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ORIGINAL PAPER

Transfracture medial transposition of the radial nerve associated with plate fixation of the humerus

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Abstract

Purpose The aim of this study was to illustrate safety, feasibility and advantages of transfracture medial transposition of the radial nerve during the lateral approach and lateral plating of humeral fractures located in the mid and distal shaft.

Methods This was a retrospective review and analysis of medical records and radiographs of 19 patients who underwent a transfracture medial transposition of the radial nerve. Fifteen patients were treated for fresh fracture and four for nonunion. All patients were followed up clinically and radiographically for a minimum of 12 months.

Results Pre-operative radial nerve paralysis was present in four patients in the fresh fractures group; post-operative paralysis occurred in two. All patients completely recovered a few months after the index procedure. Except for two, all patients achieved bone healing. One patient from the fresh-fracture group developed nonunion, and one from the nonunion group experienced persistent nonunion; both underwent successful revision surgeries. In addition, four patients with a fresh fracture underwent revision surgery for hardware removal. All but two patients showed no restricted elbow or shoulder joint motion compared with the opposite side.

Conclusion Transfracture transposition of the radial nerve during open reduction and internal fixation of humeral shaft fractures is a safe, harmless and feasible procedure when applied for fractures of the middle and distal humeral shaft; it removes the nerve from the surgical field during fracture manipulation and fixation, with a gain in length of the nerve by transforming its course from spiral to straight. Following radial nerve transposition across the fracture, a repeat surgical approach to the humerus for hardware removal or treatment of nonunion transforms the procedure into a simple one; the skin incision is carried straight down to the bone without the need to identify or dissect the nerve that was previously transposed to the medial compartment of the arm.

Keywords Humeral shaft fracture · Open reduction and internal fixation · Humeral shaft fracture · Humerus nonunion · Radial nerve · Radial nerve transposition

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Introduction

The unique anatomic location and trajectory of the radial nerve in the arm generally causes technical difficulties during open reduction and internal fixation (ORIF) of humeral shaft fractures [1–4]. In addition, a revision surgery for nonunion or hardware removal is always hazardous because of the increased risk of injuring the radial nerve that runs directly over the plate and is usually surrounded by fibrous scar tissue [5]. The aim of transfracture transposition of the radial nerve is to displace the nerve from the plate so there is virtually no danger of injury during revision surgery. This technical method has seldom been reported in the literature, in either clinical or cadaveric studies [5–10]. We report our experience with 19 patients in whom a transfracture medial transposition of the radial nerve was performed during open reduction and lateral plating of the humerus.

Materials and methods

This was a retrospective review of medical records and X-rays of patients in whom a transfracture radial nerve transposition was performed between January 2008 and December 2015. There were 19 patients, six of whom were the subject of a preliminary report by two of the authors [10]. In 15 patients, the procedure was carried out during plating of a fresh fracture, while in the remaining four, it was performed during treatment of nonunion and autologous iliac bone grafting. There were ten men and nine women ranging in age between 20 and 74 (mean 39) years. The right side was affected in 11 patients and the left side in eight. The cause of the fracture could be specified from the medical records of 13 patients, as follows: road traffic accident (5), sports injury (3), fall at home (3), fall from the first floor (1) and blast injury (1). All fractures, excluding the blast injury, were closed and displaced upon presentation. Fracture location and Arbeitsgemeinschaft für Osteosynthesefragen (AO) classification is shown in Table 1 for fresh fractures and Table 2 for nonunion. Preoperative radial nerve paralysis was present in four fresh fractures (Table 1). No patient in the nonunion group had radial nerve paralysis at the time of the index procedure. Plate and screw types used for fixation are detailed in Table 3.

