Orthopaedics & Traumatology: Surgery & Research 101 (2015) S41–S49

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Review article

Acute and chronic humeral shaft fractures in adults

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ARTICLE INFO

Article history:
Accepted 10 July 2014

Keywords:
Humeral shaft fracture
Humeral anatomy
Radial nerve palsy

ABSTRACT

Humeral shaft fractures account for up to 5% of all fractures. Many of these fractures are still being treated conservatively using functional (Sarmiento) bracing or a hanging arm cast. Union is achieved in 10 weeks in more than 94% of cases. Angulation of less than 30° varus or valgus and less than 20° flessum or recurvatum can be tolerated by the patient from a functional and esthetic point of view. The ideal candidate for this treatment is a patient with an isolated fracture. Plate and screw fixation of the fracture results in union in 11 to 19 weeks. Reported complications include non-union (2.8–21%), secondary radial nerve palsy (6.5–12%) and infection (0.8–2.4%). Anterograde or retrograde locked intramedullary nailing requires knowledge of nailing techniques and regional anatomy to avoid the complications associated with the technique. Union is obtained in 10–15 weeks. Reported complications consist of non-union (2–17.4%), infection (0–4%) and secondary radial nerve palsy (2.7–5%). Hackethal bundle nailing is still used for fracture fixation, despite an elevated complication rate (5–24% non-union and 6–29% pin migration) because of its low cost and simple instrumentation. Union is achieved in 8–9 weeks. Controversy remains about the course to follow when the radial nerve is injured initially. If the fracture is open, significantly displaced, associated with a vascular injury or requires surgical treatment, the nerve must be explored. In other cases, the recommended approach varies greatly. Conservative treatment is inexpensive and has a low complication rate. Humeral shaft fractures are increasingly being treated surgically, at a greater cost and higher risk of complications.

1. Introduction

Humeral shaft fractures account for about 5% of all fractures [1]. They almost exclusively occur in young people following a high-energy trauma or older people following low-energy trauma.

A humeral shaft fracture is defined as one where the fracture line is located between the insertions of the pectoralis major muscle proximally and the brachialis muscle distally [2]. The AO defines a diaphyseal fracture of a long bone as one occurring between the two epiphyseal squares [3]. When these fractures are treated non-surgically, union is obtained in an average of 10 weeks, making the humerus a well-suited bone for conservative treatment.

The surgical indications (plate, nail, K-wire, external fixator) are based on the surgeon's school of training and presence of immediate complications (open fracture, radial nerve palsy). However surgical fixation has many secondary and delayed complications associated with it (non-union, secondary radial nerve palsy, etc.) that require long treatment periods.

This review will focus on humeral shaft fracture studies, but will exclude those involving diseased bone or that are periprosthetic in nature.

2. Anatomy

Numerous muscles insert onto the humerus, which can explain the displacement of fracture fragments. Its medullary cavity is funnel-shaped: the proximal portion has a larger diameter and relatively round shape; the distal portion is flatter and has a smaller diameter. It has a very elongated S-shape on an oblique posterior and medial plane, which corresponds to the humeral head retroversion axis [4]. The axial torsion in the humeral shaft results in two smooth surfaces, a longer anteromedial one and a shorter anterolateral one (area where radial nerve passes through).

Its anatomical relationship with three nerves is important to know when the fracture is being treated surgically [5]:

- radial nerve: it is in contact with the posterior side of the shaft; this explains the high number of primary nerve palsy cases. It passes in an oblique posterior groove from inside to outside and superior to inferior over 6.5 cm. It crosses the lateral intermuscular septum at 16 cm from the lateral humeral epicondyle,

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http://dx.doi.org/10.1016/j.otsr.2014.07.034
1877-0568/

which makes it vulnerable to displaced fractures in the middle third, particularly at the junction between the middle and lower thirds. Individual variations in the crossing point results in a "danger area" located 10–15 cm from the lateral epicondyle [6]. The exact position of the radial nerve was defined in a cadaver study [7]. It comes into contact with the posterior side of the humerus at 20.7 ± 1.2 cm from the medial epicondyle and leaves it at 14.2 ± 0.6 cm from the lateral epicondyle;
- axillary nerve: it surrounds the posterior side of the surgical neck from inside to outside, while following a horizontal arc 45 mm below the greater tuberosity of the humerus. It is flattened against the posterior side of the humerus;
- ulnar nerve: located behind the medial septum, it is near the posteromedial edge of the distal part of the humerus, where it can be damaged during the surgical approach or when using forceps.

