

NERVE MAGNIFIED REGENERATION BY DISTAL NERVE TRANSFER IN HIGH ULNAR NERVE INJURY

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Abstract

The concept of nerve-magnified regeneration, part of which is end-to-side nerve transfer, provides a theoretical basis for the treatment of high ulnar nerve injuries. High injury to the ulnar nerve causes severe consequences, such as loss of sensation, loss of movement and “claw hand” deformity, affecting the fine motor skills of the hand. A method of nerve-magnified regeneration – distal nerve transfer – interosseous anterior (median nerve) to the deep ulnar nerve at the wrist level is presented, used in 20 patients (2 to 66 years of age) with an average follow-up period of 3 years (10 months to 5 years). This is a microsurgical method for rapid re-innervation of the most distal hand muscles in proximal neurotmesis of ulnar nerve.

Key words: high ulnar nerve injury, nerve-magnified regeneration, nerve transfer

Introduction. Ulnar nerve injuries are the most frequent major upper extremity peripheral nerve injuries that require early repair when compared with median, radial, and brachial plexus injuries [1]. They can result in paresthesia, dysesthesia, and muscle weakness in the affected hand. Unfortunately, repair of the ulnar nerve often results in incomplete recovery with functional results that are inferior to those achieved following radial nerve and median nerve repair, leading to deteriorations predominantly in males in the working age group (18–45 years) [1, 2].

Ulnar nerve injuries can be broadly divided into low injuries and high injuries. In low ulnar nerve injuries, the nerve is damaged distal to the motor branch of the *m. flexor carpi ulnaris* (FCU) and motor branch to the *m. flexor digitorum profundus* (FDP) of the ring and little fingers. In high injuries, the nerve is damaged above the origin of the motor branch of the FCU and the FDP muscles.

High ulnar nerve injuries traditionally result in poor intrinsic muscle recovery, because functional recovery is determined by the time required for the motor end plate to be reinnervated and by the number of regenerated motor axons that can reach target muscle. In adults, primary repair of high ulnar nerve injury is unsatisfactory. Although sensation is restored in most cases, recovery of motor function in the intrinsic muscles of the hand is almost always poor, with resultant claw hand deformity [3,4]. This is essentially due to the considerable distance between the site of injury and the motor end plates to be reinnervated. The required time of several months for regenerating axons to go through this distance leads to irreversible atrophy and fibrosis in the denervated muscles. To decrease the time to reinnervation within the hand and preserve motor end plates in high ulnar nerve injuries, distal nerve transfers have been recommended as an alternative to restore intrinsic hand function [3].

Nerve transfers, also called “neurotizations”, provide restoring a distal denervated nerve segment by using a proximal functioning nerve as a donor to neurons and their axons, which will reinnervate distal target muscle groups. The concept is to sacrifice the function of (less valuable) donor muscles to restore the function of the recipient nerve and muscle. Since TUTTLE’s first report in 1913 [5] and popularization by NARAKAS [6] four decades ago, nerve transfers have been increasingly used to repair brachial plexus injuries, especially in cases where the proximal motor neuron of the denervated element is unrepairable due to spinal cord avulsion [7,8]. Recommendations for the use of nerve transfers are increasing in cases where the proximal motor neuron is functioning, but the regeneration distance is so long that the result will be poor. In these cases, based on nerve-magnified regeneration, nerve transfer in the denervated distal nerve segment near the motor plate will restore function that would not otherwise be possible [9–11].

Animal experiments have confirmed that two types of nerve-magnified regeneration exist [11,12]. One type involves a smaller proximal nerve dominating a larger distal nerve, i.e., a proximal axon can dominate up to three or four distal axons by nerve-magnified regeneration. Another work demonstrates that recovery of function – motor or sensitive – after nerve end-to-side anastomosis is also an example of nerve-magnified regeneration [13]. Together, these two types support the nerve-magnified regeneration concept providing a theoretical basis for treating complete high ulnar nerve injury [11].

