JPRAS Open 44 (2025) 308–315

Contents lists available at ScienceDirect

JPRAS Open

journal homepage: www.elsevier.com/locate/jpra

Original Article

Timing and Predictors of Upper Extremity Peripheral Nerve Reconstruction☆,☆☆

Kelsey M. Gray[a,*], Andrzej J. Burkat[a], Lucas A. Arney[b], Nicholas J. Peterman[c], Sahith R. Mandala[a], Anthony E. Capito[a]

[a] *Virgina Tech Carilion School of Medicine, Section of Plastic and Reconstructive Surgery, Roanoke, Virginia*
[b] *Virginia Tech Carilion School of Medicine, Roanoke, Virginia*
[c] *Virginia Tech Carilion School of Medicine, Department of Orthopaedics, Roanoke, Virginia*

A R T I C L E I N F O

Article history:
Received 3 December 2024
Accepted 23 February 2025
Available online 27 February 2025

Keywords:
Peripheral nerve repair
Nerve repair timing
Nerve calculator
Nerve grafting
Nerve primary repair
Nerve defect

A B S T R A C T

Primary neurorrhaphy is the preferred reconstruction modality over nerve grafting, especially for motor nerves. The main limitation to primary repair is often dictated by tension secondary to increased nerve defect length. A retrospective review was conducted on sharp transections of mixed motor and purely sensory nerves in the upper extremity to assess factors influencing defect length. Two groups of either primary repair or nerve graft/conduit were created for comparison. Overall, 71 injured mixed motor nerves and 224 injured sensory nerves were included in the analysis. There were no significant differences in patient demographics between the groups. The primary repair group had a significantly shorter time interval between injury and surgical fixation when compared to the conduit/graft group. Conduit or graft technique was associated with a significantly larger tissue gap after preparation of the nerve ends. Our data suggest that the optimal time for primary repair is within 3 days after injury for mixed nerves and within 7 days for purely sensory nerves. A total of 167 nerve reconstructions were included in a random forest plot, which demonstrated nerve defect size to be influenced by days from injury, type of nerve injured, age, and hypertension. A publicly available 4-feature calculator, nerve evaluation and retraction variability estimator—

☆ Work attributable to: Department of Surgery, Section of Plastic and Reconstructive Surgery, 1906 Belleview Ave SE, Roanoke, VA 24014.

☆☆ Partial data on digital nerve repair timing presentation at AAHS 2022.

* Correspondence: Kelsey Gray, MD, Department of Surgery, Section of Plastic and Reconstructive Surgery, 1906 Belleview Ave SE, Roanoke, VA 24014; f: 540.981.8681; t: 540.750.3642.

E-mail address: kelseygraymd@gmail.com (K.M. Gray).

https://doi.org/10.1016/j.jpra.2025.02.018

NERVE, was developed from the forest plot to predict a patient's nerve deficit of ± 3.78 mm on an average, R^2=0.89. This calculator could aid surgeons with surgical planning by estimating the potential need of grafts or conduits for reconstruction.

Introduction

Peripheral nerve injury is known to occur in 2.8% of trauma patients referred to Level I centers, whereas a review of United States private insurer encounter and claims data reveals associated nerve injury in 1.6% of the patients with limb trauma.[1,2] Although the incidence is relatively low, the results of traumatic upper extremity motor nerve dysfunction can be disastrous, with less than 50% of patients achieving functional recovery and up to 30% of patients facing long-term disability.[3,4] Sensory nerve disruption can also lead to impaired hand function, which is most noticeable when the thumb or index fingers are involved, while also contributing to neuropathic pain that results in reduced quality of life and socioeconomic burden.[3,5–8] Optimizing outcomes and recovery becomes more imperative when the dominant extremity is involved, as patients continue to prefer using the injured dominant hand even when the other is relatively more functional.[9]

