A Cadaveric Feasibility Study for a Delayed Supinator Nerve Transfer for Restoration of Hand Function after Infraclavicular Brachial Plexus Injury

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Abstract

Objectives: Infraclavicular brachial plexus injury is an uncommon complication of shoulder dislocation. Medial cord injury is known to yield poor functional recovery due to paralysis of the intrinsic hand muscles. This study aims to determine the anatomical feasibility of a conceptual technique involving the use of the lateral cutaneous nerve of the forearm (LCNF) as an *in situ* reversed vascularized graft with the nerves to supinator as the donor in a staged nerve transfer procedure for medial cord injury. **Methods:** Limb measurements were conducted on five fresh cadaveric upper limbs and surgical demonstration performed on a formalin-fixed upper extremity. Each arm was dissected by a peripheral nerve surgeon to identify the LCNF, nerve to flexor digitorum profundus (FDP), deep branch of the ulnar nerve (DBUN), and the anterior interosseous nerve (AIN). The distance of each nerve from recognized limb landmarks was measured and neurorrhaphies attempted in surgical demonstration. **Results:** The mean available length of the LCNF graft was found to be 221.4 mm (range: 103.9–304.4 mm). The mean required graft lengths for medial cord motor targets were 38.6 mm (range: 29.3–51.9 mm) for the nerve to FDP, 164.5 mm (range: 126.7–197.9) for the DBUN, and 177.1 mm (range: 151.4–202.2 mm) for the AIN. **Conclusions:** Based on the results of this cadaveric study, the LCNF is sufficiently long to form tension-free neurorrhaphies when used as an *in situ* reversed vascularized graft to reinnervate distal medial cord motor targets.

Keywords: Brachial plexus neuropathies, hand strength, nerve transfer, peripheral nerve injuries, shoulder dislocation

Introduction

Brachial plexus injuries (BPI) occur in all age groups and may result in lifelong disability. The current optimal management of medial cord BPI has been reported to yield poor rates of useful functional recovery. Infraclavicular BPIs occur by various mechanisms, but they are typically associated with shoulder dislocation in elderly patients.[1] Birch attributed this to the humeral head protruding into the axilla during dislocation and applying traction on the cords and high-terminal branches.[2] Primary nerve compression may also occur due to the formation of a hematoma and secondary compression may ensue due to the hyperplasia of constrictive fibrous tissue during its subsequent resolution. This fibrous tissue impairs blood flow to the nerve, which may result in the retardation or cessation of axonal regeneration. Shoulder dislocation mainly results in Sunderland Class 1–3 injury, and in most cases, there is a chance of spontaneous recovery after releasing the pressure exerted on the nerve. This is the physiological basis for the current first-line approach of either employing conservative management or performing simple neurolysis.

Leffert and Seddon have highlighted that infraclavicular BPIs generally have a good prognosis and so have proposed that they are managed with conservative treatment.[3] However, loss of continuity has been recognized to occur in rare cases, triggering the need for early surgical intervention for the best chance of useful functional recovery.[2] Several authors have

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also made the case for early exploration of these injuries with the aim of performing nerve decompression, and in some cases, nerve repair or reconstruction.[2,4] If this initial approach is unsuccessful, then distal nerve transfers could potentially be considered for reconstruction. However, the nature of infraclavicular BPIs typically involves all cords at presentation and so no donor nerves may initially be available for transfer. In addition, there is the possibility of some early recovery, which could offer an opportunity for donor nerves to transfer to the medial cord, but the reinnervation distances are so great that this is unlikely to be successful for improving hand function.

