Treatment of upper extremity nerve defects by direct suturing in high elbow or wrist flexion

Laurent Mathieu[1,2,3,4] · Constance Diner[1,2] · Anaïs Chataigneau[1,2] · Georges Pfister[1,2] · Christophe Oberlin[5] · Zoubir Belkheyar[5]

Abstract

Purpose To evaluate functional outcomes after direct suturing of upper extremity nerve defects in high elbow or wrist flexion.

Methods A retrospective review was conducted in patients treated for median, ulnar, or radial nerve defects between 2011 and 2019. Inclusion criteria were a defect > 1 cm and a minimal follow-up period of 1 year. Nerve defects were bridged by an end-to-end suture in 90° elbow flexion or 70° wrist flexion for 6 weeks.

Results Nine patients with a mean age of 30.2 years were included. The patients presented with two ulnar nerve defects, four median nerve defects, and three radial nerve defects at various levels. The mean time to surgery was 13.5 weeks for recent injuries. The mean defect length was 2.9 cm, and the mean follow-up time was 22.4 months. Two patients had joint stiffness that was more likely related to the associated injuries than the 6-week immobilization. Successful outcomes were achieved in eight of the nine patients. Meaningful motor recovery was observed in seven patients, and all recovered meaningful sensation. Excellent nerve recovery was noted in pediatric patients and in those with distal nerve defects.

Conclusion Temporary high joint flexion allows for direct coaptation of upper extremity nerve defects up to 4 cm located near the elbow or wrist. In this small and heterogenous cohort, functional outcomes seemed to be comparable to those obtained with short autografting.

Keywords Median nerve · Nerve defect · Nerve repair · Radial nerve · Ulnar nerve

Introduction

Selection of the proper treatment for peripheral nerve defects continues to pose a challenging problem due to a wide variability in approach and outcome depending on the nerve considered and the level of injury. Direct tensionless end-to-end repair achieves the most predictable outcomes [1, 2]. However, excessive tension has been shown to significantly impair regeneration across a nerve repair by causing a reduction in microvascular flow and an increase in scarring [2–4]. When a tension-free direct suture is not possible, defects in mixed nerves are addressed by autografts (which remains the gold standard treatment) or nerve transfers [1, 2].

Another alternative has been specifically developed for sciatic nerve defects in which autografts give mixed results due to the large to the size of the nerve in both diameter and length [5, 6]. This technique involves a direct end-to-end nerve coaptation with the knee flexed at 90° for 6 weeks, as initially described by Bourrel [7, 8] and improved by Oberlin and Rantissi [9]. Using this approach, we have found that defects up to 8 cm could be bridged with meaningful motor and sensory recovery in both sciatic nerve territories without an impairment of knee function [5, 6, 10].

Considering these promising results, we have applied this technique to limited-sized nerve defects in the upper

✉ Laurent Mathieu
laurent_tom2@yahoo.fr

1 Department of Orthopedic, Trauma and Reconstructive Surgery, Percy Military Hospital, 101 avenue Henri Barbusse, 92140 Clamart, France

2 French Military Hand Surgery Center, Percy Military Hospital, 101 avenue Henri Barbusse, 92140 Clamart, France

3 Department of Surgery, French Military Health Service Academy, Ecole du Val-de-Grâce, 1 place Alphonse Laveran, 75005 Paris, France

4 Military Biomedical Research Institute (IRBA), 1 place Général Valérie André, 91220 Brétigny-sur-Orge, France

5 Nerve and Brachial Plexus Surgery Unit, Mont-Louis Private Hospital, 8 rue de la Folie Regnault, 75011 Paris, France

extremity when we found that autografting should be avoided [11]. A similar strategy has been used by Roganovic [12, 13] to manage median and ulnar nerve defects caused by missile injuries during the Balkans war. However, in these latter studies, direct suturing was performed in a timely manner after the treatment of associated fractures by humerus shortening or external elbow fixation, with ulnar flexion already present at the time of nerve repair [12, 13]. Various authors have described both anterior transposition and elbow positioning to overcome ulnar nerve defects, but such procedures have only been rarely used to treat median or radial nerve defects [12–18].

