RESEARCH ARTICLE

Secondary Ulnar Nerve Reconstruction of High Ulnar Nerve Injuries: A Comparative Study of Sural Grafting and Anterior Interosseous Nerve Transfer

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Abstract

Objectives: High ulnar nerve injuries often cause severe functional impairment, and the best secondary repair method remains debated. This study compared the effectiveness of sural nerve grafting and anterior interosseous nerve (AIN) transfer following failed primary ulnar nerve repairs.

Methods: This retrospective cohort study included 42 patients with isolated high ulnar nerve injuries who required secondary surgical intervention. Patients were allocated to either the sural nerve grafting (n = 23) or AIN transfer (n = 19) group based on predefined clinical criteria. Motor and sensory functions were assessed using the British Medical Research Council (BMRC) grading system and a two-point discrimination (2PD) test. Grip and pinch strength were measured, and functional recovery was evaluated using the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire.

Results: The AIN transfer group exhibited significantly superior motor recovery, with 68.5% of patients achieving BMRC grades M4–M5, compared to only 17.4% in the sural grafting group (P = 0.03). Sensory recovery was also markedly better in the AIN group, with a higher proportion of patients reaching BMRC sensory grades S3–S4 (P = 0.04). Additionally, the AIN transfer group demonstrated significantly greater grip strength (30.1 ± 6.1 kg vs. 24.3 ± 5.2 kg; P = 0.03) and pinch strength (7.2 ± 1.5 kg vs. 5.8 ± 1.3 kg; P = 0.04). Improvement in DASH scores was more substantial in the AIN group (–26.6 ± 5.7 vs. –14.6 ± 4.3; P = 0.02), indicating better functional recovery. Although the AIN group showed a trend toward improved 2PD, the difference was not statistically significant (P = 0.18).

Conclusion: AIN transfer provides superior outcomes compared to sural nerve grafting for the secondary repair of high ulnar nerve injuries, demonstrating significantly enhanced motor and sensory recovery, grip and pinch strength, and overall functional improvement.

Level of evidence: III

Keywords: Anterior Interosseous Nerve, High Ulnar Nerve Injury, Nerve Graft, Nerve Transfer, Sural Nerve,

Introduction

Peripheral nerve injuries of the upper extremity, particularly those involving the ulnar nerve, remain a significant challenge in reconstructive surgery.[1,2] The ulnar nerve plays a crucial role in hand function by innervating the intrinsic muscles and providing sensation to the ulnar aspect of the hand.[3,4] Complete loss of ulnar nerve function typically results in significant disability, including diminished grip strength and the development of a claw-like deformity in the ring and little fingers.[5] Although various surgical techniques have been developed for nerve reconstruction, the outcomes following the repair of high ulnar nerve injuries remain suboptimal compared to those of other peripheral nerves in the upper extremity.[6-8]

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Traditional approaches to ulnar nerve reconstruction have primarily relied on direct nerve repair when possible or interpositional nerve grafting when a tension-free repair cannot be achieved.[9] However, nerve grafting presents several challenges, including donor site morbidity, the necessity for two coaptation sites, and diminished axonal regeneration across the graft.[10-12] Studies have shown that functional recovery following grafting for high ulnar nerve injuries is often incomplete, with only 56-73% of patients achieving useful motor recovery.[13-15] High ulnar nerve injuries frequently result in significant motor and sensory deficits, primarily due to the extensive regeneration distance required for axons to reach the intrinsic hand muscles before irreversible motor endplate atrophy occurs.[16,17] While traditional methods, such as sural nerve grafting, have shown limited efficacy in restoring motor function, particularly in proximal injuries, nerve transfer techniques, such as anterior interosseous nerve (AIN) transfer, offer distinct advantages.[16,18] The AIN transfer provides a closer axonal source to the target muscles, thereby reducing the reinnervation distance and expediting recovery.[19] Moreover, it bypasses the site of injury, minimizes donor site morbidity, and enhances motor recovery through precise fascicular alignment and 'double innervation' in supercharged configurations.[16,19] Consequently, AIN transfer demonstrates superior outcomes in motor strength, grip, and pinch function, as well as overall functional recovery compared to nerve grafting.[16,18] These findings underscore its potential as the preferred technique for addressing high ulnar nerve injuries.

Recently, nerve transfer techniques have emerged as alternative options for reconstruction. This concept involves redirecting expendable donor nerve branches to reinnervate critical functions, typically performed closer to the target muscles.[20] This approach offers several theoretical advantages, including a single coaptation site, a shorter regeneration distance, and the ability to bypass the zone of injury.[21-23] The anterior interosseous nerve (AIN) transfer to the deep motor branch of the ulnar nerve has gained particular interest for treating high ulnar nerve injuries.[19,20]

Despite the increasing adoption of nerve transfers, there is ongoing debate about the optimal approach for reconstructing high ulnar nerve injuries.[20] Some studies have demonstrated superior outcomes with nerve transfers compared to grafting,[24] while others suggest comparable results between the two techniques.[25] Additionally, the criteria for selecting between grafting and transfer techniques remain incompletely defined.

The timing of surgical intervention also represents a critical consideration.[26] While early repair is generally preferred, many patients present for delayed reconstruction due to failed primary repairs or late referrals. Secondary repair introduces additional challenges, such as muscle atrophy and scarring, which can potentially affect functional recovery.[27-29] Understanding the relative efficacy of grafting and transfer techniques in the context of secondary repair is crucial for optimizing surgical decision-making.

The present study aimed to compare the outcomes of sural nerve grafting and anterior interosseous nerve transfer for the secondary repair of high ulnar nerve injuries. We hypothesized that nerve transfers would demonstrate superior motor recovery and functional outcomes compared to grafting techniques. These results may assist in informing surgical decision-making and establishing evidence-based criteria for technique selection in this challenging patient population.