The vascularization of the humeral shaft is heterogeneous. It is poor in the distal third, which can explain the greater number of non-unions at this level.

The humerus is subjected mainly to rotational and distraction forces; it is not subjected to compressive forces. The chosen fixation method must neutralize all of these rotational forces to achieve union by first intention [8].

3. Epidemiology [2,4,9–14]

Humeral shaft fractures are the third most common type of long bone fracture. Men are affected in more than half the cases (55–63%). The fracture occurs between 43 and 47 years of age, with extremes of 15 and 97. However, there are two age clusters for these fractures:

- 20–30 year-old males following high-energy trauma (motor vehicle accident, fall from elevated high or sports injury);
- 60–70 year-old women following low-energy trauma, such as a fall from her standing height.

The fracture line is located:

- in the proximal third in 15–25% of cases and is often oblique;
- in the middle third in 49–64% of cases and is often transverse;
- in the distal third in 11–35% of cases with increased incidence of radial nerve injury.

The fracture is simple in 56–63% of cases: spiral (18–29%), transverse (21–32%) or oblique (11–15%). A third fragment is present in 26–34% of cases and the fracture is comminuted in 10% of cases.

4. Clinical

A conscious trauma patient will present with the classical picture of an acute upper-limb injury. Immediate complications must be identified [2,4,9,11,14].

4.1. Radial nerve palsy

Radial nerve palsy is present initially in 10–20% of fracture patients and typically manifests itself as paresthesia/paralysis of wrist dorsiflexion, finger extension at the metacarpophalangeal joints, thumb extension and abduction and hypo-/anesthesia of the dorsal side of the first inter-digital corner.

Radial nerve involvement must be pointed out to the patient and/or family, and recorded in the observations. It plays an important role in the treatment choice and follow-up. The fracture is typically located in the middle third or at the junction of the middle and distal third and is highly displaced. This is determined more on the basis of the energy of the trauma than based on the radiographs, because the fracture can be realigned during transport or when the radiographs are performed.

The neurological status cannot be determined in an unconscious patient.

4.2. Cutaneous trauma

The skin overlying the fracture will be opened in 2–9% of cases following high-energy trauma.

4.3. Ulnar and median nerve palsy

Ulnar and median nerve injuries are rare, but can be observed in open fractures with significant muscle damage. One must be aware of the possibility of associated total or partial plexus injury (1.6–3%). Signs of radial nerve palsy must prompt the surgeon to look for axillary nerve palsy; this combination is generally evidence of damage to the posterior fascicle of the brachial plexus. This is an important element to clarify before surgery and before regional anesthesia.

4.4. Vascular injuries

Vascular injuries are rare (0.5–3%). They are mainly due to brachial artery rupture and require urgent care in collaboration with a vascular surgeon. The fracture must be stabilized before any blood vessels can be repaired.

4.5. Other associated injuries

In high-energy trauma cases, the fracture may be associated with another musculoskeletal injury in the upper limb. The humeral shaft fracture must be treated surgically first, so that any underlying fractures can be treated without the risk of secondary damage to the radial nerve.

5. Additional assessments

Two standard orthogonal A/P and lateral radiographs of the entire humerus (including its ends) will be sufficient to identify the fracture type, unless there are associated injuries. Traction X-rays can be performed in the operating room under anesthesia if other small fracture lines are suspected and need to be further evaluated before selecting a fixation method.

