Options for Digital Nerve Gap

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THE PATIENT

A 27-year-old bicyclist fell during a race, crushing the ring and little fingers of the dominant hand between the handlebar and the ground. The associated skin laceration was primarily repaired over a 1 × 1-cm area of soft tissue crush injury at the base of the little finger. She has no fractures and good perfusion to the fingers but has lost sensation on the ulnar aspect of the little finger. She is taken to surgery within 3 days for nerve repair; intraoperatively, there is a 9-mm gap between nerve ends. Trimming the nerve back to normal fascicles leaves a 12-mm nerve gap.

THE QUESTION

Based on the existing clinical evidence, which technique of nerve reconstruction will offer good sensory recovery for a patient with a digital nerve gap?

CURRENT OPINION

When tension-free end-to-end nerve repair is unachievable, as in this patient, several options are available, including nerve autograft, nerve allograft, and various autologous or synthetic nerve conduits. Over the past decade, surgeons have used all of these options with moderate to good recovery of 2-point discrimination (2PD). Use of off-the-shelf collagen conduits and other conduits is becoming more popular because they avoid potential donor site morbidity and result in shorter operative times.

THE EVIDENCE

Comparative studies

A prospective randomized trial comparing polyglycolic acid (PGA) synthetic conduits, direct repair, and nerve autograft in 136 nerve repairs demonstrated equivalent or better sensory outcomes with PGA conduits. For gaps 4 mm or less, PGA conduits restored a moving 2PD of 3.7 ± 1.4 mm compared with 6.1 ± 3.3 mm for end-to-end repairs ($P = .03$). For gaps larger than 8 mm, PGA conduit reconstructions similarly had improved 2PD (6.8 ± 3.8 mm) relative to direct repairs (12.9 ± 2.4 mm; $P < .01$). It was also noted that avulsion or crush mechanisms resulted in poorer 2PD: 9.3 ± 5.1 mm compared with 6.7 ± 3.8 mm for non-crush/avulsion mechanisms ($P = .04$).[1]

A recent prospective randomized trial compared 32 autogenous vein conduits (ipsilateral dorsal forearm or hand) with 36 PGA synthetic conduits[2] for patients with a mean 10-mm nerve defect. The moving 2PD for the PGA conduit group was 5.6 ± 2.2 mm compared with 6.6 ± 2.9 mm for the vein conduit group 12 months after surgery (not statistically significant). The costs were similar owing to longer operative time for the vein harvest. Smokers and workers' compensation patients had significantly worse sensory recovery 12 months after repair, but the authors did not explain how insurance status could affect 2PD.[2]

Bertleff et al[3] reported a randomized trial evaluating sensory recovery in nerve deficits less than 20 mm by comparing Neurolac (poly[DL-lactide-ε-caprolactone], Polyganics BV, Groningen, The Netherlands) reconstruction against standard repair techniques (direct end-to-end repair or nerve autograft). This was a multicenter study that included 34 nerve reconstructions. The researchers found that the Neurolac was well accepted in most patients; however, some experienced wound problems such as delayed wound healing, inflammation, and foreign body responses. There were no statistically significant differences in sensory outcomes (static and moving 2PD) between the Neurolac and standard repair groups; however, these numerical results and *P* values were not quantified in the article.[3]

Nerve autografts

Stang et al[4] reported similar sensory outcomes when comparing patients treated with posterior interosseous nerve (PIN) grafts with medial antebrachial cutaneous nerve (MABCN) grafts. Fourteen of the 16 patients with PIN grafts achieved S3+ or S4 sensibility, as did 9 of the 12 patients with MABCN grafts. The PIN

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graft harvest, however, offered less donor site scar formation, unpleasant paresthesia, and neuroma-associated pain than MABCN harvest.

