Surgical interventions for traumatic lesions of the brachial plexus: a retrospective study of 134 cases

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Object. Surgical therapy for traumatic brachial plexus lesions is still a great challenge in the field of peripheral nerve surgery. The aim of this study was to present the results of different surgical interventions in patients with this lesion type.

Methods. One hundred thirty-four patients with traumatic brachial plexus lesions underwent surgery between January 1991 and September 1999. In more than 50% of the patients, injury was caused by a motorbike accident. Patients underwent surgery an average of 6.3 months posttrauma. The following surgical techniques were applied: neurolysis for nerve lesions in continuity (27 cases), grafting for lesions in discontinuity (149 cases), and neurotization for root avulsions (67 cases). Sixty-five patients were evaluated for at least 30 months (mean follow-up 42.1 months) after surgery.

Function was graded using the Louisiana State University Health Sciences Center classification system. Only 2% of the patients had Grade 3 or better function preoperatively, increasing to 52% postoperatively. The effect of surgical measures on the functional results for different muscles were compared (supra- or infraspinatus, deltoïd, biceps, and triceps muscles); the best results were obtained for biceps muscle function (57% of patients with Medical Research Council Grades M3–M5 function). Graft reconstruction yielded a better outcome than neurotization. Surgery within 5 months posttrauma clearly resulted in improved recovery of motor function compared with later interventions. Sural nerve grafts (monofascicular nerves) showed better results.

Conclusions. The results of neurosurgical interventions for brachial plexus lesions are satisfactory, especially when the operation is performed between 3 and 6 months after trauma.

Key Words • brachial plexus injury • motor deficit • surgical management

The treatment of traction or stretch injury to the brachial plexus has changed in the last four decades. Prior to 1970, conservative therapy including intensive physiotherapy was generally recommended. Surgical exploration and repair of brachial plexus injuries were not performed because of poor results. After Millesi and Narayana and Hudson and Tranmer obtained good results using microsurgical techniques, a more aggressive approach was generally followed.

Later, Kline and Judice and Hudson and Tranmer revealed support for surgical treatment through intraoperative electrophysiological investigations. Nevertheless, brachial plexus surgery in patients with severe motor deficits of the arm remains a great challenge for peripheral nerve surgeons.

Brachial plexus lesions mostly are a mixture of nerve injuries due to traction and stretch. Although it is difficult to define the severity of nerve injuries, there are different established grading systems used for this purpose. The first classification system was established by Seddon and included neurapraxia, axonotmesis, and neurotmesis. This system was then extended by Sunderland into five subgroups. In turn, Millesi, et al. supplemented this system by adding a grading scale for the fibrosis type, with special reference to the procedure that must be performed for each lesion type.

Lesions of the brachial plexus can be found at any level. We distinguish affected root and lesions of trunks in the supraclavicular region from lesions of cords and terminal branches in the infraclavicular/retroclavicular area. It is very important to determine the exact location of the lesion.

Patients with lesions of the brachial plexus must undergo an exact clinical examination to determine muscle strength according to the MRC scheme and the LSUHSC system, sensory deficit, presence of Horner syndrome (as an indicator for proximal lesions of the C-8 and T-1 roots), and character of pain. Associated injuries must also be documented. Additionally, specific investigations such as computerized tomography or myelography are essential to detect root avulsions and pseudomeningocele formations. Sometimes we see an indication for a diagnostic intradural revision to rule out root avulsion. Many patients with root avulsion suffer from deafferentation pain. If medical treatment fails to relieve this kind of pain, dorsal root entry zone lesioning can be performed during the same session as the root inspection. Rath, et al. reported pain reduction surpassing 75% in 61.5% of patients and between 25 and 75% in 15.4% of patients. Electromyography can be used to demonstrate muscle denervation 2 to 3 weeks after total nerve transection. Sensory nerve conduction velocity measurements can be helpful to differentiate pre- and postganglionic lesions.
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The first step in therapy for brachial plexus stretch injury is to observe the patient and await spontaneous recovery. The patient must be followed up regularly on a clinical and electrophysiological basis. During this period it is important for the patient to receive intensive physiotherapy. Several months are required for reinnervation to become apparent. It is important to note, however, that prolonged follow up also has its risks, as muscular atrophy may develop. In general, most surgeons recommend intervention between 3 and 6 months after trauma, if there is no sign of reinnervation. This strategy contrasts with the recommended management for sharp lacerating injuries, which should be explored acutely and repaired by end-to-end anastomoses within the first 72 hours.

Several surgical techniques can be used to treat brachial plexus lesions: external and internal neurolysis for nerve lesions in continuity with regenerative NAPs, autologous grafting for the interruption of continuity or for nerve lesions in continuity with the absence of regenerative NAPs, and nerve transfer for root avulsions. To optimize the results of surgery, all possible techniques must be considered and adapted individually, depending on the findings of detailed preoperative studies and intraoperative electrophysiological monitoring.16

The aim of this report is to present the results of an extended series of brachial plexus operations such as internal and external neurolysis as well as autologous grafting and neurotization with different donor nerves, alone or in combination. The effect of different parameters (the timing of surgery, the quality and length of the nerve graft, and the use of different donor nerves for neurotization) on the functional results will also be discussed.