6. Treatment

The treatment must match the fracture characteristics and complications, along with the patient characteristics. In a 2003 French multicenter study [4], surgical treatment had been used in 78% of fractures and non-surgical treatment in 22%. This distribution was affected by the recruitment of patients who often had multiple fractures and by the nature of the participating hospital centers.

6.1. Conservative treatment

This consists of immobilization of a non-displaced or reduced fracture with or without anesthesia. This is the preferred treatment of many surgical teams, despite the progress made with surgical fixation methods. As noted by Chauveaux [4], this treatment method is constrained by the need for bracing and the current patient's expectations.

All types of humerus fractures can be treated, even cases with radial nerve palsy. However, this treatment strategy is challenging

Fig. 1. Conservative treatment using functional (Sarmiento) bracing of a 3-fragment humerus shaft fracture without radial deficiency. (a) At admission. (b) With the functional brace at day 14. (c) At the third month post-injury.

for the surgeon and patient, as weekly follow-up visits are required early on. It also requires that the patient adhere to the instructions. Some surgeons believe these methods are outdated.

6.1.1. Hanging arm cast

This is a "classic" treatment method as evidenced from the De Mourgues [10] and Babin [15] publications, but it was still used in 50% of patients treated conservatively in a 2003 French multicenter study [4].

The fracture is reduced because of the traction induced by the weight of the long-arm cast (1–1.5 kg). Patients must be able-bodied and well-informed, so as to let the casted arm hang, carry out pendulum movements of the shoulder and let the cast rest on their chest at night. The cast is worn for at least 6 weeks. Union is obtained after an average of 52 days (7.5 weeks). The non-union rate is between 2 and 5% [4,10,15]. There is a risk of shoulder and particularly elbow stiffness developing, along with neck pain due to the weight of the cast.

6.1.2. Functional (Sarmiento) bracing

This method is based on the fact that muscle pressure induced by the circular device gradually reduces the fracture and preserves its alignment [16], and that micro-movements at the fracture site contribute to bone union (Fig. 1).

The treatment initially consists of immobilization with an arm-to-chest bandage to help align the fragments, without trying to anatomically reduce the fracture. This initial immobilization period lasts 9 to 20 days [11,17]. In the next step, a plastic or resin device is custom made for the patient's arm by an orthotist. Velcro straps are used to regularly tighten the brace, ideally during daily visits to the clinic, but in reality every week. An arm-to-chest bandage can be added for 2–3 weeks to help reassure the patient. Patients must make regular muscle contractions once the sleeve is applied and must move their shoulder and elbow later on. This treatment can be started in the emergency room on an outpatient basis, without the need for hospitalization. The sleeve must be worn until union is achieved after an average of 11 weeks (range: 5–22) [11,17,18].

Sarmiento [11] reported a 43.7% rate of more than 5° varus angulation (with 12% having more than 16°) and 1.5% rate of more than 5° valgus angulation (all less than 16°) on A/P radiographs. On lateral radiographs, 16.1% of cases had anterior angulation greater than 5° (4.8% > 16°) and 13.9% with posterior angulation greater than 5°.

Zagorski [18] reported a similar portion of more than 5° varus or valgus angulation in his study. He also reported an average shortening of 4 mm (range: 0–15), without functional consequences.

Because of the shoulder's mobility, malunion can be tolerated since there are no functional or esthetic consequences. Thus, a varus or varus angulation of less than 30°, or flessum or recurvatum of less than 20° can be tolerated. The shoulder function is normal in 70–88% of cases and the elbow function is normal in 76–88%. Rotational malunion and its potential repercussions on internal and external rotation movements of the shoulder have not been evaluated. Union is obtained in 94–98% of fractures, depending on if they are open or closed [4,11,17,18].

6.1.3. Other non-surgical treatment options

Other non-surgical treatment options are:

- the shoulder spica cast [15] dates back many years. It has very little use now because of its bulk and secondary stiffness [12].
- transolecranon traction at the apex can be used as a temporary treatment [15].
- arm-to-chest bandage ("Dujarrier" or "Mayo-clinic bandage") requires that the device be changed regularly and is not well-tolerated by patients because of the two-month treatment duration; the resulting reduction and bracing are not satisfactory but this method might be required under certain circumstances.