Materials and Methods

Study Design and Setting

This retrospective cohort study evaluated the efficacy of secondary ulnar nerve repair using sural nerve grafting in comparison to AIN transfer. The study was conducted at a tertiary care university hospital in Isfahan, Iran, from January 2020 to March 2024. Ethical approval was obtained from the Institutional Ethics Committee (approval no. IR.MUI.MED.REC.1403.244). All procedures adhered to the ethical standards outlined in the Declaration of Helsinki.

Participants

All patients who underwent secondary ulnar nerve repair at our institution during the study period were included using a census sampling method. Eligible participants were adults over 18 years of age who had sustained a complete and isolated high ulnar nerve injury between the elbow and the axilla. To qualify for secondary repair, at least six months must have elapsed since the initial nerve repair, which involved direct end-to-end suturing without grafts or nerve transfer. Additionally, patients exhibited persistent functional deficits following the primary repair, as evidenced by the lack of nerve function recovery during preoperative clinical assessments.

The exclusion criteria were rigorously applied to ensure a homogeneous study population. Patients were excluded if their injuries involved other major nerves, such as the median or radial nerve, or if they had systemic conditions known to impair nerve healing, such as diabetes mellitus, peripheral vascular disease, or advanced neuropathy. Additional exclusion criteria included cognitive impairments or psychiatric conditions that could affect compliance with rehabilitation, significant musculoskeletal deformities, complex injuries necessitating simultaneous reconstruction of other tissues, and an inability to tolerate secondary surgery due to other health issues.

Surgical Methods

All secondary ulnar nerve reconstructions were performed under general anesthesia by a fellowship-trained hand surgeon and a peripheral nerve specialist (A.D.) to minimize inter-surgeon variability. The decision to employ either sural nerve grafting or AIN transfer was guided by predefined clinical criteria to ensure unbiased allocation.[30,31] Specifically, patients presenting with a nerve gap exceeding 5 cm or those exhibiting painful neuromas were directed toward AIN transfer.[28] Conversely, individuals with a nerve gap shorter than 5 cm and without neuroma formation underwent sural nerve grafting.[31-33] The measurement of the nerve gap and the presence of neuromas were confirmed intraoperatively through direct visualization and palpation.

For the AIN transfer procedure, an incision was made to encompass the distal forearm and the region of Guyon's canal, allowing for meticulous identification of both the deep and superficial divisions of the ulnar nerve at the wrist.[34] The motor division of the ulnar nerve was traced proximally through intraneural dissection, whereas the AIN was accessed by laterally dissecting the flexor tendons over the pronator quadratus muscle. A tension-free, direct end-to-end anastomosis between the motor division of the ulnar nerve and the distal segment of the AIN was achieved using 10-0 nylon sutures.[16,19] In the sural nerve grafting technique, the sural nerve was harvested from the posterior calf through a small incision located posterior to the lateral malleolus. The harvested nerve was carefully isolated and sectioned into multiple cable grafts, each extending approximately 10% beyond the measured nerve gap to accommodate individual anatomical variations and minimize tension. These grafts were then sutured to the proximal and distal stumps of the injured ulnar nerve using 9-0 or 10-0 nylon epineural sutures.[34,35] In both procedures, meticulous microsurgical techniques were employed to ensure accurate fascicular alignment and optimal conditions for nerve regeneration. Hemostasis was maintained, and surgical incisions were closed in the anatomical layers, with suction drains placed as necessary.

Rehabilitation

Postoperative rehabilitation was implemented as a structured and essential phase of recovery to ensure optimal motor and sensory restoration following the repair of a high ulnar nerve injury. In accordance with established protocols, the affected limb was immobilized with a splint for approximately four weeks to protect the surgical site, stabilize the repair, and support graft integration.[36]

A standardized rehabilitation program was initiated under professional supervision and included evidence-based interventions. Daily low-intensity electrical stimulation was applied to the affected limb, as research has demonstrated its efficacy in promoting nerve regeneration and muscle re-education.[37] Additionally, gentle passive range-of-motion exercises were initiated immediately post-surgery to prevent joint stiffness and maintain mobility. These exercises were performed multiple times daily, with gradually increasing intensity over the first six weeks based on validated tissue healing protocols.[38]

Following the immobilization phase, a personalized rehabilitation protocol was developed based on the established recovery parameters. Progressive resistance training was introduced at 6 to 8 weeks post-surgery, focusing on strengthening both intrinsic and extrinsic hand muscles in accordance with evidence-based guidelines for peripheral nerve rehabilitation.[39] This training utilized resistance tools such as hand grippers and elastic bands to rebuild grip strength, pinch strength, and dexterity for fine motor tasks.[37]

Functional training was integrated using validated therapeutic approaches.[40] Tasks included gripping objects of varying sizes, performing fine motor activities, and engaging in simulated occupational tasks. Occupational therapy further supported these efforts by assisting patients in adapting reinnervated muscles to daily functional demands, thereby improving their independence in activities of daily living.[41,42]

Outcome Measures

The outcomes were assessed by two orthopedic specialists who were blinded to the type of surgical intervention received. Follow-up evaluations were conducted at one month, three months, six months, and annually, with the final assessment at 24 months post-surgery. Throughout the follow-up period, patients were continuously monitored for potential complications at the graft or transfer sites to ensure a comprehensive outcome assessment.