Clinical Material and Methods

Patient Population

In our department we undertook surgery in 134 patients with traumatic brachial plexus lesions between January 1991 and September 1999. The patient population was mostly referred from within Germany, but also from other countries, including 12 patients from Bosnia-Herzegovina. The mean age of the patients was 26.8 years, with a range from 4 to 65 years. As many as 86.6% of all patients were 35 years old or younger at the time of surgery.

One hundred twelve brachial plexus lesions were complete within the supra- and infracavicular sections. Eighteen lesions were exclusively at the supraclavicular level and four were confined to the infracavicular level. The lesions were caused by traffic accidents in 109 cases, involving a motorcycle in 68, a car in 19, a moped in 12, a bicycle in eight, and pedestrians in two. Other causes included falls from 4 to 65 years. As many as 86.6% of all patients were 35 years old or younger at the time of surgery.

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Preoperative Diagnostic Methods

The pre- and postoperative motor function of each muscle was graded using the MRC muscle power grading scale from M0 (no contraction palpable) to M5 (full range of motion with maximum force). The LSUHSC grading system was also used to score neural function. Several scales are available to grade important motor functions individualized for different nerves and different anatomical levels. The scales used are presented in Table 1. A Grade 3 or better was defined as “good motor function.”

Radiological investigations included x-ray films of the neck, shoulders, and chest (inspiration and expiration) to check the function of the phrenic nerve. Cervical myelography followed by computerized tomography scanning (1 mm, C3–T1), the gold standard in detecting ventral/dorsal or complete root avulsions, was performed in all cases. In

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**TABLE 1**

The LSUHSC grading system for brachial plexus lesions*

<table>
<thead>
<tr>
<th>Grade</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>0</td>
<td>No function in C5–6 or upper trunk distribution</td>
</tr>
<tr>
<td>1</td>
<td>Some supraspinatus muscle contraction, trace of biceps/brachialis against gravity or more force, biceps/brachialis or brachioradialis muscle contracts against mod resistance, infraspinatus muscle may or may not contract</td>
</tr>
<tr>
<td>2</td>
<td>Supraspinatus muscle contraction, trace of deltoid muscle against gravity &amp; at least mild resistance, biceps/brachialis or brachioradialis muscle contracts against gravity &amp; some resistance, triceps muscle contracts against gravity &amp; some resistance, trace of triceps muscle</td>
</tr>
<tr>
<td>3</td>
<td>Supraspinatus muscle contraction, deltoid muscle contracts against gravity &amp; some resistance, trace or better contraction of triceps muscle</td>
</tr>
<tr>
<td>4</td>
<td>Supraspinatus muscle contraction, deltoid muscle contracts against gravity or better; biceps/brachialis or brachioradialis muscle contracts against gravity &amp; at least mod resistance; triceps muscle contracts against gravity &amp; some resistance; some recovery of supination; infraspinatus muscle may or may not contract</td>
</tr>
<tr>
<td>5</td>
<td>Good recovery of supraspinatus muscle function, deltoid muscle contracts against gravity &amp; at least mild resistance, biceps/brachialis, or brachioradialis muscle contract against great resistance, some recovery of supination, infraspinatus muscle may or may not contract</td>
</tr>
</tbody>
</table>

* Mod = moderate.
most cases magnetic resonance imaging studies of the cervical spine were also obtained. Intradural revision was deemed necessary in 32 patients (23.9%). During this intervention, eight of these patients underwent dorsal root entry zone lesioning for severe deafferentation pain. Preoperative EMG examinations were performed in 109 patients (81.3%).

Surgical Techniques

A combined supra- and infraclavicular approach was used in the majority of cases. An intraoperative electrophysiological investigation was performed in 85 patients prior to 1996 and in every patient since that time. Nerve lesions in continuity were directly stimulated, both proximal and distal to the lesion. Electrically evoked NAPs were recorded using steel electrodes (Fig. 1). Impulses of 0.2 msecs in duration and supramaximal strength were used (Viking III/IV; Nicolet, Madison, WI), and bandpass filters were set at 2 Hz and 5 KHz. If axonotmetic lesions in regeneration could thus be detected, the surgical procedure was restricted to neurolysis. If no NAP response was detected, accompanied by neuromatous changes of the nerve, we saw an indication for resection and grafting. End-to-end epineural repair was performed or, if this procedure was not possible, repair by nerve grafts was indicated (Fig. 2). The sural nerve was most often used for this purpose. The following techniques were used: neurolysis alone (27 cases), nerve grafting (149 cases), and neurotization (67 cases). Subgroups are described more exactly in Table 2.

Interpositioned grafts were most frequently used for cord-to-cord anastomoses and suprascapular, musculocutaneous, axillary, and radial nerve reconstructions. Between one and four plexus elements were grafted in 62 patients. Twenty patients underwent neurotizations, almost half of which consisted of accessory nerve transfers to the musculocutaneous and suprascapular nerves. Twenty-five patients were treated with a combination of grafting and neurotization. Twenty-seven patients were treated with external/internal neurolysis alone. Table 3 details the techniques used.

