

Nerve Transfer Surgery for Penetrating Upper Extremity Injuries

Efstathios Karamanos, MD; Ilya Rakitin, MD; Sophie Dream, MD; Aamir Siddiqui, MD

Perm J 2018;22:17-156

E-pub:04/09/2018

<https://doi.org/10.7812/TPP/17-156>

ABSTRACT

Context: Nerve transfer surgery is an option for repair of penetrating injuries of the upper extremity. In the right setting, it has advantages over tendon transfers and nerve grafting.

Objective: To review our experience since 2006 of nerve transfer surgery in the upper extremities.

Design: We included cases performed to repair penetrating trauma within three months of injury with at least three years' follow-up.

Main Outcome Measures: Preoperative and postoperative muscle strength of the affected extremity.

Results: All 16 patients were males aged 16 to 43 years. Six patients underwent nerve transfer surgery because of elbow flexion; 5, finger extension; 3, finger flexion; and 2, wrist pronation. Nine patients (56%) had associated vascular injury, and 4 (25%) had fractures. Average follow-up was 6 years. No perioperative complications occurred. Patients had a mean of 3.7 operations after the initial trauma. All patients received physical therapy. All patients improved from 0 of 5 muscle strength preoperatively to a mean of 3.8 (range = 2/5 to 5/5) within 1 year after surgery. In all cases, strength was maintained, and 8 (50%) had continued improvement after Year 1. Ten (63%) returned to their previous employment level. Mean Disabilities of the Arm, Shoulder and Hand score improved from 68 to 83 postoperatively.

Conclusion: Nerve transfer is a safe, effective technique for correcting penetrating trauma-related nerve injury. In appropriate patients it offers advantages over other techniques. Outcomes can be maintained long term, and many patients can return to their previous level of function.

INTRODUCTION

In traumatic peripheral nerve injury of the upper extremity, clinical outcomes with typical techniques, including tendon transfer and nerve grafting, are inconsistent and prone to sub-optimal outcomes.^{1,2} Zone of injury, concomitant injuries, donor site morbidity, and need for staged procedures can all affect the outcome. Major drawbacks of the current treatment strategies can include delayed reinnervation for high injuries requiring nerve grafts, donor morbidity for tendon transfers and autologous nerve grafts, and prolonged reliance on trained therapists for good outcomes.

Nerve transfer surgery involves taking nerve branches from a neighboring nerve and redirecting them to the distal end of the injured nerve. Functioning branches close to the recipient non-functioning nerve are ideal donors as long as the donor nerve

function is redundant or less critical. The body then regenerates axons along the new path, and the motor cortex subsequently rewires itself to relearn muscle functions. This technique provides a nearby source of nerve for faster recovery because the healing and regeneration is occurring closer to the target site along the course of the recipient nerve.

Nerve transfer surgery has the potential to address many of the weaknesses of other surgical options. This study outlines our experience and results with nerve transfer surgery for repair of upper extremity penetrating nerve injuries.

METHODS

After institutional review board approval, a retrospective review was performed of all patients admitted to a Level I urban trauma center with penetrating injury to the upper extremities from January 2004 to December 2011 undergoing nerve transfer for repair of nerve injury. Inclusion criteria included penetrating injury to the upper extremities with subsequent sensorimotor deficit secondary to nerve injury, operative intervention within three months of initial presentation, and follow-up of at least three years after the initial operation.

Abstracted patient variables included age, sex, indication for surgery, the presence of associated vascular or osseous injury, follow-up duration, number of operations, and any perioperative complications. Primary outcome included preoperative and postoperative muscle strength of the extremity using the Oxford Scale.³ Secondary outcomes included the Disabilities of the Arm, Shoulder and Hand (DASH) score and surgical complications. The DASH score is an outcome measure that is scored in 2 components: The disability/symptom section (scored 1-5) and the optional high performance Sport/Music or Work section (scored 1-5).^{4,5}

RESULTS

During the study period, 16 patients underwent nerve transfer for repair of penetrating upper extremity injury. The patients identified were all males, with a mean age of 27 years (range = 16-43 years). Of the 16 cases of nerve transfer, 6 were caused by loss of elbow flexion, 5 were for loss of finger extension, 3 were caused by loss of finger flexion, and the remaining 2 for loss of wrist pronation. Associated vascular injury was encountered in 9 patients, and 4 patients had an associated osseous injury (Table 1). The mean follow-up was 6 years, and the median number of surgeries required was 4 (range = 2-5). No perioperative complications were encountered.

