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Management of supracondylar fractures of the humerus in children

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- Supracondylar fractures of the humerus are the most frequent fractures of the paediatric elbow, with a peak incidence at the ages of five to eight years.

- Extension-type fractures represent 97% to 99% of cases. Posteromedial displacement of the distal fragment is the most frequent; however, the radial and median nerves are equally affected. Flexion-type fractures are more commonly associated with ulnar nerve injuries.

- Concomitant upper-limb fractures should always be excluded. To manage the vascular status, distal pulse and hand perfusion should be monitored. Compartment syndrome should always be borne in mind, especially when skin puckering, severe ecchymosis/swelling, vascular alterations or concomitant forearm fractures are present.

- Gartland's classification shows high intra- and inter-observer reliability. Type I is treated with casting. Surgical treatment is the standard for almost all displaced fractures. Type IV fractures can only be diagnosed intra-operatively.

- Closed reduction and percutaneous pinning is the gold standard surgical treatment. Open reduction via the anterior approach is indicated for open fractures, absence of the distal vascular flow for > 10 to 15 minutes after closed reduction, and failed closed reduction.

- Lateral entry pins provide stable fixation, avoiding the risk of iatrogenic ulnar nerve injury.

- About 10% to 20% of displaced supracondylar fractures present with alterations in vascular status. In most cases, fracture reduction restores perfusion.

- Neural injuries occur in 6.5% to 19% of cases involving displaced fractures. Most of them are neurapraxias and it is not routinely indicated to explore the nerve surgically.

Keywords: supracondylar fractures; children; management

Introduction

Supracondylar fractures of the humerus are the most frequent fractures affecting the paediatric elbow[1] and their correct management is important because they can cause catastrophic complications. Despite there being a clear consensus about some issues regarding proper treatment of these fractures, controversy remains with regard to aspects such as the fact that there is no good classification that guides treatment or predicts complications. In addition, the debates remain unresolved about the timing of emergency reduction or whether reduction can be safely delayed, the controversy regarding proper treatment of Gartland type II fractures, the adequate reduction technique, the risk/benefit ratio of open reduction, the best pin configuration, whether to use a medial pin, the adequate management of a pink pulseless hand, the remodelling capacity of the distal humerus and the long-term consequences of a cubitus varus deformity.

Epidemiology

Supracondylar fractures of the humerus account for 55% to 80% of total elbow fractures in children and up to two-thirds of paediatric elbow injuries requiring hospitalization.[2] Supracondylar fractures usually occur as result of a fall from height or from sports or leisure. Their incidence has been estimated at 177.3 per 100 000.[3]

Although they can occur throughout childhood, the median age is approximately six years, with higher incidence between five and eight years. There is a higher incidence of supracondylar fractures in boys, affecting the non-dominant arm 1.5 times more frequently.[4]

Pathophysiology and applied anatomy

The distal humerus anatomy is especially predisposed to injury because its configuration in two columns connected by thin bone represents a zone of weakness.

Fig. 1 a) Skin puckering at the antecubital fossa should warn of a high energy fracture which transects the brachialis muscle and biceps. b) Very displaced type III fracture. When the fracture is very displaced, 'S-deformity' and skin puckering are usually present, and the possibility of neurovascular injury and compartment syndrome should be considered; c) The so-called 'S-deformity' is present in very displaced extension-type fractures.

When a fall on the outstretched hand occurs, the olecranon engages on the olecranon fossa and if elbow extension progresses, the olecranon finally acts as a fulcrum on the fossa. Therefore, the bone begins to break at first anteriorly and the fracture progresses posteriorly. If the energy is high, the posterior cortex disrupts, and finally complete posterior displacement of the distal fragment occurs with the posterior periosteum acting as a hinge. This is the mechanism of extension-type fractures, which represent 97% to 99% of the total.[4]

Analysis of distal fragment displacement and posterior periosteum integrity is essential. Although previous literature has described posteromedial displacement of the distal fragment as the most frequent direction of displacement (75% of cases[1]), in our series we have found an almost equal rate of posteromedial and posterolateral displacement.[5] When posteromedial displacement occurs, the posterolateral periosteum is torn but the posteromedial periosteum is usually intact. For this reason,

forearm pronation will put the medial periosteum in tension, facilitating closure of the fracture and avoiding varus collapse.[2,6] On the other hand, when posterolateral displacement happens, forearm supination at the time of reduction will put the lateral intact periosteum in tension, facilitating reduction.

Flexion-type fractures represent about 1% to 3% of cases and the fracture is usually caused by direct trauma to the flexed elbow.[1] In these cases, the anterior periosteum acts as a hinge, and the progression of the injury goes from the posterior to the anterior part of the distal humerus. The distal fragment also tends to be translated in the coronal plane.

Clinical examination

Although elbow deformity is usually the most striking aspect (especially in very displaced fractures), examination of the entire extremity is essential to exclude associated distal radius (most frequent), forearm or proximal humerus fractures. Concomitant upper-limb fractures not only cause a more severe trauma and instability, but also create increased difficulty in treatment and an increased incidence of neurovascular injuries or compartment syndrome.[7-9]

In displaced extension-type fractures, the so-called 'S-deformity' is usually present (Fig. 1). However, light ecchymosis or swelling can be the only external manifestation of a minimally displaced extension fracture or a flexion-type fracture.

Signs such as extensive ecchymosis, soft-tissue swelling and skin puckering indicate severe trauma (Fig. 1). Special attention should be taken when skin puckering is present. This sign appears when the proximal fragment transects the brachialis muscle, 'puckering' the deep dermis (Fig. 1a). For this reason, when skin puckering is present, severe displacement and soft-tissue damage, including brachial artery and median nerve entrapment, should be expected,[10] although no differences are found in long-term outcomes with correct management.[10]

Vascular status evaluation is paramount in displaced fractures. It has been reported that vascular compromise exists in up to 10% to 20% of displaced fractures.[2,11,12] It is mandatory to check the distal pulse and hand perfusion pre-operatively and post-operatively.

