

Nerve transfers of the forearm and hand: a review of current indications

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ABSTRACT

Nerve transfer surgery, also referred to neurotization, developed in the mid 1800s with the use of animal models, and was later applied in the treatment of brachial plexus injuries. Neurotization is based on the concept that following a proximal nerve lesion with a poor prognosis, expendable motor or sensory nerves can be re-directed in proximity of a specific target, whether a muscle or skin territory, in order to obtain faster re-innervation. Thanks to the contribution of several authors including Oberlin, MacKinnon and many others, the field of nerve transfer surgery has expanded in treatment of not only the brachial plexus, but also the arm, forearm and hand. This article reviews the recent literature regarding current concepts in nerve transfer surgery, including similarities to and differences from tendon transfer surgery. Moreover, indications and surgical techniques are illustrated for different types of nerve injury affecting the extrinsic and intrinsic musculature of the hand as well as sensory function.

Key words:

Brachial plexus, nerve transfer, peripheral nerve

INTRODUCTION

The concept of nerve transfer developed almost two hundred years ago when Flourens^[1] reported his first experiments with the brachial plexus of a rooster. He demonstrated that proximal nerve stumps could be coupled to different target nerves, obtaining not only re-innervation, but also a function that was dependent on the new motor nerve.^[2] This report stimulated a number of animal studies under the label of “nerve crossing”,^[3] followed by a series of clinical cases in the early twentieth century showing the feasibility of suturing a proximal nerve stump to a distal one with a different target organ.^[4-7]

Using this concept, several options have been developed over the years, in which expendable donor nerves or their fascicles are re-directed to recipient nerves in close

proximity to their target muscle or skin territory. The technique was initially used in brachial plexus injuries and has slowly become a routine procedure for peripheral nerve lesions where poor functional results are expected due to the distance between the site of injury and the innervated muscles.

GENERAL CONCEPTS IN NERVE TRANSFERS

Brachial plexus injuries and peripheral nerve lesions at or proximal to the elbow result in denervation and loss of sensation and may not recover due to the long distance between the lesion and the target organ. Even when treated early, the axon regeneration process does not always have the capacity to reach the proper muscle before irreversible changes have taken place. The primary aim of nerve transfers is to promote re-innervation in proximity to a certain target organ (whether a muscle or a skin territory) following a proximal nerve injury.^[8-11]

Axonal regeneration progresses at a rate of 1-2 mm/day.^[12] Because muscle fibers undergo irreversible changes after 12-18 months of denervation,^[13] it is imperative that treatment be undertaken promptly for functional recovery.^[14] Very proximal lesions in the arm or brachial plexus, even

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when treated within 3 months following injury, carry a high risk of incurring irreversible muscle atrophy before the regenerating axons can reach the motor end plates. Transferring a motor nerve that is close to the motor end plate shortens the distance for axon regeneration and consequently the time for muscle re-innervation. In this respect, nerve transfer promotes a functional rather than an anatomical reconstruction.^[15] This is the main concept in nerve transfer surgery. Other equally important concepts include the use of tension-free sutures directly between the donor and recipient nerves without the use of nerve grafts to ensure that the maximal number of regenerating axons is directed toward the end organ. By working at a location distal to the zone of injury, a pristine, vascular field can be used, which will not interfere with nerve regeneration.^[9-11]

Although sensory receptors have a wider margin for recovery even many months after the injury, earlier repairs clearly lead to better outcomes.^[14,16]

Postoperative rehabilitation is facilitated when a nerve with synergistic function is chosen for re-innervation.^[8,17-19] To ensure a tension-free transfer, it is essential to dissect the donor nerve as distal as possible and the recipient as proximal as possible. When antagonistic nerves have been used, the learning process is more difficult and the patient may require additional time to understand how to activate the injured muscles.^[20] The process of re-adaptation is still unclear, but a certain grade of brain plasticity is involved in learning how to utilize a muscle that is now supplied by a different motor nerve.^[21-24]

INDICATIONS

Nerve transfer surgery has evolved greatly over the last two decades due to a better knowledge of intraneural anatomy and a better understanding of functional re-innervation rather than anatomical reconstruction. As a result, in select cases with high-level nerve lesions, it is advisable to address the injury in terms of functional recovery rather than pure anatomic restoration.

