Neurol Med Chir (Tokyo) 42, 114～122, 2002

Clinical Analysis of 16 Patients With Brachial Plexus Injury

Takeshi MATSUYAMA, Kazuo OKUCHI, Manabu AKAHANE, Yuji INADA, and Yoshinori MURAO

Department of Emergency and Critical Care Medicine, Nara Medical University, Kashihara, Nara

Abstract

Brachial plexus injury is very rare in neurosurgical practice, so many neurosurgeons have never experienced this problem in Japan. This study describes a clinical analysis of 16 patients aged 5 to 62 years (mean 32.9 years) who presented at our institution with brachial plexus injuries. Nine patients presented with paralysis and seven with paresis. Head injury was the most common associated injury in eight of 16 patients. Six patients were managed conservatively. All patients with C8–T1 paresis spontaneously recovered to a useful level. Surgery was performed in 10 patients: six neurolysis, two neurotization, and three nerve grafting procedures. All six patients who underwent neurolysis of the brachial plexus attained useful recovery. Four of five patients achieved useful recovery after nerve repair. Nerve grafting achieved a better outcome than neurotization in this study. The difference of outcome was attributed to the graft length. The management of brachial plexus injury is a great challenge, but surgical outcome can be improved if the optimal repair procedure is selected for brachial plexus injury.

Key words: brachial plexus injury, nerve repair

Introduction

Brachial plexus injury is usually very complex, because of the involvement of both spinal nerve and spinal root ruptures, with associated avulsion of one or several roots from the spinal cord. This injury occurs mainly in young individuals and may lead to devastating neurological dysfunction in some patients. The prevalence of brachial plexus injuries in the multiple trauma population is about 1.2%.[16] Brachial plexus injury occurs when the head and neck are forced in one direction and the shoulder and arm are pushed in another.[1] The most common lesions of the plexus are due to the stretching mechanism initiated by motor vehicle accidents. Other causes are sport-related injuries such as football, bicycling, skiing, sledding, horse-riding, wrestling, gymnastics, and golf.[4,11,16,23] The reconstructive procedures including nerve grafting, neurotization, muscle transplantation, tendon transfer, and bony manipulation remain unsatisfactory.[13,16,23] This type of injury presents a surgical challenge and is usually addressed by orthopedic or plastic surgeons in Japan, so is very rare in neurosurgical practice, and many neurosurgeons have never experienced this problem. This study describes the clinical analysis of 16 patients who presented at our institution with brachial plexus injury.

Received October 3, 2001; Accepted January 17, 2002

Material and Methods

Sixteen patients were treated for traumatic brachial plexus injury at the Department of Emergency and Critical Care Medicine, Nara Medical University between January 1997 and June 2001 (Table 1). Detailed history was obtained and thorough physical examinations and radiological studies of the neck, shoulders, and chest were performed to confirm the nature and severity of the injury. Patients were also examined by magnetic resonance imaging, myelography, electromyography, and nerve conduction studies.

The aim of our treatment strategy is to restore maximal motor functions of the arm, shoulder, and hand. Multiple root avulsions were treated to reconstruct elbow flexion and shoulder abduction. In addition, intractable pain in patients with paresis was treated surgically. Individuals who spontaneously recovered within the first 4 months after injury with

Table 1 Summary of 16 patients with brachial plexus injury

Case No.	Age/ Sex	Lesion	Interval to treatment	Follow-up period
1	17/M	C8–T1 paresis	7 days	1.5 years
2	35/M	C5–6 paralysis	3 years	5 years
3	57/F	C8–T1 paresis	6 months	4 years
4	17/M	C5–T1 paralysis	3 months	2.5 years
5	18/M	C5–6 paralysis	4 months	3 years
6	39/F	C8–T1 paresis	8 months	2 years
7	5/M	C5–T1 paralysis	3 hours	3 years
8	28/M	C-5 root injury	17 days	5 years
9	17/M	axillary nerve injury	19 days	3.5 years
10	19/M	C5–6 paralysis	4 months	3 years
11	55/M	axillary nerve injury	8 months	1 year
12	62/M	C5–6 paralysis	4 years	5 years
13	33/F	C8–T1 paresis	2 weeks	0.5 years
14	42/F	C8–T1 paresis	8 months	4 years
15	45/F	C5–6 paralysis	12 months	2 years
16	38/F	C8–T1 paresis	8 months	1 year

incomplete injuries received conservative treatment. Surgery was also avoided when referral to our institute was over 3 years after injury, when the optimal time for surgery was thought to have passed. Surgical exploration was performed in patients who did not show clinical and electromyographical signs of recovery by 4 months after injury. Exceptions included lesions associated with vascular injuries or sharp transections such as stabbing, laceration by fractured bone, and apparent total avulsion.