All patients had an arm sling for seven to ten days after surgery and underwent immediate post-operative rehabilitation with active and active-assisted mobilisation for range of motion (ROM) recovery of shoulder and elbow joints. All were clinically and radiographically evaluated at one to two month intervals and up to 12 months after surgery to assess fracture healing, ROM and radial nerve function. Four patients with fresh fractures presented back two to three years postfixation for hardware removal because of annoyance and pain at the lateral aspect of the distal humerus due to soft tissue irritation by a prominent end of the plate. Two patients, one with fresh fracture and another with nonunion, underwent revision surgeries for occurrence and persistence of nonunion respectively.

Operative procedure

The surgical procedure for fresh fractures followed the description previously reported by two of the authors [10]. Under general anaesthesia, the patient is placed in a semisitting position, with the forearm resting on an arm board. The skin incision is along a portion of a line extending from the deltoid insertion on the humerus (deltoid V) to the lateral epicondyle and extended proximally into the deltopectoral interval when needed. The radial nerve is initially identified between the vertical fibres of the brachialis muscle and the oblique fibres of the brachioradialis muscle. The nerve is then dissected anteriorly and distally between these two muscles. The lateral intermuscular septum is carefully opened at the emergence of the radial nerve. The proximal part of the nerve is dissected proximally and posteriorly to create a space between it and the radial groove at the posterior aspect of the humerus. This step typically consists of blind careful dissection of this part of the nerve using the tip of the index finger, along with a cautious pulling manoeuvre of the proximal humeral fragment using a bone clamp or a thumb–index pinch using the other hand; this should result in complete separation of the radial nerve from the posterior aspect of the humerus. A limited elevation of the brachialis and brachioradialis muscles from the distal humeral fragment is performed as needed, along with dissection of the medial intermuscular septum in order to prepare the future anteromedial bed of the nerve. At the end of the dissection, the radial nerve should be completely liberated and freely movable from its most proximal to distal part as it emerges from the lateral intermuscular septum. The two main bone fragments are then gently distracted, and the fracture site is angulated to allow gentle transposition of the nerve from the lateral to the medial side of the humerus; the nerve should ideally "fall" from lateral to medial through the two main humeral fragments, which have been distracted and angulated (Fig. 1). Fracture reduction and plating is next

Table 1 Fifteen patients treated for fresh fracture: Arbeitsgemeinschaft für Osteosynthesefragen (AO) type according to location and preoperative radial nerve paralysis

Location (*n*)	AO type			
	Simple spiral: A1 (3)	Transverse < 30°: A3 (4)	Spiral wedge: B1 (8)	Total
Mid shaft	0	2 (pre-operative radial nerve paralysis in 1)	4	6
Distal third	3	0	4 (pre-operative radial nerve paralysis in 3)	7
Distal fourth	0	2	0	2
Total	3	4	8	15

Table 2 Four patients treated for nonunion: Arbeitsgemeinschaft für Osteosynthesefragen (AO) type according to location and previous method of fixation

	AO type		
Location (*n*)	Transverse < 30°: A3 (3)	Spiral wedge: B1 (1)	Total
Distal third	0	1	1
Distal fourth	3	0	3
Previous fixation	Plate and Screws: 2 IM nail + plate and screws + cerclage: 1	IM nail	
Total	3	1	4

IM intermedullary nail

carried out according to AO principles and as dictated by each particular fracture pattern (Fig. 2). The radial nerve is now displaced to its new location at the medial aspect of the humerus and lies within the muscular mass of the brachialis, lateral and anterior to the medial intermuscular septum (Fig. 3).

When the procedure is applied to patients with nonunion, the same surgical steps for radial nerve dissection are performed after careful identification of the nerve within the surrounding fibrous scar tissue; transposition of the nerve through the nonunion site is accomplished after removal of the pre-existing hardware [plate and screws or intermedullary (IM) nail] and complete surgical release of the nonunion site. After nerve transposition, the nonunion is treated according to the initial fracture pattern: parallel cuts of the nonunion edges with mild shortening of the humerus (1 cm) and fixation with compression technique in three cases (AO type A3) (Figs. 4 and 5) and reduction with interfragmentary compression along with careful debridement and refreshment of the nonunion area in one case (AO type B1). A bone graft, harvested earlier from the inner table of the posterior iliac crest, was applied at the site of nonunion for all four cases at the end of fixation. Except for the anatomic proximal humerus locking plate and the Lecestre distal humerus plate, all 17 other plates were intra-operatively molded to fit the proximal and distal lateral aspects of the humerus, as needed.