The current study aims to evaluate functional outcomes following the repair of upper extremity nerve defects by end-to-end suturing with elbow or wrist flexion. We hypothesized that this strategy is safe, provides the same favorable results obtained with sciatic nerve defect repairs, and can be proposed as an alternative to autografting in certain circumstances.

Methods

Population studied

A retrospective study was conducted in patients with median, ulnar, or radial nerve defects treated by direct suturing in high elbow or wrist flexion between 2011 and 2019. The inclusion criteria were a nerve defect larger than 1 cm with a minimal follow-up period of 1 year. Patients with a shorter follow-up and those presenting with defects up to 1 cm were excluded, since such small defects can be treated by direct coaptation without high joint flexion. Institutional review board approval was obtained for the study, and all patients (or parents) gave their oral consent for the scientific use of any data or images obtained during treatment.

Operative protocol and postoperative care

End-to-end nerve coaptation was performed using a protocol similar to that described previously for sciatic nerve defect management [5–9]. The procedure began with a mobilization of the distal nerve stump before elbow flexion, or with a mobilization of the proximal nerve stump before wrist flexion. In cases of ulnar nerve defects at the elbow level, a subcutaneous anterior transposition was performed prior to nerve suturing [12, 14–17]. The nerve ends were brought together by elbow flexion at 90° or wrist flexion at 70°, and circumferential 9–0 sutures were placed before adding fibrin glue. During the postoperative period, the joint was immobilized in this position using a dorsal splint. The splint was retained in place for 6 weeks without dressing changes. No wound care was performed to avoid any deleterious joint motion exposing to nerve suture rupture. Splint removal was then followed by a gradual recovery of elbow or wrist extension, with a 2-week period of self-rehabilitation before starting active physiotherapy, to permit a very progressive stretching of the suture site [5].

Data analysis

The preoperative parameters collected were demographics, injury mechanism, injured nerve, defect level, and associated bone injury. Surgical parameters included time elapsed from trauma to surgery, nerve defect length, and eventual procedures combined for nerve repair. At the last follow-up, clinical outcomes were evaluated using the Medical Research Council's Grading System for motor (M) and sensory (S) assessment and the Visual Analog Scale (VAS) for the patient's perception of pain [19]. Electrodiagnostic examinations agreed with the physical examinations but were not analyzed since there were not carried out on all patients. Limitations in elbow or wrist range of motion were also assessed.

Motor recovery and global functional results in the distributions of the median, ulnar and radial nerves were assessed according to a standardized scoring system adapted from Kim et al. [20–22] (Tables 1 and 2). Motor recovery was defined as meaningful for a M score ≥ 3 in the nerve territory. Superficial pain sensation and some tactile sensation (S ≥ 2) had to be regained for meaningful sensory recovery [12, 13]. In cases of recent nerve injury, good and excellent recoveries were considered a successful outcome, and poor, fair, and moderate recoveries were considered an insufficient outcome. In cases of neuroma, a VAS score < 2 was considered successful. The outcomes were analyzed according to the injured nerve and the injury level.

Results

Nine patients (7 males and 2 females) with a mean age of 30.2 years (range 8–66 years) met the inclusion criteria during the study period (Table 3). The injury mechanisms included displaced fractures, open wounds, and iatrogenic trauma. The iatrogenic injuries occurred during carpal tunnel release (Case 6) or radial head arthroplasty revision (Case 9). The patients presented with two ulnar nerve defects, four median nerve defects, and three radial nerve defects at various levels, including one posterior interosseous nerve lesion. There were seven recent or subacute nerve injuries operated on after a mean time of 13.5 weeks (range 1–40 weeks), and two cases of neuroma-in-continuity of the median nerve lasting for several years (Fig. 1).

After nerve end trimming or neuroma resection, the mean nerve defect length was 2.9 cm (range 1.5–4 cm).

