Distal Nerve Transfers for the Upper Extremity: A Review

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Abstract

Introduction Injuries to the peripheral nerves have troubled surgeons since time immemorial. Repair of the nerves, either primarily or using grafts, has been the method of treatment of nerve injuries. Nerve transfers revolutionized the results by bringing the coaptation closer to the target receptor, hence improving results. There is constant refinement, with newer, innovative nerve transfers which can be used for even more specific function. The concept of collateral sprouting has allowed specific targeted transfers, with minimal loss of the donor function.

Materials and Methods This was a review of novel distal nerve transfers for the upper extremity. The indications include high-nerve injuries, brachial plexus injuries, and spinal cord injuries. These transfers include novel transfers around the elbow as well as transfers in the forearm and hand.

Discussion These transfers aim to improve the recovery of patients with proximal nerve injuries, minimizing donor site morbidity at the same time. However, the use of these procedures is not yet widespread, with the jury still out regarding the efficacy of these procedures.

Keywords

- collateral sprouting
- distal nerve transfer
- end to side coaptation
- nerve transfer

Injuries to the peripheral nerves have troubled surgeons since time immemorial. Although great strides have been taken in this field, there is still a long way to go in establishing optimal results. Nerve transfers have become the standard for treatment of such injuries. The advantages of nerve transfers are many. The convert a proximal injury to a distal injury and hence allow earlier recovery to take place.[1] The repair is away from the zone of injury and hence is less affected by the changes associated with the primary trauma itself. They are especially useful in multilevel injuries, where a primary coaptation may not work due to injuries at subsequent levels. Nerve transfers are targeted to specific functions and hence the recovery is more precise and predictable. Since the tendons are not disturbed, they preserve the biomechanics of the motor system. These advantages make the nerve transfer an attractive alternative to primary nerve repair or grafting.[2]

End-to-side neurorrhaphy, first described in the late nineteenth century, was reexamined in 1992 by Viterbo.[3] The distal recipient nerve is coapted to the side of the donor. The mechanism differs slightly in motor and sensory nerves. The sensory neurons undergo spontaneous collateral

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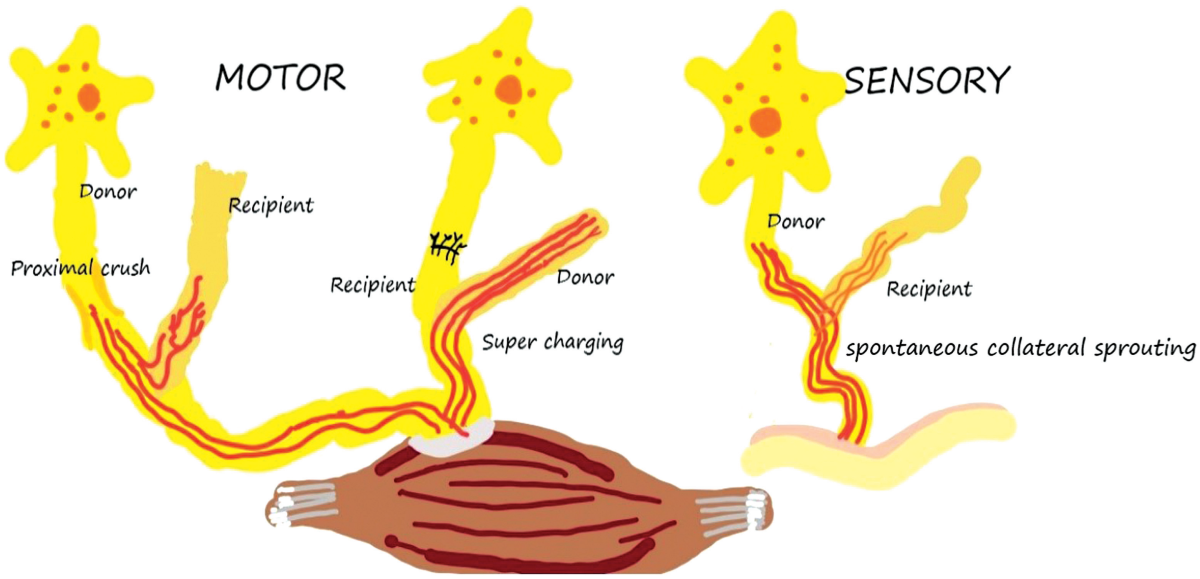

Fig. 1 Diagram depicting the end to side neurorrhaphy. Spontaneous collateral sprouting is depicted in the right, supercharging of a recipient is shown in the idle, and collateral sprouting in response to an insult to the donor, proximal to the coaptation is shown in the left.