Repeat surgical procedure after radial nerve transposition

A repeat procedure was necessary in six patients: hardware removal in four patients from the group with fresh fractures, and two new cases of nonunion (one patient from each group). Exposure of the lateral plate inserted during radial nerve transposition was performed using a straightforward incision from the skin down to the plate, without attempting to identify or expose the radial nerve, which had already been transposed medially (Fig. 6). Plates used to treat the two new cases of nonunion were molded to fit the lateral aspect of the humerus.

Results

Radiographic bone healing

Fourteen patients with fresh fractures showed complete bone healing between three and five months postfixation. One patient

Table 3 Plate and screw types according to Arbeitsgemeinschaft für Osteosynthesefragen (AO) fracture type, patient group and fracture location (A1, A3, B1: AO type)

AO type & location (number) Hardware for fixation (number)	A1: FF D 1/3 (3)	A3: FF MS (2)	A3: FF D 1/4 (2)	B1: FF MS (4)	B1: FF D 1/3 (4)	A3: NU D 1/4 (3)	B1: NU D 1/3 (1)	Total
Conventional broad plate CS 4.5				(1)				1
Conventional lecestre plate CS 3.5					(1)			1
LCP anatomic PHP LHS 3.5				(1)				1
LCP metaphyseal plate LHS 5.0 & 3.5			(2)		(2)			4
LCP broad plate LHS 5.0	(3)	(2)		(2)	(1)	(3)	(1)	12
Total	3	2	2	4	4	3	1	19

FF fresh fracture, *NU* nonunion, *D 1/3* distal third, *D 1/4* distal fourth, *MS* mid shaft, *PHP* proximal humerus plate, *LCP* locking plate, *CS* conventional screws, *LHS* locking head screws

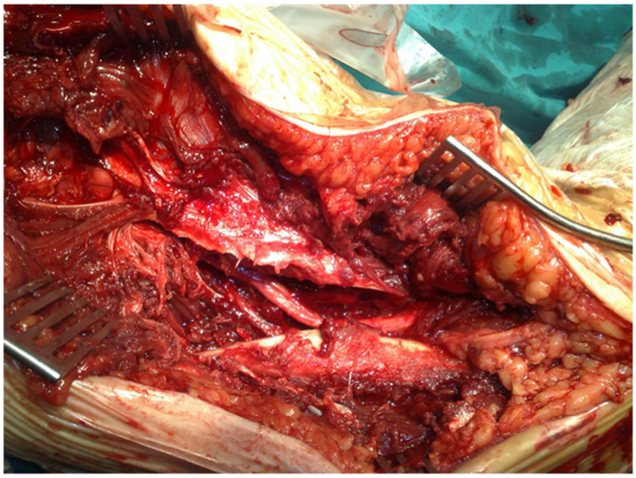

Fig. 1 Intra-operative photograph showing medial transposition of the radial nerve through the fracture site after distraction and angulation of the two main bony fragments (from [10], with permission

with a fresh fracture was a 59-year-old woman who sustained a midshaft spiral wedge fracture extending to the proximal third (AO type B1) and treated with a long anatomic proximal humerus locking plate. She developed nonunion and was considered a technical failure; she was successfully revised at one year with insertion of a broad locking plate, debridement of the nonunion site and application of cancellous iliac bone graft. Three patients in the nonunion group achieved bone healing between seven and nine months. A 48-year old man from this group had persistent nonunion after the index procedure; he underwent two further operations in another centre and presented back to us with a 10-cm bone loss at the nonunion site. He was successfully treated according to a three-stage protocol: (1) hardware removal with extensive debridement, culture and application of back slap; (2) three weeks later, a broad locking plate and screws with antibiotic-impregnated cement spacer was inserted, which restored humeral length; (3) six weeks later, the spacer was removed and replaced with a hemifibula, along with abundant cancellous iliac bone graft.

