Ulnar Nerve Injuries (Sunderland Grade V): A Simplified Classification System and Treatment Algorithm

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Background: This study introduced a novel technical approach to the ulnar nerve injuries. The ulnar nerve was divided into 4 distinct surgical zones, each mandating a unique management strategy.

Methods: A prospective observational study was conducted to verify the hypothesized algorithm. The study included 110 patients diagnosed with ulnar nerve injury (Sunderland grade 5). We divided the patients into 4 groups depending on the site of injury. Each group of patients was managed in accordance with a particular strategy, exploiting nerve transfer techniques along with the updated knowledge of the internal topography of the ulnar nerve. The motor recovery of the small muscles of the hand was assessed after 2 years of follow-up, using the disabilities of the arm, shoulder, and hand score, and other parameters including key pinch strength, hand grip strength, and the motor power of the first dorsal interosseous muscle on the Medical Research Council scale.

Results: The mean values of the disabilities of the arm, shoulder, and hand score, key pinch strength, and hand grip strength showed a statistically significant improvement across all patient groups ($P < 0.05$). Of those with zone (I) injury, postoperatively, 79.9% patients attained a first dorsal interosseous muscle power grade >3 on the Medical Research Council scale, while 93.9% of patients with zone (II) damage achieved the same result. Surprisingly, 84% of patients included in both zones (III) and (IV) also recovered to the same extent.

Conclusions: This prospective observational study examined and successfully confirmed the validity of our proposed novel algorithm for the management of ulnar nerve injuries (Sunderland grade 5). *(Plast Reconstr Surg Glob Open 2019;7:e2474; doi: 10.1097/GOX.0000000000002474; Published online 27 November 2019.)*

INTRODUCTION

Ulnar nerve injuries have a deleterious impact on the patient's daily activities and professional life. Many patients with severe injuries are forced to change their professions, whereas some have to contend with permanent disabilities.

The prognosis of ulnar nerve trauma, irrespective of the level of injury, is usually poor, as compared with that of the median or radial nerve. Specifically, injuries sustained at or above the elbow level exhibit the worst prognosis, even after attempted repair using procedures like primary neurorrhaphy or autogenous nerve grafts.[1]

The traditional nerve repair is ineffective for shortening the time for reinnervation, which is crucial for an optimum functional outcome. A nerve transfer is a relatively recent addition to the evolving reconstructive armamentarium. The rationale of a nerve transfer is based on the conversion of higher level nerve injuries into lower level ones, using the nearby expendable nerves, thus shortening the reinnervation time, and leading to a better subsequent functional outcome.[2] The other beneficial effect is in the utilization of a nerve transfer with an end-to-side repair, for supercharging a traditional reconstructive procedure of a proximally

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injured nerve. The recently acquired comprehensive knowledge of the internal topography of the peripheral nerves has expanded the applications of nerve transfer procedures.[3]

Distal to the elbow joint, the fascicular architecture of the ulnar nerve is discrete, and it is surgically traceable. Conversely, at a more proximal level, the fascicles are intricately intertwined. Besides, the ulnar nerve gives no significant branches proximal to the elbow joint. However, the accepted procedures for the surgical management of ulnar nerve injuries fail to address these anatomical factors.[4,5]

The current literature lacks a solid treatment algorithm for the management of ulnar nerve transection which would be crucial for reproducible improved clinical results and finely tuned research with fewer confounders. In this study, we propose a simplified algorithmic approach to the management of ulnar nerve injuries (Sunderland grade V), based on the updated knowledge of its internal topography and a prudent application of revolutionary supercharge end-to-side transfer techniques.

PATIENTS AND METHODS

A prospective observational study of 110 patients diagnosed with ulnar nerve transection (Sunderland grade V injury) was conducted at the Department of Plastic and Reconstructive Surgery, Tanta University, between 2013 and 2018. The proposed algorithm was applied and used for the surgical management of all patients included in the study.

Patients

Inclusion criteria:
- All patients diagnosed with ulnar nerve injury (Sunderland grade V), at any level, who had presented within 1 week of sustaining the injury.
  Exclusion criteria:
- Pediatric age group (<18 years of age).
- Electrophysiological evidence of Martin-Gruber's anomaly.
- Concomitant injuries involving the median nerve, the radial nerve, or the brachial plexus.
- Delayed presentation (>1 week after sustaining injury).
- Comorbidities that could hamper the nerve healing process, for example, patients with diabetes mellitus.

Methods

The ulnar nerve injuries were categorized into 4 surgical zones. The eligible patients were managed according to the zone of injury. Each surgical zone exhibited characteristic anatomical features, which defined the unique surgical approach.

Surgical Zones of the Ulnar Nerve (Fig. 1)

Zone (I): Extends distal to the proximal hiatus of Guyon's canal.

Zone (II): Extends from the proximal hiatus of Guyon's canal to the proximal border of the pronator quadratus (PQ).

Zone (III): Extends from the proximal border of the PQ to the first motor branch of the ulnar nerve.

Zone (IV): Extends proximal to the first motor branch of the ulnar nerve.

