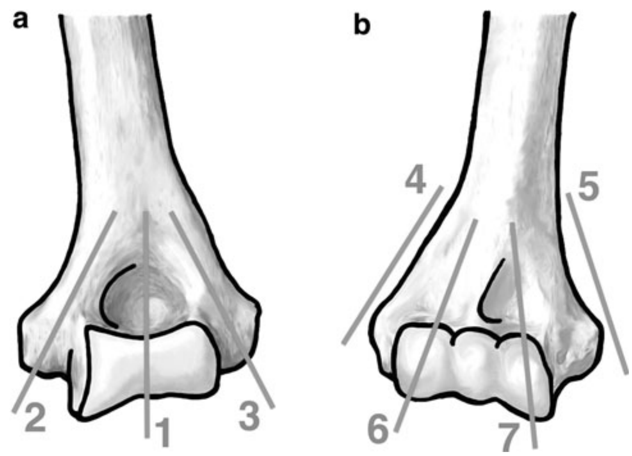

Fig. 1 **a** Longitudinal dorsal US sections across the distal humerus. **b** Longitudinal ventral US sections across the distal humerus

positive fat pad sign due to joint effusion (Fig. 3a, b) can be detected with high sensitivity. As shown in Fig. 2b, the posterior joint capsule arises almost in a straight line from the posterior humeral cortex, and the dorsal fat pad can be identified as a hyperechoic structure lying in the fossa olecrani. In the case of bony injury and consecutive joint effusion, the joint capsule is dorsally expanded. An inhomogeneous, echogenic effusion with fluid levels indicates hemarthrosis and therefore a fracture (Fig. 3a). Direct sonographic fracture signs can be, for example, cortical gaping (Fig. 3c, d) or a kink or bulging formation (Fig. 3e).

For US estimation of displaced supracondylar fractures, the ventro-radial longitudinal US section is used, and the so-called Rogers' line is positioned, similar to the radiographic determination, along the anterior humeral cortex to determine the position of the capitellum (Fig. 4a–c). Additionally, the dorso-radial and/or dorso-ulnar US sections, described by Pistor [20], could serve as promising sections for determining fracture displacement (Fig. 4d).

Results

In 21 children, US showed no direct or indirect fracture signs, resulting in a diagnosis of elbow distorsion/contusion. These findings correlated with the X-ray diagnosis in 19 patients. Of these 21 patients, one child had an undisplaced fracture of the proximal ulna, which was detected by X-ray on the edge of the radiograph but not by US. Another patient had a Chaissagnac lesion. Because of