Neurological examination can be challenging. In the acute setting, the pain and anxiety of the child and his/her parents can make the examination difficult. However, enough time should to be taken to assess adequately the pre-operative neurological status. The median nerve and anterior interosseous nerve (AIN) can be assessed with active flexion of the distal interphalangeal joint of index and thumb. For the radial nerve, thumb extension is usually easy to achieve, even in the young child. For ulnar
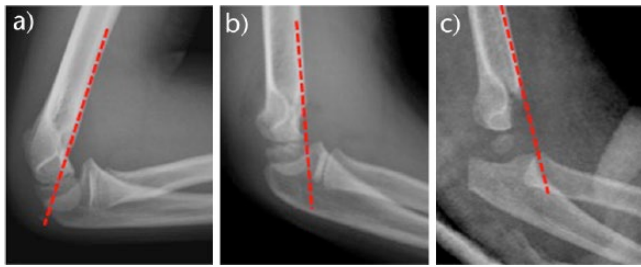
Fig. 2 a) The anterior humeral line (AHL) should traverse the middle third of the capitellum nucleus in normal anatomy and type I fractures; b, c) in extension-type fractures, the line crosses anteriorly.

nerve assessment, at least first interosseous contraction is usually easy to achieve. The inability to perform a complete neurovascular assessment should be documented for medicolegal reasons.

Compartment syndrome should always be borne in mind, especially when skin puckering, severe ecchymosis/ swelling, vascular alterations or concomitant forearm fractures are present.

Radiological evaluation

Standard anteroposterior (AP) and true lateral radiographs of the elbow are usually sufficient to characterize the fracture. Careful evaluation should be performed, because it is not unusual to underestimate the severity of a fracture as result of an inadequate radiological technique.

A true lateral view of the elbow is essential because the majority of classifications and treatment algorithms are based on the degree of extension or flexion displacement. The main anatomical landmark to be evaluated in the lateral view is the anterior humeral line (AHL).[13] This line continues the anterior cortical of the humerus and, in a normal elbow, should traverse the capitellum in its middle third (Fig. 2). In a displaced fracture in extension, the AHL will pass anteriorly or may not even cross the capitellum. In case of a flexion-type fracture, the AHL passes posteriorly to the capitellum. The lateral view also allows assessing the degree of displacement and the integrity of the posterior cortex.

The anterior and posterior 'fat-pad sign' can also be evaluated in the lateral radiograph. While diagnosis of displaced fractures is usually evident, diagnosis of minimally or non-displaced fractures can be challenging. The posterior fat-pad sign is suggestive of the presence of a non-displaced fracture of the elbow (Fig. 3). According to Skaggs et al,[14] 76% of patients with a positive fat-pad sign had a non-displaced fracture of the elbow, and in 53% of them, the fracture was a supracondylar fracture. However, the anterior fat-pad sign can be present in a normal flexed elbow and, therefore, is not so specific for fracture diagnosis.

Fig. 3 Posterior fat-pad sign (asterisk) is specific to an occult elbow fracture in almost 75% of patients. However, anterior fat-pad elevation (arrow) is not so specific to fracture diagnosis and can appear in a normal elbow.

Regarding the AP radiograph, we should evaluate the direction of displacement, the presence of varus or valgus alignment, and the extent of the fracture comminution. Baumann's angle, which is the angle formed in the AP view by the diaphyseal axis of the humerus and the physeal line of the capitellum, is used to assess varus or valgus alignment of the distal humerus (Fig. 4). However, Baumann's angle has a broad range of normal values (64° to 82°) and varies greatly with humeral position on the radiograph (i.e. rotation).[15] The ulnohumeral angle or radiological carrying angle, which is the angle formed, in the AP view, by the diaphyseal axis of the humerus and the axis of the proximal third of the ulna, is also used to assess varus or valgus deformity and it is more accurate and useful than Baumann's angle (Fig. 4).

Classification

Several classifications of supracondylar fractures of the humerus have been proposed. However, Gartland's classification[16] is the most widely used. It is a reliable classification with high intra- and inter-observer concordance,[17] based on the amount of displacement of the distal fragment. Gartland classified supracondylar extension-type fractures in his original paper as follows (Fig. 5):

- Type I. Non-displaced fractures (< 2 mm). The AHL still crosses through the centre of the capitellum. These fractures are stable because of the integrity of the periosteum.

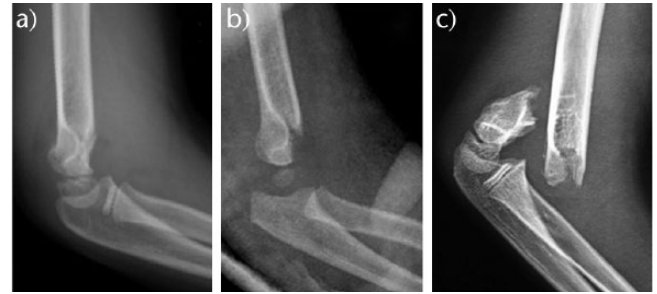Fig. 4 a) Baumann's angle; b) ulnohumeral angle.

Fig. 5 Gartland's classification for extension fractures: a) type I; b) type II; c) type III.

However, flexion of the elbow within the cast should not pass 90° because it can increase forearm pressures and impede distal vascular flow.[21,22] Although secondary displacement rarely occurs, it seems prudent to control secondary displacement with a new radiograph performed at least seven to ten days after injury. Three weeks after the fracture, the cast is removed and progressive joint motion is allowed.