There are several established principles to maximize outcomes. Coaptation of healthy nerve fascicles in a tension-free manner remains the gold standard for the repair of sharply transected nerves.[4,10,11] A tension-free neurorrhaphy may not be feasible when the tissue preparation phase of repair results in a resection defect measuring over 1 cm.[5,10] Attempting to primarily reapproximate such a gap over 1 cm results in tension on the nerve that is intolerable to axon regeneration due to ischemia and promotes further scarring. In this scenario, neural tube conduits and nerve grafts can be used to alleviate tension in these gaps, though the results would be inferior to that of direct primary repair.[12]

It has long been established that prolonged axotomy results in inferior functional outcomes; however, the exact timing of repair has not been elucidated.[13,14] Multiple time tables have been suggested as the critical timing cutoff.[5,15–17] Classic studies have suggested repair within 72 h; this was generalized from studies on facial nerve transections, which showed depletion of factors from the injured nerve stumps, making identification of the distal stump challenging.[18,19] This is not as relevant in upper extremity nerve injuries, as the transected ends are readily identifiable. Subsequent studies have suggested critical periods ranging from several weeks up to 3 months.[5,17]

Following nerve transection, histologic changes mediated by Schwann cells and other inflammatory cells occur in the proximal and distal nerve stumps.[11,17] These culminate in axonal and myelin breakdown, with the distal stump undergoing Wallerian degeneration. The proximal stump undergoes degenerative changes that may extend several millimeters to even centimeters from the injury site.[5] With increasing time from injury, the proximal stump undergoes fibrosis and consequent reduction in endoneurial tube diameter.[5,20] Recovery from these changes following repair relies on the re-establishment of functional connections, which may span weeks to months.[21]

The aim of our study was to address the paucity of information relating to how the timing of surgical intervention impacts the method used for repair. We hypothesized that a delay in repairing sharp lacerating nerve injuries of the upper extremity correlates with an increased amount of nerve resection and therefore results in the decreased ability to achieve primary repair.

Methods

Institutional review board approval was obtained to create a database of peripheral nerve repairs performed by 8 board-certified hand surgeons at a level I tertiary medical center over a course of

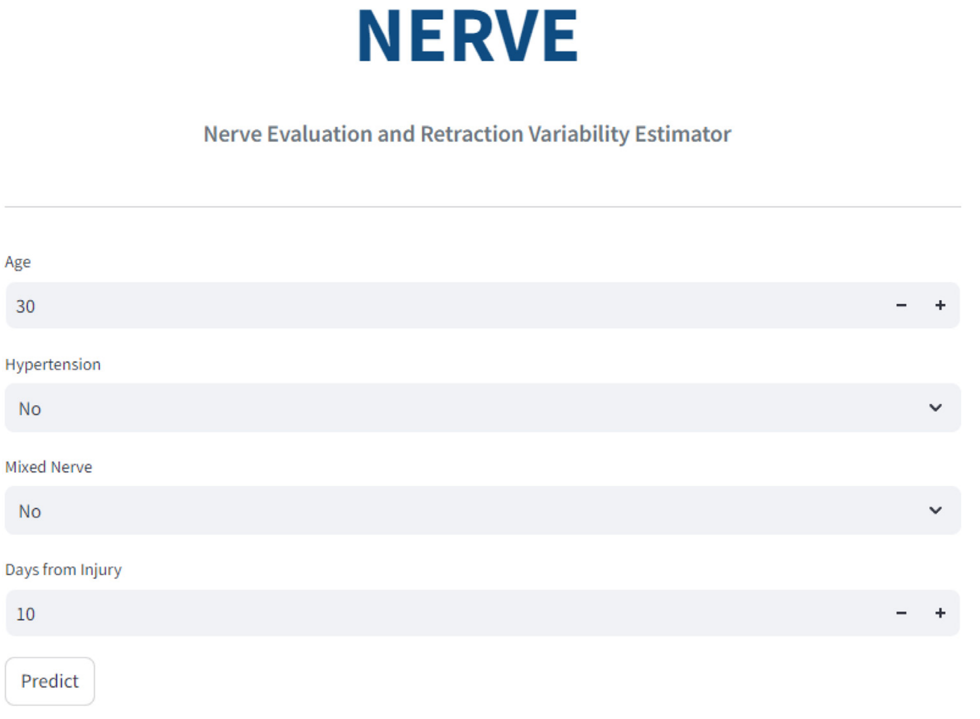

Figure 1. Calculation App User Interface. App available for public use at https://nervecalc.streamlit.app/.