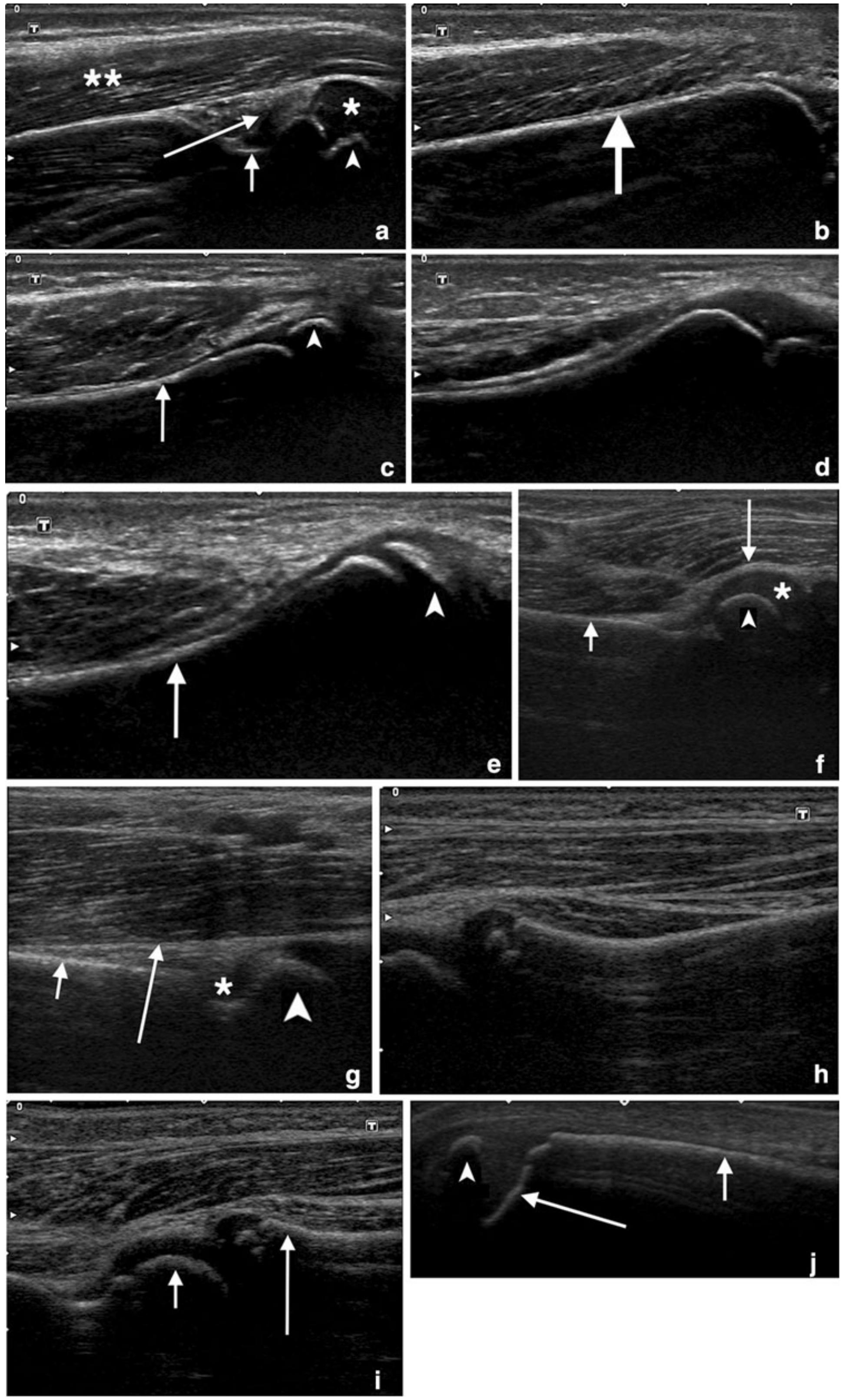

Fig. 2 Normal US anatomy of the pediatric elbow joint. **a** Longitudinal dorso-median section across the distal humerus: M. triceps humeri (*double asterisks*); dorsal fat pad (*long arrow*); fossa olecrani (*short arrow*); epiphyseal core (*arrowhead*), epihyseal cartilage (*asterisk*). **b** Longitudinal dorso-radial section across the distal humerus: hyperechoic cortex (*arrow*). **c** Longitudinal dorso-ulnar section across the distal humerus: hyperechoic cortex (*arrow*), epicondylus ulnaris (*arrowhead*). **d** Longitudinal lateral section across the distal humerus. **e** Longitudinal medial section across the distal humerus: hyperechoic cortex (*arrow*), epicondylus ulnaris (*arrow head*). **f** Longitudinal ventro-radial section across the distal humerus: capitellum (*long arrow*); hyperechoic ventral cortex (*short arrow*); epiphyseal core of the capitellum (*arrowhead*); epiphyseal cartilage (*asterisk*). **g** Longitudinal ventro-ulnar section across the distal humerus: ventral joint capsule (*long arrow*); hyperechoic ventral cortex (*short arrow*); epiphyseal core (*arrow head*); ventral fat pad (*asterisk*). **h** Longitudinal ventral section across the proximal radius. **i** Longitudinal ventral section across the radio-humeral joint. **j** Longitudinal dorsal section across the olecranon: epiphyseal core (*arrowhead*); metaphyseal plate (*long arrow*); cortex (*short arrow*)