The general consensus is that the lowest rates of useful functional recovery are observed in infraclavicular BPI patients with medial cord ulnar territory injury. Some authors also state that no reinnervation of the intrinsic musculature of the hand should be expected[5] with a major study reporting an unsatisfactory 50% rate of useful functional recovery in the hand and fingers.[1,6] The disparity is related to the extent of injury to the medial cord. A high-grade complete degenerative axonopathy has little chance of reinnervation, but a mixed nerve injury with some axonal continuity is potentially capable of some meaningful recovery after an extended period of nerve regeneration, with the intact axons maintaining responsiveness of the muscle beyond what would be anticipated for a complete nerve injury. The poor outcomes in complete medial cord injury served as the rationale for this study, which aims to test the anatomical feasibility of a novel reconstructive technique for the restoration of hand function in this patient group. This concept relies on intact function or rapidly recovered function from a predominantly conduction block injury in the posterior cord and a complete medial cord injury at presentation, presumed to be high-grade and complete axonopathy. The technique involves the use of the lateral cutaneous nerve of the forearm (LCNF) as an *in situ* reversed vascularized graft using the nerves to supinator as the donor in a staged nerve transfer procedure. Allowing reinnervation to the vascularized *in situ* graft and later rotating the neoinnervated graft distally to a medial cord target should there be no spontaneous early recovery in the medial cord territory from a mixed nerve injury.

Materials and Methods

The study involved the dissection of five fresh cadaveric upper limbs. All included specimens had no evidence of gross pathology, previous surgical intervention, or previous trauma. All specimens were dissected by one of three trained peripheral nerve surgeons, and all measurements were taken by two independent researchers. Arm and forearm lengths were taken using a ruler, while nerve lengths were measured using a digital Vernier caliper gauge micrometer accurate to 0.1 mm. The demographic data of the included cadavers were not made available for analysis by the researchers.

The cadaveric limbs were placed supine in the anatomical position for the dissection. An incision was made along the medial bicipital sulcus along the mid-portion of the medial arm. The skin and subcutaneous tissue were retracted and the underlying brachial fascia opened. The biceps muscle was retracted and the musculocutaneous nerve (MCN) identified in the interval between biceps and brachialis. The ulnar nerve (UN) was also identified. The brachialis muscle branch of the MCN (BrMBMCN) was identified and tagged. The LCNF was identified as the terminal branch from the MCN and traced lateral to the biceps and dissected into the forearm until its terminal branches. The distance from the BrMBMCN to the first main branch point of the LCNF was measured as the functional length of the LCNF and recorded [Figure 1].

An incision was made on the volar surface of the forearm such that it connected the medial epicondyle to the pisiform bone. This was subsequently extended posteriorly around the medial epicondyle to open Osborne's fascia at the cubital tunnel. The UN was dissected from its previous identification point at the medial intermuscular septum at the mid-humeral level, into the forearm identifying the branch to flexor digitorum profundus (FDP) and the dorsal branch of the UN. The FDP branch origin from the UN was measured from the medial epicondyle and recorded.

Next, the median nerve was identified at the elbow and dissected distally. The pronator teres superficial head was released with a step lengthening of the tendon and retraction allowed the exposure of the proximal flexor digitorum superficialis fibrous arch. The arch was released and the nerve elevated using a silastic loop. The anterior interosseous nerve (AIN) was identified on the lateral side of the median nerve and was tagged. The distance from the anterior interosseous trunk to the pisiform bone was recorded.

A Taleisnik incision was made 6–7 mm medially to the thenar crease and was extended proximally in a zigzag manner such that it curved medially at the distal wrist crease and radially at the proximal wrist crease.[7] The proximal end of this zigzag incision was connected to the previous incision made on the volar surface of the forearm to the pisiform bone. Superficial dissection was performed at the distal part of the incision, and the palmar fascia and palmar carpal ligament were identified and dissected. The neurovascular bundle was looped and mobilized medially to expose the UN within the hand. The hook of the hamate and the muscle fascia of the hypothenar eminence were used to identify the point at which the deep motor branch of the UN separated from the main UN. The superficial UN and the deep motor branches were tagged with silastic loops. Using gentle traction on each loop, the UN

Figure 1: Photograph showing the measurement of the lateral cutaneous nerve of the forearm

dissection between the motor and sensory components was continued proximally until the point of takeoff of the dorsal cutaneous branch was clearly identified.