sprouting, (►**Fig. 1**) where axons generate on their own, sending branches into the recipient fascicles. Motor axons do not undergo such regeneration. Hence, a traumatic insult proximal to the site of coaptation results in regeneration of axons, some of which are diverted into the recipient fascicles. This allows recovery of both the donor as well as the recipient nerves.[4] This process is facilitated by an epineurotomy on the side of the donor nerve onto which the recipient is sutured.[4] The epineurotomy itself results in injury to a few fascicles of the nerve, which results in regeneration into the graft. This is further facilitated by the proximal injury. A reverse end-to-side[5] or a supercharging coaptation has also been described, where the proximal cut end of the donor nerve is coapted to the recipient in an end-to-side fashion. This is clinically used to prevent motor unit denervation, using a small donor, where a larger axon load is expected to arrive.

Brachial Plexus Injuries

The brachial plexus is commonly injured proximally in the neck, with the nerve having a long way still to go before reaching the end plate junctions. Any repair has to be expedited, so that the regenerating axon reaches the motor end plate before its degeneration. There is loss of regenerating axons at the site of coaptation as well, which further reduces the extent of full recovery. In such a situation, the nerve transfers are even more useful. Traditionally, triple nerve transfers have been described for brachial plexus injuries. These are the spinal accessory nerve (SAN) to suprascapular nerve (SSN); the transfer of a fascicle of ulnar nerve to the branch to brachialis; and transfer of branch to triceps to anterior division of axillary nerve. Frequently, the transfer of the thoracodorsal nerve to the long thoracic nerve is also performed. Other donors for transfers to the brachial plexus are the phrenic nerve, the hypoglossal nerve, the intercostal nerves and the cervical plexus.

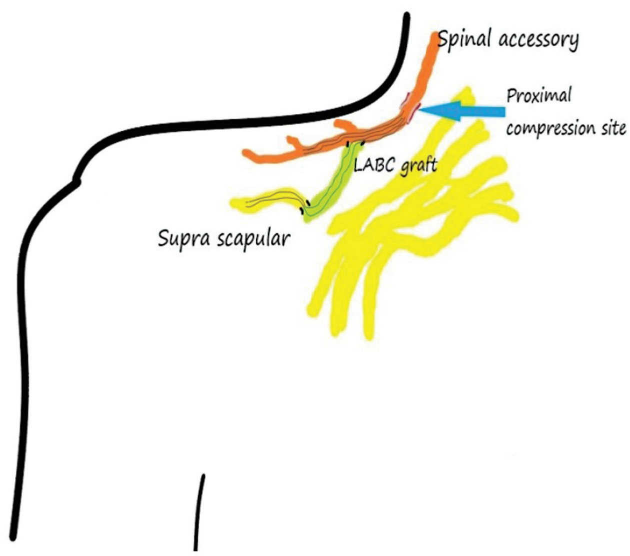

Fig. 2 Diagram depicting spinal accessory nerve (SAN) to suprascapular nerve (SSN) transfer using a lateral antebrachial cutaneous (LABC) nerve graft. The transfer uses the phenomenon of collateral sprouting to maintain the continuity of the SAN.

SAN transfer to the SSN is a common transfer. Harvest of the SAN before the branches to the upper trapezius originate may result in denervation of the muscle and a drooping shoulder.[6] This is prevented by the posterior approach of this transfer. The anterior approach has been modified, making use of the regenerative sprouting concept.[7] The SSN is coapted to the spinal accessory nerve via a nerve graft of the lateral antebrachial cutaneous nerve (LABC) (►**Fig. 2**). An insult is made on the intact spinal accessory nerve, proximal to the

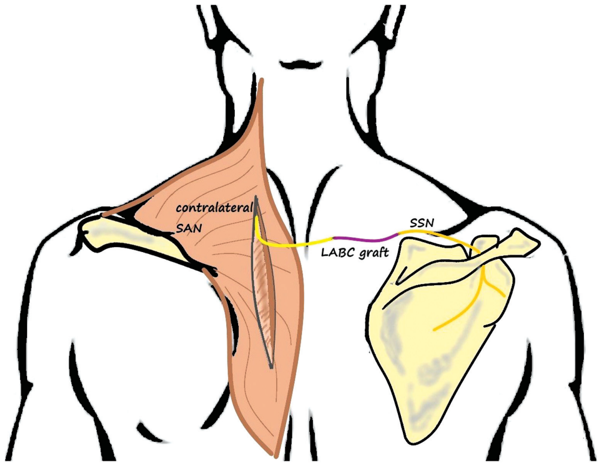

Fig. 3 Diagram depicting the posterior contralateral approach of the spinal accessory nerve (SAN) to suprascapular nerve (SSN).