Motor and sensory functions were assessed using the British Medical Research Council (BMRC) grading system.[17,43,44] Motor recovery was categorized from M0 (no muscle contraction) to M5 (normal muscle strength), with evaluations conducted at each follow-up to monitor improvements. Sensory recovery was similarly assessed using the BMRC sensory scale, which ranges from S0 (no sensation) to S4 (normal sensation). Additionally, the two-point discrimination (2PD) test was administered to quantitatively evaluate sensory nerve regeneration. In this test, patients were instructed to distinguish between two points of contact at standardized intervals using a calibrated instrument.[45,46]

Grip and pinch strength were evaluated during follow-up assessments using standardized methods. Grip strength was measured with a Jamar dynamometer set to the second handle position, while pinch strength was assessed using a pinch gauge. Each patient completed three trials for each measurement, and the highest value was recorded for analysis.[47,48]

Functional recovery was further quantified using the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire, a validated 30-item self-report instrument that assesses physical function and symptoms related to upper-extremity musculoskeletal disorders. DASH scores range from 0 to 100, with higher scores indicating greater disability.[49,50]

Statistical Analysis

All data analyses were performed using SPSS software (version 26.0; IBM Corp., Armonk, NY, USA). Descriptive statistics are presented as means and standard deviations for continuous variables and as frequencies and percentages for categorical variables. The Shapiro-Wilk test was used to assess the normality of continuous variables. For variables that exhibited a normal distribution, such as age and body mass index (BMI), comparisons between groups were conducted using independent t-tests. For variables with a non-normal distribution, including grip strength, pinch strength, and DASH scores, the Mann-Whitney U test was employed. Categorical variables were compared using either the chi-square test or Fisher's exact test, as appropriate. A significance level of $P < 0.05$ was set for established analyses. There were no missing data; thus, an intention-to-treat analysis was not necessary.

Results

Patient Demographics and Clinical Characteristics

Of the 223 patients initially screened, 181 were excluded for the following reasons: concurrent nerve injuries (63), systemic conditions (34), musculoskeletal deformities or complex tissue injuries (27), cognitive or psychiatric impairments (32), other health conditions that prevent surgery (25), prior sural graft or AIN transfer (20), and incomplete records (10) [Figure 1]. The remaining 42 patients were allocated to either the sural nerve grafting group (n = 23) or the AIN transfer group (n = 19).

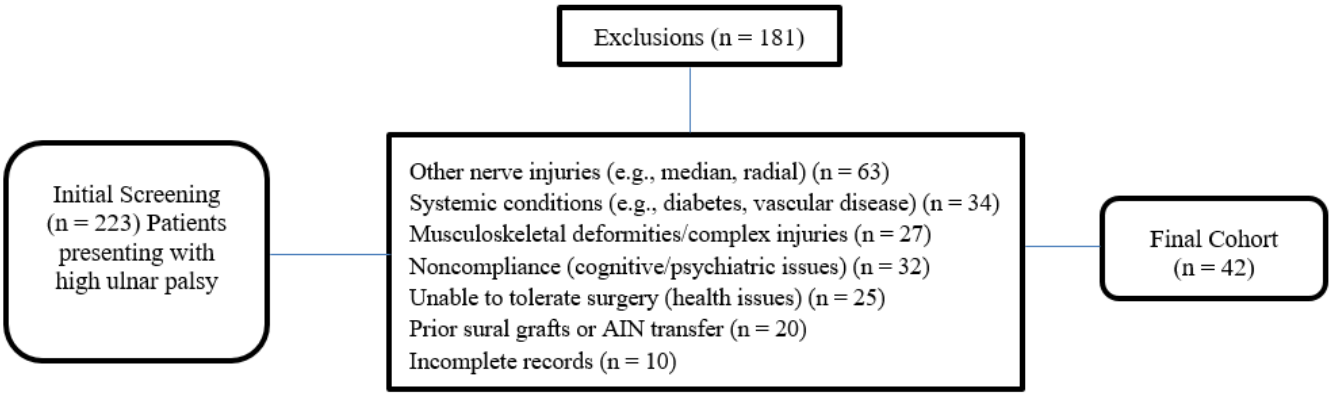

Figure 1. The patient selection flowchart illustrating the screening process, exclusion criteria, and final cohort allocation for the study

The mean age was 34.7 ± 8.3 years in the sural nerve grafting group and 32.9 ± 7.8 years in the AIN transfer group, with no significant difference between the groups (P = 0.45). The sex distribution was comparable, with males comprising 73.9% of the grafting group and 73.7% of the AIN transfer group (P = 0.87). The mean BMI was 24.8 ± 3.2 kg/m^2 in the grafting group and 25.1 ± 3.4 kg/m^2 in the AIN transfer group (P = 0.76). The dominant hand was affected in 56.5% of the grafting group and 57.9% of the AIN transfer group (P = 0.89).

The average time from initial injury to secondary repair was 8.2 ± 1.8 months for the sural nerve grafting group and 7.8 ± 1.6 months for the AIN transfer group (P = 0.54). The follow-up duration averaged 25.6 ± 6.2 months in the grafting group and 24.7 ± 5.0 months in the AIN transfer group (P = 0.56). The mechanisms of injury were comparable between the groups, with sharp lacerations occurring in 43.5% of the grafting group and 47.4% of the AIN transfer group (P = 0.84). Other causes of injury included motor vehicle accidents, occupational injuries, crush injuries, and miscellaneous injuries. The level of injury was predominantly at the elbow, affecting65.2% of the grafting group compared to 63.2% of the AIN transfer group. Distal arm injuries were observed in 21.7% of the grafting group versus 21.1% of the AIN transfer group, while proximal arm injuries were noted in 13.0% versus 15.8% of patients, respectively (P = 0.81) [Table 1].