In the absence of a proximal nerve stump, nerve transfer provides an alternative for re-innervation of the target muscle. This is often the case in brachial plexus injuries with root avulsion. Another indication is a very proximal nerve lesion or delayed presentation, where muscle atrophy most likely will have occurred prior to functional re-innervation. In cases in which surgical exploration is difficult secondary to a previous extensive injury, distal nerve transfer, will shorten the time to re-innervation and avoid nerve repair in a highly fibrotic bed.^[9,15,8,25]

The presence of a nerve defect itself represents a good indication for nerve transfer, first because there is no need to harvest a nerve graft from another site, and second because comparable if not better results with nerve transfer rather than long nerve grafts have been reported.^[14,26-28]

As a general rule, instead of focusing on anatomic reconstitution of the damaged nerve(s), the goal becomes functional reconstruction with re-innervation of specific

muscle(s) and skin territory. A specific movement will still be performed by the original muscle, without the need to re-route different tendons or muscles, which might in turn lose some of their original power.

RADIAL NERVE DEFICITS

Indications

The radial nerve can suffer from a multitude of injuries, with humeral fracture being the most common.^[29-31] Other causes include brachial plexus injuries, neuritis, direct trauma and compression. Radial nerve paralysis has been commonly treated by either neurolysis, nerve graft or tendon transfers with successful results.^[32] Nevertheless, some authors have reported the potential impairment of pronation following the transfer of the pronator teres (PT), and unnatural coordination after tendon transfer, especially while performing a full hand grip.^[33,34] In 2002, Lowe *et al.*^[34] described the possibility of transferring branches of the median nerve to recover wrist and finger extension in radial nerve palsy, alone or in conjunction with tendon transfers. Since then several reports have elucidated the technical feasibility and the possible advantages.^[35-38]

Nerve transfers

Motor

Currently, priority is given to re-innervation of the extensor carpi radialis brevis (ECRB) for wrist extension and the posterior interosseous nerve (PIN) for finger and thumb extension. The branch to the flexor digitorum superficialis (FDS) muscle (median nerve) is rotated to the ECRB and branches to the palmaris longus (PL) and flexor carpi radialis (FCR) (median nerve) are coaptated to the PIN [Figure 1].

Schematic description

A lazy “S” incision is made on the volar surface from the cubital fossa down to the mid-forearm. The lacertus

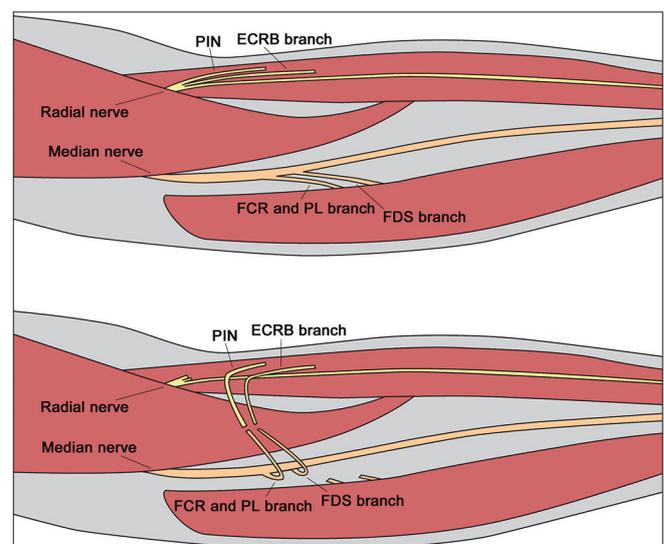


Figure 1: Radial nerve deficit. Transfer of the motor branch to flexor digitorum superficialis muscle to the extensor carpi radialis brevis, and the motor branches to flexor carpi radialis muscle and palmaris longus muscle, to the PIN. PIN: Posterior interosseous nerve, ECRB: Extensor carpi radialis brevis, FCR: Flexor carpi radialis, FDS: Flexor digitorum superficialis, PL: Palmaris longus

fibrosus is divided, and the radial vascular bundle, and the median nerve are identified. Distally, step lengthening of the superficial part of the PT allows better medial retraction of the muscle so as to visualize the branches of the median nerve to the FDS and FCR. Lateral retraction of the brachioradialis exposes the superficial radial nerve, the PIN, and the ECRB branches. Once both the donor branches to the FDS and FCR and the recipient branches are identified, they are isolated as needed in order to divide them following the rule of “donor distal/recipient proximal” described by Brown and Mackinnon,^[15] without tension on the nerve coaptation.

