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Magnetic resonance imaging in acute physeal injuries

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Abstract. Magnetic resonance imaging (MRI) permits noninvasive evaluation of the cartilage of the growth plate and epiphysis. This paper reports three cases where MRI was used to supplement conventional radiography in the assessment of acute physeal injuries. In the first patient, MRI was used for postoperative assessment of a radial neck fracture, avoiding further surgical exploration. In the second case, MRI was compared with ultrasonography in the diagnosis of proximal humeral epiphyseal separation in a neonate. In the third case, MRI and computed tomography were compared in evaluation of a Salter-Harris type 4 distal femur fracture. In all cases MRI was diagnostic. MRI is the investigation of choice in acute complex physeal injuries, and is particularly appropriate for use prior to the appearance of the secondary ossification center.

Key words: Physis – Epiphysis – Bone growth – Fracture – Magnetic resonance imaging (MRI)

The diagnosis of physeal injuries is restricted by our inability to directly visualize the cartilage of the growth plate and epiphysis with conventional radiography. In most cases detection of a fracture is possible due to displacement of the secondary ossification center and widening of the growth plate [1]. In young children prior to development of the ossification center, and in joints with multiple centers of ossification, such as the elbow, interpretation of plain films can be difficult. The normal magnetic resonance imaging (MRI) appearances of the physis and epiphysis have been described [2], and MRI has been used to assess the development of bone bridges across the physis following fractures [3–5]. There have been isolated descriptions of the use of MRI in acute physeal injuries [6, 7]. We have used MRI to assess a small group of patients in whom direct visualization of the cartilage of the physis and epiphysis was desirable. Our findings are illustrated in the form of three case reports. All MRI studies were performed on a 1.5-T unit (Signa, General Electric, Milwaukee, Wis.), using either a 3-in surface coil (patients 1, 2) or a knee coil (patient 3).

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Case reports

Case 1

A 4-year-old boy injured his left elbow and wrist in a fall from a tree. Radiographs showed a fractured olecranon and a fracture of the radial neck (Fig. 1), with 45° lateral angulation of the neck and some posterolateral displacement. The radial head was unossified. There were also greenstick fractures of the distal radius and ulna.

Closed reduction of the fractures was performed under fluoroscopic control and partial reduction of the radial neck fracture was obtained. In-cast postoperative films (Fig. 2) showed little change in alignment of the radial neck, but precise assessment was difficult.

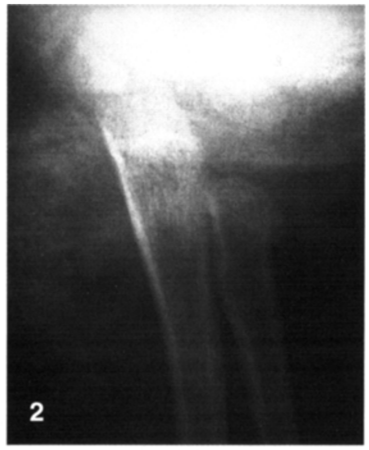
Rather than proceeding to open exploration, an MRI scan was performed on the day following reduction. The patient was sedated and the following sequences obtained: sagittal and coronal T1-weighted spin-echo 500/18 (TR/TE), sagittal and coronal T2*-weighted gradient-echo 33.5/5/20° (TR/TE/flip angle), coronal proton-density and T2-weighted fast spin-echo 2000/40 and 4000/110 (effective TR/TE) respectively. Coronal images (Fig. 3A) showed 30° residual lateral angulation of the radial neck and epiphysis. Sagittal images (Fig. 3B) showed good alignment of the radiocapitellar line. These findings were considered to indicate an adequate reduction in a child of this age.