Table 1 Assessment of motor recovery in the median, ulnar and radial nerve territories based on the Medical Research Council grading system [19] and adapted from Kim et al. [20–22]

Score	Median nerve	Ulnar nerve
M0	No motor function	No motor function
M1	Forearm muscles grade 1	Forearm muscles grade 1
M2	Forearm muscles grade $2\pm$ thenar muscles grade 1 or 2	Forearm muscles grade $2\pm$ intrinsic muscles grade 1 or 2
M3	Forearm muscles grade ≥ 3 and thenar muscles grade 1 or 2	Forearm muscles grade ≥ 3 and intrinsic muscles grade 1 or 2
M4	Forearm muscles grade ≥ 4 and thenar muscles grade ≥ 3	Forearm muscles grade ≥ 4 and intrinsic muscles grade ≥ 3
M5	Forearm muscles and thenar muscles grade ≥ 4	Forearm muscles and hypothenar/intrinsic muscles grade ≥ 4
	Radial nerve (triceps function excluded)	Posterior interosseous nerve
M0	No motor function	No motor function
M1	BR grade 1 or 2	ECU grade 1 or 2
M2	BR grade 3, wrist extensors grade 1 or 2	ECU grade 3, ECD or EPL muscles grade 1 or 2
M3	BR grade ≥ 4, wrist extensors grade $3\pm$ finger/thumb extensors grade 1 or 2	ECU grade ≥ 3, ECD grade 3, EPL grade 1 or 2
M4	BR grade ≥ 4, wrist extensors grade ≥ 3, and finger/thumb extensors grade 1 or 2	ECU grade ≥ 4, ECD and EPL grade ≥ 3
M5	BR $\geq$ grade 4, wrist extensors grade ≥ 4, and finger/thumb extensors grade ≥ 3	ECU, ECD and EPL grade ≥ 4

BR brachioradialis muscle, *ECU* extensor carpi ulnaris muscle, *ECD* extensor communis digitorum muscle, *EPL* extensor pollicis longus muscle

Table 2 Global recovery assessment in the median, ulnar and radial nerve territories based on the British Medical Council [19] and adapted from Kim et al. [20–22]

Global recovery	Median, ulnar, and radial nerves	Posterior interosseous nerve
Absent	M0/S0	M0
Poor	M1/S0 or S1	M1
Fair	M2/S ≤ 2	M2
Moderate	M3/S ≤ 3	M3
Good	M4/S ≥ 3	M4
Excellent	M5/S ≥ 4	M5

Associated fractures mostly involved the humerus, including two supracondylar fractures in children (Fig. 2). The surgical procedures are detailed in Table 3. Anterior transposition was performed not only for the ulnar nerve but also for the radial nerve at the arm level. Combined procedures included bone internal fixation and tendon transfer.

The mean follow-up time was 22.4 months (range 12–48 months). Two patients presented with a limited articular range of motion following a gunshot injury to the elbow (Case 1) and a complex regional pain syndrome in the aftermath of an iatrogenic injury of the median nerve (Case 6). Successful outcomes were achieved in eight of nine patients (Table 4). There was only one insufficient result after repair of the ulnar nerve at the elbow level (Fig. 3). Meaningful motor recovery was observed in seven patients, but all recovered meaningful sensation. Excellent sensori-motor recovery was noted in pediatric patients and in those with distal nerve defects. Patients with long-lasting neuroma

Table 3 Demographics, mechanism, injury pattern and surgical parameters

Case	Age (years)	Injury mechanism	Injured nerve	Defect level	Associated fracture	Time to surgery (weeks)	Defect length (cm)	Nerve repair	Combined procedure
1	23	GSW	Ulnar nerve	Elbow	Distal humerus	40	4	AT + suture	Humerus plating
2	31	Fracture	Ulnar nerve	Wrist	Radius & ulna	6	1.5	Suture	Ulna plating
3	8	Fracture	Median nerve	Elbow	Distal humerus	17	3.5	Suture	No
4	66	Laceration	Median nerve*	Wrist	No	NA	4	Suture	Tendon transfer
5	38	Laceration	Median nerve*	Wrist	No	NA	2	Suture	Synovial flap
6	36	Iatrogenic	Median nerve	Wrist	No	2	4	Suture	No
7	36	Fracture	Radial nerve	Brachial	Humerus	18	4	AT + suture	Tendon transfer
8	10	Fracture	Radial nerve	Elbow	Distal humerus	1	1.5	Suture	Humerus pinning
9	24	Iatrogenic	PIN	Forearm	Radial head	10	3	Suture	No