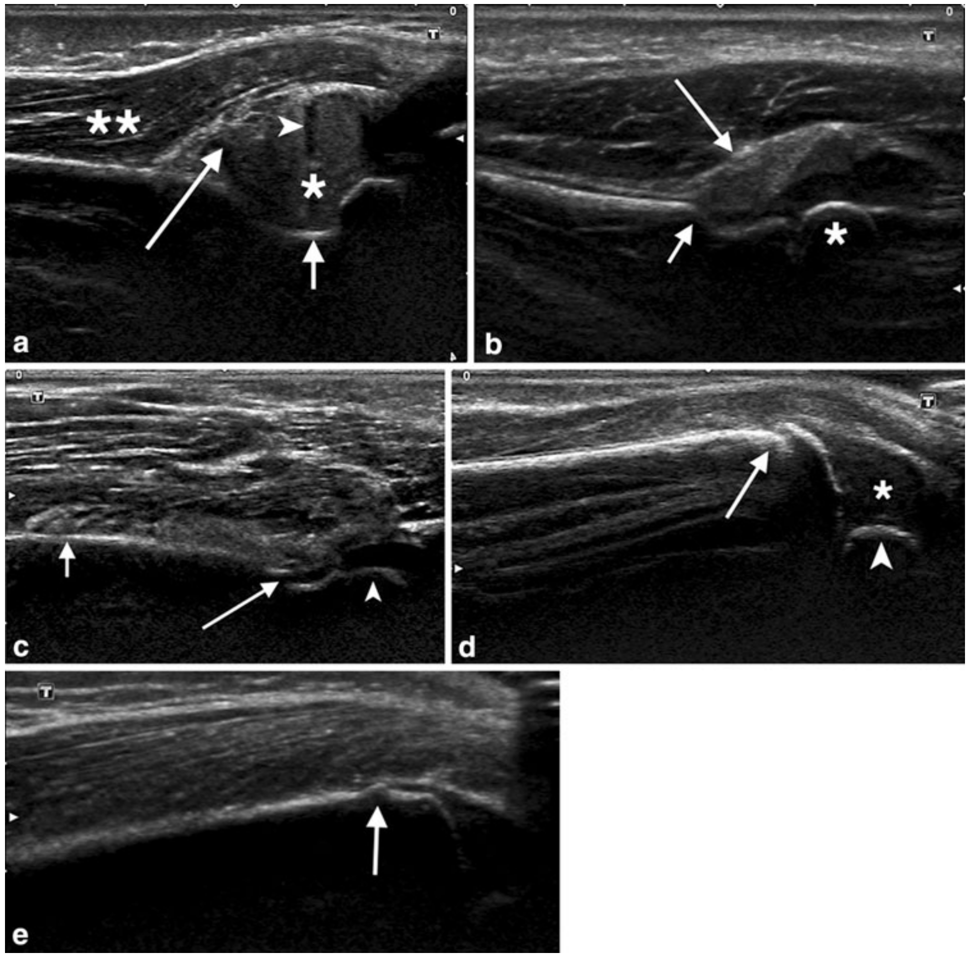

Fig. 3 **a** Dorso-median section, positive dorsal fat pad sign: dorsally extended M. triceps humeri (*double asterisks*); elevated fat pad (*long arrow*); fossa olecrani (*short arrow*); hyperechoic joint effusion (*asterisk*) with fluid level (*arrowhead*). **b** Positive ventral fat pad sign, ventro-radial section: extended joint capsule and elevated fat pad (*long arrow*); epiphyseal core of the capitellum (*asterisk*). **c** Minimally displaced supracondylar fracture, ventro-radial section across the capitellum: ventral cortex (*short arrow*); cortical gap (*long arrow*); capitellum (*arrowhead*). **d** Fracture of the condylus radialis: cortical gap (*arrow*); epiphyseal cartilage (*asterisk*); epiphyseal core (*arrowhead*). **e** Bulging fracture of the supracondylar humerus (*arrow*); longitudinal dorso-radial section

severe pain and unknown accidental mechanism, fracture exclusion was necessary.