Table 1. Demographic and Clinical Characteristics

Characteristic	Sural Nerve Grafting (n = 23)	AIN Nerve Transfer (n = 19)	*P*-value
Age (years), (Mean ± SD)	34.7 ± 8.3	32.9 ± 7.8	0.45
Male, n (%)	17 (73.9%)	14 (73.7)	0.87
BMI (kg/m^2), (Mean ± SD)	24.8 ± 3.2	25.1 ± 3.4	0.76
Dominant hand affected, n (%)	13 (56.5%)	11 (57.9%)	0.89
Time to secondary repair (months), (Mean ± SD)	8.2 ± 1.8	7.8 ± 1.6	0.54
Follow-up Duration (months), (Mean ± SD)	25.6 ± 6.2	24.7 ± 5.0	0.56
Initial Injury Mechanism, n (%)			
Sharp Laceration (knife or glass)	10 (43.5%)	9 (47.4%)	
Motor Vehicle Accidents	3 (13.0%)	4 (21.1%)	
Occupational Injuries	5 (21.7%)	3 (15.8%)	0.84
Crush Injury	3 (13.0%)	2 (10.5%)	
Other Injuries	2 (8.7%)	1 (5.3%)	

Table 1. Continued

Level of Injury, n (%)			
Elbow	15 (65.2%)	12 (63.2%)	
Distal Arm	5 (21.7%)	4 (21.1%)	0.81
Proximal Arm	3 (13.0%)	3 (15.8%)	

Motor Function Outcomes

Motor function was evaluated using the BMRC grading system, which ranges from M0 (no muscle contraction) to M5 (normal muscle strength). In the sural nerve grafting group, 26.1% of patients were classified as M0–M2, indicating minimal to no recovery, whereas 43.5% achieved M3, demonstrating moderate recovery. Only 17.4% reached M4, indicating good recovery, and none attained M5. In contrast, 10.5% of patients in the AIN transfer group were graded as M0–M2, with a higher proportion achieving M4 (47.4%) and M5 (21.1%), indicating better overall recovery. The difference in motor function recovery between the two groups was statistically significant (P = 0.03) [Table 2].

Table 2. Comparison of Motor Function Outcomes Between Groups

Motor Scale (BMRC), n (%)	Sural Nerve Grafting (n = 23)	AIN Transfer (n = 19)	P-value
M0-M2	6 (26.1%)	2 (10.5%)	
M3	10 (43.5%)	4 (21.1%)	0.03*
M4	4 (17.4%)	9 (47.4%)	
M5	0 (0%)	4 (21.1%)	

*Statistically significant difference (P < 0.05)

Sensory Function Outcomes

Sensory recovery was assessed using the BMRC sensory scale, which ranges from S0 (no sensation) to S4 (normal sensation), along with the 2PD test. In the sural nerve grafting group, 30.4% of patients exhibited poor sensory recovery (S0–S2), whereas 39.1% reached S3, indicating protective sensation. Only 13.0% achieved S3+, and none reached S4. In contrast, the AIN transfer group had 15.8% of patients classified as S0–S2, whereas a higher proportion reached S3+ (31.6%) and S4 (21.1%). The difference in sensory recovery between the two groups was statistically significant (P = 0.04). Although the AIN transfer group demonstrated a trend toward improved 2PD outcomes, with 57.9% achieving 2PD ≤ 10 mm compared to 34.8% in the grafting group, these differences were not statistically significant (P = 0.18) [Table 3].

Table 3. Comparison of Sensory Function Outcomes Between Groups

Parameter	Sural Nerve Grafting (n = 23)	AIN Nerve Transfer (n = 19)	P-value
Sensory Scale (BMRC), n (%)			
S0-S2	7 (30.4%)	3 (15.8%)	
S3	9 (39.1%)	6 (31.6%)	0.04*
S3+	3 (13.0%)	6 (31.6%)	
S4	0 (0%)	4 (21.1%)	
Two-Point Discrimination (2PD), n (%)			
2PD ≤ 6 mm	0 (0%)	2 (10.5%)	
2PD 7-10 mm	8 (34.8%)	9 (47.4%)	0.18
2PD > 10 mm	15 (65.2%)	8 (42.1%)	

*Statistically significant difference (P < 0.05)

Functional Outcomes and Quality of Life

Functional recovery, as measured by grip and pinch strength, was significantly greater in the AIN transfer group compared to the sural nerve grafting group. The mean grip strength in the grafting group was 24.3 ± 5.2 kg, while in the AIN transfer group was 30.1 ± 6.1 kg (P = 0.03). The mean pinch strength in the grafting group was 5.8 ± 1.3 kg compared to 7.2 ± 1.5 kg in the AIN transfer group (P = 0.04) [Table 4].

The DASH questionnaire showed a significantly greater improvement in the AIN transfer group. The mean improvement in the DASH score was −14.6 ± 4.3 in the sural nerve grafting group and −26.6 ± 5.7 in the AIN transfer group (P = 0.02). The final postoperative DASH scores were lower (indicating better function) in the AIN transfer group (28.5 ± 6.9) compared to the grafting group (39.7 ± 7.2; P = 0.02) [Table 5].

Table 4. Grip and Pinch Strength Outcomes in Study Groups

Parameter	Sural Nerve Grafting Group (Mean ± SD)	AIN Transfer Group (Mean ± SD)	P-value
Grip Strength (kg)	24.3 ± 5.2	30.1 ± 6.1	0.03*
Pinch Strength (kg)	5.8 ± 1.3	7.2 ± 1.5	0.04*

*Statistically significant difference (P < 0.05)

Table 5. Functional Improvement in DASH Scores

Parameter	Sural Nerve Grafting (Mean ± SD)	AIN Nerve Transfer (Mean ± SD)	P-value
Preoperative DASH score	54.3 ± 8.5	55.1 ± 9.1	0.78
Postoperative DASH score	39.7 ± 7.2	28.5 ± 6.9	0.02*
Improvement in DASH score	-14.6 ± 4.3	-26.6 ± 5.7	0.02*

*Statistically significant difference (P < 0.05)

Complications

No major complications were reported in either group of patients. Minor complications included transient numbness at the donor site in two patients (8.7%) in the sural nerve grafting group and in one patient (5.3%) in the AIN transfer group, with no significant difference between the groups (P = 0.68).

Discussion

This retrospective cohort study evaluated the efficacy of sural nerve grafting compared to AIN transfer for the secondary repair of high ulnar nerve injuries. The findings demonstrate that AIN transfer significantly outperforms sural nerve grafting in terms of motor and sensory recovery, grip and pinch strength, and overall functional improvement, as measured by the DASH questionnaire. These results provide compelling evidence to support the use of nerve transfer techniques in the reconstruction of complex high ulnar nerve injuries.