coaptation, by gentle crushing with a blunt artery forceps, which initiates the process of regenerative sprouting. This allows recovery of the rotator cuff, preserving the trapezius function. Contralateral SAN has also been used to neurotize the SSN with the help of a graft. This is done across the midline posteriorly (►**Fig. 3**)[8] or anteriorly across the neck.[9]

Direct coaptation of the SSN to the posterior cord of the brachial plexus has been described.[10] The SSN is divided and dissected along its length. It is then brought into the infraclavicular region and direct coaptation is done into the posterior cord. Direct coaptation of the nerves, either the distal ends or nerve grafts, directly into the spinal cord has also been described.[11]

Sensory restoration is an important but often neglected part of brachial plexus reconstruction. In contrast to motor restitution, sensory reconstruction allows the surgeon some time,[12] with transfer reported even after 20 years postinjury.[13] The second intercostobrachial nerve, a branch of the second intercostal nerve is transferred to the sensory branches of the medial nerve in the arm.[14] The sensory fascicles of the intercostal nerves[15] as well as the supraclavicular nerves[16] have also been used as a potential source of sensory fascicles.

Peripheral Nerve Injuries: High Median Nerve Palsy

Distal nerve transfers have come to the fore for peripheral nerve injuries as well. High median nerve palsy results in the loss of flexion of the index finger and the thumb along with denervation of thenar muscles. In the cubital fossa, the radial nerve is used as donor. The supinator branch is used for the pronator teres and branch to extensor carpi radialis brevis (ECRB) is transferred to the anterior interosseus nerve. Although the anterior interosseus nerve (AIN) is a branch of the median nerve, arising in the proximal forearm, it separates as a distinct fascicle in the arm, and intraneural dissection can delineate the AIN nerve, providing length for the transfer. This transfer allows early recovery of the hand function with pronation recovering as early as 4 months postsurgery.[17] Alternatively, the branches from the musculocutaneous nerve can also be used to innervate the AIN.[18]

The real utility of these transfers is if the coaptation can be brought near the end organs. Nerve transfers in the hand and wrist provide a great benefit to patients, allowing significantly earlier recovery. Transfer of the nerve to abductor digit quinti (ADQ), a branch from the ulnar nerve to the recurrent motor branch of the median nerve allows reinnervation of the thenar muscles[19] (►**Fig. 4**). Alternatively, the terminal division of the deep branch of the ulnar nerve is transferred to the motor branch of the opponens pollicis.[20]

For sensory restoration, the radial nerve has been used as a donor. The superficial radial nerve can be brought across the forearm to innervate the median or ulnar nerve as required.[21] However, triple sensory nerve transfer[22] provides an elegant method of restoration of sensations of the hand, minimizing the donor site morbidity at the same time (►**Fig. 5**). For a median nerve deficit, sensory fascicles for the 3rd web space are coapted to the dorsal fascicles of the ulnar

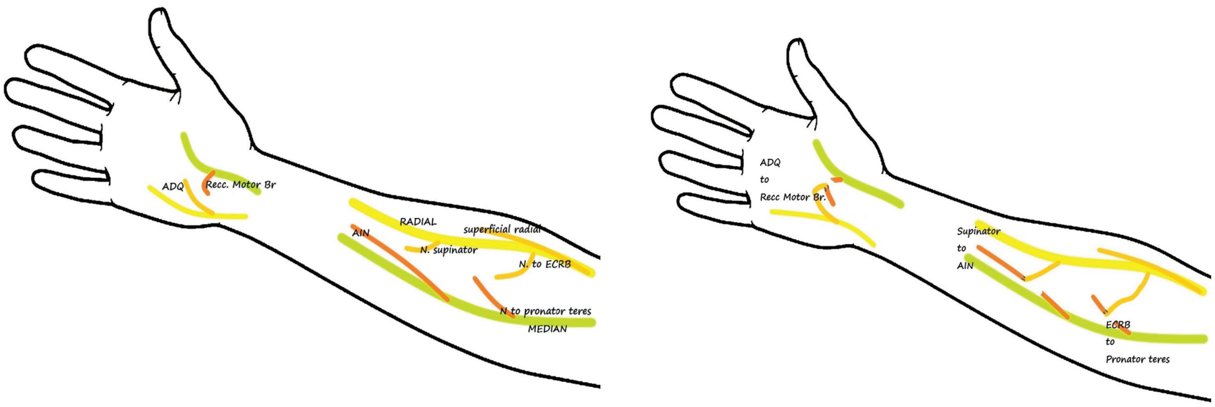

Fig. 4 Diagram demonstrating the distal nerve transfers for high median nerve palsy. The recipient nerve is green, the donor nerves are yellow, and the donor branches are depicted in orange.