In nine children, occult supracondylar fracture diagnosis by US was based only on a positive fat pad sign, without direct fracture signs. These findings correlated with the X-ray diagnosis in eight patients. In one patient, however, the radiographs revealed a rare, non-displaced fracture of the ulnar coronoid process.

In 24 patients, US showed a non- or minimally-displaced supracondylar fracture, which could be confirmed by X-ray in 23 patients, while one patient was radiologically unremarkable.

For all other patients, our US diagnosis correlated completely with the X-ray diagnosis. Figure 5 shows the sonographic appearance of a displaced radial head fracture. A comparative overview of the US and radiographic findings is given in Table 1. The sonographic fracture diagnosis or exclusion was comparatively collected in a contingency table (Table 2). Sensitivity, specificity, and negative and positive predictive values for US diagnosis in terms of an elbow fracture were calculated relative to X-ray findings (Table 3). The patient with the Chaissagnac lesion, radiographically misdiagnosed as an occult supracondylar fracture, was excluded from the calculation. Quantification of fracture displacement was not part of this work.

Discussion

X-rays are commonly indicated for exclusion or diagnosis of an elbow fracture. However, due to incomplete epiphyseal ossification and often non-exact two-plain radiographs, radiographic assessment of the child's elbow is sometimes difficult. The positive fat pad sign is an indicator for an occult fracture even in the absence of direct fracture signs, but the significance of a positive fat pad sign has been debated in the recent literature [36]. Even if an anteriorly elevated fat pad can also be seen in heavy elbow distorsion/contusion, a posteriorly elevated fat pad is usually regarded as a strong indicator for a fracture [28–30].

Our results show that US is capable of visualizing the most common fractures of the elbow joint. Above all, a joint effusion and consecutively a positive fat pad sign can be detected by US at least as sensitively as by X-ray. From our experience, however, extra-articular fractures such as

Fig. 4 US estimation of displaced supracondylar fractures: **a** longitudinal ventro-radial section: Rogers' line (*dotted line*) is positioned along the ventral cortex; epiphyseal core of the capitellum lies ventral to Rogers' line. **b** Epiphyseal core of the capitellum (*arrowhead*) approximated to Rogers' line, indicating a minimally displaced supracondylar fracture; ventral fat pad (*asterisk*). **c** Epiphyseal core of the capitellum dorsal to Rogers' line, indicating a displaced supracondylar fracture. **d** Corresponding radiograph to **c**. **e** Displaced supracondylar fracture, longitudinal dorso-radial section: large cortical gap with dorsal fracture displacement. **f** Corresponding radiograph to **e**

olecranon fractures, bulging fractures of the radial head (Fig. 6), and ulnar epicondyle fractures (Fig. 7) show no joint effusion.

In our study, two fractures were not seen by US. The first case was a non-displaced fracture of the ulnar coronoid process, which could be shown only radiologically. Although US demonstrated a positive dorsal fat pad sign due to hemarthrosis, diagnosis of the coronoid fracture was missed and the diagnosis was made in the sense of an occult supracondylar fracture. At least there were no therapeutic differences (equal treatment by immobilization); thus, US diagnosis can be considered true-positive, at least in terms of a fracture.