10 years. The current procedural terminology (CPT) codes corresponding to neurorrhaphy (64830-64837), nerve grafting (64890-64898), and conduit repair (64911, 64912) were used to populate the database.

Individual chart review was conducted to identify the mechanism of injury, site, and specific nerve involved. For the purpose of this study, we focused on transecting upper extremity injuries to purely sensory and mixed motor nerves distal to the elbow joint. We believe that sharp lacerating injuries with no significant tissue loss have a clear zone of injury and are acutely amenable to primary repair at presentation. Injuries sustained via avulsion, crush, or ballistic impact were excluded as the zone of injury and length of segmental nerve loss could not be standardized. Patients presenting late for their initial evaluation, peripheral nerve repairs at sites proximal to the elbow joint, or those with a traumatic loss of native tissue were also excluded from this study for similar reasons of standardization on injury day one.

The charts were subsequently placed into 2 cohort groups based on the repair method used: primary repair versus conduit or graft repair. The day interval elapsed between the time of injury and surgical repair and nerve defect length after tissue preparation were recorded and compared between the groups. Demographic (age and sex) and comorbidity (diabetes, hypertension, and smoking history) information were also recorded and compared between the groups.

The student's t-test was used for continuous variables and Fisher's exact test for categorical variables with a significance set at $p=0.05$. This collected data were then filtered to include only defect lengths >0 mm and analyzed in a random forest plot model to assess the factors that were predictive of nerve deficit length. Random forest modeling allowed for the successful creation of a publicly available 4-feature calculator, nerve evaluation and retraction variability estimator (NERVE), that can predict a patient's expected nerve deficit (Figure 1).

Table 1
Mixed Motor Nerve.

	Primary (n=21)	Graft/conduit (n=50)	p value
Mean Prepared Defect Size (mm)	3.52	26.76	<0.001
Mean Days to Intervention	3.23	8.68	0.006
Mean Age (years)	39.71	41.14	0.384
Sex Distribution (F/M)	7/14	16/34	>0.999
Complications			
Reoperation	1 (5%)	6 (12%)	0.638
Wound dehiscence	0	2 (4%)	0.797
Neuroma	1 (5%)	5 (10%)	0.734
Infection	0	1 (2%)	0.517
Comorbidities			
Smoking	11(52%)	29 (58%)	0.716
DM	1 (5%)	4 (8%)	0.836
HTN	2 (10%)	11 (22%)	0.414

Millimeters (mm), Diabetes Mellitus (DM), Hypertension (HTN).

Results

The database created based on the CPT codes provided 760 patient charts. Implementation of our criteria resulted in a dataset with 71 injured mixed motor nerves (Table 1) and 224 injured sensory nerves (Table 2). There was no difference between the groups regarding age, presence of hypertension, diabetes, smoking status, or complications (Tables 1 and 2).

For mixed motor nerves, the primary repair group had an average of 3.2 days from time of injury to surgical repair compared to 8.7 days for the graft/conduit group, which was statistically significant ($p<0.01$, Table 1). The graft/conduit group also had a larger average defect size of 26.8 mm compared to 3.5 mm for the primary repair group ($p<0.001$, Table 1).

For sensory nerves, the primary repair group had an average of 6.6 days from time of injury to surgical repair compared to 8.5 days for the graft/conduit group, which was statistically significant ($p=0.02$, Table 2). The graft/conduit group also had a larger average defect size of 9.8 mm compared to 0.1 mm for the primary repair group ($p<0.001$, Table 2).

A random forest model was then created to assess the factors that were predictive of nerve defect size. After excluding defects of 0 mm, a total of 167 nerve repairs were included and the associated variable distributions are represented in Table 3. Size of defect was most influenced by the type of nerve injury (39%), followed by age (28%), days from injury (23%), and presence of hypertension (11%). Smoking, sex, and diabetes were initially included, but were found to have an importance of influence

Table 2
Sensory Nerve.

