Proximal humerus fractures are rare in paediatric traumatology. Metaphyseal fractures account for about 70% of cases and epiphysyal separation for the remaining 30%. The development and anatomy of the proximal humerus explain the various fracture types, displacements, and potential complications; and also help in interpreting the radiographic findings, most notably in young children. Physicians should be alert to the possibility of an underlying lesion or pathological fracture requiring appropriate diagnostic investigations, and they should consider child abuse in very young paediatric patients. Although the management of proximal humerus fractures remains controversial, the extraordinary remodelling potential of the proximal humerus in skeletally immature patients often allows non-operative treatment without prior reduction. When the displacement exceeds the remodelling potential suggested by the extent of impaction, angulation, and patient age, retrograde elastic stable intramedullary nailing (ESIN) provides effective stabilisation. As a result, the thoraco-brachial abduction cast is less often used, although this method remains a valid option. Retrograde ESIN must be performed by a surgeon who is thoroughly conversant with the fundamental underlying principles. Direct percutaneous pinning is a fall-back option when the surgeon’s experience with ESIN is insufficient. Finally, open reduction is very rarely required and should be reserved for severely displaced fractures after failure of closed reduction. When these indications are followed, long-term outcomes are usually excellent, with prompt resumption of previous activities and a low rate of residual abnormalities.

1. The proximal humerus

1.1. Development and growth of the proximal humerus

The proximal humeral physis is composed of three ossification centres, for the head, lesser tuberosity, and greater tuberosity, respectively. The capital centre appears at 3 months of age at the latest, whereas the two other centres appear at 1 year of age and fuse between 3 and 5 years of age to produce the tuberosity ossification centre. Finally, at about 6 years of age, the capital and tuberosity centres fuse into a single proximal epiphysyal centre. At this point, the proximal humerus physis acquires a characteristic tent shape (Fig. 1a) responsible for a radiographic double contour that complicates the interpretation of the images [1].

The proximal humerus physis accounts for nearly 80% of the longitudinal growth of the humerus, a fact that translates into an extraordinary potential for remodelling (Fig. 2).

The last growth plates to close are those of the long bones (16–17 years in girls and 18 years in boys) [2]. Consequently, epiphysyal separation can occur in adolescents, who can experience remodelling in the event of malunion.

1.2. Specific anatomic characteristics of the proximal humerus

The joint capsule insertion follows the lateral edge of the physis then dips downwards vertically on the medial aspect of the metaphysis (Fig. 1b). This configuration explains the high proportion of Salter-Harris type II epiphyseal separations with a fracture line that follows the joint capsule insertion, detaching a medial wedge of the metaphysis together with the epiphysyal fragment [3].

The muscle attachments to the proximal humerus contribute to explain the displacement of the fragments. The rotator cuff attaches proximal to the pectoralis major and deltoid muscles.
2. Proximal humerus fractures (PHFs)

2.1. Epidemiology

The incidence distribution of PHFs over the life span shows an early modest peak between 10 and 14 years of age followed by a return to low levels in young adults then by an increase after 45 years to a maximum after 70 years [4].

In neonates, PHFs account for one-third of all humerus fractures, which are exceedingly rare (0.03/1000 births) [5]. In children and adolescents, PHFs contribute only 0.5% to 3.5% of all fractures [4,6].

In the youngest age groups, abuse can result in PHFs (by order of frequency, the sites of humerus fractures due to abuse are the diaphysis, distal humerus, and proximal humerus.) In patients younger than 18 months of age, two-thirds of all humerus fractures may be related to abuse [7].

Another important factor is the proximity of soft-tissue structures, including the long head of biceps tendon, which runs through the gleno-humeral joint cavity. In addition, the axillary artery and nerve trunks emerging from the brachial plexus travel medial to the humeral head. These structures should be considered when analysing PHFs and planning the treatment strategy for the fracture and potential complications.