Internal neurolysis of the main ulnar trunk was carried out to the most proximal point possible. This neurolysis was limited by the presence of interfascicular branching, and the length from the most distal interfascicular branch to the pisiform bone was measured.

Finally, a similar dissection procedure was carried out on a formalin-fixed upper extremity. The medial and lateral branches of the nerves to supinator were identified as they left the posterior interosseous nerve (PIN) in the proximal forearm. The supinator nerve branches were sectioned as distally as possible as they entered the supinator muscle, and the distal LCNF was sectioned proximal to its first major sensory branch point in the lateral mid-forearm. The supinator branches were sutured to the proximal end of the sectioned LCNF to create an end-to-end neurorrhaphy.

Next, possible distal motor targets including the AIN from the median nerve, the nerve to ulnar FDP from the UN, and the deep motor branch of the UN were identified on the exposed UN as for the fresh cadaveric dissections. The supinator LCNF graft loop was traced proximally along its LCNF limb and sectioned just distal to the point at which the MCN gave off its final branch to brachialis. This formed a free *in situ* LCNF graft, which was then dissected free and rotated in turn to each of the three identified more distally placed motor targets. Its free end, the proximal end of the LCNF, was approximated and a coaptation performed to determine the potential site of a neurorrhaphy to a target nerve as a feasibility study that can be used to estimate timelines for potentially successful reinnervation of distal motor targets.

Results

The nerves to supinator are well documented to arise at the level of the medial epicondyle from the PIN. The measured lengths facilitated the calculation of the nerve gap length to be bridged for the successful reinnervation of each of the desired medial cord motor targets. The mean length of the LCNF graft and the mean required graft length for each motor target are shown in Table 1. One specimen had an uncharacteristically short LCNF length, which is suspected to be due to dissection error. The mean length of the available LCNF graft was greater than all measured nerve gap lengths to be bridged. The measured LCNF graft was of sufficient length to form tension-free neurorrhaphies with all of the target medial cord motor nerves and the surgical procedure with all required neurorrhaphies was carried out successfully through cadaveric demonstration [Figures 2 and 3].

Discussion

Medial cord BPIs provide a unique challenge for three reasons. First, the medial cord supplies the most distal upper limb musculature. Direct repair at the injury site would require a considerable reinnervation time, by which time the target muscles would have undergone complete collapse of their intramuscular neural network. Second, the intrinsic hand muscles have been reported to lose reinnervation capability at a faster rate than other muscles, further reducing the potential window for successful reinnervation. Third, there are no potential donor nerves local to the intrinsic hand muscles in medial cord injury. Therefore, any attempt at nerve transfer reinnervation would result in a proximal donor and a proximal anastomosis with a long reinnervation distance leading to poor functional outcome. Even if performed immediately after