	Primary (n=81)	Graft/conduit (n=143)	p value
Mean Prepared Defect Size (mm)	0.06	9.82	<0.001
Mean Days to Intervention	6.63	8.45	0.029
Mean Age (years)	39.91	38.51	0.539
Sex Distribution (F/M)	27/54	52/91	0.756
Complications			
Reoperation	0	0	0.997
Wound dehiscence	0	0	0.997
Neuroma	1 (1%)	3 (2%)	0.915
Infection	0	0	0.997
Comorbidities			
Smoking	35 (43%)	62 (43%)	0.986
DM	9 (11%)	7 (5%)	0.441
HTN	13 (16%)	27 (19%)	0.726

Millimeters (mm), Diabetes Mellitus (DM), Hypertension (HTN).

Table 3
Variable distributions.

Variable	Summary n=167
Age (years), mean (SD)	39.2 (15.8)
Sex, n (%)	
Male	105 (63)
Female	62 (37)
Diabetes, n (%)	
Yes	12 (7)
No	155 (93)
Hypertension, n (%)	
Yes	33 (20)
No	134 (80)
Smoking, n (%)	
Yes	81 (49)
No	86 (51)
Nerve Type, n (%)	
Mixed	40 (24)
Sensory	127 (76)
Days From Injury, median (IQR)	7.0 (9.0)
Defect Distance (mm), median (IQR)	10.0 (12.0)

Standard Deviation (SD), Interquartile Range (IQR), Millimeters (mm).

Table 4
Random Forest Model Feature Importance.

Feature	Model Importance (%)
Mixed Nerve Status	39
Age (Years)	27
Days from Injury	23
Hypertension	11

Root Mean Squared Error: 3.777 mm, R^2: 0.8915.

of less than 2% and therefore were not included in the predictive calculator (Table 4). Ultimately, the results of the analyses allowed for the creation of a 4-feature calculator, NERVE, to predict a patient's nerve deficit of ± 3.78 mm on an average, R^2=0.89 (Figure 1).

Discussion

Open nerve injuries should always be explored. The traditional recommendation is that nerve injuries ideally be repaired within 72 h of the injury. This was based on studies by Gilliatt et. al and Chaudhry et. al., which showed a significantly decreased response of the distal stump to nerve stimulation after a period of 3 to 5 days.[18,19] After this delay, neurotransmitters disappeared from the distal nerve stump and further intraoperative identification of fascicles was no longer possible.[22] This time period is critical for repair of small caliber nerve injuries, where the identification of the distal target may require the use of a nerve stimulator, such as in facial nerve injuries. However, it is less relevant in the extremity, where the course of motor and sensory nerves are well defined. Dvali and Mackinnon expanded the period for optimal repair of peripheral nerve injury to 7 days.[15] This is in line with our data showing that primary repair was most often achieved within 6.6 days of injury for sensory nerve injuries; however, the best chance of primary repair for a mixed motor nerve occurs within the first 72 h after injury. The critical window is bound by the progressive loss of motor nerve plate viability, the desire to optimize motor recovery, and ease the surgical approach in a relatively less scarred surgical bed regardless of the nerve type.[16]

Although several well-established surgical techniques exist for repairing nerve injuries, primary repair remains the gold standard when appropriate tension is feasible.[10,23] In injuries with a resulting nerve gap of less than 1 cm, end-to-end neurorrhaphy has been found to offer superior results compared to other nerve repair modalities.[24,25] Using the NERVE calculator with the average demographics of our cohort, a 1-cm defect can be predicted at 9 days from injury.