Previously, the anterior interosseous nerve (AIN) transfer to the ulnar motor branch has been applied in the late 1990s [14]. Originally, this motor nerve transfer was described as a direct end-to-end transfer, prohibiting any potential

ingrowth from the proximal nerve; however, techniques that are more recent use the AIN in an end-to-side fashion, allowing for recovery of proximal fibres and augmentation from the end-to-side transfer. Experimental models have shown that axonal regeneration can occur across end-to-side nerve coaptation [1]. MACKINNON et al. [7, 15, 16] have termed these transfers “supercharged end-to-side nerve transfers” (SETS) and performed them as a means of preserving distal motor end plates until the native axons fully regenerate and to augment the regenerating nerve. A SETS augmentation with AIN motor branch can be considered for mid-level injuries near the elbow or in high ulnar nerve injuries with a Martin–Gruber communication. Although functional recovery has been noted in 70% to 100% of patients [1, 3, 9], long-term and comparison outcomes studies for this method are lacking.

Thus, complete high ulnar nerve injury remains a challenge for the surgeon in clinical practice. The traditionally offered treatment – primary repair only – consistently leads to a poor functional result – claw hand deformity – due to the long distance between the injury site and the innervated muscles. Here, we propose an original treatment algorithm, i.e., first repair of ulnar nerve at the site of injury and second, based on nerve-magnified regeneration, distal nerve transfer of the terminal motor branch of anterior interosseous nerve (median nerve) to the deep motor branch of the ulnar nerve at wrist level. The aim of this microsurgical method of distal nerve transfer is to shorten the nerve regeneration path and the time for reinnervation of intrinsic muscles and to significantly reduce the atrophy of these muscles for a better hand function. It is expected that when primary repair is combined with the distal nerve transfer, functional recovery will be improved.

Surgical technique. The patient is supine on the operating table under general anesthesia and a haemostatic tourniquet is applied (according to the surgeon). Through a longitudinal incision (Fig. 1A) about 12 cm along the medial

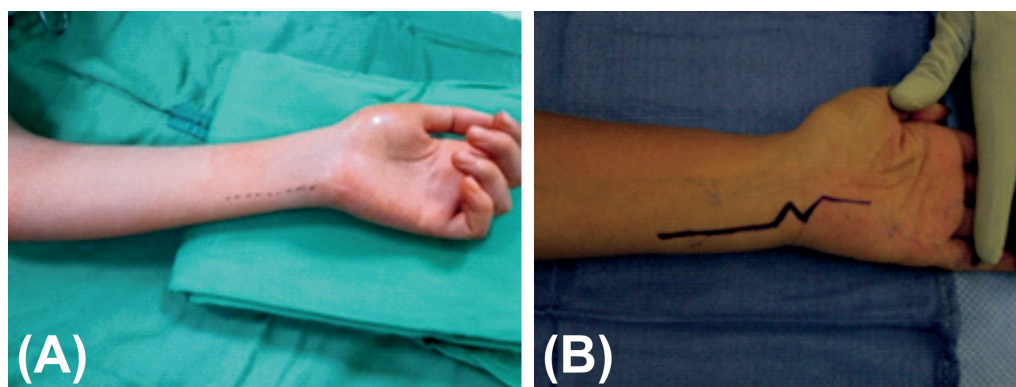


Fig. 1. Surgical approaches: (A) Without decompression of Guyon's canal;
(B) With decompression of Guyon's canal