Patients underwent surgery within several hours or within a few weeks of injury. Intraoperative nerve action potentials (NAPs) were measured across the continuous lesions. If the NAP was present, lesions were treated only by neurolysis. If the NAP was absent or the brachial plexus was partially or completely transected, neurorrhaphy including nerve grafting and neurotization was performed. If a nerve lesion was distal from the nerve foramen, the neuroma was resected and nerve grafting was performed. Donor nerve grafts were harvested from the sural or greater auricular nerve in the patient. If the proximal stump was not available because of root avulsion or damage, neurotization was performed. Patients were clinically evaluated before or after surgery using the Medical Research Council (MRC) grades as follows: excellent, G5; good, G3–G4; fair, G2; and poor, G0–G1. Useful recovery was defined as G3 or higher.

Surgical Technique

Under general anesthesia without muscle relaxants, patients were placed in the supine position with a bag or rolled sheets under the head and the posterior aspect of the upper thorax. The arm on the side to be operated upon was abducted onto a supporting board. Both legs from the toe to the thigh were draped for harvesting long sural nerve grafts. The skin incision to expose both supra- and infraclavicular parts of the brachial plexus began one fingerbreadth posterior to the sternocleidomastoid muscle at the angle of the jaw and continued vertically downwards along the posterior border of the sternocleidomastoid muscle to the clavicle. The incision then turned laterally, followed the superior border of the clavicle, and crossed the midpoint of the clavicle. The incision ran distally along the deltopectoral groove over the coracoid process to the axillary crease. The landmark of the deltopectoral groove is the cephalic vein, which was dissected and gently retracted.

A supraclavicular approach was used to expose the spinal roots, trunks, and supraclavicular branches of the brachial plexus such as the suprascapular and phrenic nerves. The posterior triangle of the neck was dissected deeply along the plane of the fifth, sixth, and seventh cervical transverse processes. The branch of the external jugular vein on the sternocleidomastoid muscle was ligated and cut, and the clavicular portion of the sternocleidomastoid was divided. The cutaneous branches of the descending cervical plexus and the spinal accessory nerve were recognized and protected for potential use as neurotized nerves. The omohyoid muscle was divided and tagged. The anterior and middle scalene muscles were easily palpated and identified. The cervical nerve roots are located between these muscles and the phrenic nerve lies on the anterior scalene muscle laterally to medially in a longitudinal direction. The phrenic nerve was dissected out, mobilized medially, and traced upward to identify and isolate C-5, C-6, and the upper trunk from the anterior scalene muscle. The remaining spinal nerves of the brachial plexus were exposed by dissecting downwards in that plane. The suprascapular nerve branching from the upper trunk was recognizable. This nerve innervates the supra- and infraspinatus muscles, the functions of which are shoulder abduction and external rotation of the upper arm.

The infraclavicular approach was applied to expose the cords and terminal branches of the brachial plexus. After dividing the pectoralis major muscle near the deltopectoral groove, the pectoralis minor was recognized more proximally and sectioned. The clavipectoral fascia was distally incised and the lateral cord was initially identified under the fat tissue. The musculocutaneous nerve innervating the biceps muscle can be visualized coming off laterally and penetrating the coracobrachialis muscle. The posterior cord lies dorsally and divides into a radial nerve and an axillary nerve innervating the deltoid muscle and the medial cord.

The best way to evaluate regeneration of the distal nerve is to stimulate and record the nerve across the injury site by intraoperative nerve conduction stimulation. This is called NAP recording. The presence or absence of an intraoperative NAP helps to decide further operative management. If the NAP is present, the lesion is managed only with external neurolysis and should not be cut. If lesions are continuous and do not transmit the NAP by 2 or 3 months after injury, the nerve should be resected and repaired by nerve grafting or neurotization.

For nerve grafting is performed, the whole of the neuroma is removed, and the proximal and distal stumps of the nerve evaluated using rapid microscopic inspection to determine whether they are healthy or not. Nerve grafting is performed with several segments of donor nerves, which are cut sufficiently long to avoid tension after placing in the gap. The sural nerve is commonly used as the donor nerve.

When spinal accessory-suprascapular neurotization is necessary, the distal branch of the spinal accessory nerve is used to reduce significant denervation of the trapezius muscle. This branch is neurotized with the suprascapular nerve via the greater auricular nerve used as an interposed graft. If intercostal-musculocutaneous neurotization is selected, the third and fourth intercostal nerves are exposed at the mid maxillary line and distally transected, then neurotized with the musculocutaneous nerve via the sural nerves.

