Nerve transfer in brachial plexus traction injuries

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Brachial plexus palsy due to traction injury, especially spinal nerve-root avulsion, represents a severe handicap for the patient. Despite recent progress in diagnosis and microsurgical repair, the prognosis in such cases remains unfavorable. Nerve transfer is the only possibility for repair in cases of spinal nerve-root avulsion. This technique was analyzed in 37 patients with 64 reinnervation procedures of the musculocutaneous and/or axillary nerve using upper intercostal, spinal accessory, and regional nerves as donors. The most favorable results, with an 83.8% overall rate of useful functional recovery, were obtained in patients with upper brachial plexus palsy in which regional donor nerves, such as the medial pectoral, thoracodorsal, long thoracic, and subscapular nerves, had been used. The overall rates of recovery for the spinal accessory and upper intercostal nerves were 64.3% and 55.5%, respectively, which are significantly lower. The authors evaluate the results of nerve transfer and analyze different donor nerves as factors influencing the prognosis of surgical repair.

Key Words • brachial plexus injury • nerve graft • nerve repair • reinnervation • spinal nerve-root avulsion

The results of nerve repair in cases of traction injury of the brachial plexus, and especially of spinal nerve-root avulsion, are generally poor. Despite recent advances in diagnosis and microsurgical repair, restoration of motor function in cases of spinal nerve-root avulsion remains a difficult problem. The only possibility for nerve repair is nerve transfer or neurotization; that is, reinnervation of distal parts of the brachial plexus using neighboring intact nerves. Nerve transfer has been attempted with a variety of donor nerves including intercostal nerves,\textsuperscript{1,2,13,15,22,23,27,32} spinal accessory nerves,\textsuperscript{3-5,16,23} motor branches of the cervical plexus,\textsuperscript{8,9} phrenic nerves,\textsuperscript{53} and collateral motor branches of the brachial plexus in instances of partial avulsion.\textsuperscript{20-22,25,27}

The recovery of even minimal function has great value to the patient. However, the first priorities are the restoration of full-range elbow flexion, shoulder stabilization, and a certain range of active abduction.\textsuperscript{1,18,22}

For these reasons, we have reinnervated the musculocutaneous and axillary nerves using different donor nerves depending on the level and extent of spinal nerve-root avulsion.

Clinical Material and Methods

Patient Population

Since July, 1980, we have performed nerve transfers in 45 patients with traction injury of the brachial plexus.

The 37 cases with a follow-up period of at least 18 months form the basis of this series. The age of these patients ranged from 11 to 57 years, with 81% aged between 20 and 39 years.

Fourteen patients had complete and 23 had upper brachial plexus palsy. Diagnosis of the level and location of injury was based on neurological signs, histamine flare and sweat tests, electromyography of the proximal shoulder and posterior cervical muscles, cervical myelography, and more recently on somatosensory evoked potentials and myelography-computerized tomography. Various combinations of the levels and locations of nerve damage were diagnosed and confirmed at extraspinal surgical exploration (Table 1).

Reinnervation of the musculocutaneous and/or axillary nerve was performed in all patients. The spinal accessory nerve, upper intercostal nerves (usually third to fifth), and regional nerves (medial pectoral, thora-

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<td>Level and extent of brachial plexus traction injuries in 37 patients</td>
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<tr>
<td>Lesion Level</td>
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<tr>
<td>avulsion</td>
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<tr>
<td>peripheral</td>
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<td>total cases</td>
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codorsal, long thoracic, and subscapular) were used as donors depending on the level and location of the brachial plexus injury. A total of 64 reinnervation procedures were performed (Table 2). In two patients with peripheral injury we were not able to define functional and structural integrity of proximal nerve stumps, therefore, it was necessary to perform nerve transfer instead of nerve grafting. Surgical procedures were performed from 2 to 12 months after injury (mean 4 months).

Grading of Surgical Results

The results of surgery were related to the donor and recipient nerves. We modified the grading system of Ploncard,29 which we used in our previous reports,24-26 as follows: 1) Bad denotes no movement or weightless movement and usually no alteration in trophic changes or electromyography. 2) Fair denotes movement against gravity with the ability to hold position and improvements in trophic changes and electromyography, active abduction up to 45° and elbow flexion up to 90°. 3) Good denotes movement against resistance with ability to repeat movements in succession and improvement in trophic changes and electromyography, active abduction over 45° and a full range of elbow flexion.

Fair and good results were considered to represent recovery. The follow-up period was at least 18 months. Two patients were not included in the follow-up review, so the results have been analyzed in 35 patients with 60 reinnervation procedures.