In the case of nerve gaps longer than 1 cm, primary repair results in undue tension on the repair site with consequently inferior outcomes.[26] Recent digital sensory nerve meta-analysis demonstrated similar outcomes for nerve autograft and allograft, with allograft repair being comparable to primary repair, leading to some surgeons adopting this treatment for all injuries and lowering the threshold for digital nerve resection.[27] The increased use of grafting or conduits can be seen in most of our patient population, 70% in the mixed motor group and 64% in the sensory nerve repair group. However, meaningful recovery of function using grafts is not as high in motor or mixed nerve injuries compared to sensory nerve injuries, where primary neurorrhaphy remains superior.[25,28] Additionally, there also appears to be limited regeneration of nerves with grafts longer than 2 cm.[5,29,30] Therefore, repair prior to the development of gap greater than 2 cm is recommended, which we found was 12 days from sharp injury, although this estimate was limited by small number of patients in our cohort with 2 cm defect (n=16).

Several studies have demonstrated a progressive loss of neural tissue elasticity and nerve diameter in relation to the time passed since the initial insult.[5,15,20] One expects this to result in an increased extent of tissue resection required to reach viable nerve ends, which may decrease or even preclude the possibility of a successful primary neurorrhaphy. Our study offers evidence to this expected trend, revealing that each day passed since the time of injury until the definitive surgical repair correlates with an increase in resected tissue to reach healthy and viable nerve ends appropriate for suture repair (Figure 1).

Functional outcomes were not assessed following the performed repairs, which is a limitation of our study. The graft or conduit group were included as a single group for this reason, as functional outcome was not the area of interest for this investigation. Future studies may be designed to follow patient outcomes on a longitudinal basis using The British Medical Research Council muscle strength grading system, 2 point discrimination testing, or other comparable paradigm.

Other limitations of the study are inherent to its retrospective design, as the cohorts were not randomized. Selection bias precludes the generalization of the results to all populations and only reflects the outcomes of the patients included in this study. We excluded delayed presentations (greater than 30 days), as they do not correlate with the question at hand regarding the optimal timing of repair from a nerve injury presenting acutely to our institution. We attempted to address the question of whether these cases should be treated on immediate presentation to a hospital system, or if appropriate, referred to outpatient care, which would delay surgical timing. We also excluded ballistic injury cases, which cause mixed injury pattern rather than nerve transection and are often associated with soft tissue loss where one can assume that there could be segmental loss of neural tissue negating the option of primary repair based on the mechanism of injury.[16] An additional limitation was that the nerve reconstruction modality was based on 8 different hand surgeons. Furthermore, individual preference for neural tissue preparation could have altered the results and was not controlled for in this study.

When considering the technical and temporal aspects of repair, to ensure the best possible result, one must acknowledge that the outcome is ultimately multifactorial. Other factors aside from the used repair modality have been identified. These include age, sex, medical comorbidities, proximal or distal site of injury, and the specific nerve involved.[31,32] Our study and NERVE calculator, in particular, found age, hypertension, and type of nerve involved to be predictive of the final defect size along with the time from injury. Our findings related to age, are also suggestive that the elastin found in peripheral nerve perineurium and epineurium could degenerate with age, as is similarly observed in the skin, resulting in decreased retraction and therefore decreased nerve defect length after transection with older age.[33,34]

In conclusion, surgeons should consider early exploration of sharp lacerating peripheral nerve injuries of the upper extremity, especially in young patients with hypertension and mixed motor injuries to maximize the chances of a tension-free primary nerve repair. This study demonstrated that timing does effect the nerve defect size with the best chance of primary repair within 3 days for mixed nerves and within 7 days for purely sensory nerves. Defect size increased from time of injury, and the

NERVE calculator could aid surgeons with surgical planning by estimating the potential need of grafts or conduits for reconstruction.

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors had no financial support for the research, authorship, and/or publication of this article.

Statement of Human and Animal Rights Procedures:

This retrospective article was in accordance with the ethical standards of the responsible committee on human experimentation (Institutional Review Board 21-1357).

Acknowledgements

Camden Novikova, BS for statistical support and Peter Apel, MD, PhD for general support.