Finally, the proportion of metaphyseal fractures is higher in pre-pubertal patients, whereas the proportion of epiphyseal separations is higher in adolescents.

2.2. Causes and mechanisms

In neonates, traction on the upper limb during a difficult vaginal or caesarean extraction can result in a PHF [5,8]. In young paediatric patients, particularly those who are victims of abuse, PHFs result from repeated brutal traction on the abducted upper limb. Among older children and adolescents, boys are affected in 60% of cases, and PHFs chiefly involve the non-dominant arm.

For all PHF types, the usual cause is a backwards fall on the arm with the upper limb adducted, the elbow extended, and the shoulder extended and rotated externally. In adults, this mechanism usually results in antero-medial dislocation of the gleno-humeral joint. A direct fall on the tip of the shoulder is less common, and torsion forces are the least frequent mechanism.

The falls that cause these mechanisms occur in a variety of circumstances. About one-fourth of the falls are related to sports and another third to motor vehicle accidents. Furthermore, one-fourth of patients have a lesion at another site (fracture of another long bone, injury to an internal organ, or neurosurgical injury).
Finally, little leaguer’s shoulder is a stress fracture or overuse injury seen in young baseball players [9]. The patient reports pain in the proximal humerus, particularly during the act of throwing. Radiographs show non-displaced Salter-Harris type I pseudo-epiphyseal separation, with widening of the proximal physis area, lateral physeal fragmentation or calcification, sclerosis, and metaphyseal demineralisation or even subchondral geodes.

2.3. Pathological patterns of proximal humerus fractures

Two variants are distinguished: metaphyseal fracture and epiphyseal separation (Fig. 3) [1]. Metaphyseal fractures account for 70% of all PHFs. The fracture line is usually at the surgical neck and less often at the metaphysis-diaphysis junction. A transverse or short oblique line is the rule. Epiphyseal separation contributes the remaining 30% of PHFs. The type of separation depends on the degree of skeletal maturity. Salter-Harris type II is the most common type and occurs chiefly in adolescents. Pure intra-physeal separation, or Salter-Harris type I, is less common and can be seen at all ages before growth-plate closure. Salter-Harris types III and IV are exceedingly rare. Little leaguer’s shoulder with Salter-Harris type I pseudo-epiphyseal separation, or thrower’s stress fracture, is a separate entity.

Finally, among all pathological fractures, 40% involve the proximal humerus [10]. Unicameral bone cyst is the leading cause, as this lesion develops in the proximal humerus in 51% of cases [11]. The other tumours responsible for pathological PHFs are aneurysmal bone cyst, non-ossifying fibroma, fibrous dysplasia, and bone malignancies such as osteosarcoma [10].

2.4. Displacement

Varus is the usual direction of PHF displacement, with the humeral head moving medial to and behind the shaft: traction of the pectoralis major muscle attachment pulls the distal fragment medially, while the rotator cuff and deltoid muscle attachments pull the proximal fragment upwards, with a tendency towards flexion and external rotation [12].

Displacement is absent or minimal in 40% of metaphyseal fractures. In contrast, 85% of patients with epiphyseal separation exhibit displacement.

The Neer-Horowitz classification system based on displacement severity [13] is widely referred to in the literature (grade I, no displacement; grade II, displacement no greater than one-third of shaft width; grade III, displacement greater than one-third but no greater than two-thirds of shaft width; and grade IV, displacement greater than two-thirds of shaft width).

2.5. Complications

Acute complications are rare. Nevertheless, there have been a few reports of injury to the axillary artery, reflecting the close proximity of the shoulder-girdle vessels and nerves [14]. Nerve trunk stretching, which may be fairly common in the elderly [15], is exceedingly rare in paediatric patients (of 578 skeletally immature patients, only 0.7% had symptomatic nerve lesions [16]). Injuries to vessels and nerves occur chiefly in severely displaced fractures [16].

