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ORIGINAL ARTICLE

Nerve Transfers for Traumatic Brachial Plexus Injury: Advantages and Problems

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Abstract In recent years nerve transfers have been increasingly used to broaden reconstructive options for brachial plexus reconstruction. Nerve transfer is a procedure where an expendable nerve is connected to a more important nerve in order to reinnervate that nerve. This article outlines the experience of the Scottish National Brachial Plexus Injury Service as our use of nerve transfers has increased. Outcomes have improved for reconstruction of the paralysed shoulder using transfer of the accessory nerve to the suprascapular nerve. Medial pectoral to musculocutaneous nerve transfer has proved reliable for restoration of elbow flexion for patients with C5,6 and C5,6,7 injuries. Problems with nerve transfers include morbidity in the donor nerve territory, co-contraction, and pre-existing injury to the donor nerve. There is a balance of risks in these procedures which should be weighed up in individual cases.

Keywords Brachial plexus · Injury · Nerve graft · Nerve transfer

Introduction

If a nerve has been divided by a clean laceration then repair by direct suture is usually possible. If there has been damage to a length of nerve, which often occurs when it has been subjected to severe stretch injury, then repair will require a nerve graft. In the brachial plexus nerve grafts are usually required even for lacerations in order to achieve a repair without tension. The traditional method of reconstruction of post-ganglionic injuries of the brachial plexus has been the use of nerve grafts to bridge the ruptured segments of nerves.

In recent years nerve transfers have been increasingly used in brachial plexus reconstruction. A nerve transfer is a procedure where an expendable nerve is connected to a more important nerve in order to reinnervate that nerve. The concept of nerve transfer has been known for many years. Lurje [1] reported the use of multiple nerve transfers for treatment of injuries to the upper trunk (C5, C6) of the brachial plexus. He recommended transfer of the long thoracic nerve to the suprascapular nerve, triceps branches of the radial nerve to the axillary nerve, and the lateral pectoral nerve to the musculocutaneous nerve. Seddon and Yeoman [2] reported re-innervation of the musculocutaneous nerve with intercostal nerves. Distal accessory nerve to suprascapular nerve transfer has been widely used for reconstruction of paralysis of the shoulder. Over recent years there has been a trend towards increased use of nerve transfers, with many new transfers being described. These include:

- Accessory to suprascapular nerve
- Nerve to long head of triceps to axillary [1, 3]
- Ulnar nerve fascicle to nerve to biceps [4]
- Medial pectoral to Musculocutaneous nerve [5]
- Thoracodorsal to Musculocutaneous nerve [6]
- Intercostal nerves [2]
- Phrenic nerve [7, 8]
- Contralateral C7 [9]

In brachial plexus reconstruction nerve transfers are indicated, when possible, in situations where nerve roots have been avulsed from the spinal cord (pre-ganglionic injury) or when the proximal nerve is otherwise unavailable

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for repair using nerve grafts. In addition there has been a trend towards using transfers for re-innervation of some nerves even when nerve graft repair might be possible. Nerve transfers offer a number of advantages.

1. They provide an additional source of neurotisation.
2. Nerve transfers may make reconstruction possible in cases where some or all the nerve roots have suffered a preganglionic avulsion.
3. In more favourable cases, where nerve grafting is possible, the addition use of nerve transfers may enable reconstruction of each function using a different source of neurotisation. This approach appears to give better results with less co-contractions.
4. Nerve transfers generally effect repair close to the target muscle and therefore reinnervation is likely to occur earlier or may be effective even after later operation.

This article outlines the experience of the Scottish National Brachial Plexus Injury Service for reconstruction for shoulder paralysis and elbow flexion as our use of nerve transfers has increased.