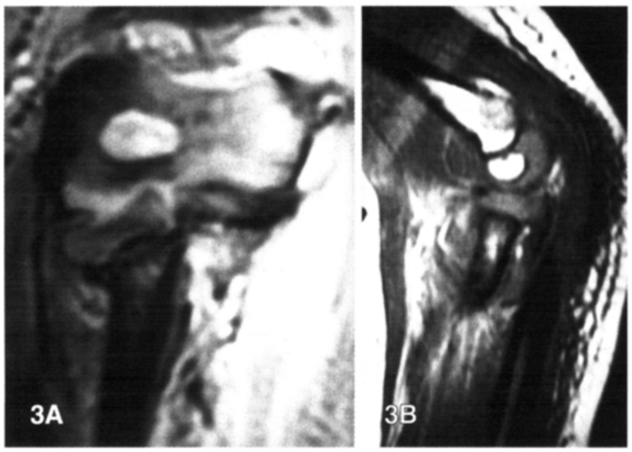
Follow-up films of the elbow 3 months after the injury showed remodelling of the radial neck (Fig. 4). Five months after the injury the patient had a full range of flexion and extension, and supination/pronation was reduced by 20°.

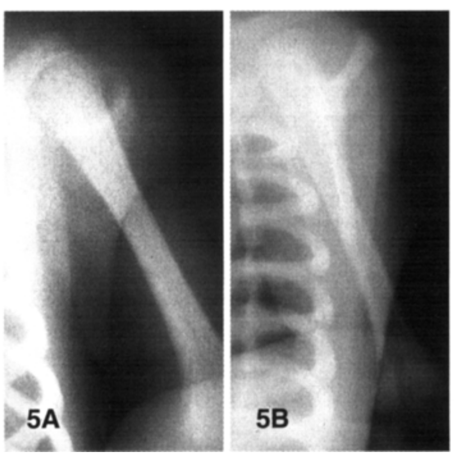
Case 2

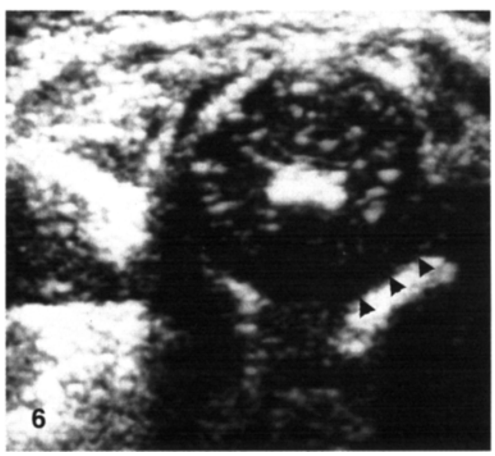
The patient, a female neonate, was one of twins and had been delivered in the breech position. Following delivery swelling and deformity of the left shoulder was noted.

Radiographs of the shoulder (Fig. 5) taken 1 week after delivery showed superior and anteromedial displacement of the humer-









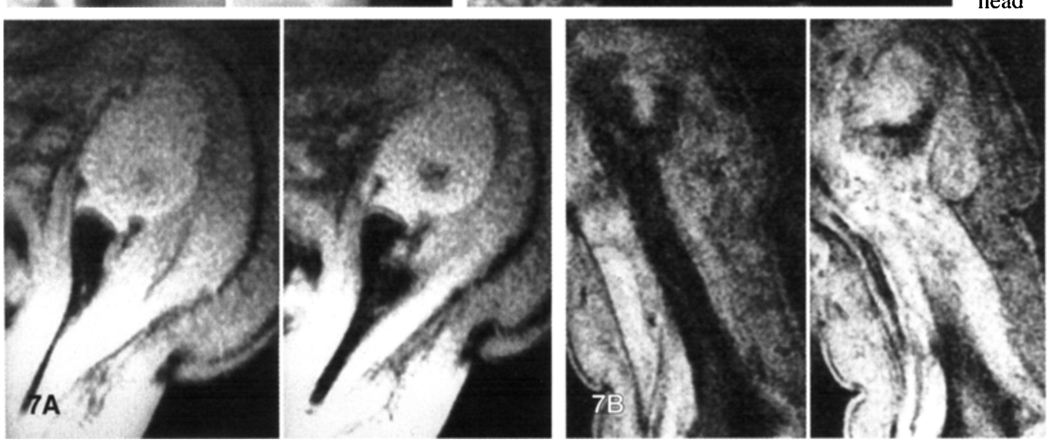


Fig. 1. Case 1. Radiograph of left elbow showing olecranon fracture and radial neck fracture with 45° lateral angulation. The radial head is unossified