Finally, the long head of biceps tendon runs through the joint cavity, suggesting a risk of entrapment within severely displaced fractures, precluding closed reduction (Fig. 4). Despite some controversy [1,17], this possibility is accepted by most authors and...
considered to indicate open reduction (via the delto-pectoral approach) when closed reduction fails [15,18].

2.6. Healing

No cases of non-union have been reported in the literature. Time to healing of a metaphyseal fracture or epiphyseal separation is 6 weeks. Nevertheless, the considerable bone-formation potential at the proximal humerus allows mobilisation during domestic activities or pendulum exercises (with limited loading) as early as 3 to 4 weeks.

2.7. Course and sequelae

The vast majority of PHFs have a favourable outcome with resumption of previous sporting activities within a few months and no pain or noticeable discomfort [1,6,19]. Possible sequelae include residual pain and shoulder abduction limitation related to residual varus. Shortening of the humerus (nearly always by less than 2 cm and well tolerated) and mal-union with residual angulation but no clinical impact have been reported [1,19]. A few cases of transient epiphyseal necrosis with a favourable outcome have been described in patients with Salter-Harris type III or IV epiphyseal separation [20]. Overall, the risk of sequelae is greatest in patients with severe displacement and, according to some authors, in very young paediatric patients who are treated surgically [21].

2.8. Diagnosis

The diagnosis is readily achieved in most cases, particularly in patients with displaced metaphyseal fractures. After a typical injury, the patient presents with pain, swelling, and functional impairment of the shoulder. Identification of the fracture line on antero-posterior and lateral radiographs confirms the diagnosis.

Diagnostic challenges may arise, however, in young paediatric patients with normal radiographs, as the double-contour appearance related to the distinctive shape of the physis may mistakenly suggest non-displaced epiphyseal separation. Comparative radiographs provide the definitive diagnosis when doubt persists. Finally, ultrasonography can visualise the fracture, particularly in neonates and infants [5].

A pathological fracture should be considered routinely if the fracture occurred after a low-energy trauma or the patient reports shoulder pain antedating the fracture. Standard imaging techniques provide an initial characterisation of the underlying lesion. Computed tomography with or without contrast injection delineates the features of the most typical lesions, such as unicameral bone cyst. The images should be scrutinised for evidence of a cystic lesion, such as the presence within the lesion of fluid levels or of a bone splinter indicating a cavity. It has been suggested that unicameral cyst can be diagnosed based only on the radiographic findings [22]. Computerised tomography (CT) and magnetic resonance imaging (MRI) can be used to complement the imaging work-up and is indispensable when a malignancy is suspected. However, care should be taken to avoid unnecessary imaging studies, as the underlying lesion is most often a unicameral cyst (exhibiting the usual distinctive features) and PHF is the most common mode of discovery of unicameral cyst at this location.

When the imaging studies cannot convincingly rule out a malignancy, a definitive diagnosis must be obtained. A biopsy is required in this situation. Two precautions are in order: comprehensive local and regional imaging studies must be obtained before the biopsy (including MRI with the appropriate protocols), as the local changes induced by the biopsy can bias the interpretation of subsequent imaging studies; and the time from fracture to biopsy must be kept short to avoid difficulties with the histological interpretation, as the osteogenic foci normally seen in a healing fracture site may mistakenly suggest a malignant osteogenic bone tumour.

3. Therapeutic management

3.1. Treatment options

The two main treatment options are non-operative management and surgery. The best criteria for choosing between these two options are still under debate.