Efstathios Karamanos, MD, is a Surgeon at Henry Ford Hospital in Detroit, MI. E-mail: ekarama1@hfhs.org. Ilya Rakitin, MD, is a Surgeon at Henry Ford Hospital in Detroit, MI. E-mail: ilyarakitin@gmail.com. Sophie Dream, MD, is a Surgeon at Henry Ford Hospital in Detroit, MI. E-mail: sdream1@hfhs.org. Aamir Siddiqui, MD, is a Plastic and Reconstructive Surgeon at Henry Ford Hospital in Detroit, MI. E-mail: asiddiq1@hfhs.org.

Muscle strength of the affected extremity was checked preoperatively. All patients had 0 of 5 strength for the function in question, with 0 indicating no contraction and 5 indicating movement against gravity with full resistance (normal power). Muscle strength was reassessed at 6 weeks, 3 months, 6 months, and then annually. The median postoperative muscle strength at 1 year after surgery was 4/5, with a range of 2/5 to 5/5 ($p < 0.05$). All patients were followed for at least 3 years. Fifty percent of patients (8/16) maintained the same level of strength at 3 years that they had at the 1-year mark. The other 50% experienced improvement of their strength level from Year 1 to Year 3. No patient had deterioration in strength level after the first year (Table 2), and 10 of the 16 patients were able to return to their previous level of employment. When the DASH score was calculated for each patient preoperatively and postoperatively, a significant increase postoperatively was noted (score of 68 preoperatively vs 83 postoperatively, $p < 0.05$ respectively, Table 2).

Table 3 depicts the type of operation performed for every patient depending on his functional loss. The Modified British Medical Research Council Classification for muscle strength was documented preoperatively as well as at 3 years postoperatively.

DISCUSSION

In terms of traumatic sequelae of a penetrating injury to the extremities, nerve injury is of particular importance. Unlike with many other injuries, timely, good surgical technique is not the only predictor of outcome. Direct nerve repair of a proximal nerve injury can take months or years to produce good results. The disability can become permanent. Surgeons have developed ancillary procedures designed to correct the deficit by using other functioning neuromuscular or neurosensory units. The growing list of techniques includes nerve grafting (via autologous grafts, allogeneic grafts, or synthetic conduits), tendon transfer, nerve transfer, joint fusion, and adaptive splinting. Nerve transfer is a newer concept that involves redirecting a nerve segment from a neighboring noncritical or redundant branching nerve to the distal edge of the injured nerve (Figure 1).

Nerve grafting is employed to bridge gaps when primary repair of a transected nerve cannot be performed without tension or scarring. Even with excellent technique, the nerve regeneration length is unchanged and the biology of nerve regeneration (1 mm/d) remains the rate-limiting step.⁶ The number of axons that make it to the end organ is always reduced.⁷ Grafting also means 2 coaptations and successful healing at both sites. The outcome is a decrease in the quantity and eventual quality of the neuromotor unit by the time the regeneration is complete. During nerve grafting, the entire donor nerve domain, usually sensory, is lost. Nerve conduits and allografts decrease donor site impact but have not been shown to improve the clinical outcomes over nerve grafting.⁸⁻¹⁰

Many surgeons treating patients with nerve injuries prefer tendon transfers. For adept surgeons, the results are predictable. In most cases, tendon transfers are irreversible. They require the sacrifice of a neuromuscular unit; alteration of biomechanics, which can result in secondary trauma remote from the original injury; and the need for therapy and retraining.^{11,12} Because of the

Table 1. Demographic and clinical characteristics (N = 16)

Characteristic	Number
Sex, male	16
Age range, y	16-43
Indication for surgery	
Elbow flexion	6
Finger extension	5
Finger flexion	3
Wrist pronation	2
Associated vascular injury	9
Associated fracture	4
Mean follow-up, y	6
No. of operations, mean (range)	3.6 (2-5)
Perioperative complications	0

Table 2. Outcomes of nerve transfer surgery

Outcome	Number
Muscle strength of affected muscle group ^a	
Preoperatively	0/5
Postoperatively, mean (range)	3.8/5 (2/5-5/5)
Strength level change more than 1 y after follow-up	
Stable	8/16
Improvement	8/16
Deterioration	0/16
Return to previous level of employment	10/16
Mean DASH score	
Preoperatively	68
Postoperatively	83

^a Using the Oxford Shoulder Score.