Materials and Methods

Details of the injury, surgical repair, and outcome are routinely recorded for all patients attending the brachial plexus service. Patients are followed up until recovery has reached a plateau or for at least 2 years from injury. A result is recorded if a patient has a minimum of 2 years follow-up or if a good outcome is achieved earlier. Muscle power is measured according to the Medical Research Council (MRC) scale. The outcome for each nerve repair is graded as good, fair, or poor using the peripheral nerve injury (PNI) unit scale [10] (Table 1). For shoulder function the range of active abduction of the shoulder was recorded, this being considered a more useful indication of recovery than MRC grade alone.

Patients with brachial plexus injury are assessed as early as possible to establish whether disruption of all or part of the plexus is likely and if they are likely to benefit from surgical repair. When indicated exploration is arranged within 3 months of injury whenever possible and in some cases was performed within 2 weeks. Full exploration of the damaged part of the plexus is carried out to establish the severity of injury before deciding on reconstruction. Repairs are carried out at the same procedure.

No new or additional procedures were performed for the study. Results which are routinely recorded for audit were used. Therefore approval by the Research Ethics Committee was not required.

Surgical Technique

The supraclavicular brachial plexus was explored through a transverse supraclavicular incision and the infraclavicular plexus through a deltopectoral incision. Where necessary the incisions were connected and clavicular osteotomy performed. Full exploration of the supraclavicular plexus was carried out to confirm the extent and severity of injury and establish whether any nerve roots were suitable for nerve graft repair.

Nerve Grafts

When the C5 and C6 roots were available, nerve grafts were attached to the root stumps proximally. The distal ends of the grafts were directly to the target nerves, suprascapular, axillary and musculocutaneous in most cases.

Accessory to Suprascapular Nerve Transfer

All the accessory to suprascapular transfers were performed from an anterior approach through the transverse supra-clavicular incision. The accessory nerve was identified on the deep surface of trapezius and traced inferiorly. Two or three branches to the upper trapezius were preserved and stimulated to confirm function. The nerve was then divided below these branches. The suprascapular nerve was divided from the upper trunk preserving as much length as possible and passed backwards through the supraclavicular fat, before suture to the accessory nerve using 8/0 or 9/0 nylon. The coaptation was reinforced with Tisseel fibrin glue.

Medial Pectoral to Musculocutaneous Nerve Transfer

In our unit the preferred transfer for reconstruction of elbow flexion is medial pectoral nerve to the musculocutaneous nerve. This transfer is indicated in patients with C5,6 or

Table 1 Peripheral nerve injury unit scale (Birch and Bonney [10])

Good:	Restoration of functional active movement in at least one axis of a joint. (Medical Research council (MRC) grade 3 or better)
Fair:	Nerve regeneration proven by clinical and neurophysiological examination but of little functional worth. MRC grade 1 and 2.
Poor:	No regeneration. (MRC grade 0).

C5,6,7 lesion who have good power in the pectoralis major. The technique was described by Brandt and MacKinnon [5].

The infraclavicular plexus is exposed through a delto-pectoral incision. The medial pectoral nerve is identified and stimulated to check for a satisfactory response. The nerve and its branches are traced distally towards pectoralis minor and major to give sufficient length and then divided. The musculocutaneous nerve is divided close to the lateral cord and any branches to coracobrachialis are separated from the main trunk. The branches of the medial pectoral nerve are sutured to the distal end of the musculocutaneous nerve.

Results

The results for reconstruction of shoulder movement and elbow flexion with nerve grafts and nerve transfers (Table 2) will be presented separately.

Reconstruction for Shoulder Paralysis

In cases of supraclavicular injury affecting the upper roots or complete injuries repair was performed for shoulder paralysis. For optimal reconstruction we aimed to re-innervate both of the suprascapular and axillary nerves. It is desirable to regain abduction of the shoulder and, if possible, active external rotation.