Radial nerve paralysis

The four patients with preoperative radial nerve paralysis from the fresh fracture group completely recovered between three and seven months post-operatively. Two other patients from the same group developed a transient post-operative radial nerve paralysis, which completely recovered after two and six months, respectively. None of the four patients treated for nonunion or the six who underwent revision surgery developed post-operative radial nerve paralysis.

Shoulder and elbow range of motion

At the 12-month follow-up, a 42-year old man from the nonunion group treated with shortening, compression and bone

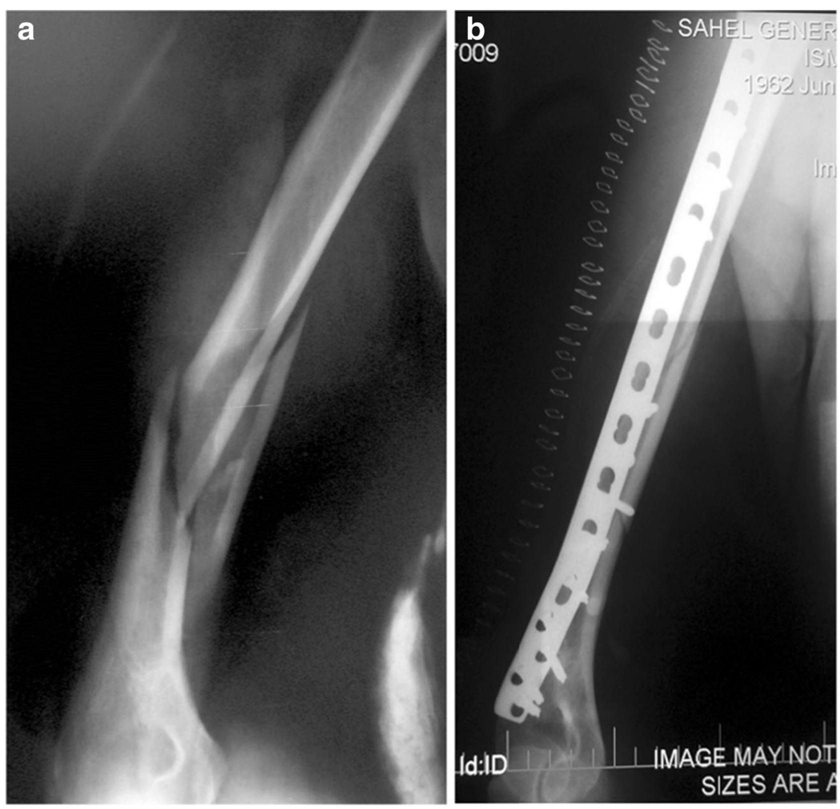

Fig. 2 Radiographs of distal third fracture [Arbeitsgemeinschaft für Osteosynthesefragen (AO) type B1] **a** before and **b** after fixation using interfragmentary compression and metaphyseal locking plate following medial radial nerve transposition