DASH = Disabilities of the Arm, Shoulder and Hand.

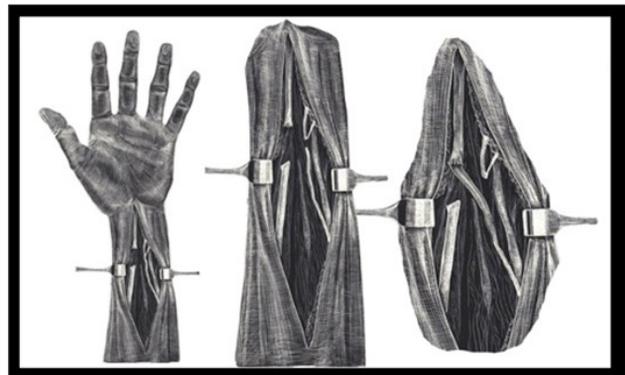


Figure 1. Surgical technique for nerve transfer (Illustration by Kelly Rosso, MD).

Ulnar nerve to anterior interosseous nerve branch of median nerve in an end-to-end fashion.

rerouting required for tendon transfer, there is almost universally a drop-off in strength and mobility after transfer.¹²

Nerve transfer may be superior to nerve grafting because the surgical field during transfer is generally away from the site of injury, using healthy, recognizable tissues, instead of crushed or

scarred tissue found at the site of injury. Despite recent improvements and use of grafts, nerve grafting continues to have a poor prognosis.¹³ It is for this reason that the focus of nerve repair has shifted toward the technique of nerve transfer. Results of the present study show that nerve transfer can achieve higher functional results and more predictable outcomes over those typically obtained with nerve grafting.

Compared with tendon transfer, nerve transfer has been shown to have several advantages. Nerve transfers are performed outside the zone of the original injury using healthy, recognizable tissues, instead of crushed or scarred nerve tissue. Nerve transfer allows reinnervation of native muscle and preservation of the natural anatomy. This is beneficial, because it does not alter the biomechanics, which can decrease range of motion, restrict muscle or tendon gliding, or cause secondary trauma such as adhesions or tendon rupture. Additionally, tendon transfer may require extensive dissection, and precluding this dissection with nerve transfer may lead to less donor site morbidity. Nerve transfers occur closer to the motor endplate, resulting in shorter interval to reanimation and less loss of functional motor units.¹⁴ In theory, this can improve detailed nerve function, including fine and gross motor function, as well as sensation. Details of current practices in nerve transfer for sensation are outlined in an article by Boyd et al.¹⁵

Nerve transfers do have some disadvantages. The clinical results of a nerve transfer, unlike tendon transfer, do take months to materialize. Tendon transfers allow one to see the results of the surgery within weeks. Nerve transfer is a technically demanding surgery. Poor outcomes may not manifest for a while and may delay any discussion and plan for further surgery and intervention. Patient morbidity and expenses are extended. There is a risk with nerve surgery of unintended damage to the donor nerve.

Although it was not seen in our study, donor nerve injury can be irreversible. There are also technical limitations to nerve transfer surgery. For now, safe and effective surgery should be guided by tenets outlined elsewhere.¹⁶

Nerve transfer has not yet become the standard treatment of penetrating injuries to the upper extremities. Initially nerve transfer was used for repair of severe brachial plexus injuries; now indications have expanded to include distal nerve deficits of the upper extremity as well. More evidence on nerve transfer is needed to develop a treatment algorithm.