Surgical Management Strategy (Fig. 2)

Zone (I) Injuries

These were managed with primary neurorrhaphy or with an autogenous nerve graft whenever a tension-free nerve repair was impossible. An epineurial pattern of repair was used (Fig. 3A).

Zone (II) Injuries

A primary neurorrhaphy or an autogenous nerve graft was performed to repair these injuries. The motor and sensory components of the ulnar nerve were isolated before the group fascicular pattern repair was carried out (Fig. 4).

Zone (III) Injuries

An anterior transposition of the ulnar nerve was performed routinely in these patients, as a prerequisite for a tension-free primary repair or a shorter-cable graft (Fig. 5A). A primary neurorrhaphy or an autogenous nerve graft was performed, after isolation of the motor and sensory components (Fig. 5B and C). Identification of motor and sensory components was based on the knowledge of the internal topography of the ulnar nerve at this level with the motor component being dorsal and central in relation to the sensory components. A longitudinal slit was created at the epineurium of the ulnar nerve under the operating microscope to find the plane between the 2 superficial sensory components. A meticulous microdissection through this plane was performed to expose the motor component.

A group fascicular pattern repair was also undertaken (Fig. 3B). Additionally, baby-sitting of the motor component of the ulnar nerve was performed via an end-to-side supercharged transfer of the anterior interosseous nerve (AIN), which innervates the PQ muscle, to the motor component of the ulnar nerve (Fig. 5D).

Zone (IV) Injuries

An anterior transposition was the very first procedure performed in such injuries. Thereafter, a primary neurorrhaphy or an autogenous nerve graft was executed using an epineurial repair process (Fig. 6). A supercharged end-to-side transfer of the AIN (to PQ) to the motor component of the ulnar nerve was also performed. Finally, a flexor digitorum superficialis tenodesis was performed in all these cases.

In all patients, irrespective of the zone of injury, a decompression of the deep motor branch of the ulnar nerve was conducted within Guyon's canal (Fig. 7).

Postoperative Care

Postoperatively, the affected limb in all patients was splinted using a bulky soft dressing for 3 weeks while maintaining the wrist in 20–30 degrees flexion, the metacarpophalangeal joint at 60 degrees, and the interphalangeal joints in extension. A pulsed magnetic field therapy was initiated 2 days after surgery. At 2 weeks, during suture removal, the patients were instructed in edema and scar management techniques. At 4 weeks, motor rehabilitation exercises including passive movements of the fingers and wrist, active finger movements, electrical stimulation of the deinnervated musculature, and pinching exercises during resisted forearm pronation were initiated.
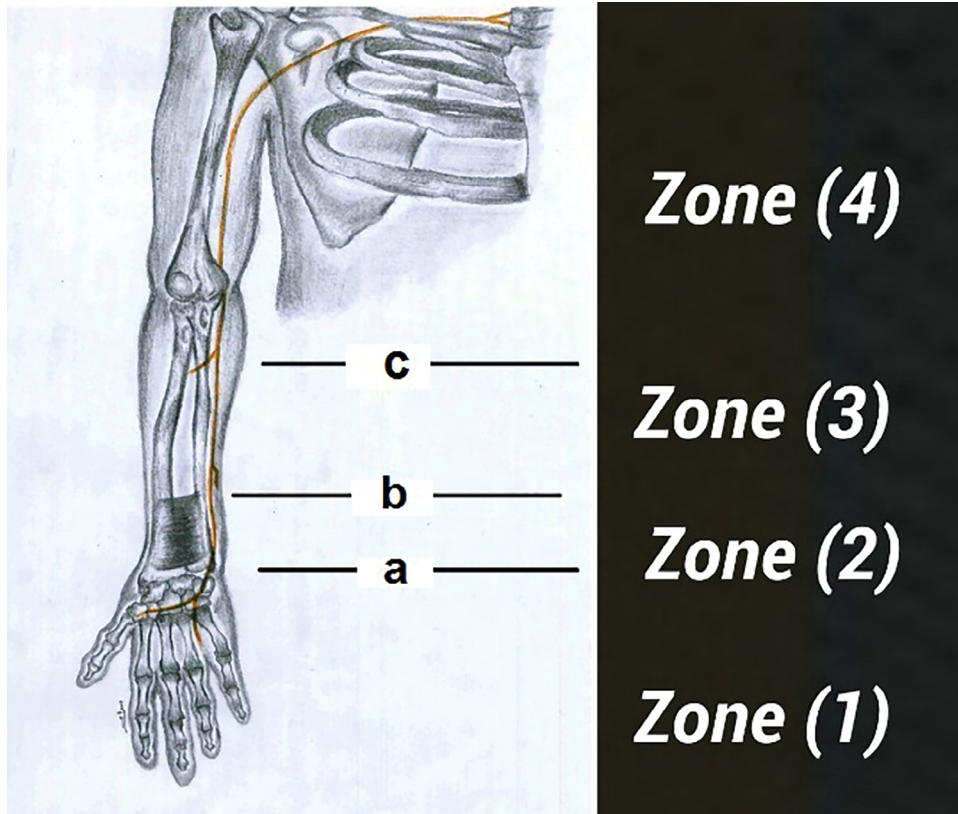
Fig. 1. Surgical zones of the ulnar nerve. A, The proximal border of Guyon's canal. B, The proximal border of the pronator quadrates. C, The first motor branch of the ulnar nerve.
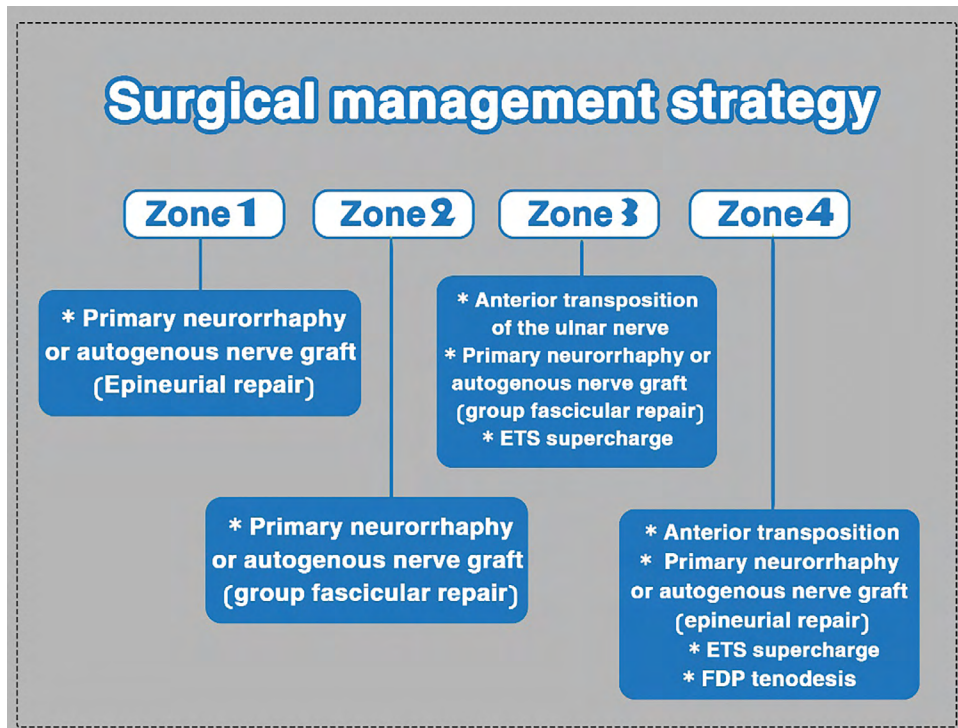