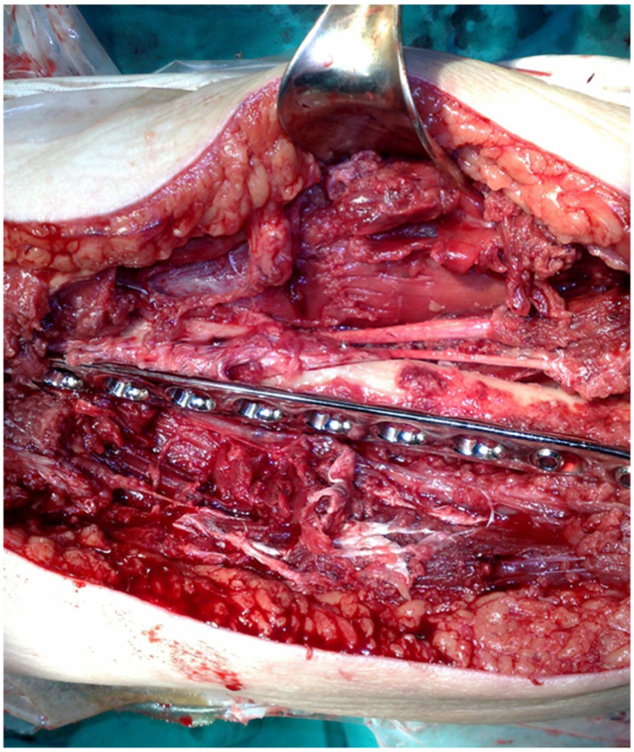

Fig. 3 Intra-operative photograph after medial transposition of the radial nerve and fracture fixation. Note the lateral position of the plate and the new location of the radial nerve, which is now completely running medial to the humerus into the bed of the brachialis muscle in the medial compartment of the arm (from [10], with permission]

graft had a 10° extension lag of the elbow but a full range of shoulder motion. The 59-year old woman from the fresh-fracture group who developed nonunion due to technical reasons underwent successful revision but with a resultant 10° limitation of forward elevation and external rotation in shoulder abduction. All other patients showed no restricted elbow or shoulder ROM compared with the opposite side.

Discussion

The unique anatomic location of the radial nerve in the arm puts it in danger of injury during humeral shaft fractures and surgical intervention. As many as one third of radial nerve palsies associated with humeral fractures occur at the time of surgery [2, 4]. Although preoperative radial nerve paralysis was reported in 10–18% of cases, with spontaneous recovery in the majority [1, 3, 11–15], faster and more complete recovery has been associated with early ORIF [16]. Post-operative radial nerve paralysis occurs in 4–6.5% of patients, with spontaneous recovery in 80–90% [1, 11, 12, 14, 15]. Finally, nonunion and infection may complicate humeral ORIF in 2.8–5.8% and 1–5% of cases, respectively [12].

Causes of post-operative radial nerve paralysis are poorly documented in the literature. This complication is generally thought to be related to laborious reduction manoeuvres, inappropriate placement of bone holders and retractors,

Fig. 4 **a**, **b** Pre-operative anteroposterior (AP) and lateral radiographs of a 32-year-old patient with nonunion of the distal fourth of the humerus [Arbeitsgemeinschaft für Osteosynthesefragen (AO) fracture type A3]. **c**, **d** Post-operative radiographs showing fixation with compression after shortening and copious application of cancellous bone graft following radial nerve transposition. **e**, **f** Radiographs at 9 months showing complete bone healing