*Neuroma, *AT* anterior transposition, *GSW* gunshot wound, *IBP* infraclavicular brachial plexus, *NA* not applicable, *PIN* posterior interosseous nerve

Fig. 1 Case 6: Median nerve defect after excision of a neuroma-in-continuity (right). Direct suturing in 70° wrist flexion (left)
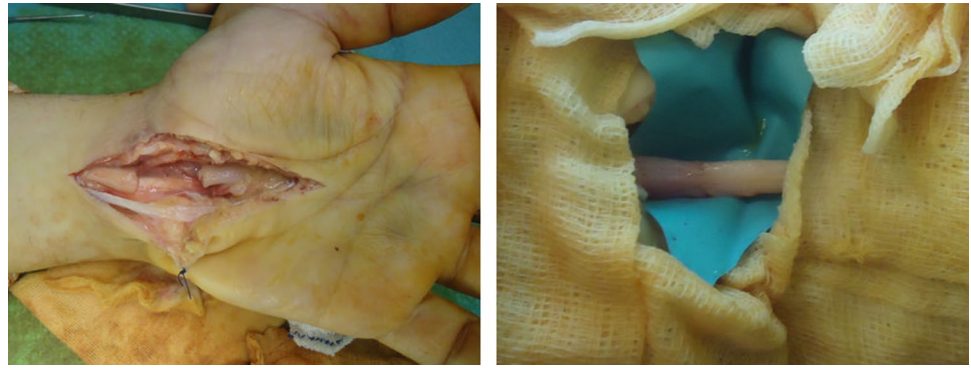

Fig. 2 Case 3: Median nerve defect related to a supracondylar humerus fracture in an 8-year-old boy (right—arrows show nerve ends before trimming). Direct suturing in 90° elbow flexion with a bowstringing effect (left)
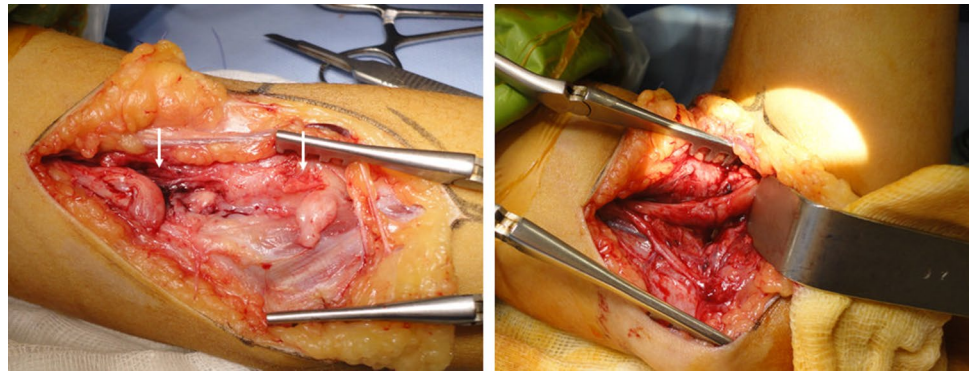

Table 4 Functional outcome at the last follow-up

Case	Injured nerve	Defect level	Follow-up time (months)	Joint stiffness	VAS	M score	S score	Global recovery	Outcome
1	Ulnar nerve	Elbow	14	Yes	2	2	2	Fair	Insufficient
2	Ulnar nerve	Wrist	26	No	0	5	4	Excellent	Successful
3**	Median nerve	Elbow	24	No	0	5	4	Excellent	Successful
4	Median nerve*	Wrist	48	No	0	3 (TT)	2	Moderate	Successful
5	Median nerve*	Wrist	30	No	0	2	2	Fair	Successful
6	Median nerve	Wrist	12	Yes	2	3	3	Moderate	Successful
7	Radial nerve	Brachial	12	No	0	4 (TT)	3	Good	Successful
8**	Radial nerve	Elbow	24	No	0	5	4	Excellent	Successful
9	PIN	Forearm	12	No	0	5	NA	Excellent	Successful

*Neuroma, **pediatric patient, *NA* not applicable, *TT* tendon transfer, *VAS* visual analogic scale

were free of pain but had a fair or moderate recovery. Good or moderate recovery was achieved in the other cases.

