

Ultrasound in the diagnosis of fractures in children

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We compared the results of primary ultrasonographic examination of 163 children with 224 suspected fractures with the subsequent radiological findings. The aim was to assess the value of ultrasound in the diagnosis of fractures in children. We found a good correlation for fractures of the long bones of the upper and lower limbs. Ultrasound was most reliable for the detection of simple femoral and humeral diaphyseal fractures and fractures of the forearm. It was less dependable for compound injuries and fractures adjacent to joints, lesions of the small bones of the hand and foot, non-displaced epiphyseal fractures (Salter-Harris type 1) or those with a fracture line of less than 1mm.

We were able to distinguish several types of fracture in which the use of ultrasound alone gave reliable information and further radiography was unnecessary. We discuss the advantages and disadvantages of skeletal ultrasonographic studies in children.

J Bone Joint Surg [Br] 2000;82-B:1170-3.

Received 1 April 1999; Accepted after revision 11 February 2000

The use of ultrasound for the examination of soft tissues has been established for many years. In children it is of particular value as it is comfortable, often diagnostic and does not involve the use of ionising radiation. Ultrasound waves are, however, almost completely reflected by cortical bone and research into the possible benefits of skeletal ultrasound has been neglected apart from its use in the examination of the hip in infants. The cartilaginous nature of the infant joint makes ultrasound superior to radiography. The use of ultrasound for the diagnosis of fractures has only been discussed in single case reports and occa-

sional experimental work. The aim of this study was to evaluate its use in children with possible fractures.

Patients and Methods

Ultrasound examination was carried out on 163 children (224 bones) with suspected fractures. The scans were performed by three of the authors (UH, WS, SO), all of whom were paediatric surgeons experienced in ultrasound examination. They had each performed at least 1500 scans and had attended a training course on scanning bony surfaces.

The scans were performed in unsplinted limbs without, in most cases, causing distress to the children. Toddlers were held by their parents. Open fractures of class 2 or class 3, and those which were obviously deformed or unstable were not scanned.

We used a standard ultrasound machine (Sonoline; Siemens/Nürnberg, Germany) equipped with a 5 MHz and 7.5 MHz linear probe. A water stand-off was added as needed. In the later stages an 8 MHz linear probe (US Scanner Type 2003; B+K Medical/Norderstedt, Germany) was also used. The findings were documented using a video printer. The region of the bone in question was examined in four planes longitudinally. Transverse planes were scanned in special cases. For orientation of the images we used the international guidelines.

Interruptions, steps or axial deviations were demonstrated on the surface of the bone and additional findings included periosteal lesions, haematomas and soft-tissue changes. The long bones of the limbs were examined most frequently; the clavicle, skull and the smaller bones of the hand and foot less often (Table I). Radiographs were taken immediately after scanning. The mean scanning time was 5 to 10 minutes.

The authors, together with two additional consultants, compared the ultrasound and radiological findings to confirm the incidence of fractures. In addition, assessment of the degree of angulation and the direction of displacement were analysed.

Results

Ultrasound was most commonly used in the distal forearm since this is the commonest site of fracture in children. We

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0301-620X/00/810087 \$2.00

Table I. Results of sonography compared with those of radiography in 224 suspected fractures

	Correct positive	Correct negative	Correct (total) (%)	False-positive	False-negative	False (total) (%)
Radius (85)	58	18	76 (89.4)	8	1	9 (10.5)
Ulna (54)	21	27	48 (88.8)	4	2	6 (11.1)
Tibia (19)	7	9	16 (84.2)	0	3	3 (15.7)
Humerus (20)	10	8	18 (90.0)	0	2	2 (10.0)
Femur (18)	10	7	17 (94.4)	1	0	1 (5.5)
Other (28)	12	7	19 (67.8)	6	3	9 (32.1)
Total (224)	118	76	194 (86.6)	19	11	30 (13.4)

examined the distal radius in 85 patients (Fig. 1). Of 59 fractures recognised radiologically 58 were identified by ultrasound (sensitivity 98.3%). In 18 patients a fracture was correctly excluded, but there were eight false-positive results (specificity 69.3%). Eight control radiographs did not support the tentative diagnosis of an undisplaced fracture with a displacement of less than 1 mm or a Salter-Harris type-1 lesion. The ultrasound diagnosis was correct in 89.4% (Table I).