Gartland type II

Operative treatment of these fractures has become more popular recently. The limited potential of remodelling of the distal humerus is the strongest argument in favour of surgical management. The distal humerus represents only 20% of total growth of the bone and the ability to remodel is limited after the age of four years.[2] After the ages of eight to ten years, only 10% of growth of the humerus remains, so anatomical reduction is thought to be imperative.

Closed reduction and casting of these fractures is becoming less popular because of the excessive flexion of the elbow beyond 90° needed to maintain reduction, which increases the risk of compartment syndrome and neurovascular injuries.[9,21-23]

Regarding conservative treatment with simple immobilization, Moraleda et al[24] described the long-term results of Gartland type II fractures treated with immobilization and no attempt at reduction. The authors described a mild cubitus varus deformity in 26% of cases, pain or instability in 17% of patients, and a mild increase in elbow extension and a mild lack of elbow flexion that was present in almost every patient. However, the authors found that functional results were excellent in most of the patients and were not predictors of bad results.

It is thought that Gartland type II fractures with medial column comminution, varus or valgus angulation, or rotation should be treated surgically, even if the fracture is minimally displaced. However, identifying rotation is difficult in plain radiographs.

Closed reduction and percutaneous pinning of type II fractures seems to be easy, safe and reliable.[25,26] The risk of complications is low. In fact, Skaggs et al[26] described no

- Type II. Moderately displaced (> 2 mm). The AHL passes anterior to the centre of the capitellum; the posterior periosteum is intact but acts as a hinge.
- Type III. Completely displaced. This type of fracture is more unstable, with extensive soft-tissue and periosteal damage and increased incidence of neurovascular injuries.

Gartland's classification was modified by Wilkins in 1984,[18] subdividing type II fractures into IIA or IIB according to the absence (IIA) or presence (IIB) of malrotation. However, this sub-classification of type II fractures does not show a good intra- and inter-observer reliability.[19]

In 2006, Leitch et al[20] introduced a new type IV fracture, in which the periosteum is completely torn, which leads to a high instability of the fracture both in flexion and extension. Multidirectional instability of type IV fractures can be caused by the injury itself or by repeated failed attempts of reduction. Type IV fractures can only be diagnosed intra-operatively.

Treatment

Gartland type I

Non-displaced or type I fractures can be managed easily with a long-arm cast or splint (Fig. 5). There is not usually severe swelling or ecchymosis, so elbow flexion up to 80° to 90° and mid pronation-supination are well tolerated.

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radiographic or clinical loss of reduction, and no complications in their series. For these reasons, in our opinion, if any doubt exists about the need for reduction, a closed reduction and percutaneous pinning fixation of a Gartland type II fracture is indicated.

Types III and IV

It is widely accepted that type III and type IV fractures should be managed surgically.[2] Nowadays, closed reduction and percutaneous pinning is the gold standard for all displaced fractures. Blount's method with closed reduction and hyperflexion of the elbow to maintain reduction is no longer used because of the risk of compartment syndrome or neurovascular injury. However, Pham et al have described their results with Blount's method when treating Gartland type IIB and III supracondylar fractures.[27] The authors described a secondary displacement in 5% of their cases, a cubitus varus deformity in 2% of their cases, no cases of compartment syndrome and satisfactory results according to Flynn's criteria in 90% of their cases. The authors concluded that Blount's method is a reasonable option for treating type IIB and III supracondylar humeral fractures in children. Muccioli et al also described good results with Blount's technique.[28] Other treatments, such as traction, have only historical interest.[29-31]

Management in the emergency room

In the emergency department, immobilizing the elbow with a long-arm splint at 30° to 40° of flexion is sufficient until surgery is performed, in order to control pain, avoid neurovascular injuries and minimize the risk of compartment syndrome. A careful physical examination and regular monitoring, including integrity of the skin and neurovascular status, are mandatory.

Delayed treatment

Displaced supracondylar fractures have been traditionally treated as surgical emergencies due to the risk of neurovascular complications or the belief that open reduction instead of closed reduction will be needed if surgery is delayed.[16,32] Debate still exists as to whether reduction can safely be delayed in the absence of neurovascular compromise.[33-38] On the other hand, it should also be taken into account that performing surgery at night, with inadequate facilities or staff, can potentially increase surgical errors.[39] The majority of previous studies, including our series, shows that surgical delay does not correlate with a higher rate of open reduction or an increase in complications.[5,33,37,38,40-43] We also found that pinning errors were significantly more frequent in surgeries performed at night.[5] In our opinion, those cases with an open fracture, vascular or nerve injuries, severe swelling, a floating elbow

or when the fracture affects a toddler or a patient with neurological disability who, therefore, cannot complain of pain correctly, should be treated urgently. Otherwise, treatment can be safely delayed. Furthermore, surgery at night should be avoided in the absence of contraindications.

Surgical technique

Reduction

Fractures can be reduced by closed or open means.[44] Open reduction has been related to a higher incidence of infection and stiffness. Closed reduction is a reliable technique for the majority of displaced fractures.