Fig. 2. Algorithm of surgical management of ulnar nerve injuries. FDP, flexor digitorum profundus; ETS, end to side transfer.
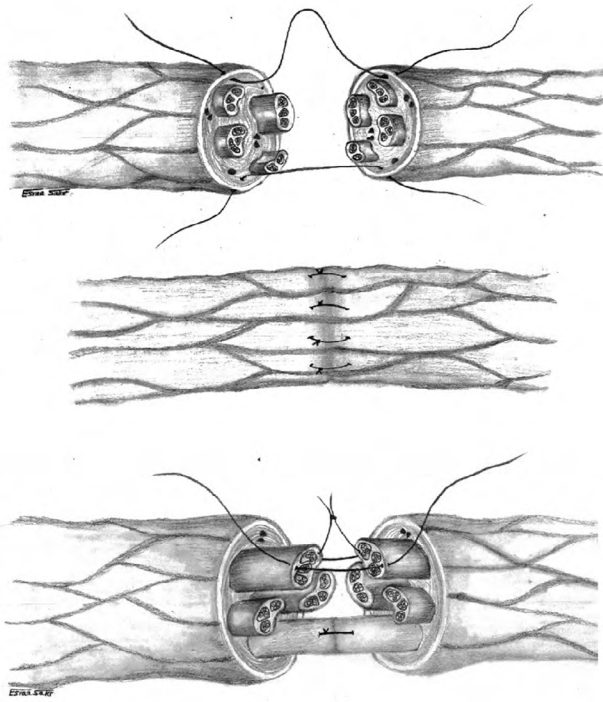
Fig. 3. Patterns of nerve repair. A, Epineurial repair. B, Group fascicular repair.
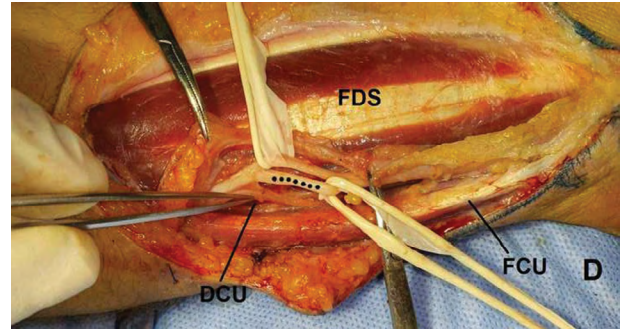

Fig. 4. The internal topography of the left ulnar nerve at zone II. *The motor component is dotted in black, D, distal; DCU, dorsal ulnar cutaneous nerve; FCU, flexor carpi ulnaris muscle; FDS, flexor digitorium superficialis muscle.