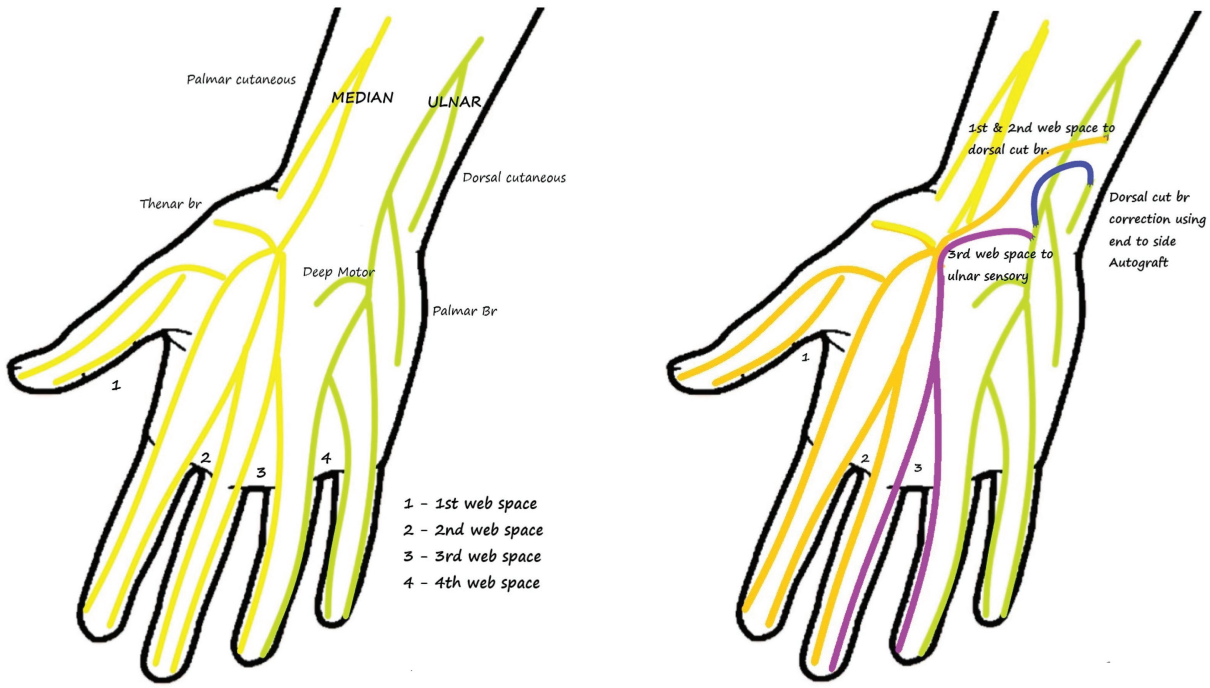

Fig. 5 Diagram depicting the sensory nerve transfers for median nerve palsy. Left shows the arrangement before the transfer with yellow being the deficit and green being the donor. Right side depicts the transfer. Green is for the native ulnar nerve. Orange is for transfer of the dorsal cutaneous branch to the index and middle fingers. Purple is for transfer from the ulnar nerve to the middle and ring fingers, and blue depicts the side to side transfer of ulnar nerve to restore the dorsal sensation.

nerve in an end-to-side fashion. The fascicles to the 1st and 2nd web spaces are coapted to the dorsal cutaneous branch of the ulnar nerve via a nerve graft. This loss of the dorsal cutaneous branch of the ulnar nerve is then subsequently corrected by coapting the distal stump of the dorsal cutaneous branch to the sensory ulnar fascicles in and end-to-side fashion via a nerve graft. This relies heavily on collateral sprouting of neurons, providing sensation to the lost areas of the hand, while maintaining the innervation in the donor areas to an extent. Very distal nerve transfer is performed in the fingers.[23] To restore sensation over the radial aspect of the index finger, the radial digital nerve is coapted to the dorsal cutaneous branch of the radial nerve running in the dorsum of the index finger.

