Original Article

Indian Journal of Neurotrauma (IJNT)
2005, Vol. 2, No. 1, pp. 35-39

Microsurgical Reconstruction for Devastating Brachial Plexus Injuries

P S Bhandari M Ch, **L P Sadhotra** M Ch, **P Bhargava** M Ch, **A S Bath** M Ch, **P Singh*** M Ch
M K Mukherjee M Ch
Departments of Reconstructive Microsurgery & *Neurosurgery
Army Hospital (Research & Referral) Delhi Cantt-110010.

Abstract: Forty-four patients with brachial plexus injuries were treated in the period between Jun 1999 and Nov 2004. The ages of these patients ranged from 15 to 57 years (average 26 yrs). Most of the cases (72%) were caused by high velocity motor vehicle accidents. Gunshot and splinter injuries, direct hit from a motor vehicle (pedestrians), fall from height were responsible for rest of the cases (28%). Associated skeletal and vascular injuries were present in 43% of cases. The denervation time ranged from 4 months to 11 months. Majority of the patients had injuries in the upper brachial plexus involving C5, C6 & C7 roots. Global palsy was present in 8 cases. Reconstructive procedures included microneurolysis in 13 cases, nerve grafting in 7 and neurotization in 24 cases. Motors for neurotization included accessory nerve, inter-costal nerves, phrenic nerve, ulnar nerve fascicles and motor branch of radial nerve to triceps. Useful results were obtained in 64% of cases. Almost all patients had pain relief following surgery. In none of the case results worsened after surgery. Microsurgical techniques can obtain gratifying results in traumatic lesions of brachial plexus, provided surgical intervention is undertaken at an early stage.

Keywords: autologous nerve graft, brachial plexus, microneurolysis, neurotization

INTRODUCTION

Brachial plexus palsies in the young soldiers represent devastating injuries with a poor prognosis. The treatment of injuries to the brachial plexus is a demanding and difficult. The plexus anatomy is complex and variable. Treatment requires comprehensive care, cross specialty consultations, prolonged hours of surgery and protracted period of pre & post surgery physiotherapy and splinting. Even then the result of surgery may not be favorable. In 1963, Sir Herbert Seddon, an eminent specialist in brachial plexus surgery even stated: *"Repair of the brachial plexus has proved so disappointing that it should not be done except for the upper trunk"*[1]. This situation has changed in the last two decades. Improvements in general anesthesia allow longer, safer operations. Furthermore, advances have been made in the efficiency of hemostasis, microsurgical repair of nerves, electrophysiological preoperative testing of nervous pathway and in microsuture materials, glues, instruments and the operative microscope. Introduction of microsurgery in brachial plexus reconstruction brought in novel ideas, improving the scope of successful surgery.

The aim of this paper is to show the current status of this type of surgery in the light of the authors' personal experience with 44 operative cases.

Address for correspondence: Lieut Col P S Bhandari M Ch Department of Reconstructive Microsurgery, Army Hospital (Research & Referral), Delhi Cantt 110010

MATERIAL AND METHODS

From Jun 1999 to Nov 2004 a total of 44 patients with post traumatic brachial plexus injuries were treated at command hospital Pune and Army hospital (R&R) Delhi Cantt. All of them were soldiers, ex-servicemen and their dependents. Their ages ranged from 15 to 57 yrs (mean 26yrs). A total of 29 patients (66 %) were injured on their right side. High velocity motor vehicle accidents were the most common cause of injuries. A total of 20 patients (45%) had motor cycle accidents, 12 patients (27%), were traumatized in car accidents. 6 palsies (14%) were the results of gunshot and splinter wound and 5 patients (11%) were hit by a vehicle. One patient (2%) developed injury following a fall from rooftop (Table 1). Associated skeletal and vascular injuries were present in 19 patients (43%) (Tables 2 & 3).