Regarding extension fractures, the fracture is first reduced in the coronal plane with the elbow in extension while gentle traction is applied. When skin puckering is present because the proximal fragment is transecting the brachialis muscle, the 'milkman's manoeuvre' of the anterior part of the arm is useful to release the proximal fragment (Fig. 6).[10] Surgeons need to be aware of the higher risk of neurovascular injury associated with skin puckering. Later, pronating or supinating the forearm corrects rotation of the fragment (Fig. 7). Finally, the elbow is flexed while pushing the olecranon to the correct extension. Maintaining the elbow in maximum flexion to stabilize the fracture until fixation with percutaneous pinning is performed (Fig. 6). Sometimes, maintaining the elbow flexed does not stabilize fractures while pinning (fractures with an oblique line and Gartland type IV fractures). In those cases, a K-wire can be passed through the distal fragment from medial to lateral and used as a joystick to reduce the fracture and maintain reduction while pinning (Fig. 8). Results obtained by Leitch et al with the 'joystick technique' were excellent, with no malunion, stiffness or additional surgery needed. Although their series is small (nine cases), it seems to be a reliable alternative for reduction of these fractures. In our experience, open reduction and fixation of these unstable fractures is not easy at all, so we prefer to treat them by closed means.

Another technique proposed to facilitate reduction of the fracture is to use a K-wire introduced percutaneously from the posterior aspect of the arm through the medullary canal of the humerus, similar to Kapandji's technique for the distal radius. Few papers have been published regarding this technique.[45,46] Although the results are similar to those published with other techniques, there is a risk of nerve palsy, wire migration and, in contrast with the joystick technique, it is not useful when the posterior periosteal hinge is disrupted.[45]

Open reduction is indicated when the surgeon is not able to reduce the fracture by closed means, when there is soft-tissue entrapment (i.e. muscle, median nerve, brachial artery) or when a cold hand remains without perfusion after an attempt at closed reduction has been

Fig. 6 Reduction technique. Reduction is performed under fluoroscopy. First, traction is applied. Then, coronal plane deformity is corrected, applying varus/valgus. Sagittal plane correction is then performed. The last step is fixation with smooth 1.8 to 2.0 mm K-wires.

Fig. 7 When posteromedial displacement is present, forearm pronation helps with fracture reduction. Forearm supination will be a difficult reduction in these cases.
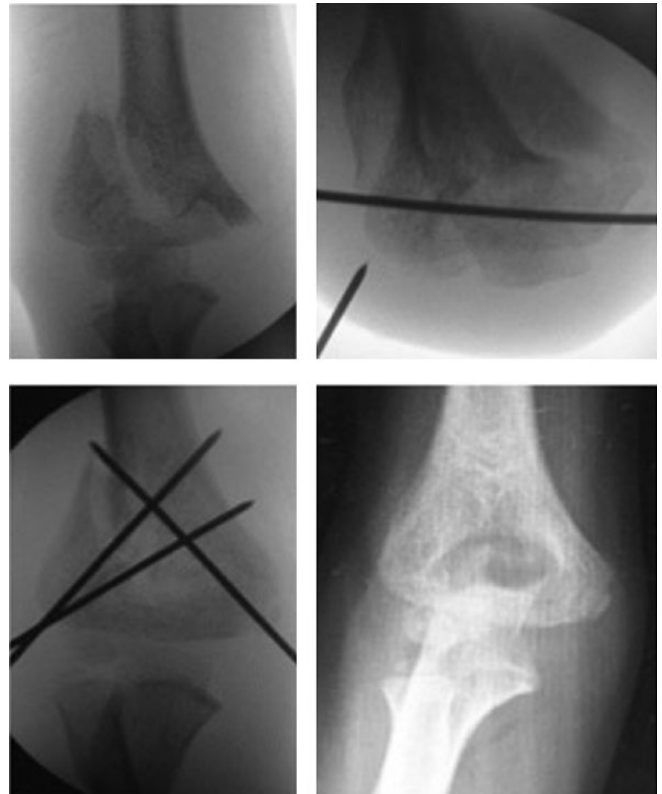

Fig. 8 In very unstable fractures (such as type IV), a provisional pin in the distal fragment is helpful to achieve reduction. Once reduction is achieved, fixation is performed. In very unstable fractures, three-wire fixation is preferred.
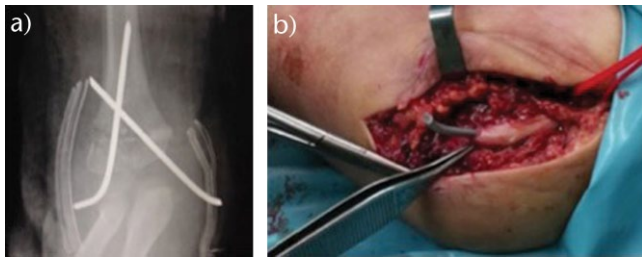
Fig. 9 Fracture fixated with crossed pins percutaneously. Ulnar nerve was traversed by medial pin and post-operative palsy was present.

performed. Neurovascular entrapment can be suspected when a soft stop to reduction is observed.

The anterior approach is the most widely used approach for open reduction. This approach is especially indicated when vascular repair is necessary. It is a safe approach and results are similar to or better than a traditional lateral approach.[47] The lateral approach is the standard approach for elbow surgery. However, in supracondylar fractures, which are extra-articular, it does not give any advantage over the anterior approach and increases the risk of radial nerve injury and stiffness. The bilaterotricipital posterior approach (Alonso-Llames approach) was initially described at our institution to treat supracondylar fractures.[48] However, currently it is not widely used because of the high rate of complications described, such as stiffness, unsightly scarring and risk of trochlea osteonecrosis.[49] In our experience, the posterior approach is an easy and safe approach that allows surgeons to manage both columns for proper reduction. Classically, the open approach was associated with a high rate of complications, such as stiffness or myositis ossificans. However, recent studies have reported a lower incidence of complications[50] and no differences compared with closed reduction regarding loss of motion, infection, malunion or subsequent surgery.[51,52] In a series reported by Reitman et al,[50] the authors found that open reduction had a low rate of complications. However, despite the fact that fractures that need an open reduction are usually more severe, up to 22% of their patients were rated as having a poor or fair result according to Flynn's criteria[53] after an average follow-up of 5.8 months. Loss of motion is the most commonly reported complication, affecting about 10% of patients.[44] In our opinion, vascular entrapment and type II or III open fractures are the main indications for open reduction. We try to reduce by closed means all fractures that do not have an associated vascular injury and we use all possible manoeuvres to avoid an open reduction. When a fracture needs to be open because of a vascular lesion, we use an anterior approach.