Chen et al[5] described a procedure for reconstruction of proper digital nerve gaps in the thumb using a neurovascular graft based on the second dorsal metacarpal artery. The pedicled nerve, which is a dorsal branch of the proper digital nerve of the index finger, is transferred with its vascular supply to the thumb. In their comparison with nonvascularized nerve autograft from sural nerve or MABCN, the authors noted significantly better sensory recovery with the neurovascular graft in 2-point discrimination ($P = .000$) and Semmes-Weinstein monofilament testing ($P = .001$). They also reported results of a similar transfer of the dorsal branch of the proper digital nerve without vascularized pedicle. This nerve transfer also demonstrated superior sensory function relative to sural autograft.[6]

Pilanci et al[7] also reported on the ability to harvest up to 3.0 cm of lateral antebrachial cutaneous nerve in the forearm. They evaluated 15 patients, most of whom had flexor zone 2 digital nerve injuries, and examined sensory recovery and 2PD after lateral antebrachial cutaneous nerve digital nerve reconstruction. Nine patients had S4 sensation, 6 had S3+, and 13 had good to excellent 2PD results. They noted minimal donor site morbidity; only 2 patients reported minimal cold intolerance at the donor site.

Nerve allograft

The largest retrospective evaluation was a multicenter study that assessed 76 peripheral nerve allograft reconstructions, of which 48 were digital nerve injuries. They found an overall functional recovery rate of 87% with successful reinnervation of 89% of sensory nerves.[8] Taras et al[9] prospectively evaluated 18 nerve allograft reconstructions for mean nerve gaps of 11 mm and found that 15 had good or excellent results. Static and moving 2PD improved to 5.0 and 5.2 mm, respectively, and patients had good visual analog scale pain scores, with no evidence of infection or graft reaction.

Another study found that allografts might be effective for nerve gaps up to 50 mm in the upper extremity, demonstrating meaningful sensory recovery (S3 or greater) in 31 of 35 digital nerve reconstructions (89%; mean gap, 23 mm; range, 5−50 mm).[10]

Autologous vascular graft conduits

Venous and arterial grafts have also been used for nerve reconstruction, although veins have historically had more success than arteries.[11] In addition to the study described above, studies with lower levels of evidence have also used venous grafts for nerve gaps up to 30 mm (static 2PD 11.1 ± 3.4 mm; moving 2PD 6.5 ± 2.6 mm),[12] chronically neglected digital nerve injuries (static 2PD 4−6 mm; moving 2PD 3-5 mm),[13] and traumatic nerve injuries treated within 24 hours (static 2PD 8−13 mm).[14] However, vein grafts may be effective only for short nerve defects because of their collapsibility.[11,15]

Muscle-in-vein grafts

Battiston et al[16] described a novel clinical use of vein grafts surrounding skeletal muscle fibers that acted as a scaffold for nerve repair in 2000. A retrospective series of 22 digital nerve reconstructions in 17 patients by Ignazio and Adolfo[17] for gaps up to 35 mm demonstrated improvements in static and dynamic 2PD, Semmes-Weinstein monofilament testing, and Disabilities of the Arm, Shoulder, and Hand scores in most patients. Of the 22 reconstructed nerves, 17 had S3 or S4 results and 5 had S2 or S1 results.[17] Tos et al[18] also supported the use of muscle-in-vein nerve grafts in a retrospective study of 16 patients who had crush injuries to digital nerves and other mixed nerves. Fifteen of 16 patients had some functional recovery, including all 8 with digital nerve injuries. This method of muscle-in-vein nerve repair may be advantageous for small to moderate nerve gaps up to 60 mm, while avoiding sacrifice of a donor nerve. The tissues are abundantly available and easily fashionable into a graft, and the conduits are immunologically compatible.[15,17,18]

Collagen conduits

Bushnell et al[19] reported good or excellent sensory outcomes in 8 of 9 patients (89%) treated with collagen nerve conduits, whereas Wangensteen and Kallianen[20] retrospectively reviewed 82 digital nerve reconstructions and noted improvements in only approximately 40% of repairs, with a higher revision rate. Lohmeyer et al[21] prospectively evaluated 12 patients and found 9 of 12 (75%) to have good or excellent results for mean nerve gaps of 12.5 mm, and Taras et al[22] reported similar good to excellent sensory outcomes in 16 of 22 of patients (73%). However, Lohmeyer et al[23] more recently reported that only 20 of 40 patients (50%) had excellent or good sensory outcomes in a larger 2-center prospective cohort, with 9 of 40 nerve reconstructions achieving no sensation recovery. Another series found a 59% sensory recovery rate in 45 nerve repairs at 12 months postoperatively,[24] and collagen conduits were also found to be useful for posttraumatic neuromas of digital nerves.[25]