Fig. 2. In-cast postoperative appearance

Fig. 3A, B. Proton-density fast spin-echo (2000/40) magnetic resonance (MR) images. **A** Coronal image showing 30° lateral angulation of the cartilaginous radial head. **B** Sagittal image showing good radiocapitellar alignment

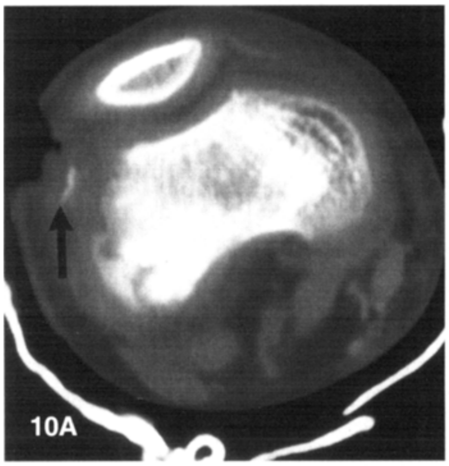
Fig. 4. Appearance 3 months after injury

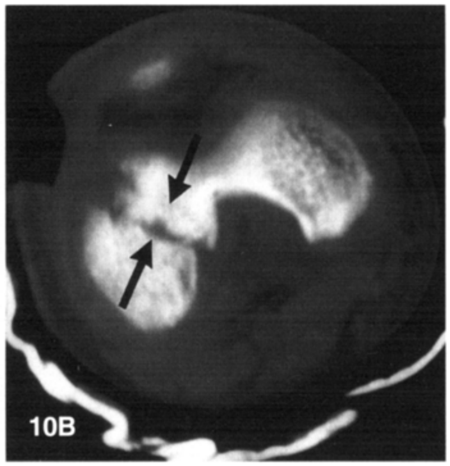
Fig. 5A, B. Case 2. Radiographs of left humerus 1 week after delivery show superior displacement of humerus, callus around the upper shaft of the humerus, and no visible ossification of the humeral head

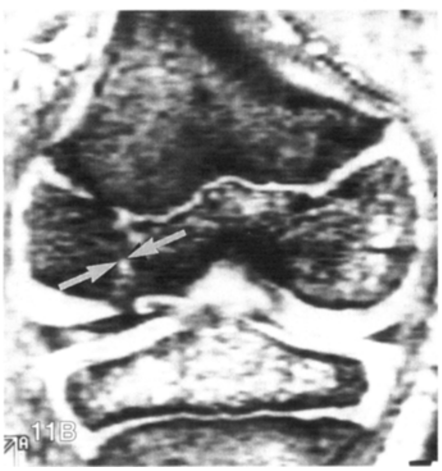
Fig. 6. Transverse ultrasound image of the left shoulder showing normal congruity of the humeral head and glenoid (*arrowheads*)

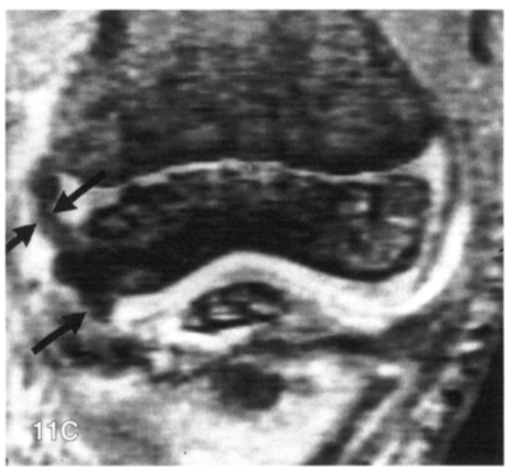
Fig. 7A, B. T2* gradient-echo (600/15/20°) MR images. **A** Axial images showing normal congruity of the humeral head and glenoid. **B** Sagittal images showing the position of the humeral head in relation to the humeral shaft

Fig. 8. Appearance 4 weeks after delivery, with remodelling of the humerus and development of the ossification center of the humeral head