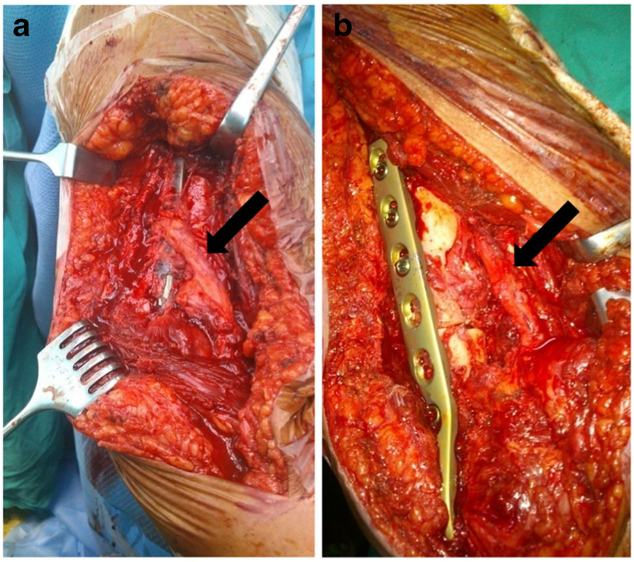

Fig. 5 Intra-operative photographs showing position of the radial nerve (*black arrow*) in a 42-year-old patient with nonunion of the distal fourth of the humerus [Arbeitsgemeinschaft für Osteosynthesefragen (AO) fracture type A3]: **a** Nerve running over the pre-existing plate before transposition; **b** nerve located medial to the humerus after transposition and fixation of the nonunion using a broad locking plate

overstretching of the nerve over the plate, unintended compression of the nerve underneath the plate and inadvertent direct injury from the surgical blade [6]. The nerve is frequently encountered and manipulated during reduction and plating of humeral shaft fractures. The usual application of the plate underneath the radial nerve causes overstretching, which is directly related to plate thickness and width [6]. Elongation of the nerve by 5 mm has been reported over a lateral humeral narrow plate 3.2-mm thick and 13-mm wide in a cadaveric study by El Ayoubi et al. [6]; these authors recorded 11-mm length gain in the nerve when it was experimentally transposed through the fracture site to the medial aspect of the humerus. We prefer using a broad plate (Table 3), and this necessitates further nerve dissection, resulting in more tension–elongation by the additional mass and bulk effect of the plate itself [5, 8]. Insertion of the plate on the medial aspect of the humerus through an anterolateral skin incision has been reported [3, 16, 17]: the interval between biceps and brachialis muscles is dissected with protection of the musculocutaneous nerve; the medial aspect of the humerus is then exposed by longitudinal division of the medial aspect of the brachialis after external rotation of the arm. This procedure is usually performed without exposure of the radial nerve, and it avoids any conflict between nerve and plate. Plate positioning on the anterior surface of the humerus using an anterior approach for fractures of the distal shaft [18] includes radial nerve control, with plate placement relatively distant from the nerve. A posterior approach to the humeral shaft, with plate insertion underneath the radial nerve on the posterior aspect of the humerus has also been used [19].

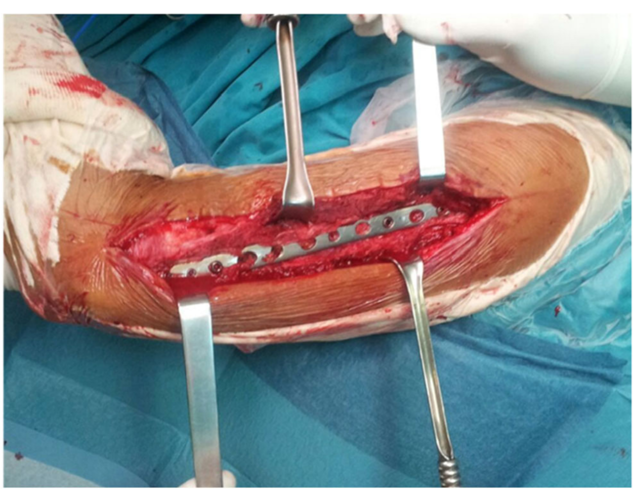

Fig. 6 Intra-operative photograph during a lateral humeral plate removal. Note complete plate exposure and absence of the radial nerve from the surgical field

Although transfracture transposition of the radial nerve during lateral and posterior approaches has sometimes been proposed in association with ORIF of humeral shaft fractures, it has not been advised as a routine procedure [5–10]. The aim of transposition was to remove the radial nerve from the surgical field (particularly during complex reduction–fixation manoeuvres), reduce tension on the nerve during surgical manipulation, avoid wrapping of the nerve around the plate at the end of fixation and thus avoiding a stretched nerve [5–10]. Mutz [20] reported that anterior transposition of the radial nerve induces length gain in the nerve by converting it from spiral to straight course. Pollock and Birch [21] reported an amazing case of traumatic medial transposition of the radial nerve with paralysis complicating an open fracture of the humeral shaft; the nerve was returned to its anatomical location during treatment of nonunion after a few months. In 1949, Schnitker [22] described a technique for transhumeral fracture transposition of the radial nerve, with cadaveric illustrations, and recommended this procedure in complicated cases of midshaft humeral fractures during ORIF; however, supportive clinical data was not provided.