Peripheral Nerve Injuries: High Ulnar Nerve Palsy

The transfer of the AIN to the deep branch of the ulnar nerve is a well-established nerve transfer[24] (►**Fig. 6**). The AIN is dissected deep to the pronator quadratus muscle. This is coapted to the motor fascicles of the ulnar nerve in the forearm. The internal topography of the ulnar nerve is such that the motor fascicles are sandwiched between the two sensory fascicles, namely, the dorsal ulnar branches and the ulnar sensory branches. This reinnervates the intrinsic muscles in the hand. For compression neuropathies of the ulnar nerve, decompression can be combined with a reverse end-to-side repair[25] (►**Fig. 7**). The axons are delivered into

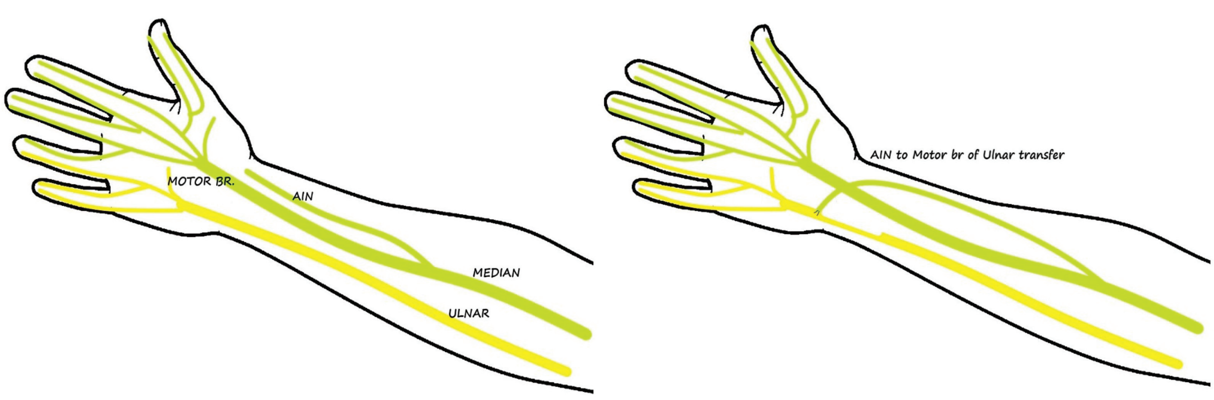

Fig. 6 Diagram depicting the transfer of the anterior interosseus nerve (AIN) to the deep motor branch of the ulnar nerve.

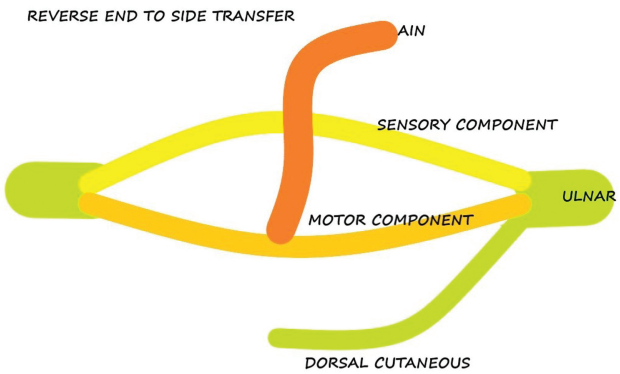

Fig. 7 Diagram depicting the supercharged transfer of the anterior interosseus nerve (AIN) to the ulnar nerve.

the ulnar nerve at the same time, allowing for recovery to occur via the native nerve as well. In this form of transfer, the axonal counts are found to be similar to end-to-end transfers.[26]

Ulnar nerve supplies sensation on the resting border of the hand. The radial nerve is transferred in the forearm and coapted to the ulnar sensory fascicles (►**Fig. 8**). Triple nerve transfers like the one described for the median nerve can also be performed for the ulnar nerve. The 4th web space is reinnervated by fascicles from the branches to the 3rd web space, form the median nerve, in an end-to-end fashion. The dorsal sensory branch of the ulnar nerve is neurotized via a nerve graft to the other sensory fascicles from the median nerve, supplying the 1st and the 2nd web space in an end-to-side fashion. Similarly, another nerve graft neurotizes the distal end of the divided fascicle to the 3rd web space (in the median nerve).

Peripheral Nerve Injuries: High Radial Nerve Palsy

Radial nerve palsy results in finger and wrist drop, depending on the level of injury. The nerves supplying the volar flexors, like the flexor digitorum superficialis or the flexor carpi radialis (FCR), can be used as donors and transferred to the ECRB or the posterior interosseus nerve (PIN), depending upon the deficit. This is done in the cubital fossa, reflecting the biceps tendon. The pronator teres and the AIN are to be protected and the other fascicles can be used for the transfer[27] (►**Fig. 9**).