Results

I. Patient population

The present series included 10 males and six females aged from 5 to 62 years (mean 32.9 years) (Table 1). Young individuals predominated with 11 of 16 patients between the ages of 5 and 39 years. The two peaks in the age distributions indicated different mechanisms of injury. Fourteen patients were injured in traffic accidents (Table 2). One patient suffered iatrogenic injury and one had stabbed himself. The main cause was motor cycle accidents in the younger group (first peak) and motor vehicle and pedestrian accidents in the older group (second peak). The time interval between injury and referral to our institute or reconstructive surgery varied from 3 hours to 4 years (Table 1). The follow-up period ranged from 6 months to 5 years (mean 34.5 months).

Table 2 Summary of mechanism of injury, associated injury, and treatment

Case No.	Mechanism of injury	Associated injury	Type of treatment
1	stretch	head injury	conservative
2	stretch	head injury	conservative
3	iatrogenic	none	conservative
4	stretch	head injury, hemothorax	neurotization: 6 cm graft
5	stretch	clavicular fx	neurolysis, neurotization: 4 cm graft
6	blow	none	neurolysis
7	compression	head injury, SCA injury	neurolysis
8	stab	tracheal injury	nerve graft: 2 cm × 6
9	stretch	head injury, rib fx, lung contusion	nerve graft: 3 cm × 4
10	stretch	head injury, rib fx, hemothorax	nerve graft: 5 cm × 3
11	stretch	head injury, rib fx, hemothorax, scapular fx	neurolysis
12	stretch	none	conservative
13	stretch	rib fx, hemothorax	conservative
14	stretch	none	neurolysis
15	stretch	head injury	neurolysis
16	stretch	none	conservative

fx: fracture, SCA: subclavian artery.

II. Mechanism of injury and type of brachial plexus injury

The types of brachial plexus injury were as follows: stretch injury in 12 patients, iatrogenic injury (resection of a subcutaneous tumor at the supraclavicular fossa) in one, blow to the shoulder in one, compression of the brachial plexus due to subclavian arterial injury in one, and laceration due to stabbing in one (Table 2). Nine patients presented with paralysis and seven with paresis. Fourteen patients had primary supraclavicular injuries affecting the nerve root and trunk. Neurological status at initial assessment was C5–6 paralysis in five patients, C5–T1 paralysis in two, C-5 root injury in one, and C8–T1 paresis in six (Table 1). One patient with C5–T1 paralysis had total avulsion. The axillary nerves were affected due to infraclavicular injuries in two patients.

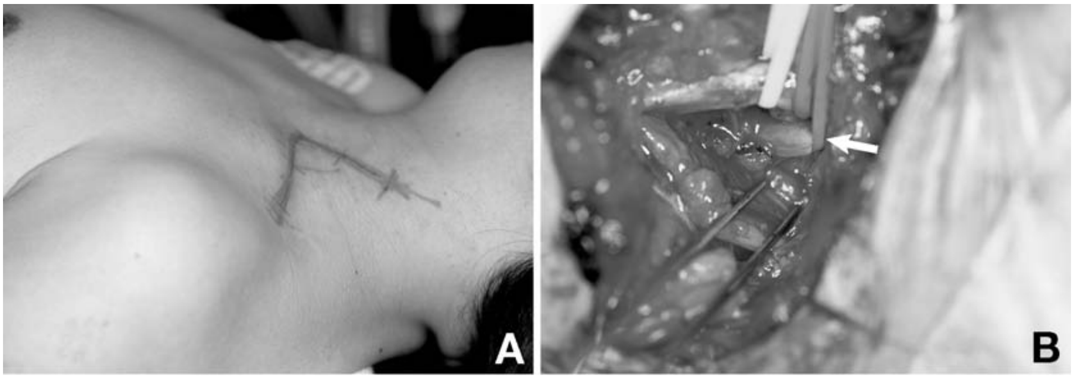

Fig. 1 Case 6. Neurolysis was performed to relieve pain and paresthesia on the ulnar side of the left hand. (A) Photograph showing the supraclavicular incision made to expose the lower trunk. (B) Intraoperative photograph showing the lower trunk (*arrow*) was neurotized circumferentially.

III. Associated injuries

Nine of 16 patients had associated serious injuries (Table 2). Head injury was most common in eight of 16 patients. Thoracic injuries including rib fracture and hemothorax were found in five patients. C8–T1 paresis tended not to be associated with injuries. The subclavian artery was injured in one patient.

IV. Treatment and outcome

Six patients were managed conservatively with physical therapy and pain medication. Four had C8–T1 paresis and two had C5–6 paralysis. All patients with C8–T1 paresis spontaneously recovered to a useful level. The two patients with C5–6 paralysis were referred too late for surgery and the functions of their biceps and shoulders never recovered (Table 3).

Paralysis with no evidence of recovery indicated surgical exploration. The only exception was one patient with C8–T1 paresis associated with severe intractable pain. This patient underwent palliative surgery. Surgery was performed in 10 patients: six neurolysis, two neurotizations, and three nerve grafting procedures (Table 2).