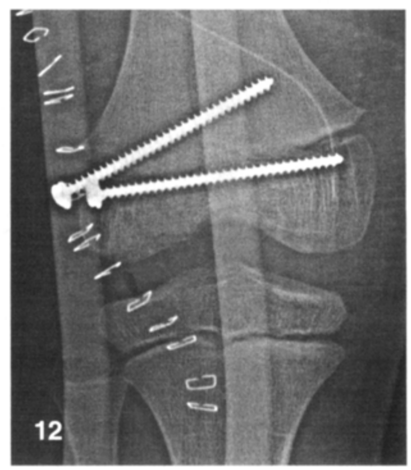


Fig. 9. Case 3. Radiographs of the right knee showing fracture of the lateral distal femoral metaphysis (*arrow*), an uneven contour of the lateral condyle, and intra-articular air

Fig. 10A, B. CT images showing **A** fracture of the lateral femoral condyle with a displaced fragment (*arrow*) and **B** an undisplaced fragment at the inferior aspect of the fracture (*arrows*)

Fig. 11 A–C. MRI appearances. **A** T1-weighted (16/500) coronal image shows low signal change in the lateral femoral condyle but the fracture line is not defined. Lateral meniscal tear (*arrow*). **B** 3D gradient-echo (15/35/35°) coronal image showing the fracture line crossing bony epiphysis (*arrows*). **C** 3D gradient-echo (15/35/35°) shows the fracture line crossing cartilage as a low signal linear band (*arrows*)

Fig. 12. Postoperative radiograph showing screw fixation of the epiphyseal and metaphyseal fractures

al shaft relative to the glenoid, and callus adjacent to the upper humerus. This injury was considered to be a Salter-Harris type 1 fracture of the proximal humeral epiphysis.

As the ossification center of the humeral head was not visible, ultrasonography of the shoulder was performed (Fig. 6). Normal location of the humeral head was confirmed, but the orientation of the head and its relationship to the shaft was difficult to assess. An MRI scan was performed 2 weeks after the injury (5 days after ultrasonography). Sagittal, axial, and coronal T2* gradient-echo 600/15/20° (TR/TE/flip angle) sequences were obtained; sedation was not required. Axial images at the level of the glenoid (Fig. 7A) showed normal location and orientation of the humeral head, and sagittal images (Fig. 7B) showed the degree of displacement of the shaft.

Follow-up radiographs 4 weeks following delivery (Fig. 8) showed development of the ossification center for the head of the humerus, remodelling of the proximal humerus, and some angulation of the shaft.

Case 3

A 9-year-old boy was struck by a motor vehicle while cycling and sustained multiple injuries. Radiographs of the right knee (Fig. 9) revealed a fracture of the lateral aspect of the distal femoral metaphysis, an uneven contour of the lateral femoral condyle, and intra-articular air.

Computed tomography (CT) of the knee, performed with 5-mm axial sections, showed fracture through the lateral condyle with a small displaced fragment (Fig. 10A) and a larger undisplaced fragment at the inferior aspect of the fracture (Fig. 10B).

An MRI scan was performed 3 days after the fracture (without sedation), and the following sequences were obtained: sagittal and coronal T1-weighted spin-echo 500/16 (TR/TE), and 3D acquisition T2*-weighted gradient-echo 35/15/35° (TR/TE/flip angle). T1-weighted images (Fig. 11A) showed an extensive area of low signal intensity in the lateral femoral condyle and adjacent metaphysis, and a tear of the medial meniscus. The fracture line was not visible on T1-weighted images. T2* gradient-echo images (Fig. 11B, C) showed a linear band of low signal intensity where the fracture crossed the cartilage of the physis and epiphysis, and the fracture was visible as a bright line disrupting the osseous metaphysis and epiphysis. MRI did not distinguish the bony fragments identified on CT from the adjacent chondral fracture, both appearing as areas of low signal intensity.

The patient underwent open reduction with internal fixation of the epiphyseal and metaphyseal fractures (Fig. 12). Inspection of the joint surface confirmed the step in the articular cartilage identified on MRI.

Discussion

The growth mechanism is a complex structure, consisting of the physis, epiphysis, metaphysis, and periphysis [8, 9]. This important structure is susceptible to a variety of injuries, which have been classified on the basis of radiographic appearances [10, 11]. The physis is involved in approximately 15% of childhood fractures, and the diagnosis and management of these injuries and their complications remain a challenge to clinicians [12, 13].

