Brachial plexus injury: factors affecting functional outcome in spinal accessory nerve transfer for the restoration of elbow flexion

AMIR SAMIL, M.D., PH.D., GUSTAVO ADOLPHO CARVALHO, M.D., PH.D., AND MADJID SAMIL, M.D., PH.D.

Department of Neurosurgery, Nordstadt Medical Center, Klinikum Hannover; Department of Neurosurgery, Medical School Hannover; and Department of Neurosurgery, International Neuroscience Institute, Hannover, Germany

Object. Between 1994 and 1998, 44 nerve transfers were performed using a graft between a branch of the accessory nerve and musculocutaneous nerve to restore the flexion of the arm in patients with traumatic brachial plexus injuries. A retrospective study was conducted, including statistical evaluation of the following pre- and intraoperative parameters in 39 patients: 1) time interval between injury and surgery; and 2) length of the nerve graft used to connect the accessory and musculocutaneous nerves.

Methods. The postoperative follow-up interval ranged from 23 to 84 months, with a mean ± standard deviation of 36 ± 13 months. Reinnervation of the biceps muscle was achieved in 72% of the patients. Reinnervation of the musculocutaneous nerve was demonstrated in 86% of the patients who had undergone surgery within the first 6 months after injury, in 65% of the patients who had undergone surgery between 7 and 12 months after injury, and in only 50% of the patients who had undergone surgery 12 months after injury. A statistical comparison of the different preoperative time intervals (0–6 months compared with 7–12 months) showed a significantly better outcome in patients treated with early surgery (p < 0.05). An analysis of the impact of the length of the interposed nerve grafts revealed a statistically significant better outcome in patients with grafts 12 cm or shorter compared with that in patients with grafts longer than 12 cm (p < 0.005).

Conclusions. Together, these results demonstrated that outcome in patients who undergo accessory to musculocutaneous nerve neurotization for restoration of elbow flexion following brachial plexus injury is greatly dependent on the time interval between trauma and surgery and on the length of the nerve graft used.

KEY WORDS • brachial plexus • nerve graft • accessory nerve • elbow flexion

Brachial plexus injuries usually result in a severe permanent handicap. These injuries represent a surgical challenge because of the complex anatomy of the brachial plexus, which is usually complicated by trauma-induced changes. Although it is well established that supra- and infraventricular lesions can be treated successfully by direct anatomical nerve reconstruction, root avulsions represent a much more puzzling problem, because direct reconstruction is impossible. In such cases, different types of nerve transfers can be performed to regain important basic functions like elbow flexion and upper-arm abduction. In 1963 Seddon39 was the first pioneer to perform a nerve transfer for the restoration of elbow flexion by grafting one intercostal nerve to the musculocutaneous nerve. The principle of this technique opened a whole new avenue of reconstructive surgery in patients with root avulsions following traumatic brachial plexus injuries. Elbow flexion in patients with complete brachial plexus lesions is usually the first priority in reconstruction by nerve transfer and can be accomplished using the following nerves as axon donors: accessory nerve, motor branches of the cervical plexus, intercostal nerves, phrenic nerve, hypoglossus nerve, and root C-7 of the contralateral side.4,6,8,10,15,21,27,32,38,42,43 Between 1993 and 2000, 324 patients with brachial plexus lesions were surgically treated in our department. Within this group between 1994 and 1998, 44 nerve transfers were performed using a branch of the accessory nerve grafted to the musculocutaneous nerve to regain elbow flexion following brachial plexus injuries with root avulsions. In the present study the long-term surgical outcome, with special attention to the impact of the time interval between incurring the lesion and undergoing surgery as well as the length of the nerve graft between accessory and musculocutaneous nerves, has been analyzed.