Fixation

Before fixation, angular and rotational alignment are assessed. We check rotational alignment both clinically and radiologically. We recommend performing four views with fluoroscopy: AP; lateral; internal oblique; and external oblique. Internal oblique and external oblique views allow us to check both columns and to be sure rotation is corrected. We have also observed that, clinically, the position of the forearm related to the trunk with the shoulder in abduction and maximus external rotation is symmetrical and serves as a control for rotation of the distal fragment.

Pin fixation for paediatric supracondylar fractures of the humerus was initially proposed by Casiano[54] in 1960 and was established as a reliable technique with good long-term outcomes by Flynn et al in 1974.[53] Many studies have been published comparing lateral-entry and crossed pin fixation.[40,55-60] Regarding biomechanical stability, results of studies are controversial. While there are studies supporting the idea that crossing pins provides more stability,[61-63] no differences are seen in others.[64,65] We use two divergent percutaneous K-wires inserted from a lateral-entry point. We usually use a 1.8-mm K-wire for percutaneous pinning. Once the fracture has been fixated, the surgeon can extend the elbow and check for stability. If the fracture remains unstable, a third lateral-entry point pin or a pin inserted from the medial part of the elbow is inserted. We prefer to use a third lateral-entry point K-wire instead of a medial pin because of the risk of damaging the ulnar nerve[66] (Fig. 9). Larson et al[67] showed that three divergent lateral pins are at least as stable as standard crossed pins. Skaggs et al[26] found that the use of lateral-entry point alone was effective for even the most unstable fractures. The authors note the importance of maximizing separation of the pins at the fracture site, engaging the medial and lateral columns proximal to the fracture, engaging sufficient bone in both the proximal segment and the distal segment, and maintaining a low threshold for use of a third lateral-entry pin if there is any concern about fracture stability or the location of the first two pins. Biomechanical studies have demonstrated that widely divergent wires starting on the capitellum, one through the lateral column and one through the medial cortex, are the best option.[68,69] It is important to have the pins separated enough at the level of the fracture to provide rotational stability.

Sankar et al classified pinning errors as types A, B and C.[70] A type A error was defined as the failure to engage both fragments by two pins or more. A type B error was defined as the failure to achieve bicortical fixation with two pins or more. A type C error was defined as inadequate pin spread to control rotation.[70] We found type C error to be the most common pinning error in our series.[5]

Several studies have proved a higher risk of ulnar nerve injury when crossing pins are placed instead of lateral-entry point alone, with no differences in other parameters.[57] Relative risk (RR) of the ulnar nerve is as high as 4.3 times with crossed pins in comparison with lateral-entry pins,[60] with an estimated incidence of 3.4% *versus* 0.7%.[59]
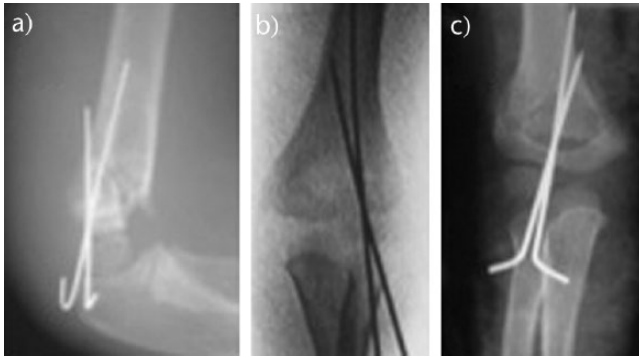
Fig. 10 According to Sankar et al,[70] a type A error was defined as the failure to engage both fragments using two pins or more; a type B error was defined as the failure to achieve bicortical fixation with two pins or more; and a type C error was defined as inadequate pin spread to control rotation.

It is important to know that direct injury (like penetration) of the nerve by the pin is not necessary to develop an ulnar nerve palsy (Fig. 9). Just the fact that the K-wire is adjacent to the nerve has been proved to provoke an ulnar nerve affection.[71] The main advantage of using crossed pins is to provide more stability that will prevent secondary displacement and malunion. However, Lee et al affirm that avoiding ulnar nerve palsy is clinically more important than having a slightly increased incidence of malunion (5.9% for lateral-entry point *versus* 3.4% for crossed pins).[59]

Several techniques have been proposed to avoid ulnar nerve injury with medial pinning.[44,72] Once lateral pins have been inserted, the elbow is semi-extended to allow posterior displacement of the ulnar nerve. When the elbow is flexed > 90°, an anterior displacement of the ulnar nerve occurs and the risk of injury is in the range of 5.7% to 17.7%.[73] The thumb is used to press over the epitrochlea to decrease the oedema and facilitate palpation of bony references. Later, the thumb is displaced posteriorly to protect the nerve and a T-handle is used to insert the pin anteriorly to the thumb.[44] A mini-open medial incision may also be used to visualize the medial-entry point and avoid injury of the ulnar nerve.[74] Ulnar nerve location by palpation only is not a totally safe technique.[75] Other techniques such as intra-operative electrical stimulation[76] or ultrasound monitoring[77] have been proposed as safe but technically demanding methods to avoid ulnar nerve injuries.