Whenever a transfer technique was planned, we ensured that the concerned patient was educated and counseled regarding the muscles involved, with an emphasis on the relationship between the recipient and the donor muscles. Postoperatively, repetitive forearm pronation exercises were encouraged in all patients, as an early activation of the donor muscle was paramount. The next step was to activate donor and recipient muscles at the same time in a repetitive pattern. These exercises were aimed at facilitating the cortical re-education and remapping of the transferred nerve.

Study Measures

The following clinical information and demographic data of all patients who met the inclusion criteria were collected—age, handedness, occupation, smoking index, comorbidities, date of sustaining injury, surgical date, details of the procedure, and the date of clinical or electromyographic recovery.

The recovery of the ulnar intrinsic functions following surgery was defined by an improvement of at least 2 of the 5 following signs from the baseline: an ability to flex the metacarpophalangeal joints without proximal interphalangeal joint flexion (achieving an intrinsic-plus position), a negative Froment's sign, resolution of the clawing deformity, a negative Wartenberg's sign, and a return of the ability to cross fingers.

We planned a follow-up over 24 months, with regular monthly visits. During every visit, the following data were collected for each patient:

- Recording the clinical signs of ulnar nerve recovery.
- Manual muscle strength testing using Medical Research Council (MRC) Grading System for the first dorsal interosseous muscle (FDI).
- The Disabilities of the arm, shoulder, and hand measure (DASH), which is a 30-item questionnaire, assessing patient-reported disability of the upper extremity. The original sheet was translated into Arabic, to ensure an accurate comprehension. The itemized responses were allocated a scoring system from 0 to 100. A higher score indicated a greater disability.
- Key pinch strength using a pinch dynamometer.
- Grip strength using a hand dynamometer.

An electrophysiological study was performed at 3-month intervals to trace the appearance of motor unit potentials (MUPs) in the flexor digitorum superficialis and to confirm the functionality of the nerve transfer techniques used in zone (III) and (IV) ulnar nerve injuries.

RESULTS

A total of 110 patients were enrolled in the study and were categorized into 4 cohorts according to the zone of injury. The zone (I) and zone (II) cohorts had 30 patients each, whereas zones (III) and (IV) groups each included 25 patients. The demographics data and the data on the frequency of cable graft use were recorded for all patients (Table 1). Of all patients, 12% developed wound complications including minor dehiscence and cellulitis which were managed conservatively.