Six patients who underwent neurolysis of the brachial plexus attained useful recovery (good, 3; excellent, 3). Pain was completely relieved in the patient with C8–T1 paresis (Fig. 1). Emergency explorative surgery was performed in the patient with total compressive paralysis due to subclavian arterial injury, to repair the vascular lesions and decompress the brachial plexus. Recovery of this patient was excellent.

Five patients who underwent neurorrhaphy had outcomes as follows: excellent, two; good, two; and fair, one. Intercostal-musculocutaneous or spinal accessory-suprascapular neurotization were performed in two patients undergoing neurotization. The outcome of biceps function was fair after intercostal-musculocutaneous neurotization (Fig. 2), and the outcome of shoulder function was good after spinal accessory-suprascapular neurotization (Fig. 3). Three patients who underwent nerve grafting attained useful recovery (good, 1; excellent, 2). Two of five patients underwent early neurorrhaphy because of laceration due to stabbing (Fig. 4) and axillary nerve injury due to dislocation of a fractured bone fragment. The extent of the lesions was limited

Table 3 Summary of outcome

Case No.	Preoperative neurological status	Postoperative neurological status	Outcome
1	abductor digiti minimi 3/5	abductor digiti minimi 5/5	excellent
2	biceps 0/5, supraspinatus 0/5	biceps 0/5, supraspinatus 0/5	poor
3	abductor digiti minimi 2/5	abductor digiti minimi 4/5	good
4	biceps 0/5	biceps 2/5	fair
5	biceps 0/5, supraspinatus 0/5	biceps 4/5, supraspinatus 3/5	good
6	pain, paresthesia	complete relief	excellent
7	biceps 0/5, deltoid 0/5	biceps 5/5, deltoid 5/5	excellent
8	biceps 0/5, deltoid 0/5	biceps 4/5, deltoid 4/5	excellent
9	deltoid 0/5	deltoid 4/5	excellent
10	biceps 0/5	biceps 3/5	good
11	deltoid 0/5	deltoid 4/5	good
12	biceps 0/5	biceps 0/5	poor
13	interossei 3/5	interossei 4/5	good
14	abductor digiti minimi 2/5	abductor digiti minimi 3/5	good
15	biceps 0/5	biceps 5/5	excellent
16	interossei 3/5	interossei 4/5	good