The best indication for conservative treatment is a patient with an isolated humeral shaft fracture. It remains the gold standard treatment in this population. Radial nerve palsy is not a contraindication. Union is nearly guaranteed; angular deviations are well-tolerated functionally, without repercussion on shoulder and elbow mobility and with few complications. However, some have pointed out that the immobilization period is too long and uncomfortable for the patient.

6.2. Surgical treatment

The goal of surgical treatment is to obtain anatomical reduction, while providing stability that allows for early mobilization of adjacent joints. It has its place in multifracture or polytrauma patients, open fractures, failed conservative treatment and obese patients. Its indications have expanded over the last 20 years due to pressure from patients who want a treatment that allows them to quickly return to their activities or who refuse to put up with the inconveniences of conservative treatment, while accepting the risk associated with surgery.

6.2.1. Plate fixation

This is a reliable, well-established technique used in 20.7% of cases in the 2003 French multicenter study [4] and 30% of cases in the 1997 French multicenter study [12] making it the second most commonly used method. It requires a very rigorous technique to minimize the associated complications (Fig. 2).

6.2.1.1. Surgical approaches. The choice of approach is dictated by the fracture location, the preoperative status of the radial nerve and the surgeon's experience. The patient is placed supine with the upper limb on an arm board, without a tourniquet:

- medial approach: it allows the humeral artery to be checked in cases of vascular injury; it is the logical approach for plating because it is far away from the radial nerve [4].
- anterolateral approach: the most commonly used approach [12]; it allows the radial nerve to be located. The plate is applied to the middle part of the anterolateral side of the humerus shaft. Particular attention must be paid to the nerve, which is dissected over the entire length of the incision. Its position relative to plate must be noted in the operative report. In a variation of this approach when the two median quarters are fractured [19], the plate can be applied on the medial aspect of the bone through a curved anterolateral incision passing between the biceps brachialis and the anterior brachial muscles. The elbow is flexed and the arm externally rotated. The location of the radial nerve does not need to be known when using this approach. No postoperative complications occurred with this approach. Union is obtained after an average of 80 days and the outcomes are satisfactory in 89% of cases.
- posterior approach: the presence of the radial nerve makes this approach challenging with the patient prone. In a cadaver study of three types of posterior approaches [7], the preferred approach consisted of medially spreading of the medial and lateral heads of the triceps brachii by sectioning the lateral intermuscular septum over 3 cm, which provided a 26.4 ± 0.4 cm long exposure of the humerus.
- minimally invasive approaches: these can be either lateral or anterior (more reliable) and have been used since minimally invasive techniques were introduced. Detailed knowledge of radial nerve anatomy is indispensable for these approaches.
- anterior transposition of the radial nerve through the fracture has been proposed [20]. This option is useful in middle third fractures of the humeral shaft, as it increases the length by 11 mm, making easier to release and move the nerve vertically and then to perform the fixation.

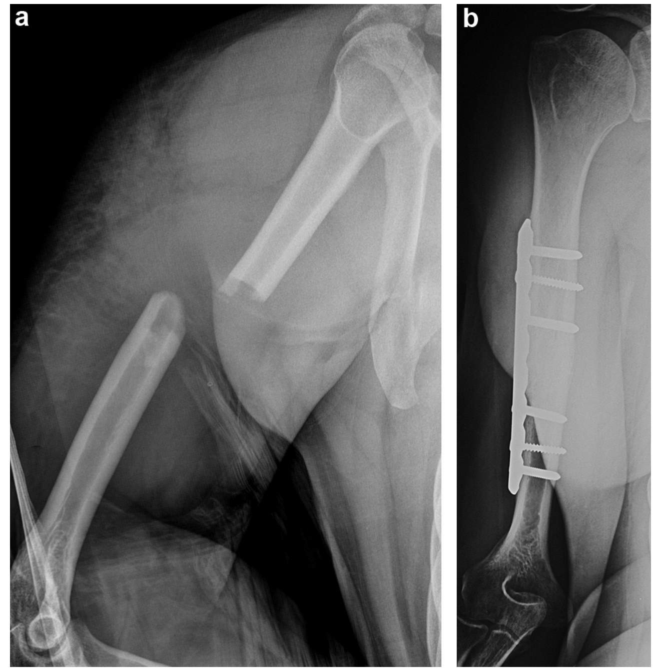

Fig. 2. Treatment with locking plate of a highly displaced fracture of the middle third of the humeral shaft. (a) At admission. (b) At union.