Clinical Material and Methods

Between 1994 and 1998, 44 patients with brachial plexus injuries underwent a nerve transfer between a branch of the accessory nerve and the musculocutaneous nerve through a sural graft. The basic principle of this procedure is illustrated schematically in Fig. 1. All patients underwent primarily conservative treatment and were then referred to our department because of incomplete or absent recovery of brachial plexus injuries. Neurological examination at admission demonstrated complete brachial plexus injury in 26 cases, complete upper plexus injury in 11 cases, and incomplete upper plexus injury in seven cases. Patient age ranged from 6 to 48 years, with a mean age (± standard devia-

Abbreviation used in this paper: MRC = Medical Research Council.
For the innervation of the trapezius muscle (TM). Note that in completing the nerve transfer, a distal branch of the accessory nerve is used to spare as many branches as possible for the innervation of the trapezius muscle (TM). Solid thick line represents the lateral fascicle of the brachial plexus (proximally) and distal median nerve; solid thin line indicates the accessory nerve, with its course from the sternocleidomastoid muscle (SCM) to the TM; dotted line denotes the musculocutaneous nerve; and dashed line represents the sural nerve graft. BM = biceps muscle.

Fig. 1. Schematic drawing illustrating the principle of an accessory to musculocutaneous nerve transfer by using a sural nerve graft. Note that in completing the nerve transfer, a distal branch of the accessory nerve is used to spare as many branches as possible for the innervation of the trapezius muscle (TM). Solid thick line represents the lateral fascicle of the brachial plexus (proximally) and distal median nerve; solid thin line indicates the accessory nerve, with its course from the sternocleidomastoid muscle (SCM) to the TM; dotted line denotes the musculocutaneous nerve; and dashed line represents the sural nerve graft. BM = biceps muscle.

In 30 cases (68%) one sural graft was used between the accessory branch and musculocutaneous nerve, and in 14 cases (32%) two grafts were necessary to match the diameter of the proximal and distal nerves. None of the patients suffered from any surgical complication.

Postoperative long-term follow up in the present study was completed between 23 and 87 months after surgery, with a mean time of 36 ± 13 months. Of the 44 patients, five were lost during the follow-up period. Evaluation of the recuperation of biceps muscle strength was performed according to the MRC scale for muscle power grading (British system): M0, no contraction; M1, flicker or trace contraction; M2, active movement with gravity eliminated; M3, active movement against gravity; M4, active movement against resistance; and M5, normal strength.

Statistical Analysis

The following statistical tests were performed: 1) mean, maximum, and minimum values; and 2) analysis of variance with the Fisher protected least significant difference post hoc test. A probability value less than 0.05 was considered significant. To detect the main factors that could influence postoperative surgical results, the following parameters were analyzed: 1) time interval between injury and surgery; and 2) length of nerve grafts. Furthermore, the time interval between the brachial plexus injury and surgery was divided into three main groups: Group I, time interval from 0 to 6 months after injury (14 patients); Group II, time interval from 7 to 12 months after injury (23 patients); and Group III, time interval longer than 12 months after injury (two patients). The number of patients in Group III was too few to be included in any statistical analyses and therefore data from these patients were not considered for further analysis. For the statistical evaluation of the impact of time interval on final surgical outcome, data from all patients who received sural grafts longer than 12 cm were not included to limit the possible influence of the graft’s length on analysis. Patients were then divided into two groups based on the length of the sural grafts used in the surgical procedure: that is, those with grafts 12 cm or shorter and those with grafts longer than 12 cm. To control the impact of the preoperative time interval during the statistical analysis of graft length, patients from Groups I and II (preoperative time interval 0–6 months and 7–12 months, respectively) were evaluated separately.

Results

Overall reinnervation (Grades M1–M5) of the biceps muscle, despite the preoperative time interval and length of the sural grafts, was demonstrated in 28 patients (72%) with a mean postoperative follow up of 36 ± 13 months (range 1.9–7.25 years). Functional reinnervation (Grades M3–M5) at the time of the last follow up was achieved in 20 patients (51.3%). Nine of these patients had Grade M3 and 11 had Grade M4, whereas none scored Grade M5.

Preoperative Time Interval

In Group I (preoperative time interval 0–6 months, 14 patients), 12 patients (86%) showed some reinnervation (Grades M1–M5) of the biceps muscle. Functional reinnervation (Grades M3–M5) was present in 10 patients (71%).
In Group II (preoperative time interval 7–12 months, 23 patients), some reinnervation was exhibited in 15 patients (65%), and functional reinnervation was achieved in only 10 patients (43%). Group III consisted of only two patients, one of whom showed some reinnervation (Grade M2) of the biceps muscle and the other of whom did not (Grade M0; Fig. 2).