Synthetic polyglycolic acid conduits

Mackinnon and Dellon[26] reported on 15 patients with nerve gaps up to 30 mm, who had PGA conduit nerve

reconstructions. Clinical recovery was comparable to that of nerve autograft and end-to-end repair as reported in prior literature: 5 patients (33%) had S4 sensory function, 8 (53%) had S3 sensation, and 2 (14%) had S2 sensation or less.

Other studies have reinforced the positive outcomes of PGA conduits for nerve reconstruction without substantial evidence of foreign body reaction or infection, and minimal conduit extrusion.[2,27]

Synthetic caprolactone conduits

Neurolac is another synthetic nerve conduit that has been shown to be a viable option for nerve reconstruction.[28] This caprolactone polyester is degraded *in vivo* over the course of 1 year[29]; therefore, there is concern that the prolonged degradation time may lead to problems such as foreign body reaction, graft extrusion, and fistulization. A recent series of 28 nerve defects treated with Neurolac demonstrated less optimal sensory recovery and complications in 8 of the patients. Mean static 2PD in Neurolac repairs was 24.9 mm compared with 6.1 mm on the unaffected contralateral limb, a difference of 18.9 mm ($P < .001$). Two of the complications involved arthrocutaneous fistula formation of the nerve conduit into interphalangeal or metacarpophalangeal joints, and overall there was a clinical failure of functional recovery in 17 of the 28 reconstructions (61%).[30] Histopathological analysis of nerve defects that failed after Neurolac conduit reconstruction suggests that a granulomatous soft tissue reaction occurs, with fibrosis between nerve fibers.[31] Further prospective controlled studies are needed to fully evaluate the effectiveness of the caprolactone nerve conduit.

SHORTCOMINGS OF THE EVIDENCE

There are few high-quality, randomized, controlled studies comparing the numerous options. Most of the evidence consists of retrospective or prospective observational case series of individual surgical techniques. For instance, semipermeable collagen tubes have been more extensively studied as nerve conduits, but all reports thus far have been case series without comparison of collagen conduits with other nerve reconstructive options. In addition, reporting of graft failure or extrusion, neuroma formation, and other complications is inconsistent. Rinkel et al[32] published a systematic review and found only 8 randomized controlled trials, of which only 5 detailed surgical techniques. Of the remaining articles, one trial was published in French and one was not relevant to our question.

DIRECTIONS FOR FUTURE RESEARCH

Digital nerve laceration with defect is relatively uncommon but is amenable to a multicenter randomized trial comparing allografts and conduits, looking at sensory outcome as assessed by 2PD and Semmes-Weinstein monofilament testing. A more standardized method of determining sensory improvement (quality of sensation, 2PD, subjective patient reporting, etc) after digital nerve repair or reconstruction is desirable. Although there is no specific outcome instrument for measuring recovery of nerve injuries, instruments that have been validated for peripheral nerve compressive neuropathies, including the Boston Carpal Tunnel questionnaire[33] and the Michigan Hand Outcomes questionnaire,[34] should be included, along with the Patient-Reported Outcomes Measurement Information System (http://www.nihpromis.org) Upper Extremity computer adaptive test.

Enrichment of neural conduits with growth factors such as nerve growth factor, fibroblast growth factor, or glial growth factor, as well as with Schwann cells and extracellular matrix proteins such as laminin and fibronectin, may contribute to an enhanced microenvironment that promotes nerve regeneration.[11] Chitosan, a polysaccharide found in crustacean exoskeleton, is another potential substrate for nerve growth that can be combined with existing materials such as PGA to create more effective conduits.[11]

OUR CURRENT CONCEPTS FOR THIS PATIENT

For patients with pure sensory nerve defects of less than 15 mm we prefer to use collagen conduits for nerve reconstruction. This has the advantage of shorter operative times than autograft or allograft reconstruction, and the outcomes appear equivalent to other options for a defect of this size. For larger defects, we would use allograft nerve, reserving autografts for mixed or motor nerves.