The preoperative baseline and the final postoperative DASH scores, key pinch strength, and hand grip strength of each cohort were also systematically recorded (Table 2). Also, the final FDI muscle strength according to the MRC scale was noted for all patients (Table 3) (Fig. 8). We found that 79.9% and 93.9% of the patients attained an FDI muscle power grade >3 on the MRC scale, in zone (I) and zone (II) cohorts, respectively. Astonishingly, 84% of the patients with zone (III) and (IV) injuries also recovered the same degree of muscle power. (**See** Video [**online**], which displays clinical signs of recovery of the left ulnar nerve after zone III injury.
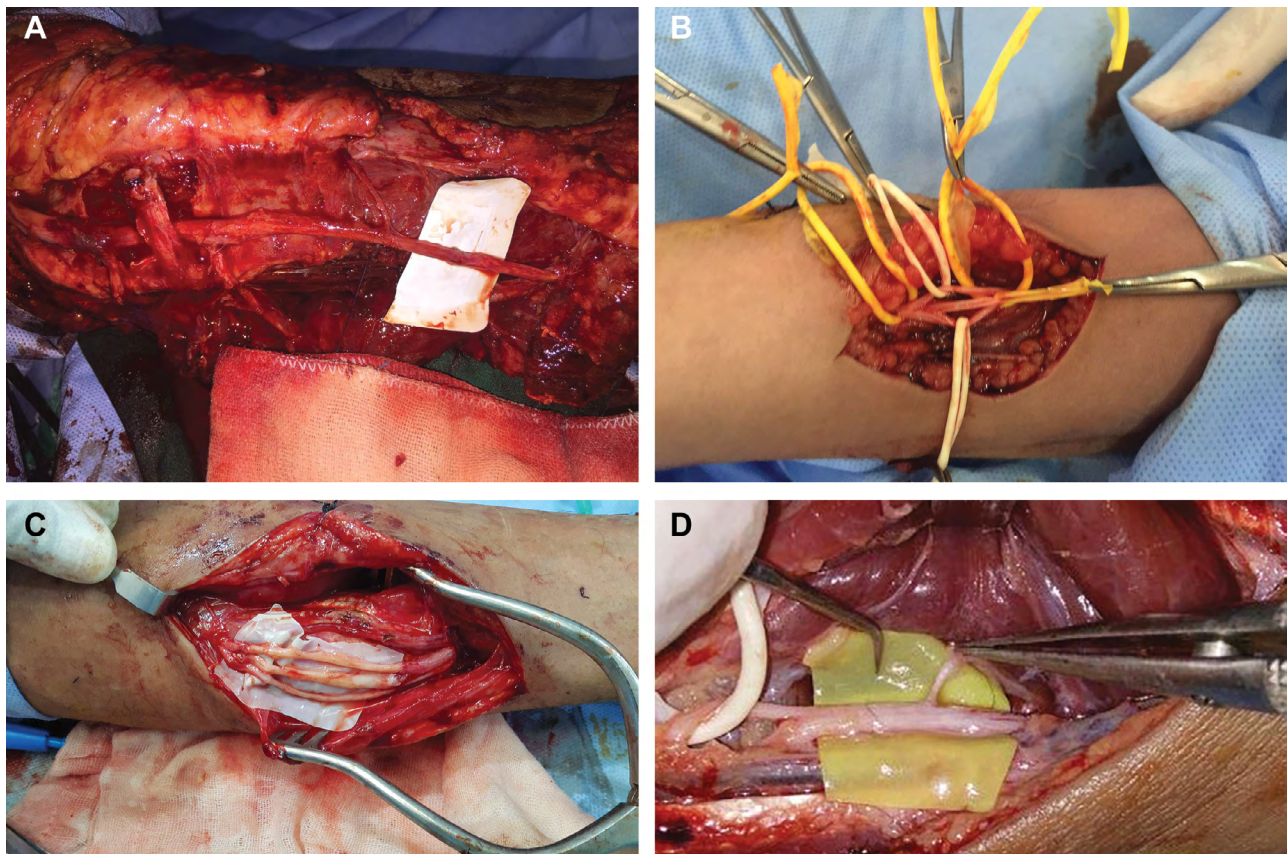
Fig. 5. Zone III management. A, Anterior transposition of the left ulnar nerve. D, distal; M, the medial epicondyle. +:right ulnar nerve,*:fascial flap is performed to hold the nerve in its new position. B, Isolation of the motor and sensory components of the left ulnar nerve at zone III. C, *Cable* graft (sural nerve) using fascicular pattern of repair of the right ulnar nerve. D, End-to-side supercharge AIN to the motor component of the right ulnar nerve. The motor component is dotted in black.
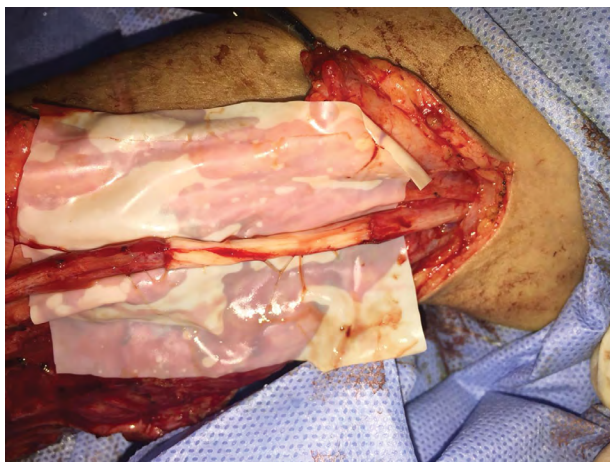

Fig. 6. Zone IV management. Cable graft (sural nerve) using epineurial pattern of repair.

Electrophysiological Analysis

We traced the true axonal regeneration of the injured nerve over time, by looking for the nascent MUPs. The test was conducted by stimulating the median nerve and detecting the reactive electrophysiological changes at the FDI. Remarkably, the reconstructed ulnar nerves with zone (III) and (IV) injuries exhibited an early axonal regeneration, comparable to that seen in nerves with zone (I) and (II) injuries. On average, we detected the nascent MUPs in the third month in patients with zone (I) injury, whereas patients with zone (II), (III), and (IV) injuries demonstrated the initial signs of regeneration within 4–6 months of the reconstruction.

Supplemental Digital Content 1 demonstrates an example of a successful end-to-side transfer of the AIN to the ulnar motor nerve in zone (III) injuries. A stimulation of either the ulnar or the median nerve in such patients resulted in an activity at the FDI, denoting dual innervation. (**See figure, Supplemental Digital Content 1**, which displays nerve conduction study reveals a successful end to side supercharge transfer, http://links.lww.com/PRSGO/B235.)