Surgical Procedure

In the majority of cases, the entire brachial plexus was explored by a combined supra- and infraclavicular approach without osteotomy of the clavicle. In several diagnostically clear cases, supraclavicular exploration was limited to the upper trunk or an infraclavicular approach.13,24-26 All elements of the brachial plexus were dissected free and examined with the aid of intraoperative stimulation; definite separation of the recipient, axillary, and musculocutaneous nerves was established. Care was taken to exclude a possible second lesion of the musculocutaneous nerve under the coracobrachialis fascia and the axillary nerve near the quadrangular space (Fig. 1). The nerves were sectioned from the cords at their origin in order to reduce the necessary length of nerve grafts or more distally in cases of reinnervation using collateral branches of the brachial plexus. The donor nerves (the spinal accessory nerve, upper intercostal nerves (usually third to fifth), and regional nerves) were dissected via the same approach (Fig. 2).

Intercostal Transfer. In 10 patients, the upper intercostal nerves were dissected well forward and anastomosed directly to the recipient nerves (Ploncard's technique27). In 22 patients, the nerves were sectioned at the midaxillary line and anastomosed to the recipient nerves using nerve grafts 5 to 10 cm in length. Usually
two or three intercostal nerves were used to reinnervate the musculocutaneous or axillary nerve.

**Spinal Accessory Transfer.** The spinal accessory nerve was approached in the omotrapezoid trigone of the neck and sectioned distally with preservation of its collateral branches in all patients but two; in these two, the branches were also used for reinnervation. The procedure modified by Allieu, et al.\(^1\)\(^-\)\(^3\) was used in all patients. In 13 patients, the spinal accessory nerve was anastomosed to the musculocutaneous nerve using cutaneous nerve grafts 10 to 15 cm in length (usually 12 cm long). In two patients, anastomosis with the axillary nerve was performed in the same way. Depending on the diameter of the spinal accessory nerve and the nerve graft, one or two grafts were placed subcutaneously. Supplementary donor nerves were used in cases where the diameter of the recipient nerve was considerably larger; the medial pectoral nerve was employed in three patients with upper brachial plexus palsy and the upper intercostal nerves in three with total palsy.

**Regional Nerve Transfer.** The thoracodorsal nerve was anastomosed directly to the axillary or musculocutaneous nerve in 15 patients and in combination with nerve grafts in two patients with a second peripheral lesion of the musculocutaneous nerve. The medial pectoral nerve, isolated or with the medial branch of the pectoral ansa, was anastomosed to the recipient nerves either directly in 13 patients or using long nerve grafts 2 to 5 cm in length in four. The long thoracic nerve was used in one patient and the subscapular nerve in two. In four nerve transfer procedures, regional donors were combined. In 13 nerve transfer procedures in which the recipient nerve was of a considerably larger diameter, the anastomoses were supplemented with the spinal accessory or intercostal nerves in order to complete the suture line and diminish fibrotic changes and fascicular misorientation (Fig. 3).

**Microsurgical Procedure.** The anastomoses were performed using standard microsurgical procedures. The epineurium of the recipient nerves was removed in order to reduce fibrosis on the suture line, but interfascicular neurolysis was not performed due to the fascicular pattern and diameter. The sutures were introduced through the epineurium of the donor nerves and cutaneous nerve grafts and through interfascicular tissue or perineurium of some fascicles of the recipient nerves. Individual anastomoses were completed with two stitches on the upper side of the nerve or with a circumferential suture using four or five stitches around the nerve. In a few cases, the suturing was combined with fibrin gluing.

**Results**

Useful functional recovery was obtained in 42 (70%) of the 60 reinnervation procedures; these included 19 (63.5%) of 29 procedures for the musculocutaneous nerve and 23 (74.2%) of 31 for the axillary nerve (Table 3). In this series, 49 reinnervation procedures in 29 patients were performed during the first 6 months after injury, and no significant correlation was found between timing and surgical results.