Sensory

The lateral antebrachial cutaneous nerve (LACN) runs close to the sensory radial branch in the distal forearm and matches it very well in size. It is expendable, and its use does not create any significant morbidity along its territory.

MEDIAN NERVE DEFICITS

Indications

In high-level injuries of the median nerve both extrinsic and intrinsic muscles of the forearm and hand, as well as the sensation on the volar-radial part of the hand, are affected and need restoration. In low-level injuries thumb, opposition and sensation in the 1st, 2nd, 3rd, and radial half of the 4th fingers are addressed for reconstruction. The most common donor is the radial nerve and its branches to the supinator and ECRB. In case of isolated injuries to the anterior interosseous nerve (AIN), intra-median nerve transfers have been described using intact branches of the median nerve which are redirected.

Motor nerve transfers

Thumb opposition

When available the AIN (branch to the pronator quadratus) is isolated and transferred to the motor branch of the thenar muscles [Figure 2]. The donor and recipient match well in size, but transfer requires a nerve graft which leads to the inevitable loss of some of the regenerating axons. In high-level injuries, ulnar nerve to median (third lumbrical motor branch)^[39] or radial nerve to median (motor branch

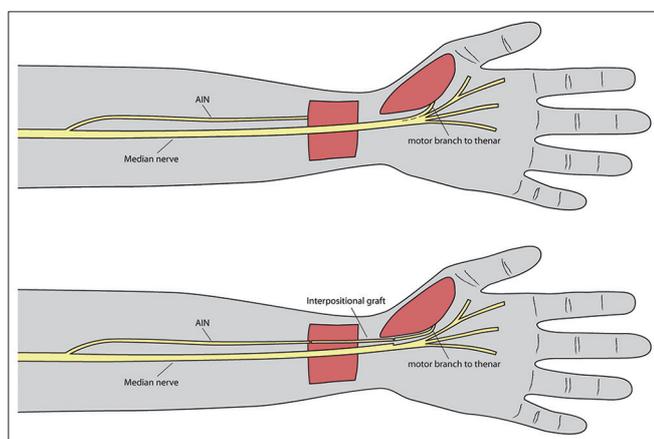


Figure 2: Distal median nerve deficit. Transfer of the terminal branch of the anterior interosseous nerve to the motor branch to the thenar muscles, using an interpositional graft. AIN: Anterior interosseous nerve

to the extensor digiti minimi and extensor carpi ulnaris) via interposition graft have been described, but results are uncertain and thus common tendon transfers might be considered instead.^[15]

Schematic description

A carpal tunnel incision is made to expose the median nerve and its motor branch at the level of the wrist. The latter is gently isolated proximally as far as its fibers can be distinguished. The AIN and its branch to the pronator quadratus are then isolated with intramuscular dissection in order to obtain the maximal possible length. A nerve graft is usually necessary for a tension-free closure. Although the number of axons matches well, the need for a nerve graft downgrades the level of outgrowth and, therefore, the actual potential for re-innervation.

Pronator function

The pronator teres function can be impaired in high median nerve injuries or secondary to an isolated deficit.^[40] In the first case the radial nerve, and specifically the motor branch to the ECRB is isolated and re-oriented to the branch, which innervates the PT.^[41] The surgical approach is similar to that described for radial nerve palsy when the opposite transfer is planned. In case of isolated PT deficiency, an intra-median nerve transfer is planned using one of the branches to the FDS^[40] sutured to the PT motor branch.

Extrinsic muscle function

In high-level median nerve injury several extrinsic muscles such as PT, FCR, FDS, flexor pollicis longus, the radial component of the FDP, and PQ are denervated. Two main problems are faced: first, the lack of flexion in the thumb, index and the long fingers, and second, the loss of pronation.^[15] The first option is to re-direct the motor branch to the ECRB towards the AIN, in a similar fashion described above for radial nerve palsy, but in a reverse direction [Figure 3]. If there is a significant discrepancy in size, the branch to the supinator can also be included.