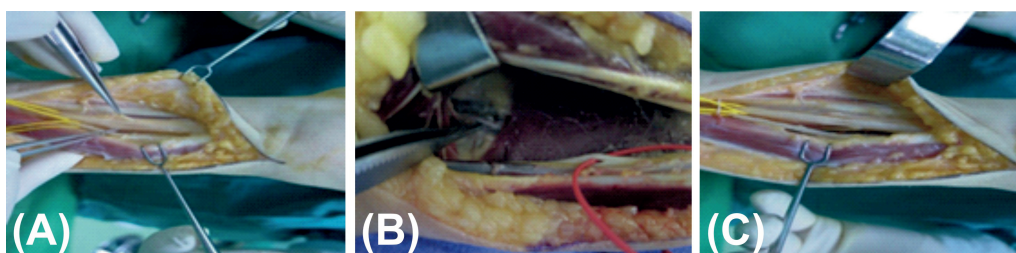


Fig. 2. Identification of (A) motor fascicles of ulnar nerve, located proximally to *m. pronator quadratus* between sensory fascicles of dorsal cutaneous branch and the superficial palmar branch for *nn. digitales palmares proprii* (sandwich type), (B) anterior interosseous nerve (AIN) proximally to *m. pronator quadratus*; (C) end-to-side anastomosis, free of tension

(ulnar) line of the distal third of the forearm, the ulnar triad (*t. m. flexor carpi ulnaris*, *n. ulnaris*, *a. v. ulnaris*) was reached. Under microscopic magnification, we neurolyze ulnar nerve, finding the site where it gives off its dorsal cutaneous branch. In our first patients with high ulnar nerve injury we opened the Guyon canal (Fig. 1B) in order to specify and separate from distal to proximal the deep motor branch that curves around the *hamulus ossis hamati*. According to the latest information in the literature [17], the fascicles of the motor branch are located between those of the sensory fascicles of dorsal cutaneous branch and those of the superficial palmar branch for *nn. digitales palmares proprii* (sandwich type, Fig. 2A). Another landmark is the longitudinally located delicate vascular bundle in the epineurium of ulnar nerve. It usually separates the motor from the sensory fascicles. By moving the entire flexor muscle group to the radial side, the AIN is located at the proximal end of *m. pronator quadratus* (Fig. 2B) more radially with its accompanying artery and vein. We dissect it as distally as possible till it starts to give off branches and then we resect it. We direct this nerve branch below the flexor muscles to the ulnar nerve. This is followed by an end-to-side coaptation, free of tension, to the motor fascicles of the ulnar nerve using 9/0 atraumatic suture (Fig. 2C). We cover the site of coaptation with tissue glue, followed by layered suture and sterile dressing. Volar immobilization in physiological position of the wrist joint for 1 week is implemented with subsequent rehabilitation according to a postoperative protocol.

Material. In the period 2015–2020 we operated 20 patients (2–62 years of age) with high ulnar nerve injury with injury-surgery interval from two months to one and a half years (Table 1). In one patient, additional tendon transposition was performed at the patient's request in order to more quickly correct the claw deformity of the IV and V fingers, and in three patients additional distal (in the palm area) neurotization was performed by cable nerve autograph between the motor recurrence branch of the median nerve and the motor deep branch of the ulnar nerve, immediately after *hamulus ossis hamati*.

Muscle strength of the first dorsal interosseous muscles of the affected side (examining abduction motion of the index finger) was measured using the Medical

T a b l e 1

Individual demographic and clinical data

Patient No.	Age (years)	Injury-Surgery interval (months)	Follow-up period (years)	Motor recovery	Sensory recovery
1	7	5	5	M4	S3+
2	53	7	5	M3	S2
3	31	7	5	M3	S2
4	6	2	5	M5	S3+
5	59	1	4	M2	S2
6	60	10	4	M3	S2
7	30	2	4	M2	S1
8	39	15	4	M3	S2
9	28	16	4	M3	S2
10	6	4	4	M4	S3
11	2	4	3	M5	S3+
12	19	4	2	M3	S2
13	18	1	2	M4	S3
14	24	3	2	M4	S3
15	43	4	1	M4	S3
16	62	1	1	M2	S2
17	56	24	1	M2	S2
18	57	5	1	M3	S2
19	41	18	1	M3	S2
20	13	10	1	M4	S3

M – scores according to the Medical Research Council (MRC) muscle strength rating system modified by Brandsma et al. [18]; S – scores according to the MRC scale for sensory recovery modified by Mackinnon and Dellon [16]

Research Council (MRC) muscle strength rating system modified by BRANDSMA et al. [18]. Grade: M0: No contraction; M1: Muscle tremor or contraction; M2: Full range active movement without gravity resistance; M3: Able to carry out active movement against gravity, not to resist resistance; M4: Able to carry out active movement against gravity and resist light resistance; M5: Normal.

