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REVIEW

Humerus shaft fracture complicated by radial nerve palsy: Is surgical exploration necessary?

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Abstract Fractures of the humerus shaft often are complicated by radial nerve palsy. Controversy still exists in the treatment that includes clinical observation and eventually late surgical exploration or early surgical exploration. Algorithms have been proposed to provide recommendations with regard to management of the injuries. However, advantages and disadvantages are associated with each of these algorithms. The aim of this study was to analyze the indications of each treatment options and facilitate the surgeon in choosing the conduct for each lesion, proposing our own algorithm.

Keywords Radial nerve · Radial palsy · Humeral shaft · Nerve graft

Introduction

Fractures of the humerus shaft often are complicated by radial nerve palsy (RNP). The overall incidence of radial nerve injury after humeral shaft fractures is 11.8 %, representing the most common peripheral nerve injury associated with bone fractures [1, 2]. Controversy still exists in the treatment of humeral shaft fractures associated with radial nerve injuries. The aim of this study is to discuss an integrated management strategy to determine the right treatment approach to different kinds of humeral fractures with complete sensory and motor RNP.

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Nerve anatomy

The high percentage of radial nerve injury associated with bone fracture is attributable to the intimate contact with the periosteum of the humerus. In particular, the radial nerve was found to be in direct contact with the posterior humerus from 17.1 cm ± 1.6 to 10.9 cm ± 1.5 proximal to the lateral epicondyle [3] (Fig. 1). Bono et al. [4] defined "danger zone" the point as the nerve pierces the later intermuscular septum, 12.3 cm ± 2.3 proximal to the olecranon fossa, because the nerve had very little mobility as it is interposed between the obliquely oriented septum and the lateral aspect of the humerus. Afterward, the radial nerve courses anterior to the humerus at the level of the metaphyseal flare, where it is separated from bone, for the first time in his ride, by the brachialis muscle, and it results in more protection. These data highlight that the radial nerve is at risk of lesion, in particular, at 2 locations: the posterior mid-shaft, where the nerve lies in contact with the humerus, and at the distal lateral humerus as it pierces the lateral intermuscular septum.

Etiopathogenesis

The mechanisms of injury can be primary or secondary. In the primary palsy, the loss of function occurs at the time of injury. In secondary palsy, corresponding to 10–20 % of the cases, the loss of function occurs during the course of treatment.

In primary, the incidence of palsy is 1.8 % in middle-proximal diaphyses fracture, in middle fractures is 15.2 % and, finally, in middle-distal fractures is 23.6 %. If a five-part classification is adopted, the respective data are 3.4 % proximally, 10.5 % middle-proximally, 21.9 % middle,

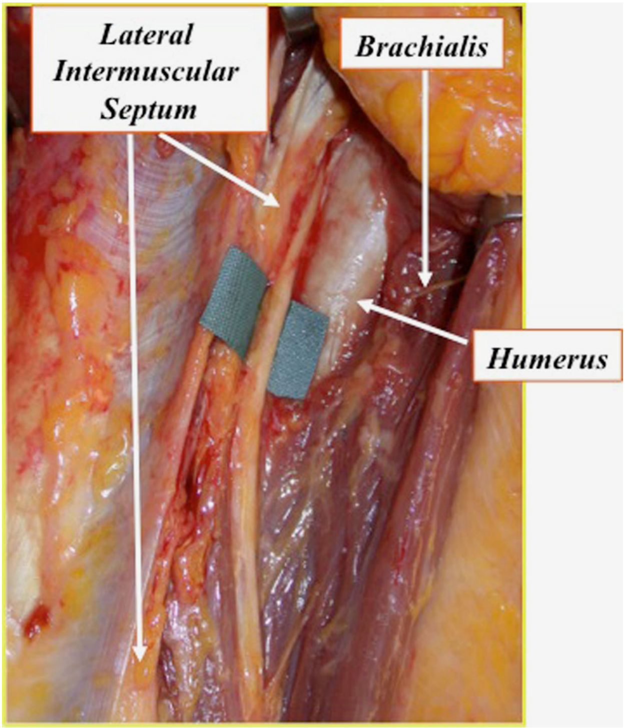


Fig. 1 Radial nerve in cadaveric study. The posterior mid-aspect of the humerus where the nerve lies in direct contact with the periosteum

20.0 % middle-distally, and 10.5 % distally [2]. Identifying the level of the fracture often provides the first clue of a radial nerve injury. Fractures of the humerus may be defined by the AO classification system [5–7]. This classification divides diaphyseal humeral shaft fractures into 3 categories depending on the amount of contact between the major fracture fragments. Holstein and Lewis affirm that radial nerve palsies are associated most commonly with spiral fracture [1] (Fig. 2), although it also occurs with transverse and oblique fractures, due to a direct trauma or to a traction mechanism [5–7].