The radial nerve supplies a small, nonvital area in the hand. Restoration of sensation in this area is of a low priority. Transfer of the LABC to the superficial sensory nerve has been described, primarily to reduce the neuropathic pain caused by the denervation.[28]

Spinal Cord Injury

Spinal cord injuries result in deficits that involve various roots. Nerve transfers depending upon the remaining roots available can be done. Ida et al[29] published a series of nine

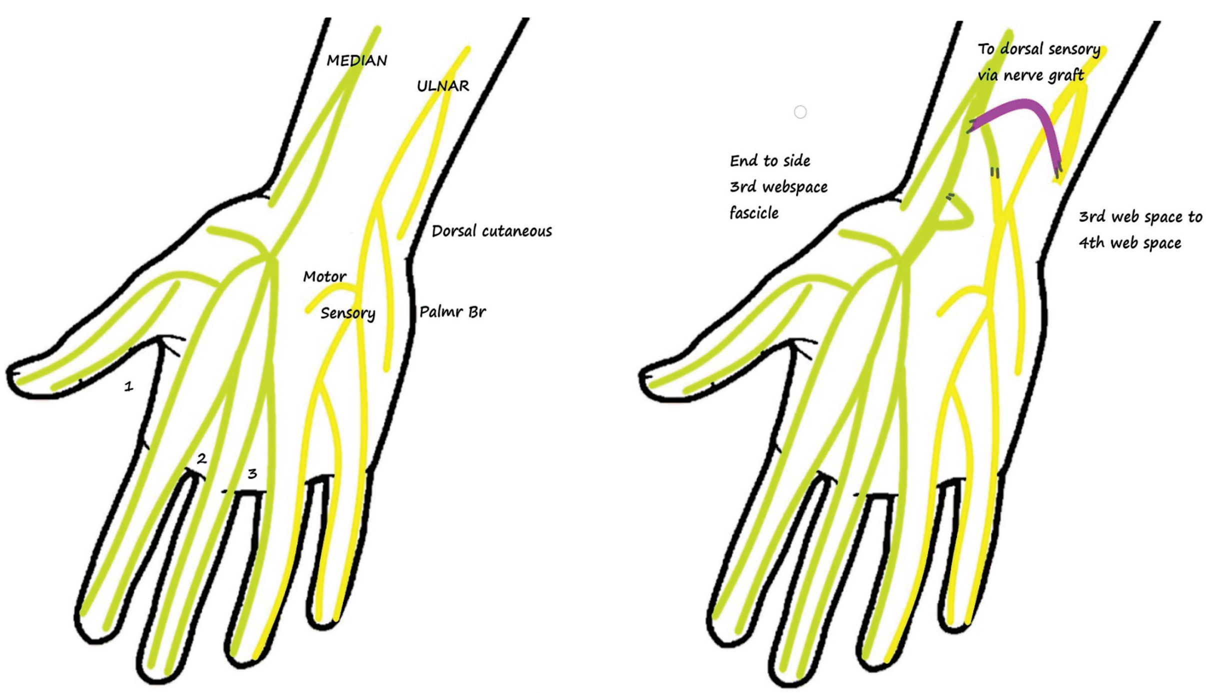

Fig. 8 Diagram depicting the distal sensory nerve transfers for ulnar nerve palsy. Left shows the area lost in yellow and the donor in green. Right depicts the transfer of the sensory branch of median to ulnar nerve. The distal end of this donor is coapted back in an end-t- side fashion to the same nerve. The dorsal cutaneous nerve is transferred using a lateral antebrachial cutaneous (LABC) nerve graft.