DISCUSSION

The development of intrinsic hand musculature has bestowed humans with skills and dexterity which have forged our civilization. A paralysis of the intrinsic muscles of the hand as seen in ulnar nerve injuries is severely debilitating, with an adverse impact on the patient's hand grip strength, key pinch strength, and global hand functions. Compared with the other major upper extremity nerves
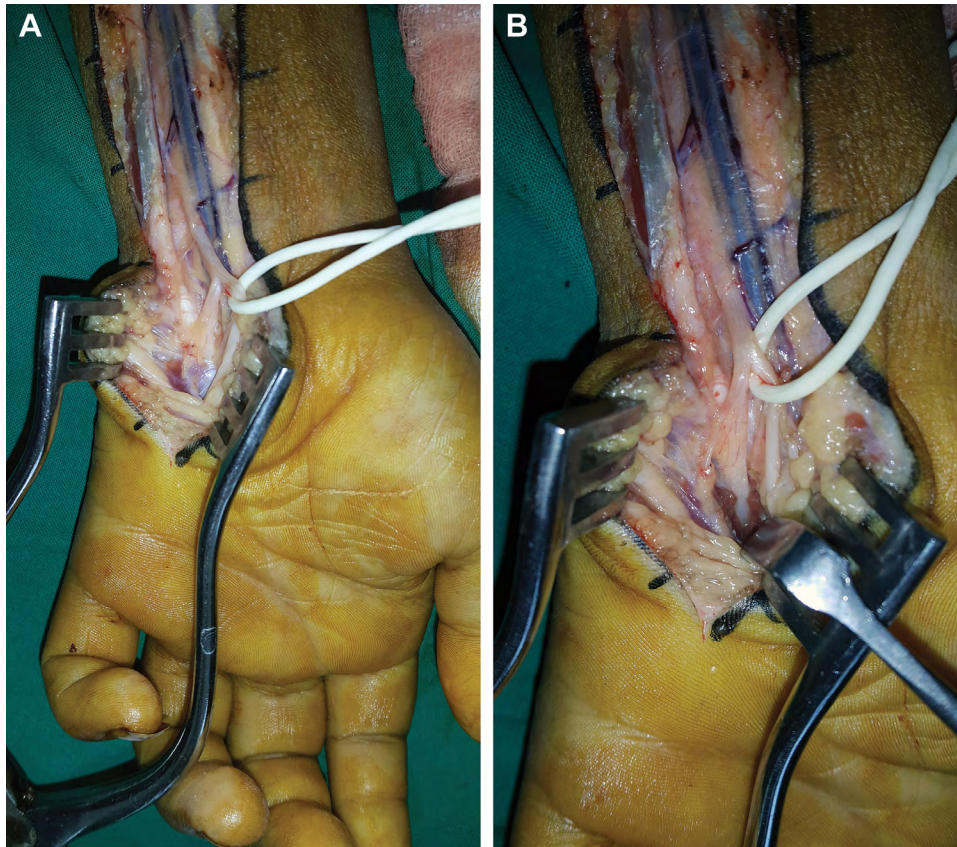
Fig. 7. Decompression of the deep motor branch of the ulnar nerve within Guyon's canal. A, Before decompression. B, After decompression.

Table 1. Demographics of the Study Population and Frequency of Cable Graft Utilization

|	Zone (I), N = 30	Zone (II), N = 30	Zone (III), N = 25	Zone (IV), N = 25
No. males	27	29	23	24
Mean age, y	30.4 ± 8.46	32.13 ± 8.26	30.64 ± 9.18	31.12 ± 9.71
Right dominant hand	22	28	25	23
Smoking	25	29	25	24
Manual workers	21	26	20	22
Cable grafts	3	7	5	8

Table 2. Preoperative and Postoperative Mean DASH Score, Mean Key Pinch Strength, and Mean Hand Grip Strength at the Time of Final Evaluation after 2 Years of Surgery

	Preoperative	Postoperative	t-test	*P*
Zone I				
Mean DASH score	55.28 ± 11.7	34.72 ± 3.5	9.221	<0.0001*
Mean key pinch strength, lb	6.96 ± 3.8	11.2 ± 3.1	4.738	<0.0001*
Mean hand grip strength, lb	30.88 ± 6.9	46.64 ± 9.4	7.412	<0.0001*
Zone II				
Mean DASH score	58.3 ± 10.5	37.1 ± 6.4	9.443	<0.0001*
Mean key pinch strength, lb	5.8 ± 4.1	11.5 ± 4.2	5.319	<0.0001*
Mean hand grip strength, lb	28.7 ± 4.3	45.33 ± 7.1	10.973	<0.0001*
Zone III				
Mean DASH score	55.28 ± 11.79	34.72 ± 3.51	7.692	0.0001*
Mean key pinch strength, lb	6.96 ± 3.84	11.20 ± 3.15	5.611	0.0001*
Mean hand grip strength, lb	30.88 ± 6.98	46.64 ± 9.42	5.644	0.0001*
Zone IV				
Mean DASH score	55.76 ± 11.69	40.64 ± 8.95	4.767	0.0001*
Mean key pinch strength, lb	6.96 ± 3.84	9.68 ± 3.27	3.613	0.0001*
Mean hand grip strength, lb	30.88 ± 6.98	39.56 ± 8.12	4.018	0.0001*

*P value <0.05 = significance.