References

1. Noble J, Munro CA, Prasad VS, Midha R. Analysis of upper and lower extremity peripheral nerve injuries in a population of patients with multiple injuries. *J Trauma*. 1998;45(1):116–122. doi:10.1097/00005373-199807000-00025.
2. Taylor CA, Braza D, Rice JB, Dillingham T. The incidence of peripheral nerve injury in extremity trauma. *Am J Phys Med Rehabil*. 2008;87(5):381–385. doi:10.1097/PHM.0b013e31815e6370.
3. Bergmeister KD, Große-Hartlage L, Daeschler SC, et al. Acute and long-term costs of 268 peripheral nerve injuries in the upper extremity. *PLoS One*. 2020;15(4):e0229530. doi:10.1371/journal.pone.0229530.
4. Lee SK, Wolfe SW. Peripheral nerve injury and repair. *J Am Acad Orthop Surg*. 2000;8(4):243–252. doi:10.5435/00124635-200007000-00005.
5. Deumens R, Bozkurt A, Meek MF, et al. Repairing injured peripheral nerves: Bridging the gap. *Prog Neurobiol*. 2010;92(3):245–276. doi:10.1016/j.pneurobio.2010.10.002.
6. Ciaramitaro P, Mondelli M, Logullo F, et al. Traumatic peripheral nerve injuries: epidemiological findings, neuropathic pain and quality of life in 158 patients. *J Peripher Nerv Syst*. 2010;15(2):120–127. doi:10.1111/j.1529-8027.2010.00260.x.
7. Bulut T, Akgün U, Çıtlak A, Aslan C, Şener U, Şener M. Prognostic factors in sensory recovery after digital nerve repair. *Acta Orthop Traumatol Turc*. 2016;50(2):157–161. doi:10.3944/AOTT.2015.15.0140.
8. Mermans JF, Franssen BBGM, Serroyen J, Van der Hulst RRWJ. Digital nerve injuries: A review of predictors of sensory recovery after microsurgical digital nerve repair. *Hand (N Y)*. 2012;7(3):233–241. doi:10.1007/s11552-012-9433-1.
9. Philip BA, Thompson MR, Baune NA, Hyde M, Mackinnon SE. Failure to compensate: Patients with nerve injury use their injured dominant hand, even when their nondominant is more dexterous. *Arch Phys Med Rehabil*. 2022;103(5):899–907. doi:10.1016/j.apmr.2021.10.010.
10. Sunderland IRP, Brenner MJ, Singham J, Rickman SR, Hunter DA, Mackinnon SE. Effect of tension on nerve regeneration in rat sciatic nerve transection model. *Ann Plast Surg*. 2004;53(4):382–387. doi:10.1097/01.sap.0000125502.63302.47.
11. Yi C, Dahlin LB. Impaired nerve regeneration and Schwann cell activation after repair with tension. *Neuroreport*. 2010;21(14):958–962. doi:10.1097/WNR.0b013e32833e787f.
12. Isaacs J, Browne T. Overcoming short gaps in peripheral nerve repair: Conduits and human acellular nerve allograft. *Hand (N Y)*. 2014;9(2):131–137. doi:10.1007/s11552-014-9601-6.
13. Fu SY, Gordon T. Contributing factors to poor functional recovery after delayed nerve repair: prolonged axotomy. *J Neurosci*. 1995;15(5 Pt 2):3876–3885. doi:10.1523/JNEUROSCI.15-05-03876.1995.
14. Jivan S, Kumar N, Wiberg M, Kay S. The influence of pre-surgical delay on functional outcome after reconstruction of brachial plexus injuries. *J Plast Reconstr Aesthet Surg*. 2009;62(4):472–479. doi:10.1016/j.bjps.2007.11.027.
15. Dvali L, Mackinnon S. Nerve repair, grafting, and nerve transfers. *Clin Plast Surg*. 2003;30(2):203–221. doi:10.1016/s0094-1298(02)00096-2.
16. Moore AM, Wagner IJ, Fox IK. Principles of nerve repair in complex wounds of the upper extremity. *Semin Plast Surg*. 2015;29(1):40–47. doi:10.1055/s-0035-1544169.
17. MacKay BJ, Cox CT, Valerio IL, et al. Evidence-Based approach to timing of nerve surgery: A review. *Ann Plast Surg*. 2021;87(3):e1–e21. doi:10.1097/SAP.0000000000002767.
18. Gilliatt RW, Hjorth RJ. Nerve conduction during Wallerian degeneration in the baboon. *J Neurol Neurosurg Psychiatry*. 1972;35(3):335–341. doi:10.1136/jnnp.35.3.335.
19. Chaudhry V, Cornblath DR. Wallerian degeneration in human nerves: Serial electrophysiological studies. *Muscle Nerve*. 1992;15(6):687–693. doi:10.1002/mus.880150610.
20. Sunderland S, Bradley KC. Endoneurial tube shrinkage in the distal segment of a severed nerve. *J Comp Neurol*. 1950;93(3):411–420. doi:10.1002/cne.900930305.
21. Cavanaugh M. Quantitative effects of the peripheral innervation area on nerves and spinal ganglion cells. *J Comp Neurol*. 1951;94(2):181–219. doi:10.1002/cne.900940203.
22. Ferrante MA. The assessment and management of peripheral nerve trauma. *Curr Treat Options Neurol*. 2018;20(7):25. doi:10.1007/s11940-018-0507-4.