Besides our preliminary report [10], we found two with limited clinical series on transfracture radial nerve transposition during ORIF of humeral shaft fractures [5, 6]. Another preliminary clinical report in the Korean language [9] was not really exploitable, except for its English abstract. All these reports stated that this procedure is technically feasible, harmless and safe. Three articles [6–8] reporting this procedure on cadaveric specimens concluded that it does not compromise nerve (or any nerve-branch) anatomy in terms of measurement. However, the decision for transposition should be considered intra-operatively [6] on the basis of surgeon experience and judgment [5, 6]. It is usually advised if the risk of nonunion and revision surgery is high [5]. Olarte et al. [5] reported that pre-existing stripping at the fracture site is suitable for transposition and is a contributing factor for potential development of nonunion, which makes even more sense for transposition in such situations. El Ayoubi et al. [6] stated that the suitable indication for transposition is a comminuted fracture of the middle and distal third of the humerus, with a transverse or oblique fracture line running in the same direction of the spiral groove and associated with radial nerve paralysis. However, this procedure would also be very helpful even when the radial nerve is not affected, especially if the surgeon encounters laborious reduction–fixation manoeuvres and faces difficulties inserting a lateral plate under the nerve during the lateral approach [6]. The ideal situation for transposition includes a fracture location that lies between 2 cm proximal and 7 cm distal to the midshaft of the humerus, a comminution that results in humeral shaft shortening and soft tissue disruption with traumatic spontaneous dissection of the radial nerve [6].

After reporting our preliminary experience [10], we intentionally began using this technique during ORIF of all humeral shaft fractures located in the area defined by El Ayoubi et al. [6]. In addition, we extended our indications to the treatment of humeral shaft nonunions in the same area. As far as we know, this procedure has not previously been reported for such an indication.

Pre-operative radial nerve paralysis was seen in four patients (26.6%) in our group of 15 fresh fractures, in three (30%) in the series of ten patients by Olarte et al. [5], in three (50%) in the series of six by El Ayoubi et al. [6] and in two (33%) of the Korean series of six by Lee et al. [9]. Although those incidences are high, all patients recovered after transfracture medial transposition of the radial nerve and fracture fixation (no mention regarding radial nerve recovery in 8). El Ayoubi et al. noted that the radial nerve was in continuity in their three cases with pre-operative paralysis: contused in two and stretched in one. Although we also noted absence of macroscopic discontinuity of the radial nerve in our four cases with pre-operative paralysis, the nerve was trapped in the fracture site in one patient and compressed by bony fragments in the other three. Olarte et al. [5] did not clarify the condition of the radial nerve in their three cases that presented with pre-operative paralysis. Post-operative radial nerve paralysis occurred in two patients in our group of 15 fresh fractures and in none of the four in the nonunion group or the six who underwent revision surgery after transposition. Olarte et al. [5] mentioned no iatrogenic radial nerve paralysis in their report, and El Ayoubi et al. [6] observed one case of post-operative paralysis, which they attributed to laborious reduction manoeuvres performed before transposing the nerve. All instances of post-operative paralysis eventually recovered completely (our two cases and the case by El Ayoubi et al.). We also believe, like these authors [6], that radial nerve dissection and transposition does not jeopardise nerve function as much as fracture manipulations do. We hypothesise that radial nerve transposition per se neither harms nor worsens any pre-existing injury to the nerve; in contrast, the gain in nerve length secondary to transposition may contribute to its functional recovery. On the other hand, like others [5], we believe that transposition has great and distinct advantages, preventing complications during subsequent procedures such as hardware removal or treatment for nonunion; the radial nerve is constantly surrounded by fibrous scar tissue in such circumstances.