The iatrogenic palsy, instead, occurs for direct trauma of surgical instruments, chronic impingement between internal fixation and the nerve, or manipulation of closed reductions by intramedullary nailing.

Although the classification of a radial nerve injury as primary or secondary is useful in diagnostic process, the difference in the rate of recovery is not significant. The overall rate of recovery was 88.1 %, with spontaneous recovery reaching 70.7 % in patients treated conservatively.

Instead, the difference rates of recovery between complete (77.6 %) and incomplete (98.2 %) fractures and those which are closed (97.1 %) or open (85.7 %) are all statistically significant [2].

Diagnosis

Radial nerve palsies can be classified as either partial or complete. A complete physical examination is important to determine the type of palsy. Active extension of the wrist, fingers, and thumb at the metacarpo-phalangeal joints suggests an intact motor function of radial nerve.

Radial nerve sensation to light touch and pinprick can be tested in the dorsal radial aspect of the hand toward the thumb/index web space. Tinel's sign can be helpful in indicating the progression of nerve recovery.

If the brachioradialis or extensor carpi radialis longus (ECRL) is not functioning, the injury should be at the level of the humeral shaft [8]. If the lesion is distal to the origin of the posterior interosseus nerve, ECRL function will be intact and the wrist will be pulled into radial deviation with attempts at extension.

Neurophysiologic tests, electromyography, and nerve conduction velocity, are useless in the initial management of patients with a RNP. These tests, however, after

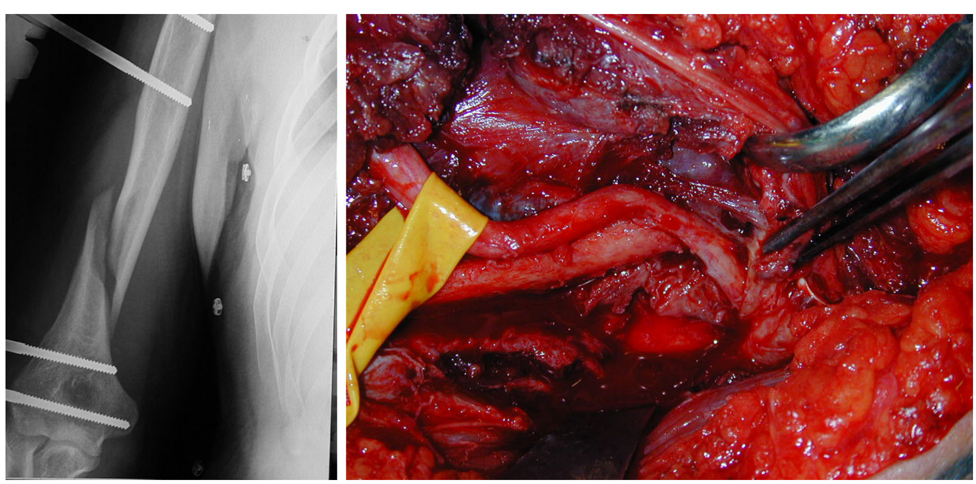


Fig. 2 X-ray of humerus showing an Holstein–Lewis fracture, with an intraoperative view of nerve entrapment

3–4 weeks, may help to determine the level and extent of the radial nerve damage, to individuate a baseline of function, and to monitor recovery, which may occur before clinical sign. If the patient has radial nerve exploration and reconstruction, an electromyogram also may be used to follow recovery of the nerve in the postoperative period [9].

Somatosensory evoked potential monitoring may play an important role during surgery, monitoring the status of the radial nerve [10, 11].