Table 3. FDI Muscle Strength According to MRC Scale

Final FDI MRC Grade	Zone (I) Patients (%)	Zone (II) Patients (%)	Zone (III) Patients (%)	Zone (IV) Patients (%)
0	1 (3.3)	0	1 (4)	0
1	3 (10)	2 (6.6)	3 (12)	3 (12)
2	2 (6.6)	0	0	1 (4)
3	10 (33.3)	13 (43.3)	10 (40)	9 (36)
4/5	14 (46.6)	15 (50)	11 (44)	12 (48)
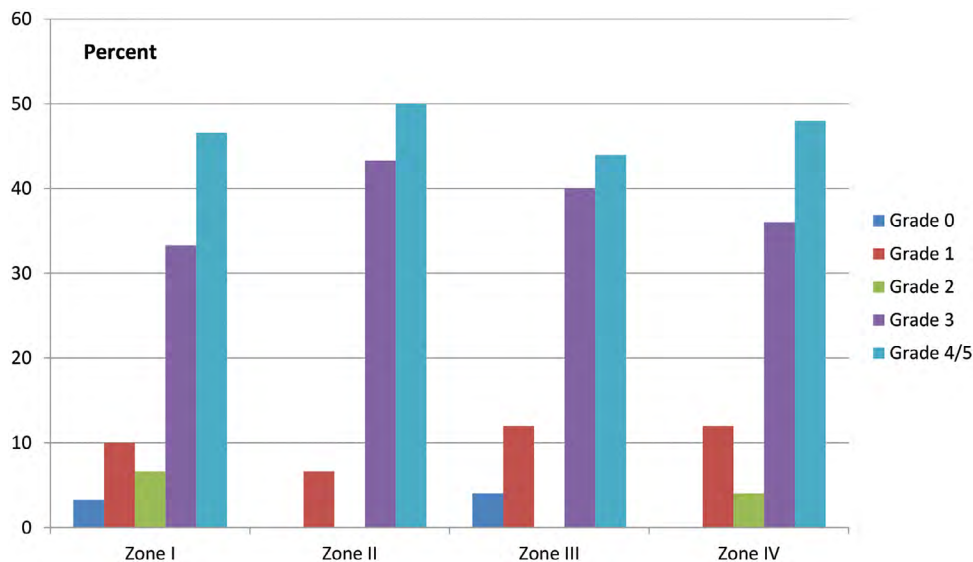
Fig. 8. Postoperative improvement of the muscle strength of the FDI according to MRC scale.

(median and radial), the treatment of ulnar nerve injuries has reportedly always had a poor functional outcome, regardless of the level of injury. A meta-analysis of 23 published studies found that ulnar nerve injuries had a 71% lesser chance of motor recovery as compared with median nerve injuries.[6]

The current system of classification categorizes ulnar nerve injuries into high and low injuries. In high injuries occurring at or above the level of elbow, reinnervation time is usually >1 year, making it impossible to achieve a timely reinnervation of the intrinsic muscles of the hand in most circumstances. Also, current surgical management techniques disregard the intricate ulnar nerve anatomy, which varies along its long course through the upper extremity. Therefore, recently, researchers suggested that an application of contemporary transfer techniques, that is, either end-to-end or end-to-side transfer could be attempted to achieve better results.

This study presents an algorithm for the judicious management of transecting ulnar nerve injuries (Sunderland grade 5), based on the updated knowledge of internal topography of the ulnar nerve with an additional implementation of nerve transfer techniques, when applicable. Ulnar nerve injuries were assorted into 4 surgical zones (I–IV) based on 3 fixed anatomical landmarks: the proximal hiatus of Guyon's canal, the proximal border of PQ, and the first motor branch of the ulnar nerve.

The zone (I) cohort included patients with nerve injury distal to the proximal hiatus of Guyon's canal. In this surgical zone, we encountered damage to pure sensory or motor branches of the ulnar nerve, with an involvement of the surrounding tissues. Consequently, conventional nerve reconstruction techniques such as primary neurorrhaphy or nerve grafting with an epineurial pattern of repair were performed.

The zone (II) group comprised patients with nerve injuries between the proximal hiatus of Guyon's canal and the proximal border of the PQ. This segment of the ulnar nerve forms the main trunk, before giving off terminal branches within the Guyon's canal. Nevertheless, its internal topography was well known, and it was easy to dissect the motor and sensory components of the nerve. With the target tissues in proximity, the injuries were repaired using primary neurorrhaphy or cable grafts in group fascicular pattern, following a meticulous dissection and isolation of the individual motor and sensory components.

The zone (III) group included patients with injuries between the proximal border of the PQ and the first motor branch of the ulnar nerve, close to the elbow joint. The nerve can be dissected into motor and sensory components at this position; however, these injuries are relatively distant to the target tissues. Therefore, zone (III) injuries were managed by primary neurorrhaphy or a cable graft repair in a group fascicular pattern combined with a supercharged end-to-side transfer of the AIN to the motor component of the ulnar nerve. An ulnar nerve transposition was routinely preferred to a tension-free neurorrhaphy or a shorter graft, in these patients.