The second patient showed a non-displaced proximal fracture of the ulna. Here, the patient was initially suspected of having a supracondylar fracture of the humerus, prompting our imaging studies to be concentrated on the elbow. Using US, the elbow joint was assessed correctly as fracture-free. But the proximal ulnar fracture could not be shown, because US imaging was limited to the olecranon,

Fig. 5 **a** Displaced fracture of the radial head, diagnosed by ultrasound. **b** Corresponding radiograph to **a**

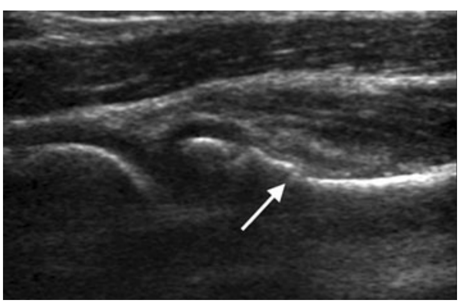

Fig. 6 Bulging fracture of the radial head

and therefore the fracture lay outside the scanned area. However, retrospectively, if US were extended across the complete ulna, this kind of fracture, at least from our experience, could also be visualized sonographically in general. Thus, the US misdiagnosis should be considered in the context of clinical misinterpretation. Even the radiological diagnosis was only given because the radiographs displayed an extended view of the ulna, so the fracture could be seen at the edge of the radiographs.

Fig. 7 Displaced fracture of the epicondylus ulnaris, longitudinal medial section; missing epicondylus ulnaris (*asterisk*). Compare Fig. 2e

In one patient, a supracondylar fracture was diagnosed only by ultrasound and was not confirmed radiologically.

In contrast, in one patient an occult supracondylar fracture was diagnosed radiographically only on the basis of a weakly positive, ventral fat pad sign. In this case, due to clinically difficult assessment and unknown accidental mechanism, imaging studies were indicated. However, after fracture exclusion, a Chaissagnac lesion could be successfully diagnosed. This case demonstrates well that US can be a useful tool, especially in the presence of historical and/or clinical examination difficulties. We suggest that unnecessary X-rays could be avoided with unremarkable US diagnosis.

Furthermore, two displaced supracondylar humerus fractures were correctly diagnosed by US in correlation with the X-ray diagnosis. All other fractures (two non-displaced bulging fractures of the radial head, three displaced fractures of the radial head, four fractures of the condylus radialis, one fracture of the epicondylus ulnaris, and two olecranon fractures) were correctly diagnosed by US in correlation with the X-ray diagnosis.

Overall, our results show a sensitivity of 97.9 % and a specificity of 95 % for the US diagnosis of an elbow fracture. Additionally, fracture displacement can also be adequately estimated by US, allowing us to confirm US imaging of the elbow as a safe alternative in the primary evaluation of pediatric elbow injuries. In particular, a positive posterior fat pad sign serves as a strong indicator for an elbow joint fracture and can be detected quickly and reliably by US, so we suggest that the sonographic fat pad sign possibly serves as a valuable primary screening parameter.

In order to integrate the appropriate use of US in routine assessment of pediatric elbow injuries, we suggest the following diagnostic procedure:

1. In the absence of direct or indirect sonographic fracture signs, additional X-rays can be avoided.

2. In the case of a sonographically positive fat pad sign without direct fracture signs or suspected displacement, no additional X-rays are needed and cast immobilization is the treatment of choice until clinical recovery.
3. In the case of sonographically positive indirect and/or direct fracture signs and/or suspected displacement, additional X-rays should be taken for appropriate fracture diagnosis.

With this algorithm and the consistent use of US in primary evaluation of elbow injuries in children, we suggest that unnecessary X-ray application in children can be minimized without loss of diagnostic safety and accuracy.

Conclusion

All characteristic pediatric elbow fractures could be visualized by US. A positive fat pad sign, in particular, can be detected very sensitively by US and serves as a strong indicator for fractures of the elbow joint. US may be a viable primary screening tool for elbow injuries in children, capable of replacing standard X-rays in selected cases, thereby reducing the X-ray burden in children without loss of diagnostic safety.

Conflict of interest None.

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