Better correlation was found in the 18 femora which were studied. A fracture was correctly diagnosed by ultrasound in 17 (94.4%) and there was one false-positive result (sensitivity 100%; specificity 87.5%).

Ultrasound-based diagnosis of fracture of the ulna ($n = 54$), tibia ($n = 19$) and humerus ($n = 20$) was correct in 88.8%, 84.2% and 90%, respectively. The incidence of false-negative results, i.e. failure to diagnose fractures, was 4.0%. This was higher in fractures of the hand, foot, elbow and knee in which correct results were obtained in only 67.8% (Table I, 'Other'). Relatively good results were seen for the clavicle and the skull, but the number of cases was small (Table I, 'Other').

In 26 cases (11.6%) the ultrasonographic result was inaccurate despite correct detection of a fracture, due to incomplete examination, e.g. examination of a radial fracture without imaging the ulna. This was due to deficiencies in the protocol for investigation which has since been rectified. For instance, in cases involving the forearm, both the radius and ulna are now always assessed.

The measurement of the angle or degree of deformity was often difficult due to the small size of the video-prints. Better results can be obtained by using goniometric meas-

urements directly on the monitor, available on most sonographic apparatus.

Discussion

Alzen et al,¹ in a retrospective analysis of 2006 radiographs of 1386 children with suspected fractures, found fractures in only 354 (17.2%). The high number of negative examinations highlights the importance of the correct indications for radiological examination and indicates the need for alternative methods which do not involve ionising radiation and are less expensive but reliable. Ultrasound may fill this role. It is pertinent to point out some of the reasons for so many negative radiographs in children. Injury in children often goes unseen. The child or toddler may be irritable, resistant to questioning and unco-operative during clinical examination. As a result the clinician may be tempted to request radiography of the entire limb under suspicion.

Anxious parents often demand radiography although the clinician may feel that it is not indicated, particularly when considering the risks of unnecessary exposure of children to x-rays. In such circumstances, some clinicians may be swayed by the legal consequences of a missed fracture.

Children differ from adults in their sensitivity to ionising radiation since their bony tissues are proliferative and more susceptible to the harmful effects of x-rays.

Single case reports of intrauterine fractures and congenital bone disease such as osteogenesis imperfecta diagnosed by ultrasound were published in the early years of the use of B-mode sonography,²⁻⁴ but regular use of ultrasound in the diagnosis of fractures has been delayed until the present decade. In the facial region of adults and children, man-

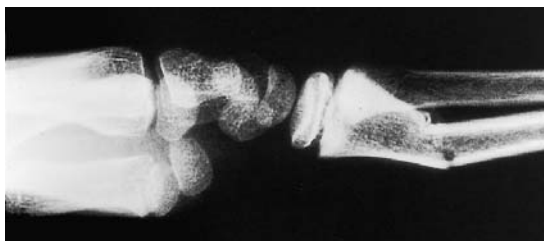


Fig. 1a



Fig. 1b

Figure 1a – Radiograph of a fracture of the distal radius in a nine-year-old boy. Figure 1b – Ultrasonogram of the fracture.



Fig. 2a



Fig. 2b

Figure 2a – Radiograph of a fracture of the subcapital humerus in a 14-year-old boy. Figure 2b – Ultrasonogram of the fracture.

dibular⁵⁻⁷ and zygomatic^{8,9} fractures as well as fractures of the orbit¹⁰⁻¹² and nasal bones¹³ have been increasingly diagnosed by ultrasound. Radiologists, traumatologists and physicians have reported that fractures of the ribs may be demonstrated better by ultrasound than by radiography.¹⁴⁻¹⁸ Good results have been reported for fractures of the sternum,^{19,20} the symphysis pubis²¹ and the scaphoid bone.^{22,23}

Ultrasound has been used to demonstrate stress fractures²⁴ and those of the humerus which have been missed on plain radiographs.²⁵ It has also been used to monitor the formation of callus in fractures of the long bones and during limb lengthening.²⁶ Grechenig et al.^{27,28} have described the ultrasonographic findings in whole and fractured bones in vitro. They showed that fissure fractures less than 1 mm in width could not be shown reliably, which is in agreement with our findings.