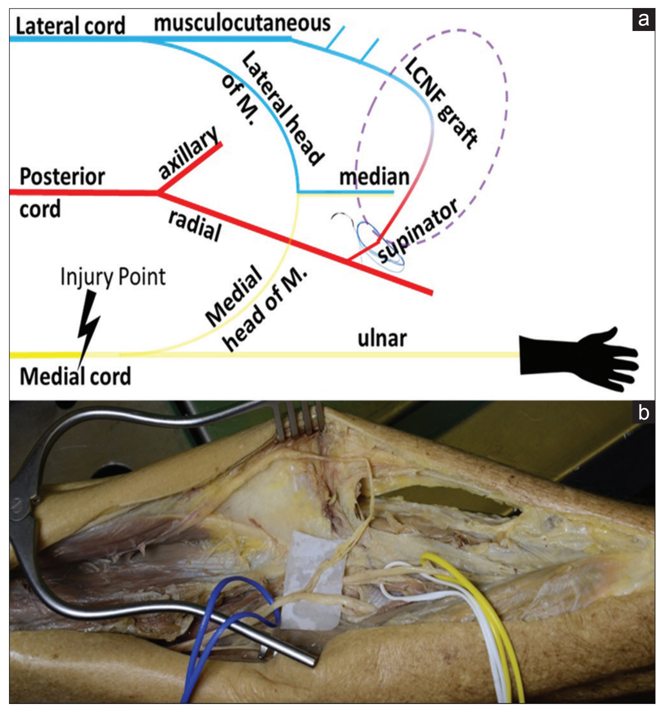

Figure 2: Stage 1 of the novel procedure: Formation of the *in situ* lateral cutaneous nerve of the forearm nerve regeneration conduit. Proximal radial nerve in blue silastic loop; white loop posterior interosseous nerve; and yellow loop ECRB- extensor carpi radialis brevis motor branch (a) Schematic representation of the nerve to supinator coapted to the proximal lateral cutaneous nerve of the forearm stump to form a nerve loop. (b) Cadaveric dissection demonstrating the feasibility of the formation of a supinator-lateral cutaneous nerve of the forearm nerve loop

Table 1: The measured required reinnervation lengths

	LCNF length	Target 1: Ulnar FDP	Target 2: Deep branch of ulnar	Target 3: Anterior interosseous nerve
Average length (range)/mm	221.4 (103.9–304.4)	38.6 (29.3–51.9)	164.5 (126.7–197.9)	177.1 (151.4–202.2)

LCNF: Lateral cutaneous nerve of the forearm, FDP: Flexor digitorum profundus

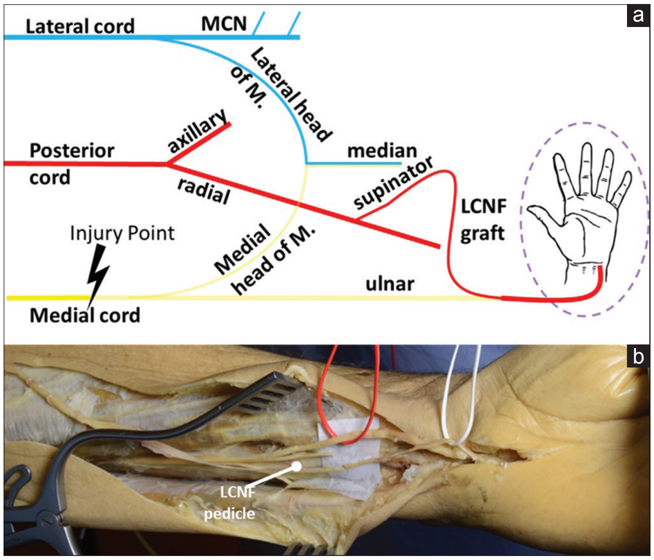

Figure 3: Second stage of the novel procedure: Transfer of the lateral cutaneous nerve of the forearm graft to distal motor targets for the restoration of hand function. (a) Schematic representation of the proximal lateral cutaneous nerve of the forearm coapted to distal motor targets. (b) Cadaveric dissection demonstrating the feasibility of the use of lateral cutaneous nerve of the forearm as a graft to reinnervate the deep intrinsic muscles of the hand through the deep branch of the ulnar nerve (white tag)

injury when the severity of injury is not yet fully defined and nerve transfer surgery is contraindicated, the distance is often too great for successful reinnervation.

This conceptual procedure involved the use of the LCNF as an *in situ* reversed vascularized graft using the nerves to supinator as the donor in a staged nerve transfer procedure to reinnervate distal medial cord motor targets. It was designed to be performed early after the injury as a banking procedure, creating a vascularized *in situ* reversed sensory graft to support axonal regeneration that may be later transposed distally with the aim of salvaging intrinsic hand muscle function. Every aspect of its design was selected to minimize the required reinnervation time.