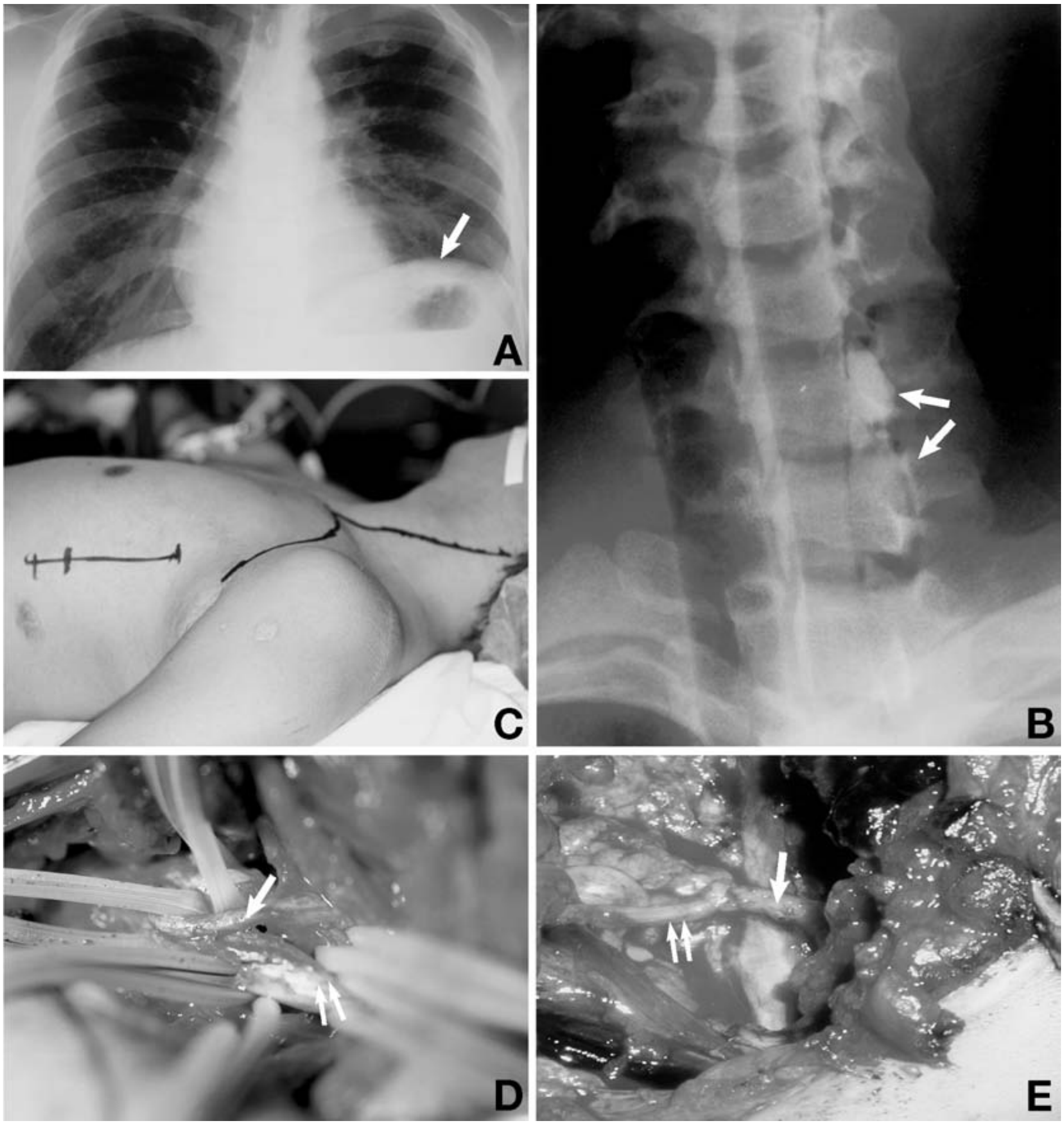

Fig. 2 **Case 4. Intercostal-musculocutaneous neurotization was performed for C5–T1 paralysis. (A) Chest radiograph showing elevation of the left diaphragm (*arrow*), indicating the left phrenic nerve paresis. (B) Myelogram showing pseudomeningocele (*arrows*) at the C-8 and T-1 levels. (C) Intraoperative photograph showing skin incisions for neurotization. (D) Musculocutaneous nerve (*arrow*) was exposed. *double arrow*: Median nerve. (E) Musculocutaneous nerve (*arrow*) was coapted to a sural nerve (*double arrow*).**

and healthy proximal and distal stumps were identified. Short cable grafting was possible because of the short nerve gap. Three patients with stretch injuries had surgery between 3 and 4 months after the injury. In the patients with neurorrhaphy, nerve grafting at the early stage tended to lead to a favorable outcome and a short graft provided a better outcome.

Discussion

I. Epidemiology

Most of our patients were between the ages of 5 and 39 years. Two peaks in the age distribution were identified according to the mechanism of brachial plexus injury. Most teenaged patients (first peak) fell from motor cycles and sustained severe injuries requiring surgical management, whereas patients in the fifth decade (second peak) were hit on the shoulder by a relatively minor force in motor vehicle acci-