The MRC scale for sensory recovery modified by MACKINNON and DELLON [16] was used to assess the sensation function of the pulp of the little finger. Grade: S0: Absence of sensibility in the autonomous zone of the nerve; S1: Recovery of deep cutaneous pain sensibility within the autonomous zone of the nerve; S2: Partial recovery of superficial pain and tactile sensibility within the autonomous area of the nerve; S3: Recovery of superficial cutaneous pain and tactile sensibility throughout the autonomous area without hyperalgesia. S2PD > 15 mm, M2PD > 7 mm; S3+: Recover to S3 level, and some recovery of two point discrimination. S2PD: 7–15 mm, M2PD: 4–7 mm; S4: Complete recovery. S2PD: 2–6 mm, M2PD: 2–3 mm.

Grip and pinch strengths of both hands are measured. The claw hand deformity, Froment's sign, Wartenberg's sign, atrophy of the intrinsic muscles (mainly

including the first, third, and fourth dorsal interosseous muscles), and the degree of rotation of the affected forearm are evaluated. According to the Highet–Zachary scheme, the mean scores for muscle strength and sensation are calculated (M0–M5 correspond to scores of 0–5, respectively; S0, S1, S2, S3, S3+, S4 correspond to scores of 0–5, respectively). The function of the affected upper limb was scored using the Disabilities of the Arm, Shoulder, and Hand (DASH) scale.

Results. Individual patients' data and results are presented in Table 1. Summarized statistical observations of the recovery of motor and sensory functions are presented in Fig. 3. It was found that 80% of patients regained muscle strength in grades M3–M5 (M3 – 40%, M4 – 30%, M5 – 10%), and none manifested absence of recovery (M0 and M1 – 0%). Average final Disorders of the Arm, Shoulder and Hand (DASH) score was 22 (DASH score ranges from 0 to 100, with lower scores indicating a better result). Atrophy of the intrinsic muscles of the hand, the rate of positive Froment's sign and incidence of the claw hand deformity were reduced. Grip strength and pinch strength were improved. Patients who had primary reconstruction of their ulnar nerves recovered S3+ sensibility in 15% of cases, S3 in 25%, and S2 in 55%. None of the patients recovered S4 sensibility.

Extremely high significant correlation was found between the recovery of motor and sensory functions, as verified by the very high positive correlation between the assessment indexes (Pearson correlation coefficient, $r = 0.900$, $p < 0.001$). A significant strong negative correlation was found between the age of the patients during surgery and the degree of recovery of both motor (Pearson correlation coefficient $r = -0.768$, $p < 0.001$) and sensory function ($r = -0.672$, $p < 0.001$), reflecting a decrease in recovery with advancing age. Although the time from trauma