The superior motor recovery observed in the AIN transfer group is particularly noteworthy. A significantly higher proportion of patients achieved BMRC Grades M4 and M5 following AIN transfer (68.5%) compared to the sural nerve grafting group (17.4%) (P = 0.03). This finding aligns with existing literature suggesting that nerve transfers offer a more efficient means of reinnervating target muscles, especially in case of proximal nerve injuries where regeneration distances are substantial.[31,32] The AIN transfer provides a direct connection between a functioning donor nerve and the distal motor endplates of the ulnar nerve, thereby reducing both the axonal regeneration distance and the time required for recovery. This approach not only facilitates quicker reinnervation but also mitigates muscle atrophy associated with prolonged denervation.[28]

Moreover, the intrinsic anatomical and physiological compatibility between the AIN and the ulnar nerve may contribute to enhanced motor outcomes. Both nerves innervate muscles that are crucial for fine motor control of the hand, potentially allowing for better functional integration following the transfer.[17] The ability of the AIN transfer to preserve the cortical representation and pre-existing motor patterns could further enhance motor recovery, as suggested by studies on cortical plasticity following nerve transfers.[51,52]

Sensory recovery was notably more favorable in the AIN transfer group, with a higher percentage of patients achieving elevated BMRC sensory grades (S3+ and S4) (P = 0.04). Although the 2PD test did not reach statistical significance, this trend suggests that nerve transfer may provide superior sensory outcomes compared to grafting. This advantage may be attributed to the more precise coaptation of sensory fascicles in nerve transfers, which reduces mismatches and enhances the specificity of reinnervation.[30] Additionally, direct transfer avoids the potential for scar formation and neuroma development at the injury site, both of which can impede sensory recovery in nerve grafts.[35]

However, the present study also demonstrates that both techniques have limitations in achieving complete sensory recovery, a challenge noted in previous research, such as that conducted by Roganovic et al.,[53] who emphasized the difficulty in restoring full sensory function for high-level injuries, regardless of the reconstructive method employed. The absence of statistically significant differences in 2PD may be attributed to the limited sensitivity of the test or the sample size. Future studies employing more sensitive electrophysiological assessments could provide a deeper understanding of sensory recovery patterns.[45,54]

The enhanced grip and pinch strengths observed in the AIN transfer group further substantiate the superiority of this technique. Grip strength averaged 30.1 ± 6.1 kg in the AIN transfer group, compared to 24.3 ± 5.2 kg in the sural nerve grafting group. A similar trend is evident in the pinch strength. These functional measures are critical for hand dexterity and directly impact the ability to perform daily activities and occupational tasks.[48] This observation is consistent with the systematic review conducted by McLeod et al.,[17] which highlighted that nerve transfers tend to restore greater strength due to more effective reinnervation of key muscle groups in the hand. Moreover, studies by Lim et al.[48] have shown normative data indicating that effective nerve transfer techniques are crucial for restoring motor function and the overall hand strength required for activities of daily living.

The significant improvement in DASH scores observed in the AIN transfer group, compared to the sural nerve grafting group, underscores the clinical relevance of these findings. Lower DASH scores reflect better upper extremity function and reduced disability, in which contribute to an enhanced quality of life. These results align with previous studies indicating that nerve transfers can lead to superior patient-reported outcomes due to more rapid and effective functional recovery.[16,55]

Several factors may have contributed to the observed differences between the two surgical techniques. Nerve grafting relies on axonal regeneration across the grafted segment, which can be impeded by factors such as scar tissue, neuroma formation, and the length of the nerve gap.[30,35] The longer regeneration distance in nerve grafting prolongs the time before reinnervation occurs, during which irreversible muscle atrophy and fibrosis may develop, ultimately limiting functional recovery.[34]

In contrast, nerve transfers bypass the site of injury by connecting healthy donor nerve directly to the distal nerve stump. This approach significantly reduces both the distance and time required for regeneration.[31] This direct approach enhances the specificity of reinnervation and may improve functional outcomes, particularly in cases of proximal injuries where the distance to the target muscles is substantial.[33,34,56] Additionally, nerve transfers can preserve end-organ receptivity by reducing the denervation period, thereby facilitating better functional integration.[52,56,57] The absence of significant complications further supports the viability of both techniques as effective treatment options, although their efficacy profiles may differ depending on the level and complexity of the nerve injury.[14,34,36]

However, some nuances of this study are worth mentioning. While nerve grafting was less effective in restoring motor function compared to AIN transfer, it was found to be somewhat more beneficial in managing pain associated with neuromas,[58] which supports the findings of Poppler et al.,[35] who noted that grafting techniques could be useful in addressing the sensory component of nerve injuries when pain control is a primary consideration. Additionally, although nerve transfer has shown superior motor outcomes, its effectiveness in restoring protective sensation across the entire hand remains limited, necessitating additional interventions or complementary grafts, as highlighted by Moore et al.[43] in their analysis of motor and sensory transfers.

These findings have significant implications for clinical practice. For patients with high ulnar nerve injuries, especially those with nerve gaps exceeding 5 cm or painful neuromas, AIN transfer should be strongly considered as the preferred surgical intervention. The potential for improved motor and sensory recovery, along with enhanced functional outcomes, could lead to greater patient satisfaction and a reduction in long-term disability.