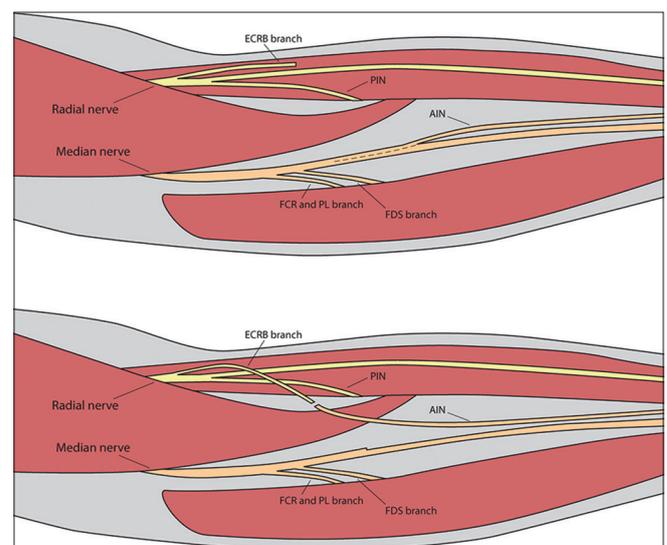


Figure 3: High median nerve deficit. Transfer of the motor branch to extensor carpi radialis brevis to the anterior interosseous nerve. ECRB: Extensor carpi radialis brevis, PIN: Posterior interosseous nerve, AIN: Anterior interosseous nerve, FCR: Flexor carpi radialis, FDS: Flexor digitorum superficialis, PL: Palmaris longus

In this case the AIN needs to be traced proximally in order to reach comfortably the motor branch to the supinator.^[15,41,42]

Schematic description: the AIN is identified in the forearm. A lazy-S incision is made over the volar aspect of the mid-forearm, and the lacertus fibrosus is divided. The tendon of the superficial part of the PT is lengthened to allow the muscle to be retracted, and the median nerve exposed. The AIN lies on the radial side of the median nerve and does not always course as a distinct fascicle. A longitudinal vessel often demarcates it from the rest of the median nerve. Once isolated, it should be traced proximally to obtain enough length for a tension-free suture. The motor branch to the ECRB is then identified under the brachioradialis muscle, coursing close to the sensory branch of the radial nerve. This is followed as distal as possible and then rotated toward the AIN. In case of a size mismatch, the radial nerve is isolated proximally in order to include the motor branch to the supinator, which in turn will reach the AIN if appropriate proximal dissection is completed.

In the event of isolated AIN palsy, an intra-median nerve transfer can be considered with redirection of branches to the FDS or PL/FCR to the AIN.

In lower brachial plexus injuries where both the median and ulnar nerve have been compromised, the AIN can be reinnervated by using the branch to brachialis muscle^[43] or the branch to the brachioradialis muscle,^[44] after both the donor and recipient are isolated for the necessary length at the elbow or a slightly proximal level.

Sensory nerve transfers

Priority is given to the ulnar side of the thumb and the radial side of the index finger in order to re-establish functional pinch and grip. Several donors can be considered depending upon their availability. The first choice includes the digital nerves to the fourth web space, innervated by the ulnar nerve^[15] [Figure 4]. An alternative is the dorsal sensory branch from the radial nerve to the thumb.^[45,46] Finally, as illustrated by Ross *et al.*^[47] in upper plexus lesions, the sensory components to the third web space come from a distinct fascicle, which can be isolated proximally in the median nerve and utilized as a donor to the thumb and index finger.

Schematic description

A carpal tunnel incision is made and prolonged distally in a zig-zag fashion toward both the first and the fourth interdigital spaces. Deep to the superficial arterial arch and the digital arteries, the common digital nerves to the ulnar side of the ring finger and the radial side of the little finger are isolated, traced proximally, and divided as distally as possible. The digital nerves to the first web space are then identified and isolated proximally in order to obtain enough length to be sutured to the donor nerves. The remainder of the sensory median nerve can then be divided proximally and coupled in an end-to-side fashion to the ulnar digital nerve of the 5th finger in order to restore protective sensation.