In our opinion, the best way to avoid iatrogenic ulnar nerve injury is to avoid medial pinning. Dorgan's technique (a proximal lateral-entry point pin going from proximal-lateral to distal-medial) for crossed lateral-entry pins has been proposed as an alternative to avoid ulnar nerve injury. However, the proximal wire enters in the supracondylar lateral region, increasing the risk of radial nerve injury.[78]

Controversy exists regarding whether or not to bury the percutaneous pins. It has been advocated that burying the pins diminishes the risk of infection; however, the risk

Fig. 11 After reduction and fixation, the elbow should be immobilized at approximately 70° of flexion. Higher flexion not only will not improve results, as the reduction is maintained by pins, but also increases the risk of compartment syndrome.

of severe deep infection associated with percutaneous pinning without burying the pins has been described as low as 0.2%.[79] On the other hand, burying the pins can cause skin complications or problems related to soft-tissue irritation and needs a second surgery to remove the pins.[77] Our recommendation is to leave the pins exposed without burying them.

It is important to note that stability is mainly provided by the pins. Fixation should be stable enough to allow immobilization of the elbow in a splint in no more than about 60° to 70° of flexion in order to avoid neurovascular complications or compartment syndrome (Fig. 11). The pins and splint are removed after three weeks. Initial physiotherapy is not recommended.[80] Schmale et al published a randomized controlled trial regarding physical therapy following a paediatric supracondylar humeral fracture. The author found no differences between groups with respect to performance of activities of daily living, time to return to sports or elbow motion.[80]

Complications

Vascular injury

About 10% to 20% of displaced supracondylar fractures present alterations in vascular status.[11,12] The radial pulse
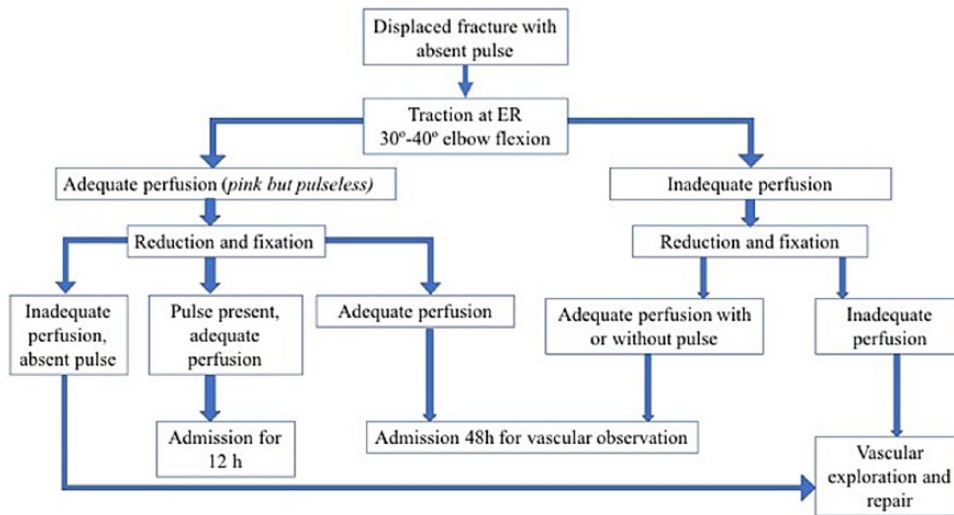
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Fig. 12 Algorithm for the management of vascular injury in the context of a supracondylar fracture.

is reported to be absent before reduction in 7% to 12% of all fractures and up to 19% in displaced fractures. Lesions of the brachial artery can occur primarily from stretching, entrapping or disrupting the neurovascular structures on the proximal fragment and, secondarily, during reduction manoeuvres or when immobilizing the elbow in the hyperflexion position.[81,82]

When facing a supracondylar humeral fracture with an associated vascular injury, our first action should be to perform a closed reduction of the fracture. There is no evidence supporting the use of angiography in pre-operative management.[83,84] In the absence of significant associated trauma at other levels, the vascular injury is localized at the fracture focus. Therefore, the use of ultrasonography or angiography only delays fracture reduction and increases the risk of complications.[83,84]

After closed reduction has been attempted, vascular status should be re-evaluated because the pulse is restored in 80% of the cases after reduction.[81] The incidence of poor perfusion of the forearm after reduction of the fracture is 0.3%.[81] The absence of radial pulse after closed reduction of the fracture has been described in 3.2% of cases.[85] The association of pulseless hand and median nerve palsy strongly predicts the need for surgical exploration.[86]

The hand is the best indicator of vascular status. According to pulse presence and limb perfusion, three situations are recognized:[87,88] 1) good pulse and well perfused limb (warm, pink, capillary refill < 3 seconds with distal pulse detected by eco-Doppler); 2) the so-called *pink-pulseless hand* when the pulse is absent but the hand is well perfused (warm, pink, capillary refill < 3 seconds, without Dopplerable distal pulse); 3) the so-called *cold-hand* when the pulse is absent and the hand is poorly perfused (pale, cold and capillary refill > 3 seconds).[12] The treatment algorithm is based on these three situations (Fig. 12).

Consensus is clear about the indication of immediate exploration of the artery for a *cold-hand* situation or in those situations when the pulse was present previously but disappears after closed reduction of the fracture.[81] In order to protect the vascular repair, it is mandatory to first reduce and fix the fracture. We recommend performing vascular exploration using an anterior approach with collaboration of the vascular surgeon.