**Intercostal Transfer**

Among 18 patients with intercostobrachial anastomosis, functional recovery was obtained in 10 (55.5%). If intercostal nerves were combined with other donor

Fig. 3. Combined reinnervation of the brachial plexus using regional and upper intercostal nerves 4 months after injury. *Left:* Diagram of reinnervation. 1: musculocutaneous nerve; 2: axillary nerve; 3: thoracodorsal nerve; 4: medial pectoral nerve; and II, III, and IV: intercostal nerves. *Right:* Intraoperative photograph showing direct anastomoses of the medial pectoral and the third intercostal with axillary nerve (right arrow); anastomosis between the thoracodorsal and two sural nerve grafts (center arrow); and anastomoses of two 8-cm long sural nerve grafts from the thoracodorsal nerve and one 12-cm long sural nerve graft from the fourth intercostal nerve with musculocutaneous nerve (left arrow).
nerves, the rate of functional recovery was significantly higher (nine (75%) of 12 patients) and the quality of recovery was better. No significant correlation between surgical results and the type of anastomosis, direct suture, or nerve graft was found. There was also no significant correlation between the rate of recovery and the use of either two or three intercostal nerves; two were enough to produce a useful recovery. The first signs of recovery appeared 8 to 12 months after surgery and were related to thoracic movement. Later signs of recovery were voluntary elbow flexion and shoulder abduction independent of respiration.

**Spinal Accessory Transfer**

Using the spinal accessory nerve as a donor, we obtained useful functional recovery in nine (64.3%) of 14 patients. Four (50%) of eight patients had functional recovery using the spinal accessory nerve alone. Recovery among six patients undergoing spinal accessory transfer combined with reinnervation using other donors was seen in five (83.3%) and the quality of recovery was also better. The first signs of reinnervation appeared 9 to 15 months after surgery or 6 to 12 months postoperatively in patients where donor nerves were combined.

**Regional Nerve Transfer**

Among 31 patients with regional nerves used as donors, useful recovery was obtained in 26 (83.3%); among 19 cases using isolated nerves, functional recovery was found in 16 (84.2%); and among 12 cases involving regional nerves combined with other donors, 10 (83.3%) had functional recovery. The quality of recovery was better in patients with combined reinnervation. The first signs of reinnervation appeared 5 to 7 months after surgery in the majority of cases and up to 12 months postoperatively in the others (Fig. 4).

**Discussion**

Recent progress in diagnostic assessment and microsurgical repair has improved the prognosis of surgically treated traction injury of the brachial plexus. However, in cases of spinal nerve-root avulsion, the results are still unsatisfactory, especially regarding complex function such as shoulder abduction.21

**Surgical Priorities**

The recovery of even minimal function has great value to the patient, as the arm can be used for support. Functional recovery may be regarded as useful if there is no subluxation of the shoulder and if the deltoid muscle enables a certain range of active abduction.12,19 The first priority in nerve repair is reinnervation of the musculocutaneous nerve and restoration of elbow flexion. There should be a full range of powerful movement.19 Recovery of the biceps muscle also contributes to shoulder stabilization.1,4,26,29 The recovery of shoulder subluxation and a certain range of active arm abduction may be obtained by reinnervating either the suprascapular nerve, the axillary nerve, or both. There is some disagreement as to the role of the suprascapular nerve is deltoid muscles in shoulder abduction.10,14,30 Several recent reports favor reinnervation of the suprascapular nerve, especially using the spinal accessory nerve.3,6,8,18,21,22,31 Based on the experience of others,12,17 we have reinnervated the axillary nerve using a combination of donor nerves and have obtained useful functional recovery of the deltoid muscle and good arm abduction in a large number of patients (74.2%). However, the functional improvement of arm abduction was better in patients with successful reinnervation of the biceps muscle.

**Nerve Transfer**

In performing nerve transfer, it seems reasonable to apply an anastomosis with nerves and not with the trunks and cords because of diminished sutureal dispersion of nerve fibers,19,19 possibilities for cross or mass innervation,20,21 and the proximity of the motor point.1,19 Aside from functional priority, additional reasons for reinnervation of the musculocutaneous and axillary nerves include: a shorter time required for nerve regeneration,10,27 the mostly monofunctional motor constitution of the nerves,10 and the mono- or oligofascicular structure of the axillary nerve.19 About 30% of the nerve fibers are necessary to restore some muscular

**TABLE 3**

Results of surgical treatment on 60 reinnervation procedures in 35 patients

<table>
<thead>
<tr>
<th>Donor Nerves</th>
<th>Recipient Nerve</th>
<th>Total Procedures</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Musculocutaneous</td>
<td>Axillary</td>
</tr>
<tr>
<td></td>
<td>Bad</td>
<td>Fair</td>
</tr>
<tr>
<td>regional</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>intercostal</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>accessory</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>combined regional &amp; intercostal</td>
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<td>0</td>
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<tr>
<td>combined regional &amp; accessory</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>combined intercostal &amp; accessory</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>total procedures</td>
<td>10</td>
<td>6</td>
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function, but only a few hundred axons appear sufficient to reinnervate a poorly differentiated muscle such as the biceps.