Outcomes for reconstruction after peripheral nerve injuries are difficult to interpret for several reasons, including lack of standardization, varying degrees of injury per patient, and lack of consensus on surgical approach. However, there is increasing interest in nerve transfer to treat injuries. Because nerve transfer is relatively new, many series have a limited number of patients, but more results continue to be published. The present study uses a large cohort and reports favorable outcomes, with more than 50% of the patients returning to their previous level of employment. Furthermore, nerve transfer in our study was shown not to be associated with any morbidity, making it a safe choice when penetrating upper extremity injuries are encountered. A very important point of this study is the fact that even after 1 year of follow-up, some patients continued to improve. Follow-up of at least 3 years was required to see this improvement. Our numbers, however, are not large enough to make any conclusions regarding predictors of late improvement. Also notable is that 63% of patients returned to work. Delayed completion of reconstruction is a strong predictor of not returning to work. Nerve transfers in this cohort were timely and appropriate so patients were able to remain motivated. The improvement in DASH score is also a strong predictor of patient-based outcome.

Table 3. Patients' operation and outcomes

Patient	Loss of function	Operation	Pre-MBMR Classification	Post-MBMR Classification (at 3 y)
1	Elbow flexion	Ulnar nerve to musculocutaneous nerve (Oberlin)	M1	M4
2	Elbow flexion	Ulnar nerve to musculocutaneous nerve (Oberlin)	M1	M4
3	Elbow flexion	Ulnar nerve to musculocutaneous nerve (Oberlin)	M2	M5
4	Elbow flexion	Ulnar nerve to musculocutaneous nerve (Oberlin)	M1	M4
5	Elbow flexion	Oberlin plus median nerve to brachialis branch of musculocutaneous nerve	M1	M4
6	Elbow flexion	Ulnar nerve to musculocutaneous nerve (Oberlin)	M2	M5
7	Finger extension	FDS branch of median nerve to PIN	M1	M4
8	Finger extension	FDS branch of median nerve to PIN	M0	M4
9	Finger extension	FDS branch of median nerve to PIN	M1	M5
10	Finger extension	FDS branch of median nerve to PIN	M1	M5
11	Finger extension	FDS branch of median nerve to PIN	M1	M4
12	Finger flexion	AIN to motor branch of thenar muscles	M2	M4
13	Finger flexion	AIN to motor branch of thenar muscles	M2	M4
14	Finger flexion	Motor branch of ECRB to AIN	M1	M4
15	Wrist pronation	Motor branch of ECRB to AIN	M1	M3
16	Wrist pronation	Motor branch of ECRB to AIN	M1	M4

AIN = anterior interosseous nerve; ECRB = extensor carpi radialis brevis; FDS = flexor digitorum superficialis; MBMR = Modified British Medical Research Council; Oberlin = Oberlin procedure; PIN = posterior interosseous nerve.

Limitations of this study include its retrospective nature. We also excluded six patients who did not complete at least three years' follow-up.

CONCLUSION

Nerve transfer has the potential to address many of the limitations associated with other treatment options used for high penetrating trauma of the upper extremity. In our study, we present 16 cases that further demonstrate that nerve transfers can be done in a systematic manner to obtain consistently strong functional outcomes. Furthermore, we show that clinical improvement continues in some patients for up to 3 years. ❖

Disclosure Statement

The author(s) have no conflicts of interest to disclose.

Acknowledgment

Kathleen Loudon, ELS, of Loudon Heath Communications provided editorial assistance.

How to Cite this Article

Karamanos E, Rakitin I, Dream S, Siddiqui A. Nerve transfer surgery for penetrating upper extremity injuries. *Perm J* 2018;22:17-156. DOI: <https://doi.org/10.7812/TPP/17-156>