On the other hand, the current literature is imprecise regarding the optimal management of a *pink-pulseless* situation.[81,85] Controversy exists regarding whether it is preferable to adopt a conservative approach based on strict supervision or whether it is better to perform an early revascularization.[89] A survey of the British Society for Children's Orthopaedic Surgery found that 60% of surgeons favour continued observation if the forearm remains pulseless but well perfused.[90] Some authors believe that the rich collateral circulation around the elbow will sustain the viability of the extremity after sustaining a supracondylar humeral fracture with a pink-pulseless hand.[85] It has been described that distal pulse is restored in most cases within six weeks after surgery.[91] Furthermore, we have to take into account that early revascularization of a pink-pulseless hand has been associated with a high rate of asymptomatic re-occlusion and residual stenosis of the brachial artery.[85] However, Blakey et al[92] note the importance of monitoring pain and signs of progressive nerve affection in the context of a pink-pulseless hand, because those patients could be susceptible to surgical exploration.

Controversy remains regarding the long-term consequences of a poor vascularization, such as cold intolerance, exercise-induced ischemic symptoms and limb-length discrepancy in some patients. Carbonell et al review 14 adults with a mean age at the latest follow-up of 20 years who sustained a pink-pulseless type III supracondylar fracture during childhood (average age at the

time of fracture of seven years).[93] Patients were managed with closed reduction of the fracture, percutaneous pinning and strict supervision of the vascular status without surgical revascularization. The authors found satisfactory results in the long term with no difference, compared with contralateral side, regarding grip strength, capillary refill, wrist brachial index, length of the arm and forearm, circumference of the arm and forearm, or oxygen saturation. Radial pulse was present in all patients. Therefore, we advocate for strict supervision of a pink-pulseless hand situation without surgical revascularization.

Neurological injury

Neural injuries can occur in 6.5% to 19% of cases of displaced fractures and they are exceptional in non-displaced fractures.[79] They can appear either before surgery (primary lesion) or after reduction and fixation of the fracture (secondary lesion). Primary lesions are caused by fracture displacement, which can stretch, entrap or disrupt the nerve. Secondary lesions are caused by excessive manipulation, immobilization in hyperflexion or iatrogenic injuries by fixation.[81,94]

When posteromedial displacement occurs, the radial nerve is at risk of primary injury or because of involvement during a reduction manoeuvre.[1] Posterolateral displacement puts at risk brachial artery and median/AIN nerves. Flexion-type fractures involve neurovascular structures more frequently than extension-type fractures, especially ulnar nerve entrapment at the fracture site.[95]

Incidence of AIN injury and radial nerve injury is similar.[94] Combined nerve injuries can be present in up to 21% of cases with nerve lesions.[94] When an AIN lesion is present, paralysis of the *flexor pollicis longus* and *flexor digitorum profundus* of the second finger is observed. The AIN is an exclusive motor branch, so sensory changes are not present. When a complete median nerve lesion is present, sensory and motor loss of function are observed in the median nerve distribution. Radial nerve injury is associated with a loss of wrist and finger extensor function and loss of sensation in the radial nerve distribution. Ulnar nerve injury is more frequent in flexion-type fractures. However, due to the low incidence of flexion-type fractures, the majority of ulnar nerve injuries are seen in extension fractures and they are thought to be caused by a medial pin.[26] In fact, Valencia et al found that in more than half of their ulnar nerve injuries, fixation was with lateral-entry point pins alone.[79] The authors hypothesized that an ulnar nerve injury may reflect the severity of the trauma or the difficulty in reducing the fracture by closed means.

The majority of these injuries are neurapraxias and heal spontaneously; therefore, surgical exploration of the nerve is rarely indicated. In our opinion, when a medial pin is present in a patient with an ulnar nerve injury, the medial pin should be removed (Fig. 9). However, Lyons et al[96] reported a full recovery in 17 patients with post-operative ulnar nerve palsy and medial pin fixation despite only four wires being removed.

Valencia et al[94] reported in their series that 100% of radial nerve injuries, 87.5% of median nerve injuries and 25% of ulnar nerve injuries were fully recovered with conservative management in the long-term follow-up. The average time for recovery was 3 months for the radial nerve, 2.5 months for the median nerve and 5 months for the ulnar nerve. Other authors have found similar results.[97] Strength and discriminatory sensation were normal in all patients. No motor deficit was present. Neurological abnormality consisted of paraesthesia that did not impair normal daily activity.

Compartment syndrome

Compartment syndrome can occur in 0.1% to 0.3% of cases.[2] Associated forearm fractures and elbow flexion > 90° increase compartment pressures.[8,22] Severe swelling, ecchymosis and pucker sign are clinical signs that can advise of the possibility of the development of a compartment syndrome. Special attention is needed if increased anxiety or analgesia requirements exist or in cases of toddlers or patients with neurological disorders or associated median nerve injury. Diagnosis is mainly clinical. Most cases affect the volar compartment, but the dorsal compartment can also be involved.[98]

To minimize the risk of compartment syndrome, the elbow should be immobilized in about 30° of flexion in the emergency room and 60° to 70° of flexion after surgery. In case of a dysvascular limb for > 6 hours, it may be prudent to open forearm compartments, but not enough evidence exists to support this.[82]

Floating elbow

The so-called 'floating elbow' occurs when the supracondylar fracture of the humerus is associated with an ipsilateral forearm fracture. This is an uncommon situation (approximately 5% of the supracondylar fractures) that reflects high-energy trauma.[7] A fall from a significant height is the usual mechanism of injury. Forearm fracture is usually in the distal third of the forearm.[99] Some authors affirm that if a more proximal forearm fracture occurs, the lever arm of the proximal fragment would be too short to generate the moment of force required to produce the ipsilateral supracondylar humeral fracture.[100] However, cases with associated diaphyseal forearm fractures have been described.[7,101] The incidence of open fractures and neurological injury is much higher than those reported for isolated supracondylar fractures.[7]

When a floating elbow presents, treatment of supracondylar fracture is the priority, which will include a closed reduction of the fracture and percutaneous pinning for fixation. However, open reduction is needed