Other authors have indicated that fractures of the diaphysis of the humerus in children can be demonstrated by ultrasound.²⁹⁻³³ Riebel and Nasir³⁴ advocate this method of diagnosis in the newborn, while Nimkin et al.³² advise it for

the detection of subperiosteal haematomata in suspected battered-child syndrome. Katz et al.³⁵ reviewed 41 neonatal fractures of the clavicle which were correctly diagnosed by ultrasound, of which one was missed by radiography. Steiner et al.³⁶ performed sonographic examinations on 210 infants with head injuries and, as well as reliably detecting fractures, were able to assess the neuroendocranium by transfontanelle ultrasound thus avoiding several negative CT scans.

Out of 234 suspected apophyseal fractures in adolescents 80 were detected by radiography and 97 by ultrasound as reported by Lazovic et al.³⁷ Rathfelder and Paar³⁸ described good results in the first substantial study on the possible application of ultrasound in the diagnosis of fractures in children.

We have been able to show that the routine diagnosis of fractures in children by ultrasound is possible and in certain cases can be a substitute for radiography. Initially, we compared every sonographic study with an obligatory radiograph. We now suggest that an ultrasound assessment without radiography should be used in particular cases such

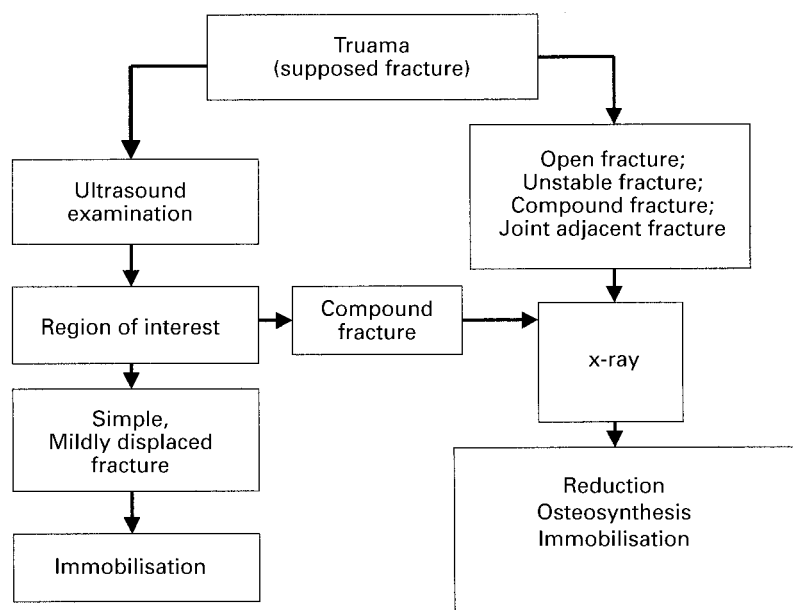


Fig. 3

Suggested algorithm for the management of suspected fractures in children.

as suspected bulge fractures or mildly displaced, simple fractures of the long bones of the forearm, humerus (Fig. 2), femur, lower leg and clavicle.

These lesions show the best sonographic imaging quality and are the most common fractures in children.

Radiological studies must be performed in every case in which there is doubt, in severely displaced fractures and fractures adjacent to joints which may need surgery. Most of our false-positive or false-negative results were with undisplaced fractures with thin fissures or those of Salter-Harris type 1. These lesions must be added to the doubtful group and examined radiologically.

Sonographic assessment of the skeleton requires time, patience and practice. The quality of our results improved with experience. Ultrasound examination may become a satisfactory substitute for radiography in certain well-defined circumstances, thus saving time and money. Based on our present study we suggest the diagnostic algorithm outlined in Figure 3 for the management of suspected fractures in children.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

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