Moreover, the absence of major complications and the low incidence of minor complications in both groups suggest that AIN transfer is a safe procedure when performed by experienced surgeons. This finding aligns with existing literature that emphasizes the importance of surgical expertise and meticulous technique in optimizing outcomes and minimizing risks.[41]

Despite the strengths of this study, it has several limitations. First, patients were assigned to treatment groups based on clinical criteria rather than randomization, which introduces the potential for selection bias and confounding variables that could influence the observed outcomes. Although we employed predefined clinical criteria and ensured comparable baseline characteristics between the groups to mitigate this risk, the inherent nonrandomized design limits our ability to fully eliminate these factors. Additionally, the retrospective nature of the study may have introduced other biases related to data collection and patient selection. The relatively small sample size and single-center setting further restrict the generalizability of our findings. Future multicenter, prospective, randomized controlled trials with larger cohorts are needed to validate these results and provide higher-level evidence. Moreover, while patient adherence to rehabilitation was monitored, variations in individual engagement could have influenced the outcomes. Standardized rehabilitation protocols and objective adherence measures should be incorporated in future studies to ensure consistent postoperative care. Furthermore, studies examining the cost-effectiveness of each surgical option would provide valuable information regarding the allocation of healthcare resources.

Conclusion

This retrospective study suggests that AIN transfer may provide better motor and sensory outcomes, greater strength, and improved functional recovery compared to sural nerve grafting for the secondary repair of high ulnar nerve injuries. These findings indicate that nerve transfer techniques could be a valuable option in appropriate clinical scenarios, potentially offering a more effective means of reinnervating the target muscles and restoring hand function. However, due to the observational nature of the study and limitations such as non-randomized group allocation and a small sample size, these results should be interpreted with caution. Further prospective, randomized controlled trials are necessary to confirm these findings and refine surgical strategies and rehabilitation protocols for patients with peripheral nerve injuries.

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References

1. Kim SJ, Kwon YM, Ahn SM, Lee JH, Lee CH. Epidemiology of upper extremity peripheral nerve injury in South Korea, 2008 to 2018. Medicine (Baltimore). 2022; 101(48):e31655. doi:10.1097/md.0000000000031655.
2. Mirzayan R, Russo F, Yang S-JT, Lowe N, Shean CJ, Harness NG. Human Amniotic Membrane Wrapping of the Ulnar Nerve During Cubital Tunnel Surgery Reduces Recurrence of Symptoms. Arch Bone Jt Surg. 2022; 10(11):969-975. doi:10.22038/abjs.2021.60743.2996.
3. Xiang Y-T, Wu J-J, Ma J, et al. Peripheral nerve transfers for dysfunctions in central nervous system injuries: a systematic review. Int J Surg. 2024; 110(6):3814-3826. doi: 10.1097/JS9.0000000000001267.
4. Soldado F, Knorr J, Haddad S, et al. Ultrasound-guided Percutaneous Medial Pinning of Pediatric Supracondylar Humeral Fractures to Avoid Ulnar Nerve Injury. Arch Bone Jt Surg. 2015; 3(3):169-172. doi:10.22038/abjs.2015.4274.
5. Arami A, Bertelli JA. Effectiveness of distal nerve transfers for claw correction with proximal ulnar nerve lesions. J Hand Surg Am. 2021; 46(6):478-484. doi: 10.1016/j.jhsa.2020.10.015.
6. Catena N, Gennaro GLD, Jester A, et al. Current concepts in diagnosis and management of common upper limb nerve injuries in children. J Child Orthop. 2021; 15(2):89-96. doi: 10.1302/1863-2548.15.200203.
7. Fones L, Freedman MK, Beredjiklian PK, Gallant GG. Dorsal Interosseous Muscle Weakness from Mid-Palm Ganglion Cyst. Arch Bone Jt Surg. 2024. doi:10.22038/abjs.2024.80728.3684.
8. Emamhadi M, Yousefzadeh Chabok S, Samini F, et al. Anatomical Variations of Brachial Plexus in Adult Cadavers; A Descriptive Study. Arch Bone Jt Surg. 2016; 4(3):253-258. doi:10.22038/abjs.2016.6491.
9. Brogan DM, Dy CJ, Rioux-Forker D, Wever J, Leversedge FJ. Influences of Repair Site Tension and Conduit Splinting on Peripheral Nerve Reconstruction. Hand (N Y). 2022; 17(6):1048-1054. doi:10.1177/1558944720974117.
10. Kornfeld T, Vogt PM, Radtke C. Nerve grafting for peripheral nerve injuries with extended defect sizes. Wien Med Wochenschr. 2019; 169(9):240. doi:10.1007/s10354-018-0675-6.
11. Kong J, Teng C, Liu F, et al. Enhancing regeneration and repair of long-distance peripheral nerve defect injuries with continuous microcurrent electrical nerve stimulation. Front Neurosci. 2024; 18:1361590. doi:10.3389/fnins.2024.1361590.
12. Yavari M, Hassanpour SE, Alizadeh Otaghvar H, Abdolrazaghi HA, Farhoud AR. The Incidence of Ossified Superior Transverse Scapular Ligament during Nerve Transfer through Posterior Shoulder Approach. Arch Bone Jt Surg. 2019; 7(3):258-262. doi:10.22038/abjs.2018.28519.1735.
13. Woo A, Bakri K, Moran SL. Management of ulnar nerve injuries. J Hand Surg Am. 2015; 40(1):173-181. doi: 10.1016/j.jhsa.2014.04.038.
14. Czarnecki P, Górecki M, Romanowski L. Factors affecting the final outcomes after reconstruction of the median and ulnar nerve at the level of the forearm: Analysis of 41 patients. Injury. 2020; 51(12):2910-2915. doi:10.1016/j.injury.2020.02.117.
15. Morris M, Brogan DM, Boyer MI, Dy CJ. Trends in Nerve Transfer Procedures among Board-Eligible Orthopedic Hand Surgeons. J Hand Surg Glob Online. 2021; 3(1):24-29. doi:10.1016/j.jhsg.2020.10.003.
16. Thakkar M, Rose A, King W, Engelman K, Bednarz B. Anterior Interosseous Nerve to Ulnar Nerve Transfer: A Systematic Review. JPRAS Open. 2022; 32:195-210. doi:10.1016/j.jpra.2022.02.007.
17. McLeod GJ, Peters BR, Quaife T, Clark TA, Giuffre JL. Anterior Interosseous-to-Ulnar Motor Nerve Transfers: A Single Center's Experience in Restoring Intrinsic Hand Function. Hand (N Y). 2022; 17(4):609-614. doi:10.1177/1558944720928482.
18. Nickel KJ, Morzycki A, Hsiao R, Morhart MJ, Olson JL. Nerve Transfer Is Superior to Nerve Grafting for Suprascapular Nerve Reconstruction in Obstetrical Brachial Plexus Birth Injury: A Meta-Analysis. Hand (N Y). 2023; 18(3):385-392.