References

- Thoder JJ, Kozin SH. Management principles to treat nerve loss after violent trauma to the upper extremity. *Hand Clin* 1999 May;15(2):289-98.
- Omer GE Jr. Acute management of peripheral nerve injuries. *Hand Clin* 1986 Feb;2(1):193-206.
- LeBlond RF, Brown DD, DeGowin RL. Chapter 14. The neurologic examination. In: DeGowin's diagnostic examination. 9th ed. New York, NY: McGraw-Hill Medical; 2009. p 683-765.
- Hudak PL, Amadio PC, Bombardier C. Development of an upper extremity outcome measure: The DASH (disabilities of the arm, shoulder and hand) [corrected]. The Upper Extremity Collaborative Group (UECG). *Am J Ind Med* 1996 Jun;29(6):602-8. DOI: [https://doi.org/10.1002/\(sici\)1097-0274\(199606\)29:6<602::aid-ajim4>3.0.co;2-l](https://doi.org/10.1002/(sici)1097-0274(199606)29:6<602::aid-ajim4>3.0.co;2-l).
- Angst F, Schwyzer HK, Aeschlimann A, Simmen BR, Goldhahn J. Measures of adult shoulder function: Disabilities of the Arm, Shoulder, and Hand Questionnaire (DASH) and its short version (QuickDASH), Shoulder Pain and Disability Index (SPADI), American Shoulder and Elbow Surgeons (ASES) Society standardized shoulder assessment form, Constant (Murley) Score (CS), Simple Shoulder Test (SST), Oxford Shoulder Score (OSS), Shoulder Disability Questionnaire (SDQ), and Western Ontario Shoulder Instability Index (WOSI). *Arthritis Care Res (Hoboken)* 2011 Nov;63 Suppl 11:S174-88. DOI: <https://doi.org/10.1002/acr.20630>.
- Sunderland S. Rate of regeneration in human peripheral nerves; analysis of the interval between injury and onset of recovery. *Arch Neurol Psychiatry* 1947 Sep;58(3):251-95. DOI: <https://doi.org/10.1001/archneurpsyc.1947.02300320002001>.
- Edds MV Jr, Small WT. The behavior of residual axons in partially denervated muscles of the monkey. *J Exp Med* 1951 Mar;93(3):207-16. DOI: <https://doi.org/10.1084/jem.93.3.207>.
- Pabari A, Lloyd-Hughes H, Seifalian AM, Mosahebi A. Nerve conduits for peripheral nerve surgery. *Plast Reconstr Surg* 2014 Jun;133(6):1420-30. DOI: <https://doi.org/10.1097/prs.0000000000000226>.
- Deal DN, Griffin JW, Hogan MV. Nerve conduits for nerve repair or reconstruction. *J Am Acad Orthop Surg* 2012 Feb;20(2):63-8. DOI: <https://doi.org/10.5435/jaaos-20-02-063>.
- Tang P, Kilic A, Konopka G, Regalbuto R, Akeina Y, Gardner T. Histologic and functional outcomes of nerve defects treated with acellular allograft versus cabled autograft in a rat model. *Microsurgery* 2013 Sep;33(6):460-7. DOI: <https://doi.org/10.1002/micr.22102>.
- Meals CG, Meals RA. Tendon versus nerve transfers in elbow, wrist, and hand reconstruction: A literature review. *Hand Clin* 2013 Aug;29(3):393-400. DOI: <https://doi.org/10.1016/j.hcl.2013.04.010>.
- Pejovich A, Ratner JA, Marino J. Update of the physiology and biomechanics of tendon transfer surgery. *J Hand Surg* 2010 Aug;35(8):1365-9. DOI: <https://doi.org/10.1016/j.jhsa.2010.05.014>.
- O'Grady KM, Power HA, Olson JL, et al. Comparing the efficacy of triple nerve transfers with nerve graft reconstruction in upper trunk obstetric brachial plexus injury. *Plast Reconstr Surg* 2017 Oct;140(4):747-56. DOI: <https://doi.org/10.1097/prs.0000000000003668>.
- Poppler LH, Wood MD, Hunter DA, Mackinnon SE, Moore AM. A reverse end-to-side sensory nerve transfer preserves muscle mass. *Plast Reconstr Surg* 2014 Oct;134(4 Suppl 1):39-40. DOI: <https://doi.org/10.1097/01.prs.0000455370.83035.70>.
- Boyd KU, Nimigan AS, Mackinnon SE. Nerve reconstruction in the hand and upper extremity. *Clin Plast Surg* 2011 Oct;38(4):643-60. DOI: <https://doi.org/10.1016/j.cps.2011.07.008>.
- Tung TH, Mackinnon SE. Nerve transfers: Indications, techniques, and outcomes. *J Hand Surg Am* 2010 Feb;35(2):332-41. DOI: <https://doi.org/10.1016/j.jhsa.2009.12.002>.

All Nerves

In all nerves there are both faculties, by which I mean the faculty of perception and the faculty of motion.

— Galen of Pergamon, 130 AD – 210 AD, prominent Greek physician, surgeon, and philosopher in the Roman Empire