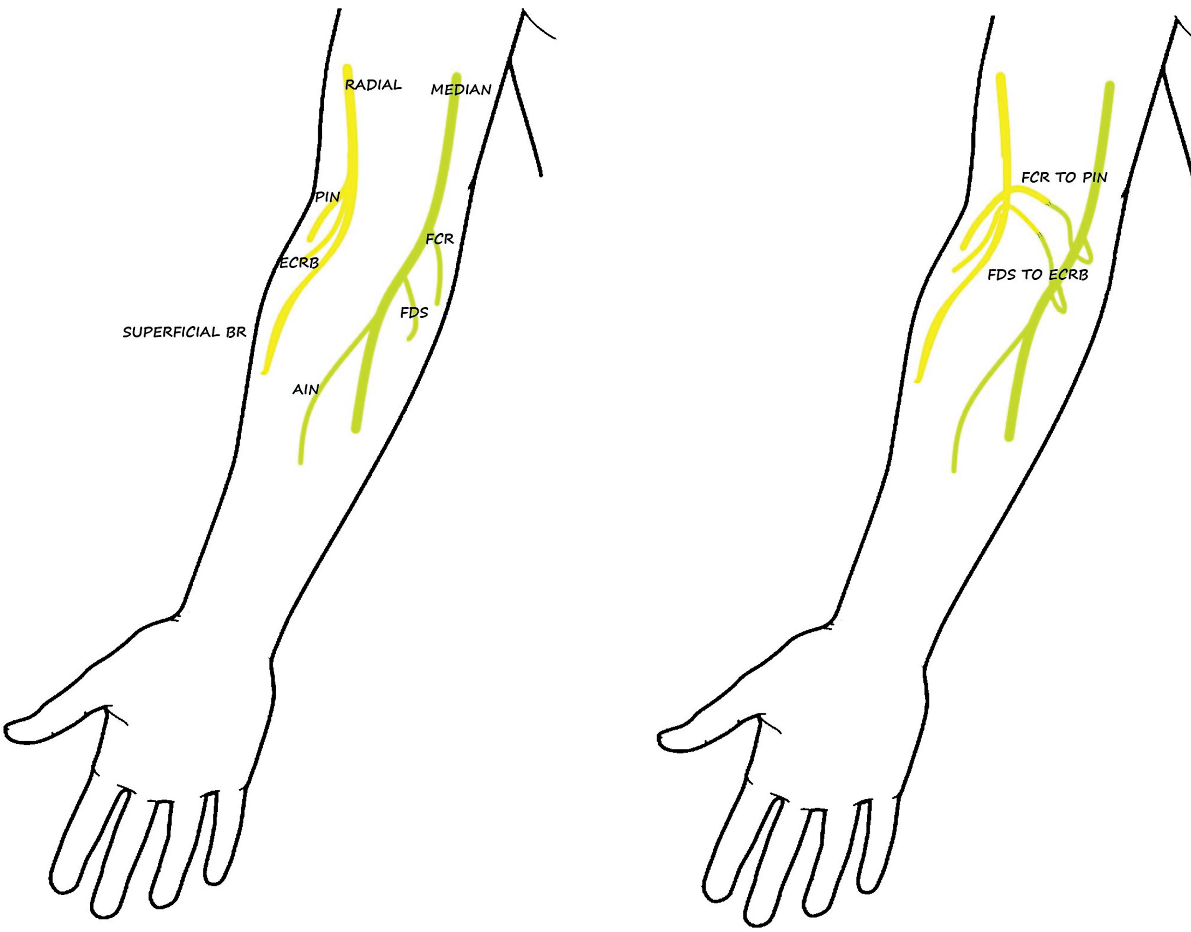

Fig. 9 Diagram showing the distal nerve transfers for radial nerve palsy. The branches to flexor carpi ulnaris (FCU) and flexor digitorum superficialis (FDS) are transferred to the posterior interosseus nerve (PIN) and extensor carpi radialis brevis (ECRB), respectively.

cases of spinal cord injuries, which were managed with nerve transfers. The major injury pattern noted was the C7, C8 and T1 nerve roots. The posterior division of nerve to deltoid was transferred to a branch to the triceps (►**Fig. 10**). The branch to brachialis is used to innervate the AIN of the fascicles to the FCR in a reverse Oberlin fashion (►**Fig. 11**). The nerve to supinator is transferred to the ECRB or the PIN.[30] Although arising from the same nerve, thee branches receive innervation from different nerve roots.

Loss of triceps function has also been corrected with the branch to teres minor, which arises from the axillary nerve.[31] A fascicle from the ulnar nerve to the flexor carpi ulnaris (FCU) has also been described for reinnervation of the triceps. The transfer is done be dissecting the fascicle to FCU, flipping it over and coapting it to the branch to triceps in the upper arm.[32]

The Verdict

It is difficult to form an unbiased opinion regarding the efficacy of these transfers. They provide a sound and viable method of correcting troublesome problems. There is an obvious benefit in bringing the coaptation as close to the target muscle as possible, thus reducing the time of recovery. The distal nerve transfers performed in the hand demonstrate the ingenuity of the surgeon by not only restoring the function but also minimizing the donor site morbidity. Being specific in nature, the incoming axons can be directed to the address specific needs of the individual patients. These procedures although attractive theoretically has not yet "caught on" by the surgical community. The few groups who have been the inventors of these procedures have published most of the literature with mixed results.[33,34] While that may be the case of individuals being ahead of their times, gradual work by the surgical community at large will, over time, determine the efficacy of these procedures. This process is already happening, with literature appearing from other centers around the world.[22,35,36] These refinements lean heavily on the concept of collateral sprouting, which is a relatively new and unproven concept. The multiple coaptations may be an obstacle to a good outcome. The innovators themselves appreciate this fact, as the important