doi:10.1177/15589447211030691.
19. Luikart MD, Kistler JM, Kahan D, McEntee R, Ilyas AM. Anterior Interosseous Nerve to Ulnar Nerve Transfers: A Systematic Review. J Hand Microsurg. 2023; 15(2):98-105. doi:10.1055/s-0041-1734399.
20. George SC, Burahee AS, Sanders AD, Power DM. Outcomes of anterior interosseous nerve transfer to restore intrinsic muscle function after high ulnar nerve injury. J Plast Reconstr Aesthet Surg. 2022; 75(2):703-710. doi: 10.1016/j.bjps.2021.09.072.
21. Koriem E, El-Mahy MM, Atiyya AN, Diab RA. Comparison between supercharged ulnar nerve repair by anterior interosseous nerve transfer and isolated ulnar nerve repair in proximal ulnar nerve injuries. J Hand Surg Am. 2020; 45(2):104-110. doi: 10.1016/j.jhsa.2019.11.005.
22. Güvenç K, Ateş E, Asfuroğlu ZM. Factors affecting functional outcomes after surgery to repair extensive volar forearm lacerations with nerve injuries identified via quantitative and qualitative methods. Jt Dis Relat Surg. 2023; 34(2):405-412. doi:10.52312/jdrs.2023.1067.
23. Basar H, Basar B, Erol B, Tetik C. Comparison of ulnar nerve repair according to injury level and type. Int Orthop. 2014; 38(10):2123-8. doi: 10.1007/s00264-014-2430-y.
24. Koshy JC, Agrawal NA, Seruya M. Nerve Transfer versus Interpositional Nerve Graft Reconstruction for Posttraumatic, Isolated Axillary Nerve Injuries: A Systematic Review. Plast Reconstr Surg. 2017; 140(5):953-960. doi:10.1097/prs.0000000000003749.
25. Chan KM, Olson JL, Morhart M, Lin T, Guilfoyle R. Outcomes of nerve transfer versus nerve graft in ulnar nerve laceration. Can J Neurol Sci. 2012; 39(2):242-4. doi:10.1017/s0317167100013317.
26. Felici N, Alban A. Timing of surgery in peripheral nerve injury of the upper extremity. J Hand Surg Eur Vol. 2024; 49(6):712-720. doi:10.1177/17531934241240867.
27. Karamanos E, Rakitin I, Dream S, Siddiqui A. Nerve Transfer Surgery for Penetrating Upper Extremity Injuries. Perm J. 2018; 22:17-156. doi:10.7812/tpp/17-156.
28. Terzis JK, Kokkalis ZT. Outcomes of secondary reconstruction of ulnar nerve lesions: our experience. Plast Reconstr Surg. 2008; 122(4):1100-1110. doi:10.1097/PRS.0b013e3181858f67.
29. Gezercan Y, Menekşe G, Ökten A, et al. The Outcomes of Late Term Surgical Treatment of Penetrating Peripheral Nerve Injuries. Turk Neurosurg. 2016; 26(1):146-52. doi:10.5137/1019-5149.jtn.14094-15.1.
30. Saffari S, Shin AY, Pulos N. Nerve Autografts Versus Allografts for Mixed Motor/Sensory Nerve Reconstruction. J Hand Surg Glob Online. 2024; 6(5):694-699. doi:10.1016/j.jhsg.2024.01.025.
31. Flores LP. Comparative Study of Nerve Grafting versus Distal Nerve Transfer for Treatment of Proximal Injuries of the Ulnar Nerve. J Reconstr Microsurg. 2015; 31(9):647-53. doi:10.1055/s-0035-1556871.
32. Sallam AA, El-Deeb MS, Imam MA. Nerve Transfer versus Nerve Graft for Reconstruction of High Ulnar Nerve Injuries. J Hand Surg Am. 2017; 42(4):265-273. doi:10.1016/j.jhsa.2017.01.027.
33. Singh S. Management of extensive nerve gaps of more than 5 cm by vein graft in three cases. International Surgery Journal. 2020; 7(6):2069-2071.
34. Ding W, Li X, Pan J, et al. Repair Method for Complete High Ulnar Nerve Injury Based on Nerve Magnified Regeneration. Ther Clin Risk Manag. 2020; 16:155-168. doi:10.2147/tcrm.s237851.
35. Poppler LH, Davidge K, Lu JC, Armstrong J, Fox IK, Mackinnon SE. Alternatives to sural nerve grafts in the upper extremity. Hand (N Y). 2015; 10(1):68-75. doi:10.1007/s11552-014-9699-6.
36. Basar H, Basar B, Erol B, Tetik C. Comparison of ulnar nerve repair according to injury level and type. Int Orthop. 2014; 38(10):2123-8. doi:10.1007/s00264-014-2430-y.
37. Smith RDJ, Wright CL, Shaw B, Bhai S, Bhashyam AR, O'Donnell EA. Peripheral neuropathies after shoulder arthroscopy: a systematic review. JSES Rev Rep Tech. 2023; 3(4):454-460. doi:10.1016/j.xrrt.2023.07.001.
38. Beris A, Gkiatas I, Gelalis I, Papadopoulos D, Kostas-Agnantis I. Current concepts in peripheral nerve surgery. Eur J Orthop Surg Traumatol. 2019; 29(2):263-269. doi:10.1007/s00590-018-2344-2.
39. Chan KM, Gordon T, Zochodne DW, Power HA. Improving peripheral nerve regeneration: from molecular mechanisms to potential therapeutic targets. Exp Neurol. 2014; 261:826-35. doi:10.1016/j.expneurol.2014.09.006.
40. Gordon T, Chan KM, Sulaiman OA, Udina E, Amirjani N, Brushart TM. Accelerating axon growth to overcome limitations in functional recovery after peripheral nerve injury. Neurosurgery. 2009; 65(4 Suppl):A132-44. doi:10.1227/01.neu.0000335650.09473.d3.
41. Bateman EA, Larocerie-Salgado J, Ross DC, Miller TA, Pripotnev S. Assessment, patient selection, and rehabilitation of nerve transfers. Front Rehabil Sci. 2023; 4:1267433. doi:10.3389/fresc.2023.1267433.
42. Rinker B. Nerve Transfers in the Upper Extremity: A Practical User's Guide. Ann Plast Surg. 2015; 74 Suppl 4:S222-8. doi:10.1097/sap.0000000000000373.
43. Moore AM, Franco M, Tung TH. Motor and sensory nerve transfers in the forearm and hand. Plast Reconstr Surg. 2014; 134(4):721-730. doi:10.1097/prs.0000000000000509.
44. Paternostro-Sluga T, Grim-Stieger M, Posch M, et al. Reliability and validity of the Medical Research Council (MRC) scale and a modified scale for testing muscle strength in patients with radial palsy. J Rehabil Med. 2008; 40(8):665-71. doi:10.2340/16501977-0235.
45. Nguyễn MV, Pierrart J, Crenn V. Sensory Neurotization of the Ulnar Nerve, Surgical Techniques and Functional Outcomes: A Review. J Clin Med. 2022; 11(7) doi: 10.3390/jcm11071903.
46. K SKP, Thatte MR, Agarwal P, et al. The Normal Static Two-Point Discrimination in the Palmar Aspect of Hand in Adults and Children in a Sample Indian Population. Indian J Plast Surg. 2024; 57(4):263-269. doi:10.1055/s-0044-1789588.
47. Parylo J, Hodgson S, Chaudhry T. Tendon Transfer versus Nerve Transfer for the Reconstruction of Key Pinch and Grip Strength in Isolated High Traumatic Injuries of the Ulnar Nerve: A Systematic Review. J Hand Surg Asian Pac Vol. 2023; 28(3):327-335. doi:10.1142/s2424835523500340.
48. Lim SH, Kim YH, Lee JS. Normative Data on Grip Strength in a Population-Based Study with Adjusting Confounding Factors:

Sixth Korea National Health and Nutrition Examination Survey (2014-2015). Int J Environ Res Public Health. 2019; 16(12). doi:10.3390/ijerph16122235.

49. Sigirtmac IC, Oksuz C. Systematic review of the quality of the cross-cultural adaptations of Disabilities of the Arm, Shoulder and Hand (DASH). Med Lav. 2021; 112(4):279-291. doi:10.23749/mdl.v112i4.11424.
50. de Klerk S, Buchanan H, Jerosch-Herold C. The validity and clinical utility of the Disabilities of the Arm Shoulder and Hand questionnaire for hand injuries in developing country contexts: A systematic review. J Hand Ther. 2018; 31(1):80-90.e1. doi:10.1016/j.jht.2017.10.004.
51. Jiravichitchai T, Farzad M, MacDermid JC, Parikh P, Pripotnev S. Exploring Outcomes and Mediating Factors Following Supercharged End-to-Side Anterior Interosseous Nerve to Ulnar Nerve Transfer: A Scoping Review with Expert Insight. J Hand Surg Glob Online. 2024; 6(5):636-644. doi:10.1016/j.jhsg.2024.06.003.
52. Barbour J, Yee A, Kahn LC, Mackinnon SE. Supercharged end-to-side anterior interosseous to ulnar motor nerve transfer for intrinsic musculature reinnervation. J Hand Surg Am. 2012; 37(10):2150-9. doi:10.1016/j.jhsa.2012.07.022.
53. Roganovic Z. Missile-caused ulnar nerve injuries: outcomes of 128 repairs. Neurosurgery. 2004; 55(5):1120-9. doi:10.1227/01.neu.0000142353.92119.fe.
54. Braga Silva J, Leal BLM, Magnus GA, de Souza Stanham V, Mattiello R, Wolff CG. Comparison of nerve conduits and nerve graft in digital nerve regeneration: A systematic review and meta-analysis. Hand Surg Rehabil. 2021; 40(6):715-721. doi:10.1016/j.hansur.2021.08.006.
55. Dahlin E, Zimmerman M, Nyman E. Patient reported symptoms and disabilities before and after neuroma surgery: a register-based study. Sci Rep. 2023; 13(1):17226. doi:10.1038/s41598-023-44027-4.
56. Chemnitz A, Björkman A, Dahlin LB, Rosén B. Functional outcome thirty years after median and ulnar nerve repair in childhood and adolescence. J Bone Joint Surg Am. 2013; 95(4):329-37. doi:10.2106/jbjs.l.00074.
57. Abaskhron M, Ezzat M, Boulis AG, Safoury YE. Supercharged end-to-side anterior interosseous nerve transfer to restore intrinsic function in high ulnar nerve injury: a prospective cohort study. BMC Musculoskelet Disord. 2024; 25(1):566. doi:10.1186/s12891-024-07650-4.
58. Mohseni MA, Pour JS, Pour JG. Primary and delayed repair and nerve grafting for treatment of cut median and ulnar nerves. Pak J Biol Sci. 2010; 13(6):287-92. doi:10.3923/pjbs.2010.287.292.