**Intercostal Transfer**

The results are greatly influenced by the type of donor nerve. Intercostobrachial anastomosis was the first procedure performed as a way of reinnervating avulsed brachial plexus. The imperfections of this method include the distance between the site of anastomosis and the denervated muscles, the use of nerve grafts, the mixing of motor and sensory axons at the suture line, and the relatively small number (500 to 700) of motor fibers. This small number is significant if we bear in mind that the recipient nerves have a considerably larger number of fibers, an average of 6000 for both nerves. Although some authors report functional recovery in a high percentage of patients, we obtained satisfactory results in only about 55.5%. This is similar to the reports of the majority of authors. In our series, the rate of functional recovery did not vary based on the use of two or more intercostal nerves in the reinnervation of one recipient nerve or on the types of nerve anastomosis; however, the results were better in cases with neurotization close to the entry point into muscle and without an intermediate nerve graft.

**Spinal Accessory Transfer**

The disadvantages and unsatisfactory results of intercostobrachial anastomosis caused the introduction of techniques using the spinal accessory nerve as a donor for reinnervation of the brachial plexus. The spinal accessory nerve is a motor nerve with 1500 to 3000 motor fibers and very few sensory fibers. Additional palsy of the trapezius muscle does not essentially alter the global functional deficit of the shoulder in spinal nerve-root avulsion. However, function of the trapezius muscle, especially the distal portion, may be partially preserved owing to independent innervation from the C-3 spinal nerve and transection of the spinal accessory nerve distally to its branches. A disadvantage of this method is the length of the long nerve grafts — 7 to 20 cm and in our patients 10 to 15 cm. Regardless of this problem, we obtained useful functional recovery in 64.3% of patients, a rate similar to that reported by others. The results were better than in cases of reinnervation with intercostal nerves, probably due to the three- to fourfold greater number of motor fibers.

**Regional Nerve Transfer**

The above-mentioned problems have led us back to the methods used by Vulpian and Stoffel and Forster in the early 1900's, as reported by Narakas. In cases of upper brachial plexus palsy, we have used as donor nerves regional intact collateral branches of the brachial plexus, such as the medial pectoral, thoracodorsal, long thoracic, and subscapular nerves. This is possible since these nerves originate mostly from intact spinal nerve roots and are voluntary motor nerves with an autonomous function. The main advantages of this

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**Fig. 4.** Photographs of a patient demonstrating the first signs of recovery, which appeared in the deltoid muscle 6 months after surgery and in biceps muscle 9 months after surgery. The patient had a powerful, full range of elbow flexion (left) and shoulder abduction up to the horizontal line (right) 16 months after surgery.
method are: there are about three times more motor fibers than in intercostal nerves (although some of them are denervated); there is insignificant axonal mixing; direct anastomosis or occasionally anastomosis using short nerve grafts is possible; and anastomosis close to the motor point can be achieved. 21, 22 Similar to sacrificing the spinal accessory nerve, we believe that additional palsy of arm abduction and internal rotation due to section of the regional nerves is not as significant in severely disabled shoulder and arm movement. 20 In cases of predominant innervation from the C-7 spinal root, the function of synergic muscles such as the teres major may sometimes be partially preserved. In addition, some function of pectoral muscles may be retained by distal sectioning of the medial pectoral nerve and sparing some of its branches. In some cases, we used only one regional nerve. With these nerves as donors we obtained useful functional recovery in 83.8% of cases, which is significantly better than the results obtained by using other donor nerves. It is important to emphasize that there was no difference in the results obtained between individual regional donor nerves.

Additional Considerations

In some cases, we combined donor nerves 23, 24 despite the opinion of some that, if two different donor nerves reinnervate the same muscle, only one will ultimately function. 21 In addition to completion of the suture line, when possible anastomosis was located close to the end organ where nerve fibers for the innervation of different muscles or their functional parts are focused. 25, 26 We obtained an even higher rate of functional recovery and quality of recovery in these patients. However, we cannot be sure whether this is the result of combined reinnervation or reinnervation by only one nerve, probably a regional nerve.

Conclusions

Nerve transfer represents the only possibility for nerve repair in cases of brachial plexus palsy due to spinal nerve-root avulsion. There is no one ideal method, but the use of regional nerves as donors in cases of upper palsy offers a better chance for useful functional recovery than intercostal and/or spinal accessory nerve transfer. Although controversial, the combined use of donors especially when regional nerves were used gave the highest rate of functional recovery and the best quality of recovery.

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