Between 1997 and 2007 fifteen patients, with a mean age of 28 year, had nerve grafts to repair the suprascapular nerve. Fourteen of these also had a nerve graft for the axillary nerve. There were 3 complete supraclavicular injuries and 12 partial upper plexus injuries. Four were the result of lacerations to the plexus and 11 had traction injuries. The mean delay between injury and operation was 48 days (Range 2 to 109 days). Seven of the fifteen had good or fair result with only three patients out of fifteen having a good (functionally useful) result. Two of these were repairs for lacerations of the brachial plexus, hence representing a particularly favourable situation. Two had abduction of 70^{o} and only one patient regained more than 90° active shoulder abduction. It is of note that 12 of the 15 patients gained a good result from nerve grafts performed for reconstruction of elbow flexion, indicating that proximal nerve roots were a viable source of neurotisation.

Twelve patients (mean age 23 years) had accessory to suprascapular nerve transfers between 2001 and 2008. There were 2 complete supraclavicular injuries and 10 partial upper plexus injuries. The mean delay was 68 days (Range 11 to 123 days). Eleven of the 12 also had repair for the axillary nerve using either nerve grafts (8) or nerve transfer (3). Eleven patients have sufficient follow-up. All have had useful recovery (Good) as a result of the transfer. Five patients have regained more than 90^{o} shoulder abduction and 3 of these have more than 150^{o} abduction. Two of the cases with less than 90^{o} abduction have regained useful (MRC grade 3) external rotation. Figure 1 shows the result in a patient who had accessory to suprascapular nerve transfer and nerve grafts from C5 to the axillary nerve.

Reconstruction for Elbow Flexion

Thirty-two patients (Mean age 33 years) had nerve grafts for reconstruction of elbow flexion between 1997 and 2008. Eight had complete supraclavicular injuries, 16 partial upper plexus injuries, and 8 infraclavicular injuries. The mean delay between injury and repair was 59 days (Range 2 to 268 days). Follow-up was available for 30 patients. Overall results were satisfactory with 25 of 30 regaining useful elbow flexion (Good, MRC >/= 3). Three had some recovery (Fair) and 2 had no recovery (Poor).

Ten cases of medial pectoral to musculocutaneous nerve transfer have been performed between 2001 and 2009. Seven of these patients have follow up of 1 year or more. Of the other three cases two have only recently had surgery and the other has been lost to follow-up. The delay between injury and operation was approximately 2 months (mean 69 days, range 52 to 123 days). The mean age was 23 years (range 17 to 38 years). Three cases had injuries only to the C5 and C6 roots, four cases to C5,6 and 7 roots and one case injury to C5,6,7 and 8. Injuries were caused by high energy trauma including motorbike road traffic accidents (7), car road traffic accident (1), bicycle road traffic accident (1) and a fall from a height (1).

Five of the 7 patients with follow-up have regained MRC grade 4 with four of these five able to lift more than

Table 2 Outcome of nerve repairs for shoulder abduction and elbow flexion with nerve grafts and nerve transfers graded using the PNI scale.

Nerve	Type of repair (Number with outcome)	Good	Fair	Poor
Suprascapular	Nerve graft (15)	3	4	8
	Accessory to suprascapular transfer (11)	11	0	0
Musculocutaneous	Nerve graft (30)	25	3	2
	Medial pectoral to musculocutaneous transfer (7)	6	1	0

Fig. 1 **a**, **b**, **c**, **d**. The result after 18 months in a patient after injury to the C5 and C6 roots of the brachial plexus. Repair included accessory to suprascapular nerve transfer and nerve grafts from C5 to the axillary nerve for reconstruction of shoulder paralysis and medial pectoral to musculocutaneous nerve transfer for elbow flexion. 1d. demonstrates scapular instability resulting from weakness of the middle and lower trapezius

3Kg. One patient, in whom there was difficulty performing the transfer because of low branching of the musculocutaneous nerve, recovered grade 3 elbow flexion. Another case who had reduced function in the medial pectoral nerve as a result of involvement of C8 had only grade 2 recovery. Six of the seven patients had good remaining power in pectoralis major.