High-resolution ultrasound (US), instead, has a limited application to evaluate radial entrapment. Bodner et al. [12, 13] examined by 11 patients affected by radial palsy using US to determine whether it was presented with a nerve damage: Five patients were operated because of severe damage, including entrapment, that was confirmed during the intervention, six of them, in which US suggested an intact nerve, were only followed up clinically, and in 100 % of cases, the nerve function was restored. The disadvantage of this noninvasive technique is the operator depending results.

Magnetic resonance neurography (MRN) could very well fill this gap, and it allows fine, detailed evaluation of peripheral nerve anatomy and pathology due to excellent soft tissue contrast and high spatial resolution. The imaging shows the normal nerve anatomy, internal architecture, course, caliber, and regional muscles [14–16].

Treatments

RNP treatment, associated with humeral shaft fracture, includes clinical observation or early surgical exploration. Controversy still exists in this topic, and many algorithms have been proposed to provide recommendations with regard to management and treatment of these nerve injuries [17–19]. However, advantages and disadvantages are associated with each of these algorithms.

Clinical observation

The supporters of expectant management claim that spontaneous recovery is reported to occur in 73–92 % of patients [2, 5, 20]. The basilar condition is closed humeral shaft fractures with complete motor and sensory radial nerve injury. According to the literature, in most cases the RNP is caused by a contusion injury, while transection of the nerve is found only in 12 % of the patients with irreversible nerve palsy [5]. The advantages are the avoiding of intraoperative risks, including wound infection and osteomyelitis, the avoiding of nerve devascularization, and the conservation of a natural environment for easier exploration in case of permanence of injury [5, 9, 21, 22]. Indeed, it may be easier for the nerve to recover from repair when the fracture is healed rather than in the acute phase of injury [23]. Postponing surgery may allow the neurilemmal sheath to thicken, which facilitates repair if neurography is needed [8]. Overall, nerve recovery can occur just as well whether the intervention comes at an early stage or a late one [24]. The potential disadvantages are the possibility that fibrosis makes more difficult the surgical exploration.

During recovery, early range of motion exercises and dynamic splinting of the wrist, thumb, and fingers are important to help prevent joint contractures. Limb edema is common and must be minimized with a compressive garment, elevation, and range of motion exercises.

A first neurophysiologic testing should be performed at minimum 25 days after the injury [25, 26]. This study may demonstrate "fibrillation potentials, positive sharp waves, and mono-phasic action potentials of short duration" [27]. Most patients with spontaneous recovery begin to demonstrate recovery during the first few months; however, another electrodiagnostic study may serve as an adjunct study for those lacking nerve recovery at the 6 weeks of follow-up [28, 29]. The brachioradialis and extensor carpi radialis longus are the first muscles to be reinnervated [13, 14, 30], and the extensor indicis proprius is the last muscle to recover. Complete recovery typically occurs within 6–12 months [2], because axons can regenerate with a speed of 1.7 mm per day distally to the site of injury [31–35].

If a follow-up electrodiagnostic study at the 12-week point shows similar findings as the baseline, then exploration may be indicated [36]. Although the optimal timing of deferred exploration is still debated, many authors consider 4–6 months to be an appropriate length of time for expectant management [5, 25, 27, 37] based on the patient's clinical course [38] and the evidence that poor functional recovery due to decreased motor neuron regeneration capacity was demonstrated already after 7–8 weeks [39, 40].

Early exploration

Early exploration must be recommended in several cases such as open fracture that requires debridement and stabilization, irreducible fracture or unacceptable reduction, associated vascular or severe soft tissue injury, radial nerve deficit after manipulation (secondary nerve palsy), intractable neurogenic pain suggesting nerve entrapment or compression, high-velocity gunshot wounds, sharp or penetrating injury, high suspicion of nerve laceration with spiral oblique fractures, and severe soft tissue injury [5, 7, 9, 11, 24, 41–45].

During surgery, complex injury patterns should be managed in the following order: fracture stabilization, definitive or temporary vascular repair, and finally nerve repair.

The most common procedure for stabilization of the humerus is compression plate and screws. The risk of radial nerve injury during this procedure is reported as 0–10 % [42, 46]. Alternatively, the fracture may be stabilized with intramedullary nailing. The incidence of radial nerve damage during intramedullary nailing is reported between 0 and 5 % [10]. Even though this procedure is a less invasive technique, it is not recommended in humeral shaft fractures associated with radial nerve injuries. In these cases, the nerve may be entrapped in the fracture. Several researchers have reported on the risk of radial nerve injury during intramedullary nailing [11, 44–47].