3.1.1. Non-operative management

The rationale for non-operative management is the limited displacement in many cases, with a fairly stable fracture site, together with the extraneous bone remodelling potential at the proximal humerus. Simple immobilisation with the elbow by the side is warranted when displacement is absent or minimal or reduction is unnecessary. The arm is positioned along the side with the elbow flexed to 90° and the forearm against the torso. The entire upper limb is included in the immobilisation system, except for the wrist and fingers. This requirement can be achieved using a simple sling and swathie system (Fig. 5a), which is removable, allowing bathing but also carrying a risk of inappropriate removal by the patient. Other methods involving straps and adhesive taping, such as the three-directional bandaging method described by Dujarrier, can be used (Fig. 5b). The Dujarrier method is applied to the seated patient wearing a long-sleeved T-shirt to protect the torso and upper limb. Gamgee absorbent pads can be placed in the armpit and between the upper limb and torso for protection. The elbow is flexed to 90°, with the forearm horizontal and the shoulder in internal rotation. This position is then maintained using 15 to 20 cm-wide crêpe (Velpeau) bandages applied along three complementary directions: vertically (between the tip of the shoulder and the elbow on the injured side), horizontally (around the arm and torso), and obliquely (between the elbow on the injured side and the shoulder on the contra-lateral side). The hand should remain free. Six to eight bandages are needed, and each is secured to the previous and following bandages by adhesive tape. The bandages should be tight enough to stabilise the upper limb but not so tight that they limit chest expansion or cause pain due to pressure on the fracture site. The bandages can be replaced by the direct application of adhesive tape, which provides greater rigidity but also increases patient discomfort.

In our opinion, the hanging cast method suggested for some types of diaphyseal humerus fractures is not appropriate for PHFs. Severely displaced PHFs require reduction under general anaesthesia in the operating room. The shoulder is abducted to counter the displacement. When impaction provides sufficient stability, the limb is immobilised with the elbow by the side. In contrast, when the displacement recurs during adduction after fracture reduction by an abduction manoeuvre, thoraco-brachial immobilisation with the shoulder abducted is required if non-operative treatment is chosen. The patient dons a T-shirt and a thoraco-brachial cast is then fashioned with several layers of protective undercast padding. The rigid component consists in three plaster bandages or plates: a circular bandage wraps around the torso and above the contra-lateral shoulder, another bandage directly supports the upper limb with the elbow in 90° of flexion, and the third bandage connects the other two while maintaining the shoulder in sufficient abduction to maintain the reduction of the fracture (i.e., 60° to 90°), in some cases with internal rotation (0° to 25°) (Fig. 5c). A rigid strut (small board) can be incorporated to strengthen the device.

However, this immobilisation system is bulky and its advantages and drawbacks should be compared to those of surgical stabilisation.

3.1.2. Surgical treatment

Although various methods have been described, retrograde elastic stable intramedullary nailing (ESIN) has become the method of choice based on many studies comparing this technique to direct percutaneous pinning.

3.1.2.1. Direct percutaneous pinning. When fracture displacement is unacceptable, the patient is given general anaesthesia in the operating room and manipulative reduction is performed using manoeuvres that overcome the displacing forces. Steel K-wires are then inserted percutaneously via the lateral aspect of the shoulder, under the deltoid muscle ‘V’, into the lateral metaphyseal cortex. The wires are advanced upwards and obliquely into the humeral head [6].

This technique has the advantage of being simple and rapid to perform. Complications include a risk of humeral head perforation and a high rate of rotator cuff muscle irritation by the wires [23]. The main drawback is limited fracture stabilisation, which requires strict post-operative immobilisation or even, according to some authors, the use of a shoulder abduction immobiliser [23]. This technique is losing ground to retrograde ESIN [24].

3.1.2.2. Retrograde ESIN. This method involves retrograde nailing in compliance with the principles of minimally invasive internal fixation that spares the neighbouring soft tissues [25,26].

The patient is given general anaesthesia then placed in an eccentric supine position towards a radiolucent arm table. Care is taken to ensure that the fluorooscopy view shows the entire humerus, including the head. A less often used position is lateral decubitus with the arm vertical and abducted on an arm support.

Sterile drapes are placed over the entire upper limb, leaving an access route for a delto-pectoral approach, which may be needed if closed reduction fails.