6.2.1.2. Standard plates. These plates are thick, fairly narrow (4.5 mm), use 3.5 mm screws and provide similar compression of the fracture site as dynamic compression plates. The construct must incorporate six to eight cortices on either side of the fracture.

About 25% of patients treated with plates in two French multicenter studies [4,12] had preoperative radial nerve palsy, which led to the decision to use a plate. The complications were non-union (8% and 21%, respectively), secondary radial nerve palsy (8% and 12%), fixation failure (1.5% and 14%) and infection (0.8% and 2%). These rates were substantially different to those reported in single-center studies, for example the Paris et al. study [14] with

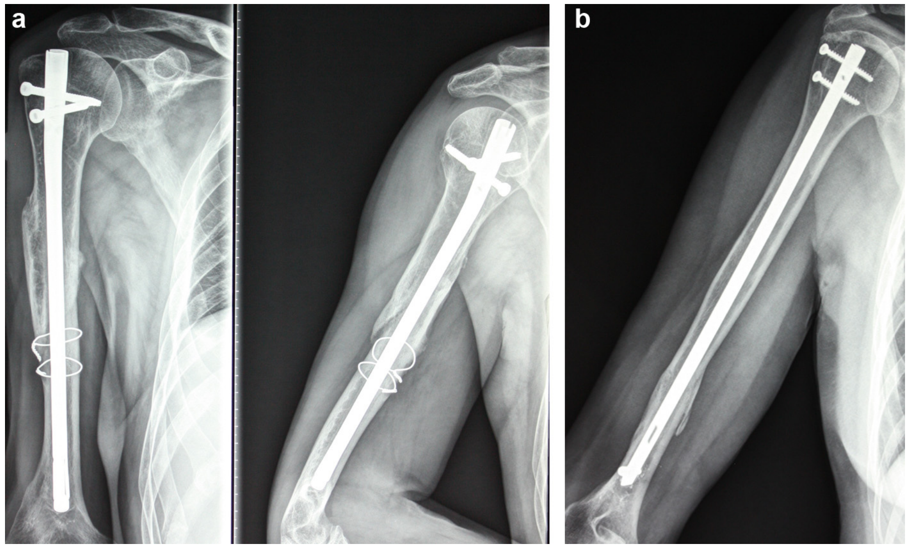

Fig. 3. Anterograde intramedullary locked nail. (a) Seidel nail inserted into closed fracture with incision made to release the radial nerve (immediate palsy). (b) Static locked nail inserted into closed fracture with freehand anteroposterior distal locking.

5% non-union, 5% secondary radial nerve palsy, 6% fixation failure and 1% infection. His analysis of published studies revealed an average non-union rate of 2.8%, a 6.5% secondary radial nerve palsy rate and a 2.4% infection rate.

Union is obtained after 11 to 19 weeks. The functional outcomes were good or very good in 96% of cases in one study [12] and 86.3% in the other [14]. In one of the French multicenter studies [4], the functional elbow range of motion was normal and shoulder abduction was normal or subnormal in more than 90% of cases.

6.2.1.3. Locking compression plates. It has been said that locking compression plates (LCP) provide no biomechanical advantage over standard plates, except probably in osteoporotic subjects [1]. No studies have specifically looked at the use of LCPs in humeral shaft fractures.

6.2.1.4. Plate removal. Removal of a plate must take into account the risk of postoperative palsy, which is not insignificant.