Conventional radiography provides adequate information in the majority of cases, but other modalities may be necessary to evaluate the cartilage and soft tissues. Arthrography can be useful in the acute situation, but is invasive and difficult to perform in the presence of a hemarthrosis [1]. References to the use of ultrasound in this context are scant [14–17], despite the advantages of this readily available, noninvasive, and inexpensive technique. The disadvantages of ultrasound include the difficulty of obtaining a suitable "window" in some trauma cases, and the operator-dependent nature of this modality. MRI provides a noninvasive means of directly visualizing the structures of the growth mechanism and adjacent joint in multiple planes. The disadvantages of MRI are its expense, limited availability, the necessity for sedation of younger children, and possible susceptibility artefacts in patients with internal fixation. Therefore the role of MRI is restricted to special situations where the benefits outweigh these disadvantages. The indications for MRI varied in the cases reported in this paper, and will be considered individually.

In case 1, MRI was used to visualize the unossified radial head following closed reduction of a radial neck fracture. Although this is an injury to the metaphysis rather than a true physeal fracture, damage to the growth mechanism, leading to premature fusion of the epiphysis, is frequently seen [18]. Prognosis is related to the degree of displacement and angulation of the radial head [18, 19]. Open reduction may be necessary in severe cases or when closed reduction is unsuccessful, but is associated with a poor outcome [18]. In this patient, arthrography was not possible at the time of manipulation because of excessive soft tissue swelling, and ultrasound could not be performed postoperatively due to lack of a suitable "window". MRI allowed precise delineation of the radial head, and further surgical intervention was avoided as the degree of angulation was compatible with a satisfactory outcome [20].

In case 2, both ultrasound and MRI were used to identify the position of the proximal humeral epiphysis following birth injury to the shoulder. A Salter-Harris type 1 fracture is typical of this injury [21, 22], but is difficult to confirm as the epiphyseal ossification center is not visible in 80% of neonates [23]. The prognosis is excellent due to the capacity of the upper humerus for remodelling [24], and although humerus varus has been described, the functional outcome was good [25]. In this case both modalities were successful in excluding fracture-dislocation, and although MRI provided more information on the orientation of the epiphysis and humeral shaft, this did not alter management. The main value of MRI was increased diagnostic confidence, as few sonographers are experienced in the assessment of this unusual injury.

In case 3, both CT and MRI were used to characterize a fracture involving the distal femoral physis. CT provided optimal visualization of the bony fragments, whereas MRI showed significant chondral and meniscal injury; in this respect the two modalities were complementary. Identification of the epiphyseal fracture facilitated appropriate surgical management in this case, with open reduction [26].

We have used a variety of MRI sequences in the imaging of acute physeal injuries. T1-weighted sequences provide good anatomical detail and show low signal change in the osseous structures due to edema and hemorrhage, but do not clearly show the fracture line or the chondral injury. Low-flip-angle gradient-echo sequences allow detection of the fracture line through both bony and cartilaginous structures. The cartilage injury is seen as a linear band of low signal intensity against the background bright signal of the normal epiphyseal and articular cartilage. This appearance is consistent with a previous report on acute physeal injury in rabbits [5]. The 3D-acquisition gradient-echo technique used in the third case is particularly useful, allowing high-resolution reconstruction images to be obtained. The disadvantage of low-flip-angle gradient-echo images is the poor contrast between cartilage and joint fluid, as both have a high signal intensity. We have used proton-density and T2-weighted fast spin-echo in only one case (case 1), but these sequences appear to provide good anatomical detail and good contrast between osseous and cartilaginous structures and between cartilage and joint fluid.

In conclusion, MRI imaging may be indicated in cases of suspected physeal injury where the epiphyseal ossification center is not visible on conventional radiographs. Ultrasound should be considered as a less expensive alternative. MRI may be appropriate in evaluation of the proximal and distal humeral epiphyses, proximal radius, and proximal femoral and distal tibial injuries. MRI is likely to be sensitive in diagnosis of the metaphyseal and epiphyseal injuries seen in nonaccidental injury, although we have not used it in this situation. MRI is also helpful in older children with suspected chondro-osseous injuries, but does not distinguish between cartilage damage and adjacent small bony fragments.

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