23. Bassilios Habre S, Bond G, Jing XL, Kostopoulos E, Wallace RD, Konofaos P. The surgical management of nerve gaps: Present and future. *Ann Plast Surg*. 2018;80(3):252–261. doi:10.1097/SAP.0000000000001252.
24. Pan C-H, Chuang DC-C, Rodríguez-Lorenzo A. Outcomes of nerve reconstruction for radial nerve injuries based on the level of injury in 244 operative cases. *J Hand Surg Eur Vol*. 2010;35(5):385–391. doi:10.1177/1753193409360283.
25. Birch R, Raji AR. Repair of median and ulnar nerves. Primary suture is best. *J Bone Joint Surg Br*. 1991;73(1):154–157. doi:10.1302/0301-620X.73B1.1991753.
26. Kalomiri DE, Soucacos PN, Beris AE. Nerve grafting in peripheral nerve microsurgery of the upper extremity. *Microsurgery*. 1994;15(7):506–511. doi:10.1002/micr.1920150714.
27. Herman ZJ, Ilyas AM. Sensory outcomes in digital nerve repair techniques: An updated meta-analysis and systematic review. *Hand (N Y)*. 2020;15(2):157–164. doi:10.1177/1558944719844346.
28. Cho MS, Rinker BD, Weber R V, et al. Functional outcome following nerve repair in the upper extremity using processed nerve allograft. *J Hand Surg Am*. 2012;37(11):2340–2349. doi:10.1016/j.jhsa.2012.08.028.
29. Saheb-Al-Zamani M, Yan Y, Farber SJ, et al. Limited regeneration in long acellular nerve allografts is associated with increased Schwann cell senescence. *Exp Neurol*. 2013;247:165–177. doi:10.1016/j.expneurol.2013.04.011.
30. Kornfeld T, Vogt PM, Radtke C. Nerve grafting for peripheral nerve injuries with extended defect sizes. *Wien Med Wochenschr*. 2019;169(9-10):240–251. doi:10.1007/s10354-018-0675-6.
31. Ruijs ACJ, Jaquet J-B, Kalmijn S, Giele H, Hovius SER. Median and ulnar nerve injuries: a meta-analysis of predictors of motor and sensory recovery after modern microsurgical nerve repair. *Plast Reconstr Surg*. 2005;116(2):484–486. doi:10.1097/01.prs.0000172896.86594.07.
32. Dumont CE, Alnot JY. Proximal median and ulnar resections. Results of primary and secondary repairs]. *Rev Chir Orthop Reparatrice Appar Mot*. 1998;84(7):590–599.
33. Tassler PL, Dellon AL, Canoun C. Identification of elastic fibres in the peripheral nerve. *J Hand Surg Br*. 1994;19(1):48–54. doi:10.1016/0266-7681(94)90049-3.
34. Zhang S, Duan E. Fighting against skin aging: The way from bench to bedside. *Cell Transplant*. 2018;27(5):729–738. doi:10.1177/0963689717725755.