6.2.2. Intramedullary nailing

Intramedullary (IM) nailing was developed by Kuntscher in the 1940s and widely disseminated by Seidel [21]. Distal locking of Seidel's nail made use of expandable fins. Long nails with distal screw locking were introduced in the early 2000s. These prevent telescoping of the fracture fragments and rotational malunion. These have replaced Seidel's nail [22], which required additional immobilization because of the precarious distal locking. This technique requires a good understanding of IM nailing and rigorous methods to avoid complications [21,23].

6.2.2.1. Anterograde nails. These nails are introduced through the greater tuberosity of the humerus under fluoroscopy control with the patient in the beach chair position and the arm in retropulsion (Fig. 3). The fluoroscopy unit must be placed in the correct position before the procedure.

The insertion point is key; it will be in the axis of the shaft at the base of the muscle–tendon junction of the rotator cuff or the cartilage–upper anatomical neck junction, with the incision made along the fibers of the rotator cuff.

The main criticism of anterograde nails lies in the approach through the rotator cuff. The nail must be driven down sufficiently to avoid any impingement between its proximal end and the acromion.

Proximal locking is carried out with frontal or sagittal screws. It must avoid the axillary nerve. The frontal screws through the head must not be too long to avoid entering the joint. Two pitfalls must be avoided when using a sagittal screw: crossing the long head of biceps tendon in front and injuring the axillary nerve in back while drilling the screw hole or inserting an overly long screw. Transverse distal locking can damage the radial nerve, thus the screw must be placed in the anteroposterior direction. A short approach is recommended to avoid these complications.

Of the 19% of fractures that were treated by IM nailing in a French multicenter study [4], there was a 17.4% non-union rate, 4% infection rate and 2.7% postoperative palsy rate. These findings were similar to the ones reported by Asencio et al. with locked nails [13]: 10% non-union, 2.6% postoperative radial palsy, no infection. Union was obtained after an average of 11 weeks (range: 4–40).

After comparing standard plates with locked nails in a meta-analysis, Kurup [24] concluded that despite an increased risk of shoulder pain and stiffness, and the need to remove the hardware, there was not enough evidence in favor of either type of fixation, even in terms of function.

6.2.2.2. Retrograde nails [25,26]. These nails are introduced through the mid-line posterior triceps splitting approach. Fracture of the distal end of the humerus during insertion or extraction is a risk that is specifically associated with this type of nail.

When using a Marchetti nail, Butin et al. [25] reported no cases of infection or postoperative palsy, however there was a 5% rate of posterior cortex cracks, 5% rate of supracondylar fractures upon nail removal and 5% rate of non-union. Union was obtained in 10 weeks (range: 6–16).

Apard et al. [26] used a static locking retrograde nail. They reported a 5% rate of postoperative palsy (regressive in 6 months), 3.5% rate of supracondylar fracture and 2% rate of non-union. Union was obtained in 15 weeks (range: 6–28). The overall functional outcomes were excellent in 86.6% of cases.

6.2.3. Other fixation methods

6.2.3.1. Hackethal bundle nailing [4,12,27]. This retrograde bundle nailing technique is performed percutaneously through the supra-olecranon approach (Fig. 4). The goal is to fill the shaft with K-wires

Fig. 4. Treatment by Hackethal bundle nailing of a humerus shaft fracture. (a) At admission. (b) Immediately postoperative. (c) Non-union with K-wire failure; the patient did not want an additional procedure (radiographs at 5 years).

to stabilize the fracture, separate the K-wires in the humeral head to increase the construct stability and lock them distally to prevent downward migration. Several variations of this technique have been described [28].

The main complications are non-union (24% for Lefevre [4], 8% for Nieto [12], 7.3% for De La Caffiniere [28] and 5% for Gayet [27]) and upward or downward migration of the K-wires (6% [27] to 29% [28]), which requires early removal. Non-union is due to a technical error; an inter-fragment gap of more than 3 mm was found to have a statistically significant negative effect on the outcome [4]. K-wire migration is secondary to poor filling of the shaft and/or inadequate impaction of the fracture [4]. Conversely, there were no fractures at the insertion point in any of these studies. The shoulder function was normal in 87% of fracture cases and the elbow function was normal in 63% [4]. Gayet et al. [27] reported that normal arm function had been achieved in 94.4% of cases; Nieto et al. [12] had similar findings (92%). Union was obtained in 8–9 weeks [4,27,28].