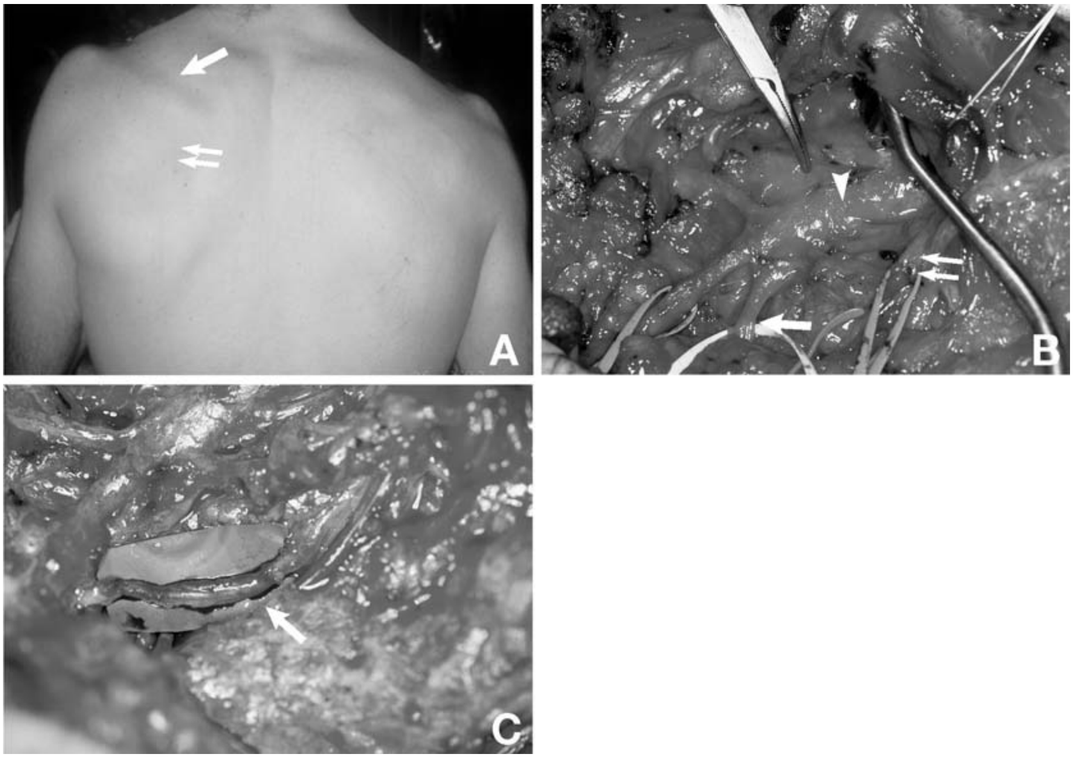

Fig. 3 **Case 5. Spinal accessory-suprascapular neurotization was performed to restore the left shoulder function. (A) Photograph showing atrophy of the supraspinatus (*arrow*) and infraspinatus muscles (*double arrow*). (B) Suprascapular nerve (*arrow*) and spinal accessory nerve (*double arrow*) were dissected in the supraclavicular exposure. *arrowhead*: Upper trunk. (C) Suprascapular nerve and spinal accessory nerve were neurotized using the great auricular nerve (*arrow*).**

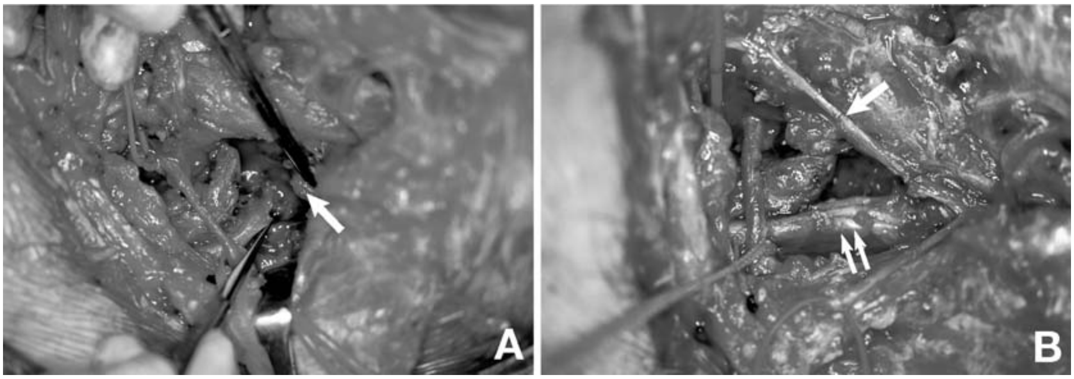

Fig. 4 **Case 8. Nerve grafting was performed for C-5 root injury. (A) Intraoperative photograph showing the C-5 root (*arrow*) was transected by stabbing. (B) Nerve grafting was performed using six short sural nerve segments. *arrow*: Phrenic nerve, *double arrow*: interposed sural nerve.**

dents or as pedestrians, sustaining mild brachial plexus injury which could be treated conservatively. The high proportion of C8–T1 injury (6/16, 37.5%) in this series was notable. A large series identified only six C8–T1 injuries among 204 patients (2.9%).[11] The difference can be explained by the referral procedure. Usually, brachial plexus injury is treated in a large specialized center. Most patients are selected and transferred from a local hospital for surgery. Patients with minor brachial plexus injuries do not go to a large center. In contrast, our institute is a prefectural multitrauma center and patients with minor to major trauma are treated daily. Patients with trivial or severe brachial plexus injuries are directly transferred from the scene of the trauma and even patients with trivial brachial plexus injury can visit our institute.

Overall, the frequency of associated injuries including head or thoracic injuries was high.[16] However, no other injuries were present in most cases of C8–T1 paresis. If symptoms are trivial, associated injury may be misdiagnosed as whiplash. In fact, the diagnosis was delayed in some patients with brachial plexus injury. Trivial brachial plexus injury should be carefully assessed at the initial presentation.

II. Treatment

Before surgery for brachial plexus injuries, complete or incomplete loss for each plexus element should be determined. Incomplete loss with spontaneous recovery or very early recovery can usually be conservatively treated. All of our patients with C8–T1 paresis achieved spontaneous useful recovery.

Paralysis with continuous neuroma should be assessed by intraoperative NAP recording. Investigation of the relationship between NAP and neurolysis found that the outcome was good in 150 of 162 patients with intraoperative findings of NAP.[11] NAP is the most important measure of nerve regeneration across the injury site. In our series, all patients with positive NAP achieved good recovery. There is a close correlation between negative NAP recording and neurotmetic lesions.[10,11] The presence or absence of NAP is more important than the amplitude, latency, or velocity. This method is very reliable for determining the type of repairs required in nerve surgery. The presence of NAP indicates neurolysis and absence indicates that recovery will not proceed without resection and repair of the lesions.