Discussion

The trend of results for reconstruction for shoulder paralysis strongly suggests better outcome for a reconstruction including accessory to suprascapular nerve transfer. Terzis and Kostas [11] have reported a similar trend of results. We now attempt reconstruction of nerves for the shoulder if there are sufficient sources of neurotisation to provide repair for both the suprascapular and axillary nerves.

The results indicate that nerve graft repair remains a useful option for restoration of elbow flexion when there is a viable proximal nerve stump. The outcomes for medial pectoral to musculocutaneous nerve transfer have encouraged us to use this transfer for restoring elbow flexion in upper brachial plexus injuries providing C8 is not injured and anatomy of the musculocutaneous nerve allows direct suture of the transfer. If the circumstances for the transfer are favourable we usually perform this in preference to nerve grafts, even if viable nerve roots are available. The nerve roots are then available for re-innervation of another nerve, usually the axillary. Thus a separate source of neurotisation is used for each nerve.

Some general problems with nerve transfers will now be discussed.

Donor Nerve Morbidity

It should be remembered that nerve transfers will cause some loss of function in the donor nerve. After accessory to suprascapular nerve transfer there will be weakness of the middle and lower parts of the trapezius. In many patients this is not a functional problem but may be demonstrated in patients who have regained powerful external rotation of the shoulder. Winging of the scapula may occur on resisted active external rotation (Fig. 1d) [12]. However, symptomatic instability of the scapula has occurred in one of our cases who regained full shoulder abduction. While each case has to be considered individually, the accessory nerve should be used with caution if the serratus anterior is also paralysed.

Co-Contraction

When a nerve transfer is performed the function produced will not be independent of the donor nerve. If we consider the accessory to suprascapular nerve transfer, contraction of trapezius is synergistic with the supra- and infraspinatus, the trapezius being important in stabilising the scapula during elevation and external rotation of the shoulder. Hence co-contraction for this transfer should not be a problem.

The Oberlin ulnar fascicle to biceps transfer has been widely used and is a reliable technique for restoring elbow flexion [13]. However, there is a tendency for finger flexion to occur with elbow flexion. Although some authors have reported that patients, who have had an Oberlin transfer, learn to separate the movements, my own observation is that co-contraction persists and some patients specifically report that it is a disadvantage. This is one of the reasons that I have favoured the medial pectoral transfer for elbow flexion. Although some simultaneous contraction of biceps and pectoralis major occurs this appears to be synergistic.

Pre-existing Injury in the Donor Nerve

Another potential problem with nerve transfers is the degree of pre-existing injury to the donor nerve, which may explain some variation in results. In brachial plexus injuries there is always some damage to the nerves which are clinically functioning on the "edge" of the lesion. It should be remembered that muscle weakness is only apparent clinically when 50% or more of the axons innervating a muscle are lost. When possible we now arrange a full neurophysiology assessment before operation. This includes needle electromyography (EMG) of the muscles supplied by nerves which may be used for nerve transfers, eg. Trapezius, sternal head of pectoralis major, and triceps. If fibrillation potentials are identified in a muscle with good power on clinical examination then this indicates partial injury to the innervating nerve. Such information can be taken into account when selecting nerve transfers.

Conclusion

Overall nerve transfers have broadened our reconstructive options and delivered more reliable results for some patterns of injury to the brachial plexus. The experience in our unit indicates a particular improvement in outcome for reconstruction of the paralysed shoulder. Nerve graft repair can give good results for elbow flexion when a viable proximal nerve is available. Medial pectoral to musculocutaneous nerve transfer has proved reliable for restoration of elbow flexion in C5,6 and C5,6 ,7 injuries. There is a balance of risks in nerve transfer procedures which should be weighed up in individual cases.

Conflicts of Interest The author does not have any commercial or other relationships that could influence the outcome of this work.

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