A repeat surgical approach to the previous site of fixation was performed in six patients in our series: four with fresh fractures underwent hardware removal due to irritation from a prominent place at the lateral aspect of the distal humerus, as reported by the patients themselves. Another patient from the same group experienced nonunion and was eventually successfully revised. Lastly, one patient from the nonunion group continued to have a resistant nonunion; he underwent five revision surgeries that finally achieved bone healing. None of these six patients developed radial nerve paralysis after repeat surgery, which was very simple. The lateral incision was carried from the skin to the plate without the need to identify the radial nerve, which had been previously transposed to the medial aspect of the humerus. El Ayoubi et al. [6] and Olarte et al. [5] made the same comment after treating one and two cases, respectively, of nonunion that occurred in their respective series of six and ten cases with previous radial nerve transposition.

Although radial nerve dissection in the four patients in our nonunion group was technically more difficult (the nerve was surrounded by a fibrous scar tissue), reduction of the nonunion site was easier after transposition, and there was no post-operative radial nerve paralysis. In addition, we noticed that the new location of the nerve makes it safer when positioning the bone graft around the nonunion, avoiding enclosing or encircling the nerve in all six cases treated for nonunion (four at initial presentation and two following the index procedure) (Fig. 4).

This technique can be criticized because of the potential for additional devascularisation of the humerus related to a more extensive dissection. However, there was no increased incidence of nonunion in our series compared with the literature: 6.6% for fresh fractures and 10.5% for the whole series. In addition, we believe the only case of nonunion in the group of 15 patients with fresh fracture was due to a lack of stability secondary to using a long proximal humerus locking plate with 3.5-mm locking screws; this plate is relatively thinner, less rigid and less stable than the classically recommended broad plate. Treatment of nonunion in this patient was successfully achieved by easily removing the pre-existing plate and refreshing the nonunion site, followed by another fixation using a broad locking plate with locking head screws of 5.0-mm diameter and iliac bone graft.

A broad locking plate was used in 12 patients in our series (Table 3). This plate is 5.2-mm thick and 17.5-mm wide [23] and consequently thicker and wider than that used in the cadaveric study by El Ayoubi et al. [6]. It is, therefore, expected to cause more nerve stretching if the nerve is left in its original anatomic location, thus wrapping around the plate and extending across its width at the end of fixation. The case of persistent nonunion that occurred in a patient with initial nonunion might be expected because of the devascularisation during the initial surgery, which consisted of combined ORIF using a plate, an IM nail and cerclage wires.

Conclusion

We believe that transfracture medial transposition of the radial nerve is a feasible and safe procedure. The ideal fracture position in which to use this technique lies between 2 cm proximal and 7 cm distal to the midshaft of the humerus. After medial transposition, the radial nerve is removed from the surgical field, routed away from the fixation hardware and protected by the brachialis muscular bed in a good and favorable vascular environment, resulting in a shorter course with less tension. We favour this procedure during the lateral approach to the humerus when treating fresh fractures and nonunion of the middle and distal humeral shaft, especially when laborious intra-operative manipulations are needed for reduction and fixation. In addition, it has important advantages when a potential revision surgery is highly expected, as in the treatment of nonunion or hardware removal. This transposition avoids the difficult and hazardous revision step of dissecting the nerve that is engulfed in scar tissue. Finally, the patient should be clearly informed by the surgeon about the procedure and provided with a detailed report to be handed to any surgeon that may be involved in subsequent treatment.

Compliance with ethical standards

Conflict of interest None.

Funding None.

Ethical approval None.

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