De La Caffinière et al. [28] preferred using this technique when the middle third of the humerus shaft is fractured, as these cases allow for more efficient filling of the shaft. Lefèvre [4] advised against using this method with distal, comminuted or bifocal fractures, and fractures in polytrauma patients.

The number of complications must be weighed against the advantages of this type of treatment (low cost, no specific instrumentation needed, fast to carry out). This can be considered an enhanced conservative treatment method, requiring an additional arm-to-chest bandage until signs of bone union are evident.

6.2.3.2. *External fixator [2,4].* The indications for use of an external fixator are rare and limited to open highly-contaminated fractures, with or without vascular complications (1–2.2% of cases in published series [4,12]) (Fig. 5). For some surgical teams, this is a temporary treatment in the context of damage control surgery for polytrauma patients.

The bicortical pins are inserted on the lateral side of the humerus under fluoroscopy control while keep the nerve locations in mind. The proximal pins must be inserted distally to the axillary nerve; the distal pins must avoid the "danger area" associated with the radial nerve. Making a small incision will help to prevent nerve damage in cases where the pins are inserted into at-risk areas. Single-rod type fixators are preferred over Hoffmann-type ones, so as to obtain the most stable construct possible. The body of the fixator must be located as close as possible to the axis of the humeral shaft. The pin openings must be cared for very carefully.

The device is worn for 14 weeks, which corresponds to the average time to union. The elevated non-union rate with this device is likely due to the type of fractures being treated (i.e. the most complex ones). No postoperative complications related to the radial nerve were reported in a French multicenter study [4].

This is a technique that must be mastered; the indications are rare and the insertion technique is very demanding because of the risk of nerve damage.

7. Radial nerve palsy

This complication continues to be controversial. Should the nerve be systematically examined and should we abandon conservative treatment, given that this treatment leads to spontaneous recovery in 85–100% of cases [1,4,17]? Should the nerve be systematically examined when performing surgical fracture fixation?

Fig. 5. Treatment with single-plane external fixator of an open Gustilo Type 3A fracture with immediate radial nerve palsy. (a) At admission. (b) Single-plane external fixator. (c) At the 15th day. (d) After removal of fixator at the 3rd month.

The possibility of radial nerve palsy must be considered at the various treatment stages; it must be reconsidered if secondary palsy develops. It is most often due to neuropraxia and rarely to nerve division.

The recommendations of the 2003 SOFCOT symposium [4] were the following:

- cases with immediate radial nerve palsy: evaluate the condition of the nerve in cases of skin opening or vascular damage, which provides information as to its macroscopic condition; if the nerve is continuous, palpate and stimulate the nerve:
  - if the nerve is only contused and still responds to stimulation, it is left as is and the fracture fixation material is placed away from the nerve,
  - if it is empty and cannot be stimulated or obviously divided, direct suture, resection-grafting or identification of the ends to facilitate secondary repair is indicated, according to the surgeon's competencies;
- other cases: monitor the clinical progression and carry out an electromyography (EMG) exam around day 45.

Alnot et al. [29] believe this nerve must be evaluated systematically when the fracture is highly displaced. In non-displaced or minimally displaced fractures, nerve evaluation is only carried out if recovery does not occur in 2–6 months. In "intermediate" cases, the procedure is appropriate in cases of polytrauma and high-energy trauma. The fact that the results are better following primary suture repair than secondary repair with grafting supports this approach.

Postoperative radial palsy has a good prognosis with fast recovery, except in cases of intra-operative injury. Even a small intra-operative trauma will further add to the initial nerve injury [29]. The radial nerve palsy rate after various treatments reported in published studies was on average 1.4% for conservative treatment, 6.5% for plating, 1.7% for bundle nailing, 1.9% for locked IM nails and 1.4% for external fixation [14]. It is recommended that the nerve be identified before performing IM nailing [13,22]. In cases of plate fixation, the position of the nerve relative to the plate must be accurately defined.