The final functional outcomes of injuries at zones (I), (II), and (III) are collectively comparable to those reported in earlier studies of low ulnar nerve injuries. However, this comparison is not completely valid because of absence of an accurate distinction between the levels of injury, therefore leaving the very definition of "low" ulnar nerve injuries unclear. Many earlier studies have counted all injuries sustained below the elbow joint as low injuries. Some studies defined only the injuries at the wrist and distal forearm as low injuries whereas proximal forearm injuries were defined as intermediate injuries.[7,8] However, unlike our study, no previous researchers have reported an application of nerve transfer techniques in ulnar nerve injuries sustained distal to the elbow.

Murovic[9] reported that 82% and 76% of their patients had good motor recovery (MRC grade ≥3), following primary repair of the ulnar nerve at elbow/forearm and wrist level, respectively. Vordemvenne et al[10] described a functional recovery of 60% in 35 patients with complete transection of the ulnar nerve. Flynn and Flynn[11] documented only 23% motor recovery in 40 patients treated for ulnar nerve injuries. Secer et al[8] reported 49.8% good motor recoveries in patients with low ulnar nerve palsies caused by gunshot wounds.

Compared with these results, we achieved better outcomes in 79.9%, 93.9%, and 84.4% of our patients with zone (I), (II), and (III) injuries, respectively, attaining a grade of motor power ≥3 during the final evaluation, 24 months after repair. Besides, the key pinch and the hand grip strength and the patient-reported outcomes had also improved remarkably.

Our better results may be due to the utilization of the unique anatomical features of each surgical zone of the ulnar nerve, along with the use of the supercharged end-to-side transfer in patients with zone (III) injuries, with an additional routine decompression of the deep motor branch within Guyon's canal.

Kristen et al[12] proposed that motor ulnar nerve decompression improved the functional outcomes by evading ischemic injury, which occurs inevitably in regenerating nerves. Thus, a motor component decompression was typically conducted in all ulnar nerve injuries, regardless of the surgical zone involved.

The zone (IV) cohort encompassed patients with injuries proximal to the first motor branch of the ulnar nerve. The complex and inextricably intertwined internal topography of the ulnar nerve in this zone, combined with its increased distance from the target tissues presented a formidable treatment challenge. Therefore, zone (IV) injuries were managed with primary neurorrhaphy or an epineurial pattern cable graft repair, and a supercharged end-to-side transfer of the AIN to the ulnar motor nerve. An anterior transposition of the ulnar nerve was performed to achieve a tension-free neurorrhaphy with a shorter graft. As paralysis of the FDP to the little and ring fingers was a characteristic feature, an FDP tenodesis was also routinely executed in these patients.

The zone (IV) injuries are equivalent to the higher level injuries that involve the infraclavicular, axillary, and brachial portions of the ulnar nerve. Although some authors declared that classic repair techniques completely failed to restore the motor functions of the small muscles of the hand,[2,3,13] other optimistic researchers have reported some motor recovery in their studies.

Roganovic and Pavlicevic[7] found that 22.2% of patients with high ulnar nerve injuries in his cohort recovered M3 motor power, whereas Secer et al[8] reported a more favorable outcome with 44% of his patients achieving similar recovery.

We preferred a supercharged end-to-side transfer of the AIN to the ulnar motor nerve over end-to-end transfer in zone (IV) injuries, for many reasons. First, numerous experimental studies declared no difference in the functional outcomes between both methods of repair.[14–16] Second, Kristen et al[12] and Baltzer et al[17] concluded that a supercharged end-to-side transfer improved the motor recovery of intrinsic muscles of a human hand with proximal ulnar nerve injuries. We also believed that an end-to-end transfer of AIN to the ulnar motor nerve did not utilize Martin-Gruber's anomaly (a naturally present communication between median and ulnar nerve), which could support the function of the intrinsic muscles of the hand. Besides, performing an end-to-end transfer precluded the recruitment of a significant number of parent axons in the reinnervation process.

This hypothesis was validated by the results of our study, wherein 84% of the zone (IV) cohort patients regained motor power grade ≥3 on the MRC scale. Also, key pinch strength and hand grip strength of the patients improved significantly. Moreover, the mean DASH score value plunged from 55.76 to 40.64, denoting a notable subjective improvement in the outcome, as experienced by the patients.

We chose to limit the application of this algorithm to adults in the first week of injury. Therefore, this management strategy should be examined in late presentations and patients younger than 18 years old. A potential limiting factor is the normal anatomical variation—early division of the ulnar nerve proximal to the Guyon's canal—which may be encountered at zone I and zone II; however, procedures for zone I injuries can be applied to the ulnar nerve branches wherever they exist. In this study, we did not encounter this issue.

The conventional classification of the ulnar nerve injuries into high and low injuries fail to address its varied internal topography along its course through the upper extremity. Our simplified algorithm accounted for this unique internal topography and the site of injury. We also confirmed the functionality of supercharge end-to-side AIN to ulnar motor nerve transfer in ulnar nerve transection at zone III and zone VI. Achieving astonishing results at these zones, supercharge end-to-side AIN to ulnar motor nerve transfer would replace the operation of end-to-end AIN to ulnar motor nerve transfer. Our results indicate that an implementation of this algorithm enhances the motor functional outcome in the surgical management of ulnar nerve injuries, and further investigation of this approach is warranted.

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