The first advantages of early exploration of the nerve, within 7–14 days from the trauma, are a more accurate determination of nerve damage. The extent of nerve injury runs the gamut from contusion to laceration. Intraoperative measurement of action potentials can be performed if the nerve is found to be in continuity. This information can aid the surgeon in choosing the following management, among leaving the neuroma in situ, resecting the lesion and grafting the resultant defect, and/or proceeding with tendon transfers [1, 9, 42, 45, 48].

Furthermore, some surgeons suggest early exploration is easier and safer, not only in the cases mentioned above, but also in closed fractures associated with nerve palsy [7, 49]. They show that functional nerve recovery is more complete and constant with this approach. The persistence of palsy after a long period of clinical observation is a serious risk because it could determine potential atrophy and motor endplate loss that could compromise nerve recovery on late exploration and significant loss of function. On the other hand, early exploration and repair can facilitate better characterization of the nerve injury, quicker nerve recovery and return to function. Moreover, after fracture fixation and stabilization is achieved, a neurolysed or repaired nerve will potentially benefit from a better environment for recovery with less tension, motion, or callus formation to impede nerve healing [7–9, 24, 38].

The potential disadvantage is over treatment of a lesion that recovers spontaneously in 73–92 % of the cases. Instead is controversial the management of secondary nerve palsy.

Early exploration has been advocated for iatrogenic nerve entrapment [24, 50]; however, a review of published series demonstrates that the rate of spontaneous recovery is comparable to those patients with primary RNP following fracture of the humeral shaft [2]. Ultrasound may be helpful in these cases [12, 13].

Surgical approach

Surgical intervention for radial nerve injury can be classified into neurography, nerve grafting, nerve transfers, and tendon transfers. The location and the time of nerve injury define the approach to nerve repair. If transection of the radial nerve is found during immediate surgical exploration, a primary nerve repair is indicated. The outcome of the repair is due to the violence of the injury [51]. During surgical exploration, adequate resection of surrounding scar tissue and neuromas should be performed until healthy nerve fibers are seen under the microscope in order to facilitate recovery.

Nerve grafting is preferred in cases of tension at the neurography site or if there is a large nerve gap that has to be bridged (Fig. 3). Results after nerve grafting are in line with primary nerve repair [8]. Factors that influence the outcome after grafting include the length of the defect that should be bridged and the denervation time [52, 53]. Currently, nerve transfer is not well described in the literature for patients with radial nerve paralysis secondary to a humeral shaft fracture. In our experience, we have used sural grafting in 7 patients with complete functional restoration.

Indications for a tendon transfer include no sign of nerve recovery at 1 year, incomplete recovery, and/or failed nerve reconstruction [54, 55]. The patient's level of function, anatomy, and level of radial nerve injury are three factors routinely used to decide on the appropriate tendons to use for transfer. Wrist extension is achieved with transfer of pronator teres into extensor carpi radialis brevis, whereas for finger extension, the flexor carpi radialis is usually used [41].

Conclusion

Through our literature review, we want to provide a simple and clear algorithm of treatment which describes the behavior in each different situation (Fig. 4).

In front of a patient with humerus shaft fracture complicated by RNP, the surgeon has to consider first the type of fracture and associated complications.

Early exploration is indicated for high risk of nerve laceration in open fractures, irreducible fractures, vascular or severe soft tissue injuries, iatrogenic secondary nerve palsy, intractable neurogenic pain, high-energy trauma, sharp or penetrating injury, Holstein–Lewis, oblique or transverse fracture of humerus diaphysis.