Table 1: Etiology of brachial plexus injuries

S No.	Etiology	No of cases
1	High velocity motor vehicle accidents	32
2	Gunshot and splinter injuries	6
3	Direct hit injuries (pedestrians)	5
4	Fall from height	1
Total		**44**

Table 2: Distribution of skeletal injuries in 17 patients (38%)

S No	Fractures and/dislocations	No of cases
1	Fractures in paralysed extremity	
	Clavicle	7
	Scapula	2
	Humerus	2
	Radius	1
	Ulna	1
2	Fractures in other extremities (tibia & fibula)	1
3	Fractures in ribs	3
Total		**17**

Table 3: Associated vascular and visceral injuries in 3 patients (6%)

S No	Vascular injuries	No of cases
1	Subclavian	1
2	Axillary	1
3	Injury to lung	1
Total		**3**

Eleven patients (25%) had associated head injury.

Clinical examination included motor and sensory examination using the British Medical Research Council grading system, and values were recorded on plexus chart. Active and passive ranges of motion of the upper extremity joints were also measured. Clinical examination included elicitation of Tinel's sign in the posterior triangle and detection of Horner's syndrome. The severity of pain was expressed on a numerical scale from 0 to 5: 5 represented intolerable pain not controlled even with analgesic medication.

Electrodiagnostic evaluation included nerve conduction studies and electromyography. Radiological examination included plain X-rays of the cervical spine and upper extremity. Inspiratory/expiratory chest X-rays were done to exclude diaphragmatic (phrenic) palsy, which is an indication of high plexus lesion. MRI myelography was done to rule out root avulsion. An angiogram of the upper extremity was done in patients with suspected vascular injury.

The denervation time (the time interval from the injury to brachial plexus reconstruction) was recorded which ranged from 4 to 11 months (Table 4)

Table 4: Denervation time

S No	Denervation time (in months)	No of patients
1	4 – 6	20
2	6 – 8	12
3	8 – 10	8
4	10 – 11	4

Surgical Technique

All patients were operated under general anesthesia, in supine position with the affected upper extremity abducted on an arm board or arm support. Access to the chest and lower extremities were also made available as needed for the harvest of donor nerves for transfer or grafting. Paralytics were withheld until all nerves were completely evaluated by electrical stimulation.

Brachial plexus was explored through an incision around the posterior border of the sternocleidomastoid muscle, curving posterolaterally over the superior border of the clavicle, and then extending to the arm through the deltopectoral groove. Phrenic nerve was located on the anterior surface of the scalenus anterior muscle travelling longitudinally. The routes of brachial plexus were searched between the scalenus anterior and medius muscles. To expose the cord and terminal branches, the incision was extended along the deltopectoral groove from the clavicle to the upper medial arm. The humeral insertion of pectoralis major and the origin of pectoralis minor were divided. The supraclavicular and infraclavicular plexuses were connected by means of retroclavicular dissection. In one clavicular osteotomy was done. The level and extent of injury was determined by gross examination and electrical stimulation with a DC stimulator at 0.5, 1.0 and 2.0 mA. This was particularly helpful in lesions in continuity in which a decision had to be made whether to proceed with neurolysis, resection of the neuroma and nerve grafting, or neurotization. If stimulation of the nerve produced muscle contraction neurolysis of the scarred portion was done. If no muscle activity was seen, the neuroma was resected until a healthy fascicular pattern seen proximally, and the gap was reconstructed with nerve grafts.

The levels of injury are reflected in Table 5. The type of nerve reconstruction performed included microneurolysis, nerve repairs with interposition of nonvascularised sural nerve grafts and neurotization (Table 6).