Sharp-tipped nails must be used. This is an important point, as blunt-tipped nails may push the proximal fragment instead of penetrating it.

The nails are inserted 1 to 2 cm proximal to the lateral epicondyle (Fig. 6). The skin incision is distal to the bone penetration point in order to facilitate the ascending oblique nail trajectory. At this point of the distal humerus, the radial nerve is anterior to the lateral bicipital groove. The cortex is marked using a square-tipped awl to ensure stability of the drill bit and to avoid trajectory errors, most notably in the lateral bicipital groove.

Fracture reducibility is checked before sterile draping and usually requires marked arm abduction. With the upper limb on the arm table, the nails are advanced into the proximal fragment, up to the edge of the fracture. The reduction manoeuvre is repeated and the nails are impacted into the proximal fragment using a mallet while maintaining the reduction (Fig. 7).

When reduction is only partial, the first nail can be rotated after being introduced into the proximal fragment to achieve final reduction before introducing the second nail.

The two nails are oriented so that they diverge in the proximal fragment (Fig. 8). Care must be taken to ensure that the nails do not wind around each other, and multiple fluoroscopy incidences must be obtained to check that no part of the nail trajectories is outside the proximal fragment.

In patients with metaphyseal fractures, impaction into the proximal metaphyseal bone up to the distal edge of the physis usually provides sufficient stability. If not, or in patients with epiphyseal separation, the nails are impacted into the head through the physis (and sharp tips are particularly useful here) (Fig. 8). The number of trajectories through the physis must be kept to a minimum, particularly in the youngest patients. A careful assessment of shoulder

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Fig. 5. Various methods for shoulder immobilisation used for non-operative treatment: a: sling and swathe; b: Dujarrier bandage; c: thoraco-brachial immobilisation with the arm abducted.

Fig. 6. Sites of insertion of retrograde elastic stable intramedullary nails (a, lateral view of the elbow; and b, section through the distal humerus).
motion and examination of multiple fluoroscopy incidences are crucial to rule out humeral head perforation and nail penetration into the joint cavity.

The nails are then cut and, if needed, impacted to only 5 mm from the cortical surface, as the covering soft tissues are thin at this level.

Immobilisation consists only in a sling worn for 2 to 3 weeks.

The nails are removed rapidly (starting at the second post-operative month), given the risk of complete distal penetration (into the humeral shaft) of the nails impacted into the epiphysis and displaced proximally by growth.

The main specific advantages of the ESIN technique are good stability and absence of insults to the fracture site. Studies have found excellent long-term outcomes [25–28].

The main drawbacks, principally in comparison to percutaneous pinning, are the longer operative time and the surgeon learning curve.

3.1.2.3. Delto-pectoral approach. A direct surgical approach to the fracture site should be avoided to the extent possible, as it produces very unbecoming scars. The only indication is failed closed reduction, which occurs chiefly in epiphyseal separation with severe displacement [21]. Entrapment of the long head of biceps tendon is controversial but has been deemed to require a direct approach to release the tendon, followed by ESIN fixation. However, in skeletally immature patients, partial reduction is usually related to interposition of periosteum and does not require a direct approach.

3.1.2.4. Metaphyseal-epiphyseal screw fixation. We believe this technique is no longer warranted, as it is not superior over ESIN fixation and can result in severe damage to the rotator cuff muscles.

3.2. Indications

A review of published studies shows some disagreement about the indications of each treatment option. Advocates of
non-operative management feel that internal fixation is used excessively in these fractures given the usually favourable outcomes [29]. Others emphasise the high-quality reduction achieved with surgical therapy and the simplicity of post-operative management.