Discussion

To our knowledge, this is the first cases series reporting on direct suturing of median, ulnar, and radial nerves defects with elbow or wrist positioning. Using this simple technique, we achieved a successful outcome in almost all cases.

The rationale for direct nerve suturing with high joint flexion in the upper extremity is more to avoid nerve graft harvesting than to improve nerve recovery. Unlike in sciatic nerve repair, there is no strong difference in efficacy between delayed nerve suturing and grafting in the upper extremity (except for long nerve grafts) [11–13, 20–24]. Only primary nerve suturing provides clearly better results [23, 24]. The current technique, however, is particularly useful in various situations: (1) to permit primary or early nerve repair of a posttraumatic defect without the need to wait for a delayed grafting; (2) to deal with limited donor
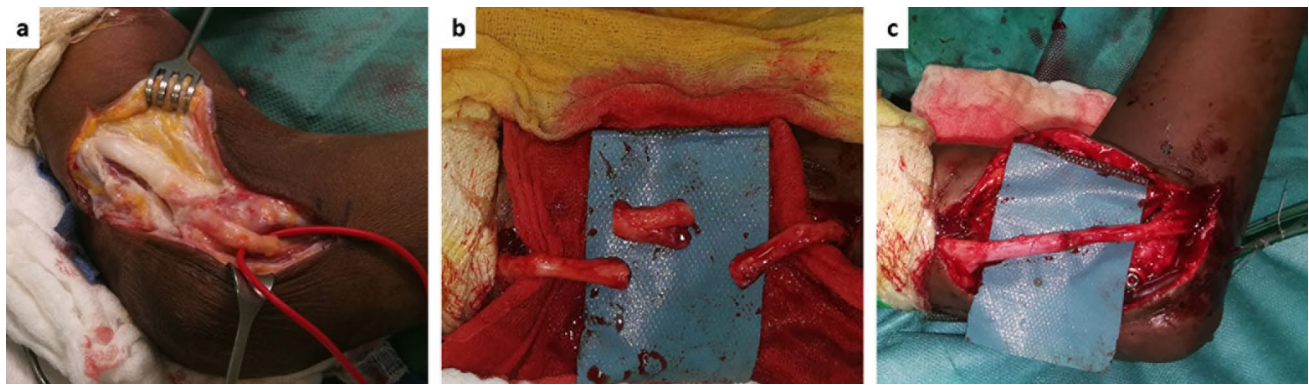
Fig. 3 Case 1: Missile injury of the ulnar nerve at the elbow level (**a**). Nerve trimming led to a 4 cm defect (**b**). Direct suturing after anterior transposition of the nerve and positioning in 90° elbow flexion (**c**)

nerve graft material; (3) to avoid painful complications at the donor site in patients with chronic pain; (4) as a primary procedure in children when graft harvesting can be avoided. All these situations were seen in the current clinical series. We believe that direct suturing of short nerve defect should be considered in patients presenting with multi-tissue injury, particularly in those requiring combined bone fixation. This technique could also be useful for management of nerve defect with limited resources or in the context of war as described by Roganovic [11–13].

The functional outcomes presented in this small and heterogenous cohort can hardly be compared to those reported in the literature [12, 13, 20–26]. However, like many authors, we found excellent recovery for young patients, short delay between injury and repair, and distal nerve defects [12, 13, 20–26]. In agreement with Kitta et al. [18], we noticed that direct suturing with 90° elbow flexion provides highly favorable results in pediatric patients presenting with nerve defects associated with supracondylar humerus fractures. We believe that this is an excellent alternative to nerve grafting in this situation considering that these defects are usually short [27, 28]. Due to the very limited number of cases, we could not compare functional results between nerves, but direct repair of distal defects resulted in successful outcomes in most cases. Conversely, fair recovery was noticed in cases with proximal ulnar nerve defect and long-lasting median nerve neuroma which are well-known factors of poor prognosis [20, 22–25]. Late repair in patients with median nerve neuroma (Cases 4 and 5) was mostly performed with the objective to treat the pain rather than to permit sensorimotor recovery which is very uncertain in these chronic lesions [25]. For this reason, an opponensplasty was combined to nerve repair in Case 4 who complained about limited thumb opposition. Outcomes for the radial nerve were good or excellent because of distal injuries, pediatric patients, or combined tendon transfer. Although Murovic [24] and Kim et al. [21] have respectively reported a 68% and 81% M3