Table 5: Level of brachial plexus injuries

S No	Level	No of cases
1	Root avulsion(30)	
	Global avulsion(5 roots)	8
	4 – root avulsion	3
	3 - root avulsion	4
	2 – root avulsion	12
	1 – root avulsion	3
2	Trunk lesions	7
3	Cord lesions	2
4	Terminal branches(5)	
	Median	2
	Ulnar	1
	Musculocutaneous	1
	Axillary	1
Total		**44**

Table 6: Type of nerve reconstruction *

S No	Nerve reconstruction	No of procedures
1	Microneurolysis	21 in 13 cases
2	Nerve grafts	12 in 7 cases
3	Neurotization	45 in 24 cases

* Almost all patients needed more than one procedure.

Microneurolysis was done when, on exploration of the brachial plexus, proximal or distal plexus elements felt hard to palpation. In these cases, a longitudinal epineurotomy was done under operating microscope. Interposition sural nerve grafts were used after neuroma excision to bridge the gap between motor donors and targets.

Neurotization of a peripheral nerve was done when the proximal nerve stump was unavailable (root avulsion injury). The aim was to neurotize selected muscles to achieve stabilization and essential function specially in the elbow and shoulder. The donor nerves that were used for neurotization included spinal accessory nerve, ipsilateral intercostal nerves, phrenic nerve, part of ulnar nerve (Oberlin transfer) and radial nerve branch to long head of triceps. In most of the cases (15 cases), spinal accessory nerve was coapted with suprascapular nerve to achieve initial 20 to 30 degree of shoulder abduction. In 6 cases phrenic nerve was coapted with suprascapular. In four cases, axillary nerve was neurotized with radial nerve branch to long head of triceps. In upper brachial plexus injury to achieve elbow flexion when ulnar nerve was intact, Oberlin transfer (direct coaption of 1 or 2 ulnar nerve fascicles with nerve to biceps) was done in 6 cases. For similar purpose musculocutaneous nerve was neurotized with 3rd to 5th intercostals nerves in 9 cases. For restoration of protective sensibility in the hand, the median nerve was neurotized with sensory intercostal nerve in two cases (Table 7).

Table 7: Neurotization procedures

S No	Donor nerve	Recipient nerve	No
1	Spinal accessory nerve	Suprascapular nerve Musculocutanous nerve (with sural nerve graft) Axillary nerve(with sural nerve graft)	15 2 1
2	Phrenic nerve	Suprascapular nerve	6
3	Radial nerve (branch to long head of triceps)	Axillary nerve	4
4	3rd, 4th & 5th ipsilateral intercostals nerves	Musculocutaneous nerve	9
5	Part of ulnar nerve (Oberlin transfer)	Branch to biceps	6
6	Median nerve	Sensory intercostal nerve	2
Total			**45**

Secondary procedures were performed in five cases to improve the final outcome. These included trapezius transfer (two cases) and shoulder arthrodesis (one case) to achieve abduction and the Steindler flexor plasty to achieve elbow flexion (one case). Free muscle (gracilis) transfer was done to achieve elbow flexion in one case.

RESULTS

The results of the repair of brachial plexus injuries in 44 patients upto five years follow-up examination were classified by level of injury and surgical method used (microneurolysis, nerve grafting and neurotization). The clinical results were graded as:

Good: the motor contractile force greater than M3 and good tactile sensation, with ability to distinguish warmth, cold and pain.

Acceptable: The motor contractile force greater than M3 and presence of protective sensation.

Failure: inability to use the extremity purposefully and effectively.

The overall results depended on the level and mode of injury, age of the patient and time of surgical intervention. Decompression of clavicular fracture yielded good results in two cases. Microneurolyses were performed in patients presenting with lesions which were in continuity but which were caught in scar tissue. The results of microneurolyses are shown in Table 8. Sural nerve grafting of an isolated upper truncal lesion produced good results in one case with good return of shoulder abduction and elbow flexion. Neurotizations (Table 9) were the most commonly performed procedure especially in root avulsion cases. Neurotization of the suprascapular nerve with spinal accessory nerve achieved 30-45 degree of abduction. Transfer of the phrenic nerve to the suprascapular nerve got an average of 30 degrees of shoulder abduction. Neurotization of axillary nerve with phrenic or spinal accessory nerve always required nerve graft the length of which varied from 6 – 10cm. Simultaneous neurotization of suprascapular and axillary nerves provide more reliable and much better results, with an average of 60 degree of shoulder abduction.