The potential for remodelling is remarkable in young paediatric patients but less marked in older children. Dameron and Reibel reported that the mean expected correction in children older than 11 years of age was less than 20° [30]. To assist in developing a consensus about indications, Pahlavan et. al. conducted a systematic review of studies published between 1960 and 2010 [21]. They identified 14 studies (765 patients) reporting data on both non-operative and surgical treatment. The results were conflicting. Overall, range of motion was better after non-operative management. Outcomes after surgical treatment seemed better in older than in younger patients. Based on these data, Pahlavan et al. suggested age-based indications, with three age groups (<10 years, 10–13 years, and >13 years). Immobilisation without reduction is the treatment of choice in the youngest age group and reduction followed by surgical stabilisation in patients older than 13 years with displaced fractures. In the intermediate group, the indications should be discussed on a case-by-case basis depending on the extent of displacement and the setting. Beaui [31] and others have suggested indications based on both age and displacement. They reserve reduction (regardless of the fixation method) for the following three patient subgroups:

- patients younger than 5 years of age with 100% translation or greater than 70° angulation;
- patients aged 5 to 10 years with greater than 50% translation or angulation greater than 70° in the younger patients and greater than 40° in the older patients;
- patients older than 11 years with translation greater than 50% or angulation greater than 40°.

In practice, when choosing the treatment strategy two questions must be answered:

- when should reduction be performed?
- if reduction is performed, when is surgery in order to stabilize the reduced fracture?

Based on our experience and on published data, we use the following age- and displacement-dependent indications. Immobilisation with the elbow by the side is the rule in patients with minimal displacement or an expected remodelling potential that is likely to correct the displacement. Reduction is indicated in three patient subgroups:

- patients younger than 10 years with translation greater than 100% and/or angulation greater than 70°;
- patients aged 10 to 13 years with translation greater than 50% and/or angulation greater than 40°;
- patients older than 13 years (with an open proximal physis) with translation greater than 30% and/or angulation greater than 20°.

Once reduction is achieved, stabilisation is obtained using retrograde ESIN. We believe this method is more acceptable than a thoraco-brachial abduction cast, as it allows a faster return to social and academic activities.

In practice, we very rarely use a thoraco-brachial abduction cast. Nevertheless, this technique remains a valid alternative when ESIN is contra-indicated or refused by the patient and family: informed consent is a crucial point in this situation.

In specific situations, retrograde ESIN stabilisation may be needed even for minimally displaced fractures. Examples include multiple trauma patients (e.g., requiring monitoring of the abdomen), underlying bone disease or fragility, and underlying chronic disease or disability.

Neonatal PHFs are treated by immobilisation with the elbow by the side, chiefly for pain relief, for 2 weeks.

Pathological fractures require a different strategy. First, if the nature of the underlying lesion remains in doubt despite a standard imaging work-up, a biopsy should be performed. When the biopsy shows a benign lesion, surgical ESIN stabilisation may be indicated depending on the nature of the lesion, displacement, and number of previous fractures. In other cases, combining specific treatment for the benign tumour (e.g., injection or curettage and filling) with retrograde ESIN is discussed on a case-by-case basis.

Finally, overuse injuries in young athletes require discontinuation of the offending activity until the lesions heal, i.e., for 3 months on average. The activity is then re-introduced gradually provided the pain is fully resolved and the radiographs are normal [9].

4. Conclusion

In patients with PHFs, the diagnostic approach requires the elimination of an underlying lesion or pathologic fracture. Abuse should be ruled out in very young paediatric patients. In-depth knowledge of the development and anatomy of the proximal humerus improves the interpretation of radiographs, particularly in young paediatric patients, and explains the various fracture types.

The treatment strategy for PHFs is governed by the extraordinary remodelling potential of the proximal humerus, which often allows non-operative management without reduction in skeletally immature patients. Retrograde ESIN of the proximal humerus should be performed only by surgeons who have experience with this method. Direct percutaneous pinning is only a fall-back option for surgeons who are not proficient with retrograde ESIN. Finally, direct open surgery is very rarely performed, its main indications being severely displaced fractures and, above all, failed closed reduction. When these indications are followed, the long-term outcomes are usually excellent and sequelae fairly uncommon.

Disclosure of interest

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