The average power strength of the biceps muscle in patients in Groups I and II, according to the MRC scale of muscle power grading, is shown in Fig. 3. A statistical comparison of Groups I and II revealed that patients who had undergone nerve grafting within a preoperative time interval of less than 6 months (Group I) have a significantly better final outcome than patients who had undergone surgery from 7 to 12 months (Group II; p < 0.05). Furthermore, nine patients (82%) in Group I with grafts 12 cm or shorter demonstrated functional recovery (Grades M3–M5) of the biceps muscle, with an average strength of 3.3 according to the MRC scale (Fig. 4).

Length of Nerve Grafts

Grafting between the spinal accessory nerve and the musculocutaneous nerve was performed using a sural nerve graft with a mean overall length of 11.5 ± 4.1 cm. In patients in Groups I and II, the average graft length was 11.8 ± 5.7 cm and 11.2 ± 2.8 cm, respectively. There was no significant difference regarding the graft length in both groups (p = 0.34). Statistical analysis of patients with short nerve grafts (≤ 12 cm) compared with patients with long nerve grafts (> 12 cm) was completed separately for both Groups I and II, to avoid the influence of the preoperative time interval. There was a significantly better outcome in patients with shorter nerve grafts in both groups (p < 0.005), as shown in Fig. 5. Reinnervation of the biceps muscle on long-term follow up was demonstrated in 100% and 83.3% of patients with grafts 12 cm or shorter and in only 33.3% and 16.7% in patients with grafts longer than 12 cm in Groups I and II, respectively.

Discussion

Most traumatic injuries of the brachial plexus result from motorcycle or car accidents, leading mainly to two different mechanisms and types of traumatic brachial plexus lesions. One is direct injury to the nervous structures (for example, by clavicular fracture) and the other is the traction-induced avulsion of one or more cervical nerve roots from the spinal cord. In cases of complete cervical root avulsions, surgical management is based on nerve transfers (neurotization) for the most important nerves of the brachial plexus through intercostal, accessory, or phrenic nerves.

There is a wide consensus revealed in the literature that reconstruction of elbow function and stabilization of the shoulder are the main surgical objectives in treating traumatic lesions of the brachial plexus. Although many reports regarding the surgical reconstruction of the musculocutaneous nerve (elbow flexion) have been published, researchers in only a few studies have analyzed different factors that influence the final surgical outcome in these young patients. Different preoperative and intraoperative factors like the time interval between brachial plexus injury and surgery, the proximal donor nerve used for the neurotization of the peripheral nerve, the length of the nerve graft, and the surgical technique surely influence the final (functional) surgical outcome. The assembly of a homogeneous group of patients for evaluation of each parameter separately is extremely difficult and can only be achieved in a large series of cases.

In several recent retrospective clinical studies researchers have shown an overall functional recovery of elbow flexion in approximately 64 to 84% of cases after nerve transfers...
with different donor nerves (accessory, phrenic, and intercostal). There are only few reports regarding functional outcome based on various pre- and intraoperative factors, however. In the current study, overall reinnervation of the biceps muscle reached 72% by neurotization of the musculocutaneous nerve with the accessory nerve. Functional reinnervation (Grades M3–M5) occurred in 71% of all patients who had undergone early surgery (preoperative interval of 0–6 months), but in only 43% of all patients who had undergone surgery 7 to 12 months after injury.

Time Interval Between Trauma and Surgery

The time interval between incurring the brachial plexus lesion and surgery is one of the most important factors affecting the final surgical result. During the last few years many authors have advocated early (4–6 months post-injury) surgical exploration of the brachial plexus. Narikes demonstrated in his series that the potentially positive results from reconstruction and nerve transfer of the brachial plexus decline substantially if the surgery is performed 8 to 12 months after injury. Bentolila, et al., have also convincingly demonstrated that a preoperative time interval of shorter than 6 months represents a significant factor with respect to recovery of biceps muscle function. In addition, Millesi stressed the importance of early exploration of the brachial plexus in patients with no sign of spontaneous regeneration and divided the preoperative time