recovery after suture or grafting of radial nerve injuries at various levels, we are used to combining nerve repair and tendon transfer for proximal radial nerve injuries in adults for several reasons [11, 26, 29]. First, tendon transfers permit early restoration of active wrist extension, eliminating the need for orthosis. A limited transfer (pronator teres to extensor carpi radialis brevis) may be sufficient [26]. Tendon transfers also avoid developing a flexion contracture during nerve recovery and likely enhance neural regeneration by stimulating neurotrophic factors in damaged nerves, thus increasing axon regeneration potential [11, 29].

In this study, the mean defect length was 2.9 cm and we found that a gap of ~4 cm could be considered the maximum limit of this technique. One can argue that we unnecessarily used high joint flexion for small-sized defects, since some authors have claimed that defects up to 2.5 cm are accessible to direct suture after nerve end mobilization [1, 12, 13]. However, this assertion is questionable because such sutures were in fact achieved after anterior transposition of the ulnar nerve or moderate flexion in the adjacent joint [12, 13]. The maximal defect length accessible to end-to-end suture depends on the nerve size. In an experimental study, we found that direct suturing of sciatic nerve defects was only possible for gaps less than 2 cm [10]. In the upper extremity, the threshold length is probably ≤ 1 cm due to the elastic properties of the nerve [2].

The conditions for application of the technique varied according to the injury level. The elbow and wrist were obviously the most compliant levels where the largest nerve defects were suturable. A bowstringing effect was noticed after the suturing of 4 cm defects, but the nerves always remained deep enough not to interfere with skin closure (Figs. 2 and 3). In the elbow, prior anterior transposition of the ulnar nerve permitted a reduction in the gap, as demonstrated by various authors [2, 12, 14–17]. Smetana et al. [17] found that transposition alone reduces the defect length by 2 cm. Like Trumble [14] and Abrams

et al. [15], we demonstrated that anterior transposition combined with elbow flexion can overcome gaps up to 4 cm (Fig. 3). Conversely, elbow flexion was less effective at bridging nerve gaps in the distal arm or proximal forearm. A 4 cm radial nerve defect was also bridged thanks to an anterior transposition of the nerve ends in front of the humerus using a double approach [30]. However, we did not apply this technique for brachial level ulnar nerve defects because the ulnar nerve normally glides in a distal direction with elbow flexion.

We acknowledge that a 6-week immobilization in high elbow or wrist flexion can be questionable regarding the risk of joint stiffness. High wrist flexion could also expose to complications such as complex regional pain syndrome or compartment syndrome. The rationale for this position and duration was to prevent tension at the suture site to minimize the development of fibrosis [2, 3]. We also decided to postpone physiotherapy after splint removal to permit a progressive and atraumatic recovery of extension, as we currently know that progressive limb elongation is possible without nerve damage [5, 9]. In this cohort, the limited articular range of motion noticed in two patients could not be attributed to the postoperative immobilization. Nevertheless, extended immobilization in 90° elbow flexion or 70° wrist flexion should be applied with caution based on associated bone and soft-tissue injuries.

This study has several limitations. First, its retrospective nature and the small size cohort make it necessary to draw conclusions carefully. In addition, this series is heterogenous regarding patient age, injury mechanism, and time to surgery. Lastly, combined tendon transfers partially biased nerve recovery assessment in two patients. However, a good sensory recovery and voluntary contractions of the reinnervated muscles attested to the success of nerve repair in these patients.

Conclusion

Temporary high joint flexion allows for direct coaptation of upper extremity nerve defects up to 4 cm located near the elbow or wrist. In this small and heterogenous cohort, functional outcomes seemed to be comparable to those obtained with conventional repair using short autografting. Careful patient selection, however, is essential to limit the risk of joint stiffness. This technique could advantageously avoid nerve grafting when combined procedures are required or in austere environments. We believe that it should be contemplated and evaluated on a larger scale.

Declarations

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