Surgical repair includes nerve grafting and neurotization. Direct coaptation is usually impossible after resection of the damaged lesions because of the nerve gap. Continuity should be initially reconstituted by nerve grafting, usually using the sural nerve as the donor nerve. Nerve grafting to reconstruct the biceps muscle has achieved a recovery rate of biceps muscle strength of over MRC G3 in 58% to 74% of C-5 and C-6 musculocutaneous nerve grafting procedures.[9,14,17,22]

Complete root avulsion of the brachial plexus due to traction requires reinnervation of the distal neural stump by neurotization. Neurotization should be applied if no healthy proximal stumps can be coapted. Suitable nerves for this procedure are the intercostal nerve, spinal accessory nerve, supraclavicular nerve, phrenic nerve, desending cervical plexus, anterior rami of the C3–4 nerves, contralateral C-7 root, and pectoralis medialis nerve.[2,3,5,12,19–21,24–26] Intercostal-musculocutaneous neurotization is one of the more common procedures used to reconstruct arm function. The third to fifth intercostal nerves can provide biceps muscle strength of MRC G3 and greater in 50% to 74% of patients.[6,15,23] The spinal accessory nerve is sometimes used to restore biceps function, but is usually used to reconstruct shoulder function when the intercostal nerve is applied to restoring biceps function. Spinal accessory-suprascapular neurotization has achieved good outcome of over MRC G3 in 80% of patients.[24] Clinical studies have established little difference in effectiveness between nerve grafting and neurotization based on outcomes.[19,23,24] Outcome was good in 54% of 53 patients treated by neurotization.[18,19]

Nerve grafting in 520 patients with traumatic brachial plexus injuries of whom 350 underwent various types of surgery resulted in a good outcome for 82% and a fair or poor recovery for 18%, whereas neurotization resulted in 69% and 31%, respectively. In our series, outcome was good in four of five patients (80%) treated by neurorrhaphy. Nerve grafting achieved better outcomes than neurotization. Nerve grafting for sharp injury at early surgery required short interposition (2 to 3 cm) but neurotization demanded longer grafts (5 to 6 cm) at delayed surgery. The relationship between outcome and graft length is controversial. Short nerve grafts may provide better results than long grafts,[7] but no correlation was found between the graft length and outcome.[8] In our series, the difference of outcome between nerve grafting and neurotization was attributed to the graft length. In addition, the pathology may affect the outcome. Nerve grafting was used to treat cut wounds and lacerations in which the nerve gap was relatively short with excellent results. These types of injuries respond more favorably than the stretch injury.

Brachial plexus injury is very rare in neurosurgical practice, so many neurosurgeons have never experienced this injury. However, if trauma patients are examined thoroughly, the incidence may be much higher. The management of brachial plexus injury presents a great challenge to neurosurgeons and constructive surgeons. We believe that surgical outcome can be improved if the optimal repair procedure is selected for brachial plexus injuries.