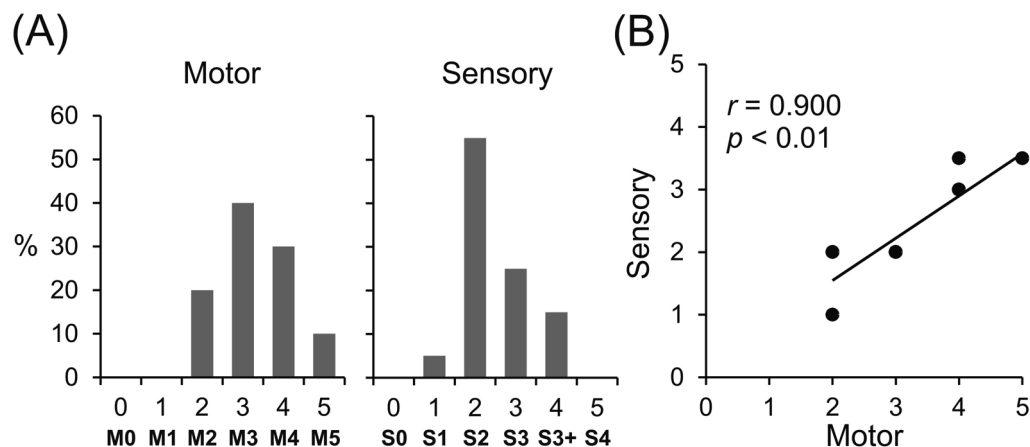


Fig. 3. (A) Rate of motor and sensory recovery. (B) Correlation between motor and sensory recovery. M – scores according to Medical Research Council (MRC) muscle strength rating system modified by Brandsma et al. [18]; S – scores according to MRC scale for sensory recovery modified by Mackinnon and Dellon [16]

to surgery correlated negatively with the degree of recovery (motor: $r = -0.282$, sensory: $r = -0.281$), indicating the beneficial effect of early intervention, this relation did not reach significance ($p > 0.1$). A similar tendency was detected for the follow-up period. It was also found that the injured nerve, the level of injury and the concomitant injuries had a most significant impact on the results.

Discussion. Long-term follow-up data of our patients who underwent the proposed here repair intervention for complete high ulnar nerve injury demonstrate that hand function can be effectively restored.

Specifically, the mean scores (the Highet Scale) for muscle strength of the first dorsal interosseous muscle indicate that the intrinsic muscle strength of the hand could be efficiently improved. Also, nerve transfer of the pronator quadratus muscle nerve branch effectively reduced atrophy of the intrinsic muscles, the rate of positive Froment's sign and incidence of the claw hand deformity, thus improving the hand function of patients.

Further, grip strength, pinch strength, and the DASH score were significantly better in comparison with patients without distal nerve transfer [11], reflecting a recovery of practical functions in daily lives [19]. The protective skin sensation of the little finger and the ulnar side of the palm that is critically important for preventing burns of the affected hand and improving the coordination ability of the hand, also was restored. Together, these results verify the efficiency of the suggested algorithm based on nerve-magnified regeneration [1, 8, 11].

The distal part of the anterior interosseous nerve is a mixed nerve with sensory fibres [12]. Although previous studies have shown that the axon size of this branch of the anterior interosseous nerve for the pronator quadratus muscle is quite different from that of the ulnar nerve [11], we confirm that transfer of the pronator quadratus muscle nerve branch can lead to innervation of multiple target muscles that are usually innervated by the deep branch of the ulnar nerve, such as the first interosseous muscle and the hypothenar muscle. Our results provide strong support to the concept of nerve-magnified regeneration and its application as a reliable methodology.

Other studies have shown that end-to-side anastomosis may result in innervation by the two motor nerves [13]. The intrinsic muscles can be innervated by the pronator quadratus muscle branch in the early stage and are expected to receive innervation from the regenerated ulnar nerve itself in the later stage. According to the follow-up data, the degree of sensory recovery in the ulnar nerve-innervated area can reach the S2 level or higher, suggesting that some regenerated nerve fibres indeed reach the distal effector after repair of the injured part of the ulnar nerve, even though the regeneration path is long. Therefore, end-to-side anastomosis can achieve an additive effect due to ulnar nerve regeneration.

Conclusion. For the treatment of complete high ulnar nerve injury, we propose a treatment algorithm based on nerve-magnified regeneration, i.e., first repair of ulnar nerve at the site of injury and second distal nerve transfer of the

motor branch of m. pronator quadrates to the deep motor branch of the ulnar nerve at wrist level. This method is a feasible technique that not only validates nerve magnified regeneration in clinical practice but also mitigates loss of function in the nerve donor area. Therefore, this technique substantially reduces atrophy of the intrinsic muscles of the hand and provides better hand function. We advocate this technique as a routine procedure in clinical practice.