First, it employs basic nerve transfer principles to minimize the required axonal regeneration distance. The nerve to supinator was selected as the donor because of its proximity to medial cord targets as well as its documented lack of donor morbidity when sectioned with functional supination preserved through biceps.[8] It was also reported to have a favorable donor-to-recipient axon ratio when coapted to the deep branch of the UN, which innervates the targeted intrinsic hand musculature. Tötösy de Zepetnek *et al.*[9] reported that a minimum ratio of 0.3 is required to achieve normal muscle function, whereas Schreiber *et al.*[10] reported that a nerve transfer procedure should aim for a donor-to-recipient axon ratio of >0.7 for optimal restoration of function. The supinator-to-deep branch of ulnar axon ratio fell in this optimal range with a reported value of 0.91.[11]

The conceptual procedure couples this nerve transfer with the use of the LCNF as a nerve autograft to bridge the remaining distance between donor and recipient. The successful use of the LCNF for nerve grafting with very limited donor-site morbidity has been reported for decades.[12] The authors have reported that only some patients experienced numbness on the anterolateral nonresting surface of their proximal forearm, which showed significant improvement and even resolution after 18 months' follow-up.[13,14] This nerve transfer may be employed in cases of combined medial and lateral cord injury where the recovery of the proximal biceps and brachialis are anticipated. In such cases, there will be no functioning axons in the LCNF in the early phase of recovery from injury and no sensory morbidity. In cases of preserved LCNF function, the technique will require a proximal neurotomy of the LCNF to allow predegeneration of the axons contained therein before retrograde repopulation with regenerating motor axons from the supinator nerve branches.

Furthermore, the proximity of the LCNF's distal end to the supinator facilitated *in situ* grafting in the reverse orientation. Stromberg *et al.* demonstrated similar conduction velocities and amplitudes in conventional and reversed grafts, indicating that axonal regeneration is not impeded by the reversed polarity of nerve channels.[15] Ansselin and Davey reported that reversing the polarity of branched grafts resulted in greater conduction velocities with a higher proportion of axons regenerating to the distal stump.[16] The LCNF is documented to have two branching points[15] and this served as the rationale for utilizing a reversed grafting technique in the design of the demonstrated procedure.

A staged procedure was favored for a few reasons. The first stage of the procedure requires very little dissection of the LCNF, and therefore, the graft would have maximal nutrient supply for the majority of axonal regeneration. For the majority of axonal regeneration, this nerve autograft is left *in situ* and experiences similar conditions to that of a vascularized nerve graft. Vascularized nerve grafting was pioneered by Taylor and Ham[17] to overcome some of the nutritional limitations of conventional free nerve grafting. Adequate nutrient provision is essential for the successful outcome of a nerve graft[18] and several studies have demonstrated superior results with vascularized nerve grafts.[19-22]

A two-staged design also facilitated retaining the standard practice of observing for spontaneous recovery of nerve injury for 3 months. A single procedure would involve sectioning the medial cord pathway quite early, relinquishing the chance of spontaneous recovery. The ingenuity of this staged design lies in the versatility and adaptability of the procedure to the variable spontaneous recovery of the medial cord pathway without any loss of axonal regeneration time. The procedure is designed such that reinnervation through the LCNF graft occurs while the original medial cord pathway is still intact. Should proximal branches of the medial cord recover, for example, the branch to flexor carpi ulnaris or FDP, then the graft created in Stage 1 can be coapted to target distal reinnervation. In the unlikely scenario that the total medial cord recovers, the banked graft could be abandoned with the patient experiencing very limited morbidity after only undergoing the Stage 1 procedure. Furthermore, the sectioning and coaptation of the LCNF would yield no donor-site morbidity in patients with a concurrent lateral cord injury.