References

1) Barnes R: Traction injuries of the brachial plexus in adults. *J Bone Joint Surg Br* 31: 10–16, 1949
2) Brandt KE, Mackinnon SE: A technique for maximizing biceps recovery in brachial plexus reconstruction. *J Hand Surg* [*Am*] 18: 726–733, 1993
3) Chuang DCC, Yeh MC, Wei FC: Intercostal nerve transfer of the musculocutaneous nerve in avulsed brachial plexus injuries: Evaluation of 66 patients. *J Hand Surg* [*Am*] 17: 822–828, 1992
4) Clancy WG, Brand RL, Bergfield JA: Upper trunk brachial plexus injuries in contact sports. *Am J Sports Med* 5: 209–216, 1977
5) Doi K, Sakai K, Kuwata N, Ihara K, Kawai S: Reconstruction of finger and elbow function after complete avulsion of the brachial plexus. *J Hand Surg* [*Am*] 16: 796–803, 1991
6) Friedman AH, Nunley JA, Goldner RD: Nerve transposition for the restoration of elbow flexion following brachial plexus avulsion injuries. *J Neurosurg* 72: 59–64, 1990
7) Hentz VR, Narakas A: The results of microneurosurgical reconstruction in complete brachial plexus palsy: Assessing outcome and predicting results. *Orthop Clin North Am* 19: 107–114, 1988
8) Junttila T, Rechardt L, Cao Y, Hokfelt T, Pelto-Huikko M: Distribution of acidic fibroblast growth factor-like immunoreactivity in rat skeletal muscle fibers. *Brain Res* 707: 81–87, 1996
9) Kanaya F, Gonzalez M, Park CM, Kutz JE, Kleinert HE, Tsai TM: Improvement in motor function after brachial plexus surgery. *J Hand Surg* [*Am*] 15: 30–36, 1990
10) Kline DG: Surgical repair of peripheral nerve injury. *Muscle Nerve* 13: 843–852, 1990
11) Kline DG, Hudson AR: *Nerve Injuries: Operative Results from Major Nerve Injuries, Entrapments, and Tumors*. Philadelphia, WB Saunders, 1995, 611 pp
12) Krakauer JD, Wood MB: Intercostal nerve transfer for brachial plexopathy. *J Hand Surg* [*Am*] 19: 829–835, 1994
13) Mackinnon SE, Dellon AL: *Surgery of the Peripheral Nerve*. New York, Thieme Medical Publishers, 1988, 638 pp
14) Malessy MJ, van Duinen SG, Feirabend HK, Thomeer RT: Correlation between histopathological findings in C-5 and C-6 nerve stumps and motor recovery following nerve grafting for repair of brachial plexus injury. *J Neurosurg* 91: 636–644, 1999
15) Malessy MJA, Thomeer RTWH: Evaluation of intercostal to musculocutaneous nerve transfer in reconstructive brachial plexus surgery. *J Neurosurg* 88: 266–271, 1998
16) Midha R: Epidemiology of brachial plexus injuries in a multitrauma population. *Neurosurgery* 40: 1182–1189, 1997
17) Nagano A, Tsuyama N, Hara T: Brachial plexus injuries. Prognosis of postganglionic lesions. *Arch Orthop Trauma Surg* 102: 172–178, 1984
18) Narakas A: Surgical treatment of traction injuries of the brachial plexus. *Clin Orthop* 133: 71–90, 1978
19) Narakas A, Hentz VR: Neurotization in brachial plexus injuries. Indication and results. *Clin Orthop* 237: 43–56, 1988
20) Ogino T, Naito T: Intercostal nerve crossing to restore elbow flexion and sensibility of the hand for a root avulsion type of brachial plexus injury. *Microsurgery* 16: 571–577, 1995
21) Samardzic M, Grujicic D, Antunovic V: Nerve transfer in brachial plexus traction injuries. *J Neurosurg* 76: 191–197, 1992
22) Samii M, Carvalho GA, Nikkhah G, Penkert G: Surgical reconstruction of the musculocutaneous nerve in traumatic brachial plexus injuries. *J Neurosurg* 87: 881–886, 1997
23) Songcharoen P: Brachial plexus injury in Thailand: a report of 520 cases. *Microsurgery* 16: 35–39, 1995
24) Songcharoen P, Mahaisavariya B, Chotigavanich C: Spinal accessory neurotization for restoration of elbow flexion and avulsion injuries of the brachial plexus. *J Hand Surg* 21: 387–390, 1996
25) Tuttle H: Exposure of the brachial plexus with nerve transplantation. *JAMA* 61: 51, 1913
26) Waikakul S, Orapin S, Vanadurongwan V: Clinical results of contralateral C7 root neurotization to the median nerve in brachial plexus injuries with total root avulsions. *J Hand Surg* [*Br*] 24: 556–560, 1999

Address reprint requests to: T. Matsuyama, M.D., Department of Emergency and Critical Care Medicine, Nara Medical University, 840 Shijo-cho, Kashihara, Nara 634-8522, Japan.
e-mail: tmatsuya@nmu-gw.naramed-u.ac.jp.

Commentary on this paper appears on the next page.

Commentary

Brachial plexus injuries now are not common. Clearly in wartime conflicts, we certainly saw more of them, as I did taking care of soldiers in the Viet Nam era in the late 1960's. It was at that time, a fellow resident Doctor David Kline, got very much interested in this. He, along with Doctor Allen Hudson, continue to be our leading experts in the United States on these problems. Their book, ref. 11 of this article, is still essential if you are going to take care of these kinds of patients. In this article on 16 patients, Doctor Matsuyama et al. have done an excellent job. They clearly show that the patients with a paresis (without total paralysis) which can be treated conservatively, and do show spontaneous recovery and tend to do well. However, some patients require neurolysis and grafting. This is challenging surgery, and they have done a good job in delineating those patients as well as helping them. As pointed out in their article, each of these cases has to be individualized. Many of them are associated with other injuries, especially cerebral injuries, so it is often some time before the patient is fully cooperative so that you have a complete understanding of what may or may not be damaged. Stretch injuries tend to still predominate in this problem. If avulsion of the roots is present, then some kind of grafting from functional roots is required. All I can do is congratulate the authors on doing a good job for this challenging group of patients.

Thomas B. Ducker, M.D., F.A.C.S.
Department of Neurosurgery
Johns Hopkins University
Annapolis, Maryland, U.S.A.