REFERENCES

- [1] WOO A., K. BAKRI, S. MORAN (2015) Management of ulnar nerve injuries, *J. Hand Surg. Am.*, **40**(1), 173–181.
- [2] LAD S. P., J. K. NATHAN, R. D. SCHUBERT, M. BOAKYE (2010) Trends in median, ulnar, radial, and brachio-plexus nerve injuries in the United States, *Neurosurgery*, **66**(5), 953–960.
- [3] HAASE S., K. CHUNG (2002) Anterior interosseous nerve transfer to the motor branch of the ulnar nerve for high ulnar nerve injuries, *Ann. Plast. Surg.*, **49**(3), 285–290.
- [4] POST R., K. S. DE BOER, M. J. MALESSY (2012) Outcome following nerve repair of high isolated clean sharp injuries of the ulnar nerve, *PLoS One*, **7**(10), e47928.
- [5] TUTTLE H. K. (1913) Exposure of the brachial plexus with nerve transplantation, *JAMA*, **61**, 15.
- [6] NARAKAS A. O. (1984) Thoughts on neurotization or nerve transfers in irreparable nerve lesions, *Clin. Plast. Surg.*, **11**(1), 153–159.
- [7] MACKINNON S. E., C. B. NOVAK (1999) Nerve transfers. New options for reconstruction following nerve injury, *Hand Clin.*, **15**, 643–666.
- [8] PATTERSON J. (2016) High ulnar nerve injuries: Nerve transfers to restore function, *Hand Clin.*, **32**(2), 219–226.
- [9] BATTISTON B., M. LANZETTA (1999) Reconstruction of high ulnar nerve lesions by distal double median to ulnar nerve transfer, *J. Hand Surg. Am.*, **24**(6), 1185–1191.
- [10] FLORES L. P. (2011) Distal anterior interosseous nerve transfer to the deep ulnar nerve and end-to-side suture of the superficial ulnar nerve to the third common palmar digital nerve for treatment of high ulnar nerve injuries: experience in five cases, *Arq. Neuropsiquiatr.*, **69**(3), 519–524.
- [11] DING W., X. LI, J. PAN et al. (2020) Repair method for complete high ulnar nerve injury based on nerve magnified regeneration, *Ther. Clin. Risk Manag.*, **16**, 155–168.
- [12] ZHANG P., Y. KOU, X. YIN et al. (2011) The experimental research of nerve fibers compensation amplification innervation of ulnar nerve and musculocutaneous nerve in rhesus monkeys, *Artif. Cell Blood Substit. Immobil. Biotechnol.*, **39**(1), 39–43.
- [13] ISAACS J. E., S. CHEATHAM, E. B. GAGNON et al. (2008) Reverse end-to-side neurotization in a regenerating nerve, *J. Reconstr. Microsurg.*, **24**(07), 489–496.
- [14] NOVAK C., S. MACKINNON (2002) Distal anterior interosseous nerve transfer to the deep motor branch of the ulnar nerve for reconstruction of high ulnar nerve injuries, *J. Reconstr. Microsurg.*, **18**(6), 459–463.
- [15] BARBOUR J., A. YEE, L. KAHN, S. E. MACKINNON (2012) Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation, *J. Hand Surg. Am.*, **37**(10), 2150–2159.

- [16] MACKINNON S., A. DELLON (1988) *Surgery of the Peripheral Nerve*, New York, Thieme.
- [17] BERTELLI J. A., M. F. GHIZONI (2013) Clinical findings in C5-C6 and C5-C7 root palsies with brachial plexus traction lesions, *J. Hand Surg. Eur.*, **38**(3), 237–241.
- [18] BRANDSMA J. W., T. A. SCHREUDERS, J. A. BIRKE et al. (1995) Manual muscle strength testing: intraobserver and interobserver reliabilities for the intrinsic muscles of the hand, *J. Hand Ther.*, **8**(3), 185–190.
- [19] MAGDI-SHERIF M., A. H. AMR (2010) Intrinsic hand muscle reinnervation by median-ulnar end-to-side bridge nerve graft: case report, *J. Hand Surg. Am.*, **35**(3), 446–450.

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