The only aspects of this novel procedure's design that may result in suboptimal axonal regeneration and outcome are the need for a graft with two coaptation sites and the discordance in modality between the selected donor nerve and that of the graft. The procedure relies on the growth of motor axons in a sensory cutaneous nerve environment, a situation that many authors have reported to be nonideal but universally accepted as a gold standard reconstructive technique.[23-25]

One major limitation of this study is the small sample size included. The demographic information of the cadavers was also not available, and hence the effect of age, sex, or ethnicity on the measured lengths could not be investigated. However, several cadaveric feasibility studies have reported no difference in nerve length proportions across patient gender and laterality. Nerve diameters and axon counts were also not primarily assessed in this study; however, several studies have previously investigated and reported those characteristics for the involved nerves, and as such, this aspect of compatibility was included in the evaluation of the novel nerve transfer procedure.

It should be noted that another nerve transfer procedure was hypothesized using similar nerve transfer techniques to those discussed in this paper. This procedure involved the use of the nerve to brachialis as the donor motor nerve with retrograde reinnervation of the medial cutaneous nerve of the forearm (MCNF) as an *in situ* graft in the upper arm. The double nerve transfer using supinator to LCNF and brachialis to MCNF could be performed in the small subset of patients who suffer isolated medial cord injury with normal function preserved in posterior and lateral cords. Using both of these procedures concurrently would allow for the specific targeting of more branches of the medial cord, including concomitant restoration of the branch to FDP and the motor branch of the UN with more motor axons leading to potentially greater functional recovery.

Conclusions

A conceptual nerve transfer technique was proven to be feasible by means of a cadaveric feasibility study and was subsequently demonstrated in a cadaveric surgical demonstration where tension-free neurorrhaphies were successfully performed at all medial cord motor targets.

Recommendations

A pilot study investigating the efficacy of the demonstrated procedure should be designed as the potential for gain far outweighs the risks of the procedure. This procedure represents a novel method of reinnervating distal medial cord targets and can potentially lead to better rates of functional recovery in this patient group. It should be considered even if it only yielded a marginal improvement in hand function because as Sterling Bunnell, the founding father of hand surgery said, "to someone who has nothing, a little is a lot."[26]

Ethical considerations

Cadaveric arms were provided by the Anatomy Departments at Keele University School of Medicine and the University of Birmingham. Consent for the use of the cadavers in scientific research was obtained from these departments. All dissection was conducted in accordance with local protocols and the Human Tissue Act. Appropriate consent was also obtained for the capture and publication of photographs.

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Conflicts of interest

There are no conflicts of interest.

Author's contributions

DNG was involved in data collection, analysis, and interpretation and also wrote the final draft of the article. IAG was also involved in all aspects of data management, that is, data collection, organization, analysis, and interpretation. CS and CE supported DMP in the design of the study, aided in data analysis, and provided logistic support. DMP conceived the novel procedure, designed the study, and collected data. All authors have critically reviewed and approved the final draft and accept responsibility for the content and similarity index of the manuscript.

References

1. Hems TE, Mahmood F. Injuries of the terminal branches of the infraclavicular brachial plexus: Patterns of injury, management and outcome. J Bone Joint Surg Br 2012;94:799-804.
2. Birch R. Surgical Disorders of the Peripheral Nerves. London: Springer; 2011.
3. Leffert RD, Seddon H. Infraclavicular brachial plexus injuries. J Bone Joint Surg Br 1965;47:9-22.
4. Burge P, Rushworth G, Watson N. Patterns of injury to the terminal branches of the brachial plexus. The place for early exploration. J Bone Joint Surg Br 1985;67:630-4.
5. Siqueira MG, Martins RS. Surgical treatment of adult traumatic brachial plexus injuries: An overview. Arq Neuropsiquiatr 2011;69:528-35.
6. Gutkowska O, Martynkiewicz J, Mizia S, Bąk M, Gosk J. Results of operative treatment of brachial plexus injury resulting from shoulder dislocation: A study with A long-term follow-up. World Neurosurg 2017;105:623-31.
7. Brown JM, Yee A, Mackinnon SE. Distal median to ulnar nerve transfers to restore ulnar motor and sensory function within the hand: Technical nuances. Neurosurgery 2009;65:966-77.
8. Bertelli JA, Ghizoni MF. Transfer of supinator motor branches to the posterior interosseous nerve in C7-T1 brachial plexus palsy. J Neurosurg 2010;113:129-32.
9. Tötösy de Zepetnek JE, Zung HV, Erdebil S, Gordon T. Innervation ratio is an important determinant of force in normal and reinnervated rat tibialis anterior muscles. J Neurophysiol 1992;67:1385-403.