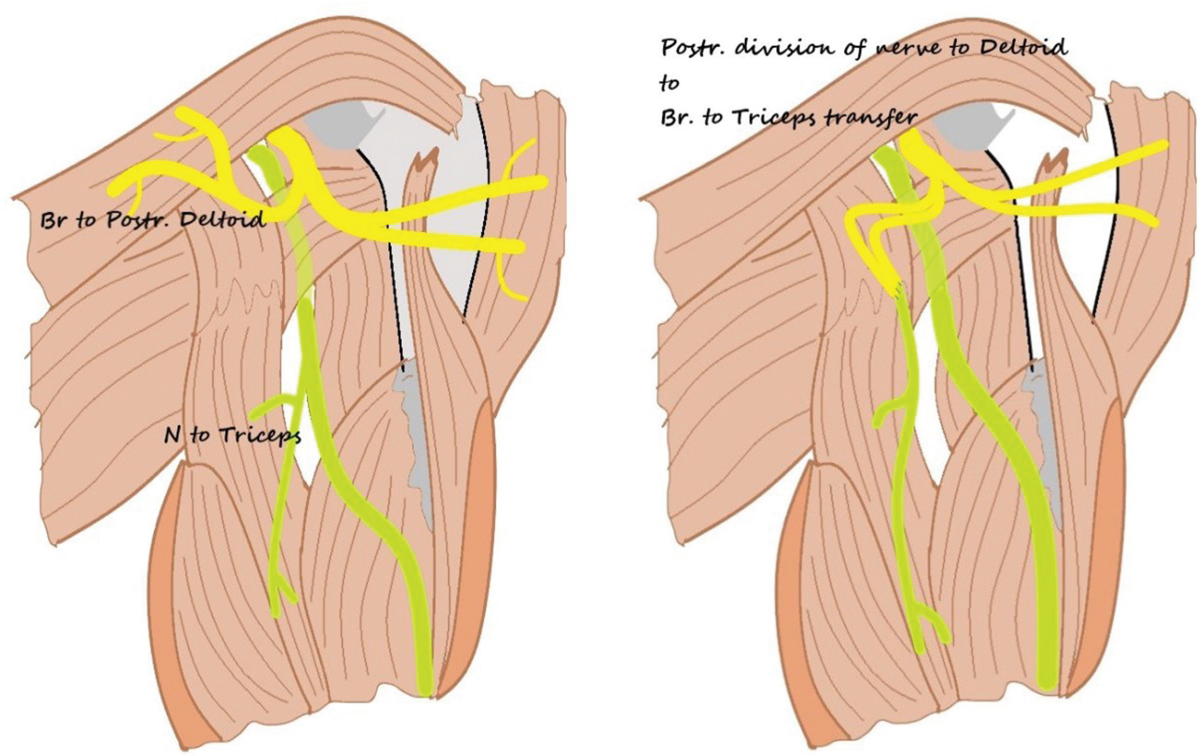

Fig. 10 Diagram showing the transfer of the posterior division of the axillary to the nerve to triceps.

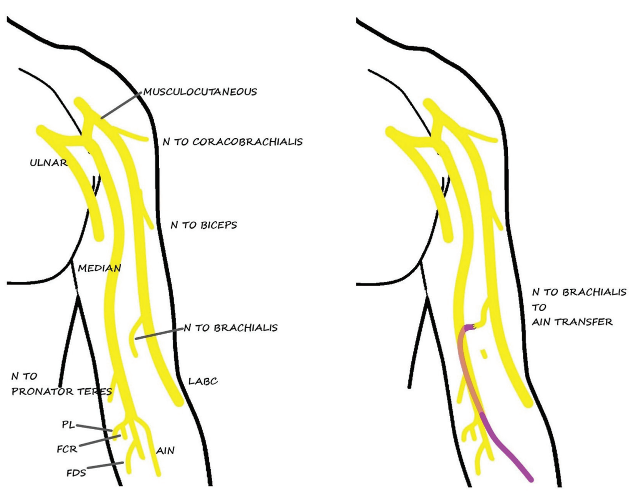

Fig. 11 Diagram depicting the transfer of brachialis branch to the anterior interosseus nerve (AIN).

or preferential outcomes are targeted in an end-to-end fashion and the secondary outcomes are targeted by end-to-side and collateral sprouting.

The International Society of Reconstructive Microsurgery, in their annual meet in 2017, had a session on these transfers. Preeminent surgeons in the field of nerve surgery expressed their views on these procedures. Dr. David Chuang[37] prefers the use of proximal nerve transfers or grafts routinely, reserving the distal nerve transfers for very specific situations. Proximal interventions help in establishing a diagnosis intraoperatively, prevents iatrogenic injury where a neurolysis sufficient, and allows easier recovery, as compared with distal nerve transfers. Dr. Doi[38] advised caution with the indiscriminate use of nerve transfers, stressing the need to objectively examine the reported results of nerve transfers. He suggested better use of technology, like prosthesis, would help patients recovering from nerve injuries. The elder generations although were cautious in prescribing these procedures, citing limited and often unfavorable experience in their hands.

Conflict of Interest
None declared.

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