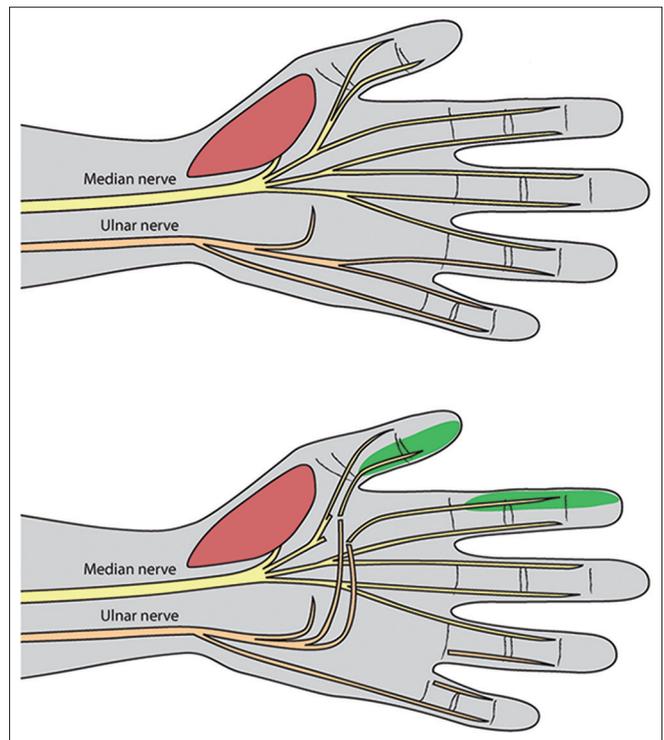


Figure 4: Sensory median nerve deficit. Transfer of the sensory branches from the ulnar nerve to the fourth web space to the sensory branches of the first web space

ULNAR NERVE DEFICITS

Indications

High-level nerve injuries lead to the loss of both grip and pinch strength in the hand, and sensation in the little finger and the ulnar side of the ring finger. Even following an early repair it is difficult to obtain a functional re-innervation of the intrinsic musculature, a fact which caused some authors to question the utility of surgical intervention at the site of lesion.^[48-51] Tendon transfers can avoid chronic deformities, but do not always allow fluid motion and adequate strength. Alternatively, the median nerve can provide motor and sensory branches in the forearm and hand that compensate for the ulnar nerve deficiency.^[52-55] In the event of a combined ulnar and median nerve injury, motor branches from the radial nerve are selected as donor axons.

Motor

If the median nerve is intact, the distal part of the AIN can re-innervate the distal motor component of the ulnar nerve [Figures 5-7]. Brown *et al.*^[56] performed the first case in 1991 and since then several authors have described successful results. Recently, Sukegawa *et al.*^[57] provided technical clarification regarding identification and separation of the motor branch of the ulnar nerve, the number of fascicles in the AIN and the motor ulnar nerve, and the shortest path required for the AIN to reach its recipient target. The motor component of the ulnar nerve can be reached through a Taleisnik incision^[58] which extends from the interthenar region proximal to the distal forearm. First, the ulnar nerve is isolated at the Guyon's canal and the motor branch is identified during its course toward

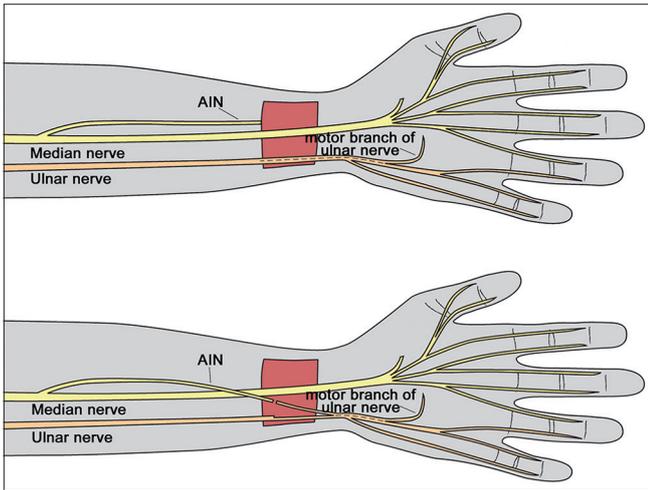


Figure 5: Ulnar nerve deficit. Transfer of the terminal branch of the anterior interosseous nerve to the motor branch of the ulnar nerve. AIN: anterior interosseous nerve

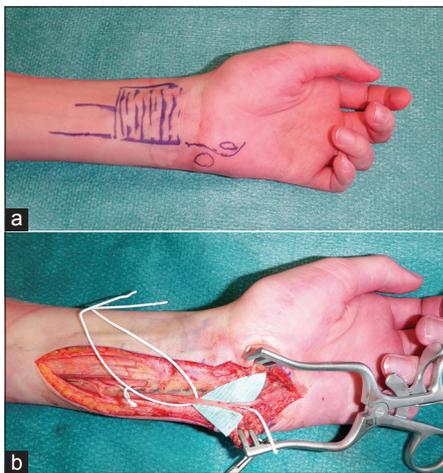


Figure 6: Ulnar nerve deficit. (a) Preoperative drawing showing the course of the motor branch of the ulnar nerve, and the terminal branch of the anterior interosseous nerve into the pronator quadrates; (b) the ulnar nerve and its motor branch after extensive neurolysis