10. Schreiber JJ, Byun DJ, Khair MM, Rosenblatt L, Lee SK, Wolfe SW, *et al.* Optimal axon counts for brachial plexus nerve transfers to restore elbow flexion. Plast Reconstr Surg 2015;135:135e-41e.
11. Namazi H, HajiVandi S. Supinator to ulnar nerve transfer via *in situ* anterior interosseous nerve bridge to restore intrinsic muscle function in combined proximal median and ulnar nerve injury: A novel cadaveric study. J Surg Res 2017;211:95-9.
12. Pilanci O, Ozel A, Basaran K, Celikdelen A, Berkoz O, Saydam FA, *et al.* Is there a profit to use the lateral antebrachial cutaneous nerve as a graft source in digital nerve reconstruction? Microsurgery 2014;34:367-71.
13. McFarlane RM, Mayer JR. Digital nerve grafts with the lateral antebrachial cutaneous nerve. J Hand Surg Am 1976;1:169-73.
14. Tenny JR, Lewis RC. Digital nerve-grafting for traumatic defects. Use of the lateral antebrachial cutaneous nerve. J Bone Joint Surg Am 1984;66:1375-9.
15. Stromberg BV, Vlastou C, Earle AS. Effect of nerve graft polarity on nerve regeneration and function. J Hand Surg Am 1979;4:444-5.
16. Ansselin AD, Davey DF. Axonal regeneration through peripheral nerve grafts: The effect of proximo-distal orientation. Microsurgery 1988;9:103-13.
17. Taylor GI, Ham FJ. The free vascularized nerve graft. A further experimental and clinical application of microvascular techniques. Plast Reconstr Surg 1976;57:413-26.
18. Tarlov IM, Epstein JA. Nerve grafts: The importance of an adequate blood supply. J Neurosurg 1945;2:49-71.
19. Shibata M, Tsai TM, Firrell J, Breidenbach WC. Experimental comparison of vascularized and nonvascularized nerve grafting. J Hand Surg Am 1988;13:358-65.
20. Doi K, Kuwata N, Kawakami F, Tamaru K, Kawai S. The free vascularized sural nerve graft. Microsurgery 1984;5:175-84.
21. Rose EH, Kowalski TA, Norris MS. The reversed venous arterialized nerve graft in digital nerve reconstruction across scarred beds. Plast Reconstr Surg 1989;83:593-604.
22. Gu YD, Wu MM, Zheng YL, Li HR, Xu YN. Arterialized venous free sural nerve grafting. Ann Plast Surg 1985;15:332-9.
23. Nichols CM, Brenner MJ, Fox IK, Tung TH, Hunter DA, Rickman SR, *et al.* Effects of motor versus sensory nerve grafts on peripheral nerve regeneration. Exp Neurol 2004;190:347-55.
24. Ghalib N, Houst'ava L, Haninec P, Dubový P. Morphometric analysis of early regeneration of motor axons through motor and cutaneous nerve grafts. Ann Anat 2001;183:363-8.
25. Brenner MJ, Hess JR, Myckatyn TM, Hayashi A, Hunter DA, Mackinnon SE, *et al.* Repair of motor nerve gaps with sensory nerve inhibits regeneration in rats. Laryngoscope 2006;116:1685-92.
26. Shin AY. 2004-2005 sterling bunnell traveling fellowship report. J Hand Surg Am 2006;31:1226-37.