![Fig. 3. Bar graph comparing the different preoperative time intervals and the resulting mean biceps muscle strength (based on the MRC scale). Note the significantly better results (asterisk) in the group of patients who had undergone early surgery (0–6 months after injury) compared with those who had undergone surgery later (7–12 months after injury; p < 0.05).](image1)

![Fig. 4. Bar graph comparing the different preoperative time intervals and the resulting mean biceps muscle strength (MRC scale) in patients in Groups I and II after excluding those who received nerve grafts longer than 12 cm. Note the better outcome in patients in Group I.](image2)
interval into early (3–6 months) and late (6–12 months) phases of direct repair. Probably one of the main factors responsible for the poor results produced by late repair is the progressive degeneration of muscle fibers in the end organ, with formation of fibrosis and scar tissue within the muscle, and distal degeneration of the nerve. Results of histopathological studies demonstrate signs of muscle degeneration as early as 3 to 4 weeks after nerve injury and the complete replacement of muscle fibers by scar tissue by 2 to 3 years. The lack of movement in the affected arm may also cause atrophy of the elbow, hand, and finger joints, leading to a negative impact on the final surgical result after nerve transfer, even in cases of good postoperative muscle reinnervation.

In cases without cervical root avulsion, reinnervation of the biceps muscle following surgical reconstruction of the musculocutaneous nerve through intact cervical roots (C-5 or C-6) has resulted in a significantly worse final outcome, as already reported.

In the current study, a significantly better outcome in elbow flexion after nerve transfer with the accessory nerve occurred in patients treated during the first 6 months after brachial plexus injury.

In fact, 87% of patients treated surgically from 0 to 6 months after brachial plexus lesion achieved some reinnervation of the biceps muscle in comparison with 64% treated 7 to 12 months postinjury. Functional reinnervation (Grades M3–M5) was clearly greater in patients who had undergone early surgery (0–6 months postinjury) compared with the group of patients who had been subjected to surgery 7 to 12 months after injury (that is, 73 compared with 41%, respectively). None of the patients who had undergone surgery 1 year after incurring brachial plexus lesion exhibited functional reinnervation at time of the last follow-up.

**Length of the Nerve Grafts**

Experimental work in the 1970s showed no correlation between the length of the nerve grafts and the final surgical results in the reconstruction of the brachial plexus. Graft vascularization, for example, occurs not only from the proximal nerve donor or distal nerve stump, but even more so from the surrounding tissue. Thus, compared with short grafts, longer grafts will not be associated with more ischemic events. In 1993, however, Chuang et al. in a series of 128 patients demonstrated that functional outcome after nerve transfer for elbow flexion was influenced by graft length in their comparison of grafts 10 cm or shorter with those longer than 10 cm. We have also previously reported an inverse relationship between graft length and functional recovery. In the present study, shorter grafts (<12 cm) have shown a positive impact on the restoration of elbow flexion in nerve transfer from the accessory nerve to the musculocutaneous nerve, compared with longer grafts (>12 cm). Patients treated with nerve grafts shorter than 12 cm showed a significantly higher reinnervation rate compared with patients treated with grafts longer than 12 cm. One underlying reason for this finding may be that the extent of the brachial plexus lesion and therefore the amount of proximal and/or peripheral nerve fibrosis was more extensive in patients who required nerve grafts longer than 12 cm.

Regarding the microsurgical technique used for nerve transfer in brachial plexus lesions, experimental and clinical studies have demonstrated that outcome is strongly affected by the surgical technique. A poor coaptation and tension at the nerve union site will stimulate the proliferation of scar tissue and further development of fibrosis and granulomas at that location, which may impair the regeneration of growing axons.

**Conclusions**

Data from this clinical study demonstrate that the outcome after nerve transfer of spinal accessory nerve to the musculocutaneous nerve for restoration of elbow flexion in
brachial plexus injury is very satisfactory and significantly influenced by the time interval between brachial plexus injury and surgery and by the length of the nerve graft.

In summary, accessory to musculocutaneous nerve transfer following brachial plexus injury may result in the best functional outcome when surgery is performed during the first 6 months following injury and the surgeons use a short (≤12 cm) sural nerve graft.

References