Table 8: Results of microneurolyses *

S No	Level of microneuroly ses	Good	Acceptable	Failure
1	For C5, C6, C7 and pathways coming from them	2	2	1
2	For C8, T1 and median and ulnar nerves	1	2	1
3	Painful syndromes	2	1	1
Total * 21 microneurolyses was done in 13 cases				

Table 9: Results with Neurotization *

S No	Neurotization	Total	Good	Acceptable	Failure
1	Spinal accessory nerve to suprascapular nerve	12	9	3	3
2	Spinal accessory nerve axillary nerve(with sural nerve graft)	1	1	-	-
3	Spinal accessory nerve to musculocutaneous nerve (with sural nerve graft)	2	Nil	1	1
4	Phrenic to suprascapular nerve	6	3	2	1
5	Intercostal nerves (3rd to 5th) to musculocutaneous nerve	9	5	3	1
6	Ulnar nerve fascicle to motor nerve to biceps	6	4	2	Nil
7	Radial nerve branch long head triceps to axillary nerve	4	2	1	1
8	Sensory intercostals nerve to median nerve	2	Nil	1	1
Total * 45 neurotizations done in 24 patients.					

The results of intercostals nerve transfer produced good range of elbow flexion in 10 patients. With Oberlin transfer recovery was first noted clinically at 2 to 5 months (mean, 3 months). Recovery of M3 strength occurred between 4 and 11 months after surgery (mean, 6 months). No loss of ulnar function was noted after surgery.

All patients experienced relief in pain syndrome and none of them worsened after surgery.

Postoperatively the extremity was immobilized for four weeks. After this time the patients were instructed to begin physical therapy, gradually increasing the range of motion, along with ultrasound and electrical stimulation, to keep the joints and the denervated muscles in good condition until reinnervation.

DISCUSSION

The advent of microsurgical techniques, availability of finer instrumentation and suture material, a greater understanding of the process of nerve healing and the development of surgical techniques to manage nerve injuries has improved the outcome of brachial plexus reconstruction in last two decades. It is now generally accepted that the time between the injury and its reconstruction is a crucial determinant of the functional result. It is important to perform an early surgical exploration within three months of the injury[2]. Surgical outcome are correlated to the level of the lesion (supraclavicular versus infraclavicular), the severity of the injury (avulsion versus rupture), the age of the patient and the denervation time. It is generally accepted that upper root palsies (C5, C6 or C7) have better overall outcome than lower root (C8, T1) injuries or complete palsies[3]. The reason for this is dual: in upper palsies, hand function is preserved and second, the muscle targets are close to the plexus. Thus the distances from motor donor to target are much shorter, leading to better outcome.

In the reconstruction of the completely paralytic upper limb after brachial plexus injury, reconstructive priorities consist of the restoration of elbow flexion followed by shoulder abduction[2].

The nerve grafting is more rewarding when the distal coaptation is near the muscle targets[4]. Most common type of nerve graft involves fragments of non-vascularized cutaneous nerves. The sural, saphenous, medial cutaneous nerve of forearm and superficial radial are most commonly used. These thin cutaneous nerves are preferred because the donor site morbidity is minimal and they have better survival rate than thicker trunk nerve grafts.

Neurotization allows reconstruction of a peripheral nerve when the proximal nerve stem is unavailable e.g. root avulsion injury. The donor nerves used for transfer include spinal accessory nerve[5], ipsilateral intercostals nerves[6,7], branches of cervical plexus[8], phrenic nerve[9], medial pectoral nerve[2] and a redundant flexor carpi ulnaris fascicle of the ulnar nerve (Oberlin transfer)[10]. A redundant triceps branch may also be used to neurotize the axillary nerve. Other possible donor nerves include the contralateral C7 root[11]. The functional donor deficit from using the contralateral C7 root is minimal, but a very long nerve to the opposite upper extremity is required.