Nerve allografts offer the advantages of no donor site morbidity, abundant supply, decreased operative time, and lower facility costs. In addition, modern tissue processing offers decellularized, irradiated allograft that can be implanted without immunosuppression.[11,29]

REFERENCES

1. Weber RA, Breidenbach WC, Brown RE, Jabaley ME, Mass DP. A randomized prospective study of polyglycolic acid conduits for digital nerve reconstruction in humans. *Plast Reconstr Surg*. 2000;106(5):1036–1048.
2. Rinker B, Liau JY. A prospective randomized study comparing woven polyglycolic acid and autogenous vein conduits for reconstruction of digital nerve gaps. *J Hand Surg Am*. 2011;36(5):775–781.

3. Bertleff MJ, Meek MF, Nicolai JP. A prospective clinical evaluation of biodegradable Neurolac™ nerve guides for sensory nerve repair in the hand. *J Hand Surg Am*. 2005;30(3):513−518.
4. Stang F, Stollwerck P, Prommersberger KJ, van Schoonhoven J. Posterior interosseous nerve vs. medial cutaneous nerve of the forearm: differences in digital nerve reconstruction. *Arch Orthop Trauma Surg*. 2013;133(6):875−880.
5. Chen C, Tang P, Zhang X. Reconstruction of proper digital nerve defects in the thumb using a pedicle nerve graft. *Plast Reconstr Surg*. 2012;130(5):1089−1097.
6. Chen C, Tang P, Zhang X. Finger sensory reconstruction with transfer of the proper digital nerve dorsal branch. *J Hand Surg Am*. 2013;38(1):82−89.
7. Pilanci O, Ozel A, Basaran K, et al. Is there a profit to use the lateral antebrachial cutaneous nerve as a graft source in digital nerve reconstruction? *Microsurgery*. 2014;34(5):367−371.
8. Brooks DN, Weber RV, Chao JD, et al. Processed nerve allografts for peripheral nerve reconstruction: a multicenter study of utilization and outcomes in sensory, mixed, and motor nerve reconstructions. *Microsurgery*. 2012;32(1):1−14.
9. Taras JS, Amin N, Patel N, McCabe LA. Allograft reconstruction for digital nerve loss. *J Hand Surg Am*. 2013;38(10):1965−1971.
10. Cho MS, Rinker BD, Weber RV, et al. Functional outcome following nerve repair in the upper extremity using processed nerve allograft. *J Hand Surg Am*. 2012;37(11):2340−2349.
11. Konofaos P, Ver Halen JP. Nerve repair by means of tubulization: past, present, future. *J Reconstr Microsurg*. 2013;29(3):149−164.
12. Chiu DT, Strauch B. A prospective clinical evaluation of autogenous vein grafts used as a nerve conduit for distal sensory nerve defects of 3 cm or less. *Plast Reconstr Surg*. 1990;86(5):928−934.
13. Lee YH, Shieh SJ. Secondary nerve reconstruction using vein conduit grafts for neglected digital nerve injuries. *Microsurgery*. 2008;28(6):436−440.
14. Laveaux C, Pauchot J, Obert L, Choserot V, Tropet Y. Emergency management of traumatic collateral palmar digital nerve defect inferior to 30 mm by venous grafting: report of 12 clinical cases. *Chir Main*. 2011;30(1):16−19.
15. Geuna S, Tos P, Titolo P, Ciclamini D, Beningo T, Battiston B. Update on nerve repair by biological tubulization. *J Brachial Plex Peripher Nerve Inj*. 2014;9(1):3.
16. Battiston B, Tos P, Cushway TR, Geuna S. Nerve repair by means of vein filled with muscle grafts: I. Clinical results. *Microsurgery*. 2000;20(1):32−36.