In cases of radial nerve palsy without nerve evaluation or of secondary palsy, clinical and EMG monitoring every 6 weeks is needed to follow the recovery and determine if nerve exploration is needed. EMG is pointless in the early days after the fracture.

8. Late complications

8.1. Non-union

Non-union is defined as the fracture not having healed in 6 months [2,28] (Fig. 4c). The non-union rate varies between 3 and 20%, depending on the treatment. The non-union rate reported in published studies was on average 4.4% for conservative treatment, 2.8% for plating, 6.3% for bundle nailing, 5.9% for locked IM nails and 3.5% for external fixation [14].

It occurs almost exclusively following transverse fractures of the middle third of the shaft [28], and the risk increases due to technical errors:

- persistent inter-fragment gap of 6.3 ± 4.5 mm following functional bracing [30];
- insufficiently stiff plate construct with insufficient number of cortical fixation points;
- failure to lock nail or use of overly small nail diameter;
- insufficient filling of shaft by K-wires.

This condition requires surgical treatment to apply stable fixation, with or without a graft.

Some authors have suggested systematic plating of the non-union site with addition of autologous bone, no matter which type of treatment was initially used [8]. The advantage of this method is that the radial nerve is inspected, the medullary canal is repermeabilized and rigid fixation is applied to compress the non-union site, and shorten the humerus as needed. The radial nerve must be identified some distance from the non-union site and carefully released.

In cases of non-union following IM nailing or pinning, a larger diameter nail will be used and more importantly, the shaft will be bored out to stimulate osteogenesis, thereby performing "in situ" autografting. IM nailing can also be performed in cases of hypertrophic non-union. However, Dujardin et al. [31] reported a 38% rate of non-healing after locked IM nail was applied for non-union, which could be attributed to lack of stability.

Hybrid external or Ilizarov-type fixation is not without risks (nerve damage upon K-wire insertion, stiffness, intolerance to pins, elbow septic arthritis) and the fixator must be worn for an average of 6 months [32].

If radial nerve palsy is associated with the non-union, the bone problem must be treated before the nerve injury so that the nerve can recovery in an environment with the least amount of inflammation possible, thereby reducing peripheral fibrosis [29,30,8,31]. The two procedures must be spaced at least 6–8 weeks apart. Union is obtained in 80% of cases in an average of 16 weeks [8] to 33 weeks [12].

8.2. Infection

This is a fact of life for any surgical treatment, but especially plate fixation. The infection rate reported in published studies was on average 4% for plating, 0.8% for bundle nailing, 1.6% for locked IM nails and 4% for external fixation [14].

A microbiological diagnosis is essential before antibiotic treatment is initiated. The treatment consists of removing the current fixation device, excising the infected tissues and then applying an external fixator.

In cases of septic non-union, removal of the internal fixation device in combination with excision of the infected tissue is carried out before an external fixator is applied. Antibiotic therapy will be adapted to the micro-organisms identified in consultation with an infectious disease specialist. The treatment duration is long and the outcome uncertain.

9. Conclusion

Although humeral shaft fractures are often treated conservatively, the progress made with internal fixation devices and the pressure from patients have led to increased use of surgical treatment. Bone union is faster with conservative treatment (9 weeks) than plate fixation (11–19 weeks).

Conservative treatment is the least costly treatment option because it is performed on an outpatient basis (hospitalization not required); the complication rate is low (especially for non-union) and functional recovery is fast.

Internal fixation leads to more anatomical reduction, but the trade-offs are iatrogenic complications such as infection, fixation failure, secondary radial nerve palsy and non-union. All the internal fixation methods are burdened by complications and their results are comparable. No matter which method is chosen, meticulous technique is essential to reduce the complication rate.

Disclosure of interest

The authors declare that they have no conflicts of interest concerning this article.

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