Secondary procedures are an integral part of brachial plexus reconstruction because only partial recovery can be achieved, especially in severe lesion. The goal for abduction and external rotation, which can be achieved by the latissimus dorsi[12] or trapezius transfers[13]. In selected cases shoulder arthrodesis[14] gives satisfactory results.

In delayed cases, a free muscle transfer (e.g. gracilis)[15] can be done alone or as a double muscle transfer for shoulder abduction and elbow flexion. The wrist can be fused if it is unstable especially in global avulsions. This enhances hand function. The thumb may be converted stable post by either arthrodesis or tenodesis.

An early, aggressive reconstruction with meticulous microsurgical techniques offers the best results in brachial plexus injuries. Neurotization with various intraplexus and extraplexus donors and secondary procedures such free functioning muscle transfers, provide rewarding results and avoid amputation even in cases of global avulsion injury.

REFERENCES

1. Seddon H J: Nerve grafting. *J Bone Joint Surg* 1963; 45 B: 447-61
2. Tung T H H, Mackinnon S E: Brachial plexus injuries. *Clin Plast Surg* 2003; 30:269-87.
3. Terzis J K, Verkris MD, Soucacos P N: Outcomes of brachial plexus reconstruction in 204 patients with devastating paralysis. *Plast Reconstr Surg* 1999; 104;1221-41.
4. Alnot JY. Traumatic brachial plexus lesions in adult. *Hand Clin* 1995; 11: 623-31.
5. Allie Y, Cenac P. Neurotization via the spinal accessory nerve in complete paralysis due to multiple avulsion injuries of the brachial plexus. *Clin Orthop* 1983; 237:67-74.
6. Narakas A O, Hentz V R. Neurotization in brachial plexus injuries: Indications and results. *Clin Orthop* 1988; 237: 43-56.
7. Nagano A, Truyama N, Ochias N, Hara T, Takahashi. Direct nerve crossing with the intercostal nerve to treat avulsion injuries of the brachial plexus. *J Hand Surg* 1989; 14A: 980-85.
8. Brunelli G, Monini L. Neurotization of avulsed roots of brachial plexus by means of anterior nerves of the cervical plexus. *Clin Plast Surg* 1984; 11: 149-52.
9. Gu Y D, Ma MK. Use of the phrenic nerve for brachial plexus reconstruction. *Clin Orthop Res* 1996; 323:119-21.
10. Oberlin C, Beal D, Leechavengvengs S. Salon A, Dauge MC, Sarcy J J. Nerve transfer to biceps muscle using a part of ulnar nerve for C5-C6 avulsion of the brachial plexus: anatomical study and report of four cases. *J Hand Surg* 1994;19A: 232-7.
11. Bertelli J A, Ghizoni MF. Selective motor hyperreinnervation by using contralateral C7 motor rootlets in the reconstruction of an avulsion injury of the brachial plexus. *J Neurosurg* 1990; 90: 1133-6.
12. Zancolli E, Mitra H. Latissimus dorsi transfer to restore elbow flexion. *J Bone Joint Surg* 1973; 55A: 1265-75.
13. Ruhmann O, Wirth C J, Gosse F, S Chmolke S. Trapezius transfer after brachial plexus palsy. *J Bone Joint Surg* 1998: 80B:109-13.
14. Mohammed NSL. A simple method of shoulder arthrodesis. *J Bone Joint Surg* 1998; 80-B:620-23.
15. Akasaka Y, Hara T, Takahashi M. Free muscle transplantation combined with intercostal nerve crossing for reconstruction of elbow flexion and wrist extension in brachial plexus injuries. *Microsurgery* 1991; 12: 346-51.