17. Ignazio M, Adolfo V. Muscle-in-vein nerve guide for secondary reconstruction in digital nerve lesions. *J Hand Surg Am*. 2010;35(9):1418−1426.
18. Tos P, Battiston B, Ciclamini D, Geuna S, Artiaco S. Primary repair of crush nerve injuries by means of biological tubulization with muscle-vein-combined grafts. *Microsurgery*. 2012;32(5):358−363.
19. Bushnell BD, McWilliams AD, Whitener GB, Messer TM. Early clinical experience with collagen nerve tubes in digital nerve repair. *J Hand Surg Am*. 2008;33(7):1080−1087.
20. Wangensteen KJ, Kalliainen LK. Collagen tube conduits in peripheral nerve repair: a retrospective analysis. *Hand*. 2010;5(3):273−277.
21. Lohmeyer JA, Siemers F, Machens HG, Mailänder P. The clinical use of artificial nerve conduits for digital nerve repair: a prospective cohort study and literature review. *J Reconstr Microsurg*. 2009;25(1):55−61.
22. Taras JS, Jacoby SM, Lincoski CJ. Reconstruction of digital nerves with collagen conduits. *J Hand Surg Am*. 2011;36(9):1441−1446.
23. Lohmeyer JA, Kern Y, Schmauss D, et al. Prospective clinical study on digital nerve repair with collagen nerve conduits and review of literature. *J Reconstr Microsurg*. 2014;30(4):227−234.
24. Haug A, Bartels A, Kotas J, Kunesch E. Sensory recovery 1 year after bridging digital nerve defects with collagen tubes. *J Hand Surg Am*. 2013;38(1):90−97.
25. Thomsen L, Bellemere P, Loubersac T, Gaisne E, Poirier P, Chaise F. Treatment by collagen conduit of painful post-traumatic neuromas of the sensitive digital nerve: a retrospective study of 10 cases. *Chir Main*. 2010;29(4):255−262.
26. Mackinnon SE, Dellon AL. Clinical nerve reconstruction with a bioabsorbable polyglycolic acid tube. *Plast Reconstr Surg*. 1990;85(3):419−424.
27. Pafilas DN, Vekris M, Gartzonikas D, et al. Digital nerve reconstruction in the hand using biodegradable polyglycolic acid conduits. *J Bone Joint Surg Br*. 2009;91(suppl I):97.
28. Cheng CJ. Synthetic nerve conduits for digital nerve reconstruction. *J Hand Surg Am*. 2009;34(9):1718−1721.
29. Griffin JW, Hogan MV, Chhabra AB, Deal DN. Peripheral nerve repair and reconstruction. *J Bone Joint Surg Am*. 2013;95(23):2144−2151.
30. Chiriac S, Facca S, Diaconu M, Gouzou S, Liverneaux P. Experience of using the bioresorbable copolyester poly(DL-lactide-ε-caprolactone) nerve conduit guide Neurolac™ for nerve repair in peripheral nerve defects: report on a series of 28 lesions. *J Hand Surg Eur Vol*. 2012;37(4):342−349.
31. Hernandez-Cortes P, Garrido J, Camara M, Ravassa FO. Failed digital nerve reconstruction by foreign body reaction to Neurolac™ nerve conduit. *Microsurgery*. 2010;30(5):414−416.
32. Rinkel WD, Huisstede BM, van der Avoort DJ, Coert JH, Hovius SE. What is evidence based in the reconstruction of digital nerves? A systematic review. *J Plast Reconstr Aesthet Surg*. 2013;66(2):151−164.
33. Levine DW, Simmons BP, Koris MJ, et al. A self-administered questionnaire for the assessment of severity of symptoms and functional status in carpal tunnel syndrome. *J Bone Joint Surg Am*. 1993;75(11):1585−1592.
34. Song JW, Waljee JF, Burns PB, et al. An outcome study for ulnar neuropathy at the elbow: a multicenter study by the surgery for ulnar nerve (SUN) study group. *Neurosurgery*. 2013;72(6):971−981.