Instead, surgical exploration could be initially deferred for fracture with low risk of radial nerve injury. The nerve palsy has to be followed up by neurophysiologic and clinic

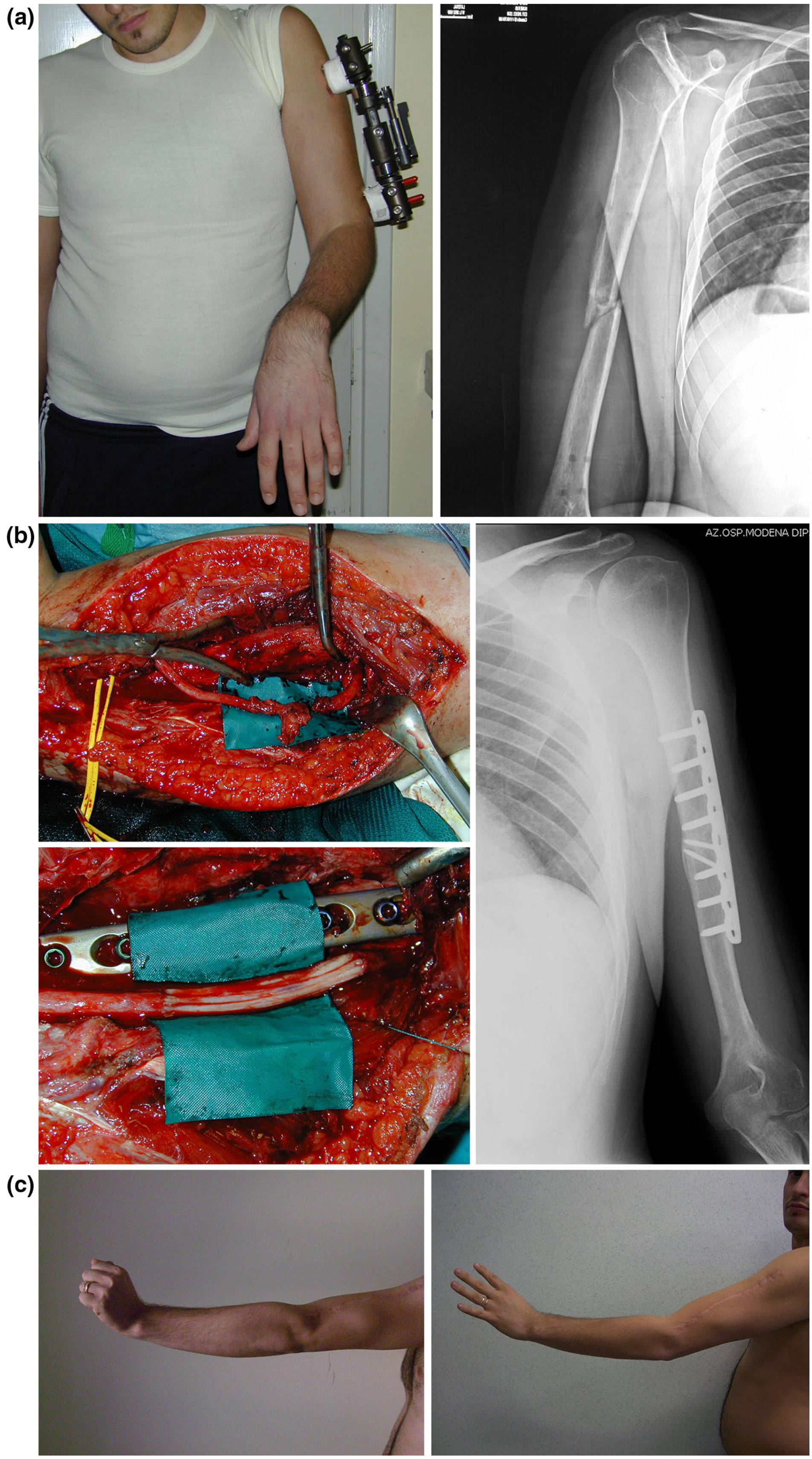
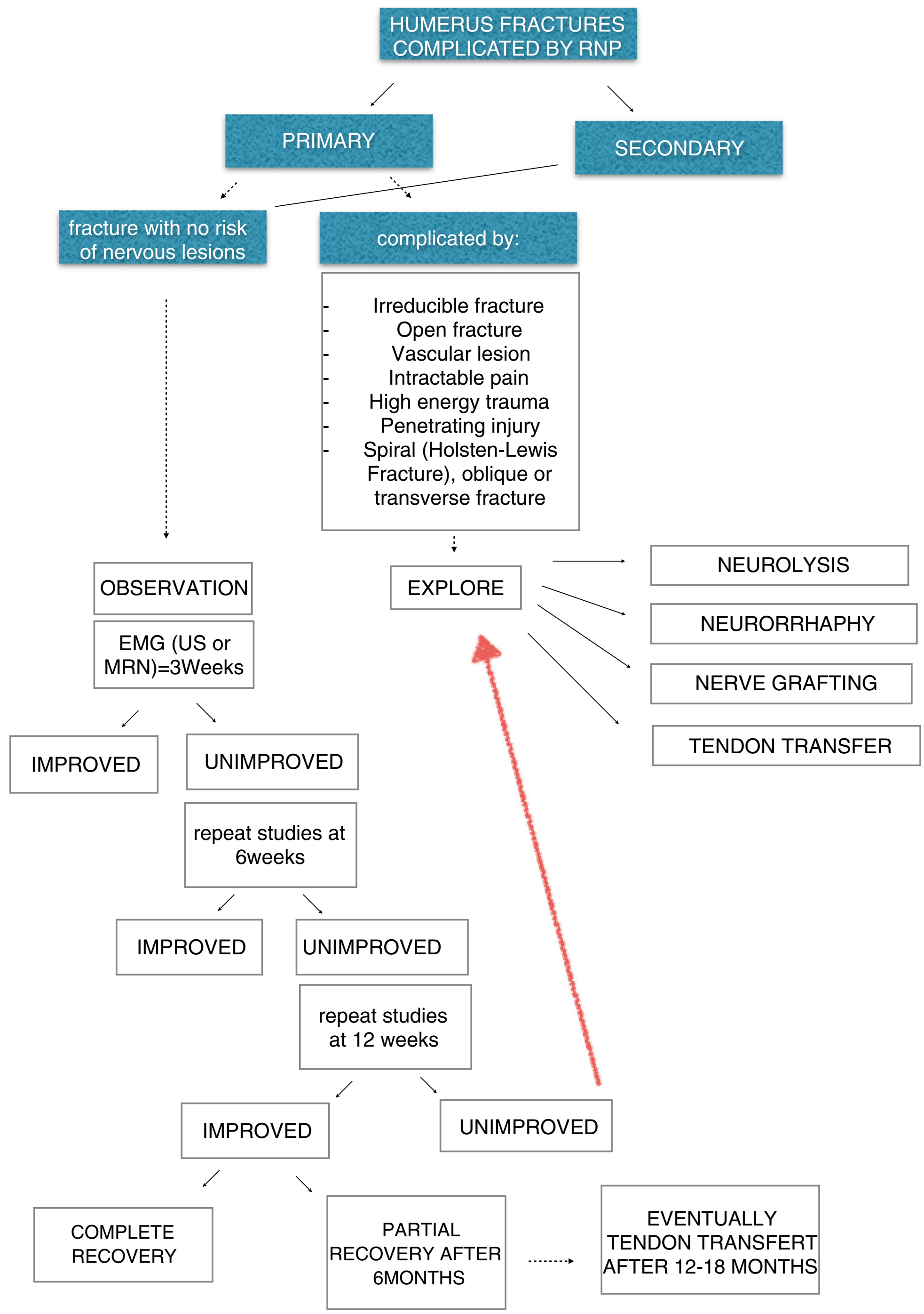


Fig. 3 **a** Mid-shaft humerus fracture treated by external fixator with clinical aspect of complete radial palsy. **b** Intraoperative view of radial nerve lesion, sural grafting, and X-ray postoperative. **c** Clinical result of complete recovery of radial function

Fig. 4 Algorithm



tests at least at 3 weeks after the trauma. The improvement of the nerve is the key: If there are no electrophysiological changes at 6–12 weeks, a surgical exploration is needed, although we could continue clinical observation until 5 months because of poor functional results of late surgical exploration and repair over this time.

Surgical intervention for radial nerve injury can be classified into neurography, nerve grafting and tendon transfers. The factors that determine the approach to nerve repair are the location and the duration of nerve injury.

Finally, the open reduction must consider the risk of secondary palsy: Intramedullary nail is not recommended, although the use of plating and screws or external fixation, when needed, can lead to higher rate of anatomic reduction and healing of the fracture.

Compliance with ethical standards

Conflict of interest None.

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