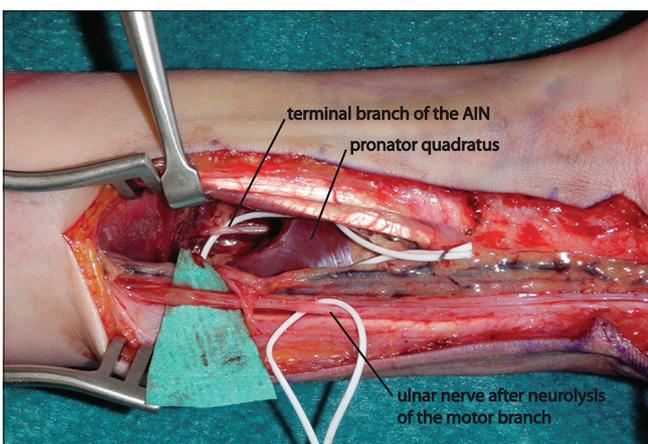


Figure 7: Terminal branch of the anterior interosseous nerve in the pronator quadratus muscle

the hook of the hamate. Once the point of divergence is identified, the motor nerve is followed proximally by blunt dissection. As reported by Sukegawa *et al.*,^[57] this is usually possible for about 33 mm. Sharp dissection is then required for an average of 19 mm. A longitudinal vascular

bundle usually separates the motor from the sensory part of the ulnar nerve. Through the forearm incision, the AIN is identified while entering the pronator quadratus. The dissection is carried as distal as possible into the muscle, and the AIN is then passed dorsal to the FDP in order to reach the motor branch of the ulnar nerve.^[56] The AIN has at this level approximately 506 axons, whereas the ulnar motor nerve 1523 axons.^[56] The transfer is not synergistic and recovery is generally suboptimal, but it is sufficient to prevent clawing of the ulnar digits.

In combined ulnar and median nerve injuries, motor branches from the radial nerve to the extensor digiti minimi and extensor carpi ulnaris originating from the PIN can be used to re-innervate the motor ulnar nerve. Coaptation is achieved by the use of an interpositional nerve graft from the mid-proximal forearm to the wrist. Although intrinsic muscle recover is not complete, it may be sufficient to prevent claw deformity of the fingers.^[59] As an alternative, branches to abductor pollicis longus, extensor pollicis brevis, and extensor indicis proprius can be re-oriented without the need for an interpositional nerve graft.^[60]

Sensory

In cases of ulnar nerve palsy, the functioning median nerve has been used by several authors with various methods to provide sensation to the ulnar nerve territory. Battiston and Lanzetta^[53] described the use of the palmar sensory branch of the median nerve to the sensory component of the ulnar nerve. Brown *et al.*^[56] used the sensory component to the third web space as a donor to the fourth web space, coupled in an end-to-end fashion, while the dorsal sensory branch of the ulnar nerve was sutured to the sensory part of the median nerve in an end-to-side manner after performing an epineural window.

In 2011, Flores^[61] described a similar technique but instead of an end-to-end anastomosis, he sutured the sensory component of the ulnar nerve in an end-to-side manner to the sensory nerve of the third web space without an epineural window. The author noted that at this level the epineural layer is thin and that the microsurgical sutures represent a sufficient trauma to stimulate the necessary sprouting into the donor's nerve. Oberlin *et al.*^[62] used the LACN as a donor in the forearm, coapted to the dorsal branch of the ulnar nerve by an interpositional nerve graft harvested from the sural nerve. In his two cases, he was able to avoid donor site morbidity when using donor sensory nerves from the median nerve territory in the hand. Ruchelsman *et al.*^[63] revised this technique by use of a longer dissection of the LACN in the forearm and suturing it without an interpositional graft in an end-to-side fashion to the ulnar nerve before the take-off of the sensory branch.

CONCLUSION

The numerous advantages offered by transposing a functional nerve stump in proximity to a target muscle or skin territory have created new and exciting alternatives for the management of nerve injuries, particularly those occurring far proximal in the arm or the brachial plexus. Some of these options have been described only

recently, and some only as case reports. In order to have a better understanding and use of such promising field, blinded randomized studies comparing traditional tendon transfers to nerve transfers are required.

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