Fig. 13 Fracture malunion in extension leads to a lack of flexion. It is an important point that stiffness in supracondylar fractures in children is not frequent and lack of mobility usually reflects a malunion.

more frequently than in isolated supracondylar fractures. Conservative treatment of supracondylar fractures is contraindicated[100,101] due to the increased risk of neurovascular injury or compartment syndrome. Conservative treatment of supracondylar fractures would include an immobilization in hyperflexion of the elbow, further increasing the risk of neurovascular complications. The results of a supracondylar humeral fracture in a floating elbow situation described in the literature are similar to the reported outcomes for isolated supracondylar fractures.[101]

Controversy remains as to whether forearm fractures need to be fixated. Authors in favour of percutaneous K-wire fixation of the forearm fracture argue that closed reduction and casting in a position of pronation and palmar flexion would make it difficult to monitor neurovascular status,[101] that circumferential cast immobilization of the radius fracture increases the risk of compartment syndrome[99] and that cast immobilization of the forearm fracture is associated with a high incidence of secondary displacement.[99] However, Blumberg et al described the results of closed reduction of the displaced forearm fracture and immobilization into a non-circumferential cast or splint. The authors described no cases of secondary displacement or necessity of re-manipulation, no signs of elevated compartment pressures, and a radiographic union without secondary procedures in all cases. Blumberg et al concluded that a floating elbow could be safely managed with operative stabilization of the supracondylar humerus fracture alone.[102]

Extension malunion

It is frequent that fractures heal in extension, whether reduction is insufficient or whether a type II fracture is treated conservatively. An extension malunion provokes an increase in extension and a lack of flexion (Fig. 13). Hyperextension of the elbow causes only cosmetic problems. However, lack of flexion can cause an inability to perform activities of daily living. It has been described that functional elbow motion is from 30° to 130°. Therefore,

careful reduction should be performed in the OR in order to avoid extension malunion. It is important to remember that condyle of the humerus is anterior to the humeral shaft and that the anterior humeral line should cross the humeral condyle in its middle third.

When facing a patient with a lack of flexion after sustaining a paediatric supracondylar fracture, we should remember that extension malunion is the cause in the vast majority of cases. Scarring does not usually play a role when deficit of flexion is present in children. Therefore, treatment should be a supracondylar osteotomy instead of a *column procedure* (capsulotomy).

Cubitus varus

The cause of cubitus varus remains uncertain. Most authors believe that cubitus varus is the consequence of malunion of the fracture rather than growth arrest. Angular deformity and rotational deformity are thought to be the cause of cubitus varus (Fig. 14). Posteromedial displacement gives a higher Baumann value indicating cubitus varus deformity, while posterolateral displacement gives a lower Baumann value indicating cubitus valgus.[103] Distal physis of the humerus has limited potential for remodelling. A child aged eight to ten years has only 10% of the total growth of the humerus remaining. While sagittal and coronal mild deformities can be remodelled in children aged < 4 years, rotational deformities cannot.[104] In a study published by Moraleda et al,[24] the incidence of cubitus varus in unreduced treated extension-type II fractures was reported to be as high as 26.1%. For that reason, the best way to avoid cubitus varus seems to be to achieve and maintain anatomical reduction of the fracture, with special attention to replicating contralateral rotation of the humerus.

Although parents consult for cosmetic reasons in the majority of cases, several complications in the long term may occur: tardy posterolateral rotatory instability; ulnar nerve palsy; shift of the medial head of the triceps; and a higher risk for condylar fractures.[105-108] O'Driscoll et al[107] affirmed that cubitus varus leads to two biomechanical disturbances: 1) medial displacement of the mechanical axis of the upper extremity and thus the lateral collateral ligament complex experience increased tensile forces and become attenuated; and 2) the triceps is displaced medially and the displaced triceps force vector leads to an external rotation (supination) moment arm on the ulna. Tardy ulnar nerve palsy with anterior dislocation of the nerve has been described[109-111] (Fig. 15). Snapping of the medial portion of the triceps may occur from the medial displacement of the triceps as well as the internal rotation of the distal humerus.[112]

Several osteotomies have been proposed to correct cubitus varus. A lateral wedge osteotomy is probably the most used osteotomy because it is easy to perform; however, it does not address internal rotation deformity and

Fig. 14 Cubitus varus deformity as a result of malunion. Internal rotation of the distal fragment is the key problem in this deformity.

Fig. 15 Ulnar nerve palsy is one of the complications related to cubitus varus deformity. In the figure, anterior transposition of the nerve is performed before the osteotomy for correction the deformity.

parents complain of aesthetic disturbances because a prominent lateral epicondyle remains. Other osteotomies have been advocated in order to avoid a prominent lateral epicondyle.[113] In our opinion, since angular and rotational deformity should be addressed, a complete osteotomy (either the dome osteotomy or a closed lateral wedge osteotomy that allows derotation and medialization of the distal fragment) seems to be a reliable and powerful osteotomy to achieve correction.[113] In our opinion, it is difficult to properly correct the varus alignment with dome osteotomy; for that reason, we advocate performing two complete osteotomies (one perpendicular to the diaphysis of the humerus and the other parallel to the ulno-humeral joint) so a resection of a lateral wedge of bone

can be performed for varus correction at the same time as derotation or flexion of the distal fragment.

Pin track infections

The literature has reported pin track infections in the range of 1% to > 25%.[114,115] Most infections are superficial and resolve with pin retirement and oral antibiotics.[26,37,114] In the rare case of deep infection or articular involvement, drainage, debridement and intravenous antibiotherapy usually resolve the infection without significant sequelae.

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ICMJE CONFLICT OF INTEREST STATEMENT
None declared.

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