The following nerves were used for nerve grafts: sural nerve (88 grafts), lateral cutaneous antebrachii nerve (15 grafts), brachial plexus (six grafts), and ulnar nerve (14 grafts). The graft length ranged from 2 to 20 cm; in most cases, however, the graft was between 5 and 8 cm in length.

Postoperative Care

The affected upper extremity was immobilized in a sling for 3 weeks to preserve the nerve sutures. This process was followed by intense physiotherapy, beginning with pendular exercises. Follow up was completed on an outpatient basis and consisted of a clinical neurological examination to determine functional status as well as regular EMG studies.
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Long-term data were available in 65 patients. The minimal follow-up period was 30 months, with a mean follow up of 42 months.

**Results**

Sixty-five patients were followed up for at least 30 months. The neural function of several muscle groups in all of these patients was graded pre- and postoperatively, according to the LSUHSC grading system. Preoperative grading was as follows: Grade 0, 43 patients; Grade 1, 14; Grade 2, seven; Grade 3, one; and Grades 4 and 5, none. Postoperative grades were quite different: Grade 0, five patients; Grade 1, nine; Grade 2, 17; Grade 3, 23; Grade 4, seven; and Grade 5, four. Grade 3 or better corresponds to satisfactory or good neural function. Only 2% of patients had neural function grades of between 3 and 5 preoperatively, whereas 52% of the patients reached these grades after surgery (Fig. 3).

To allow statements about improvements in sensory function, every patient was categorized in one of four groups: intact sensory function (two patients), good improvement in sensory deficits after surgery (26 patients), minimal improvement in sensory deficits after surgery (16 patients), and unchanged sensory function (21 patients). Improvement in sensory function was achieved in 68% of cases as a result of surgical treatment (Fig. 4).

The degrees of improvement in function were different in

![Fig. 3. Bar graph depicting pre- and postoperative LSUHSC grades in 65 patients with a minimal follow up of 30 months.](image)
supra- and infraspinatus, deltoid, biceps, and triceps muscles and were graded according to the MRC scale from M0 to M5. We regarded a Grade M3 or better as functional improvement. A grade of M1 or M2 implied that at least a positive effect had been achieved, although not enough for the patients to profit from surgical treatment. The best results were associated with interventions in biceps muscle function. Postoperatively, 57% of all interventions were graded M3 to M5 compared with 32% of supra- and infraspinatus muscle interventions, 24% of deltoid muscle interventions, and 35% of triceps muscle interventions. A comparison between nerve grafting and neurotizations revealed that transplantations led to better results in all cases with respect to motor function, especially in the supra- and infraspinatus and biceps muscles (Table 4).

Intraoperative recording of NAPs could reduce the indication for more invasive procedures such as nerve grafting: 22% of the monitored patients underwent only neurolysis, compared with 16% of nonmonitored patients. Overall results were better as well: 60% of the monitored patients had an LSUHSC Grade 3 or better and only 39% of the nonmonitored patients did so. Thus, intraoperative monitoring is indispensable in brachial plexus operations. Since 1996 every patient has been monitored.

The time interval between experiencing a trauma and surgical intervention had a major effect on outcome. Interventions that took place in the 6 months after trauma clearly gave better results: 75% of the patients (24 of 32) who had undergone surgery within the 5 months after trauma had an LSUHSC Grade 3 or better postoperatively. Only 32% of the patients (11 of 34) who had undergone surgery less than or equal to 6 months after the initial trauma had an LSUHSC Grade 3 or better.

The type of graft used also appeared to be important. Patients who had received a sural graft during surgery to restore biceps muscle function experienced better results; 62% of patients (26 of 42) with a sural nerve graft exhibited a motor function of Grade M3 or better postoperatively. On the other hand, only 38% of patients (three of eight) with ulnar grafts had Grade M3 or better.

We investigated the influence of nerve graft length by comparing the LSUHSC grade in patients with grafts longer than 6 cm and those with grafts 6 cm or shorter (Table 5). Only interventions on the deltoid and biceps muscles showed a difference: 25% (deltoid muscle) and 67% (biceps muscle) of patients with nerve grafts of 6 cm or shorter recovered postoperatively to Grades 3 to 5, compared with 12% (deltoid muscle) and 52% (biceps muscle) of patients with the longer grafts.

### Table 4

<table>
<thead>
<tr>
<th>Muscle Graft</th>
<th>No. of All Interventions</th>
<th>No. of Grafting</th>
<th>No. of Neurotizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>supraspinatus</td>
<td>38</td>
<td>12 (32) of 38</td>
<td>5 (45) of 11</td>
</tr>
<tr>
<td>infraspinatus</td>
<td>37</td>
<td>9 (24) of 37</td>
<td>5 (21) of 24</td>
</tr>
<tr>
<td>deltoid</td>
<td>9 (24) of 37</td>
<td>5 (21) of 24</td>
<td>1 (11) of 9</td>
</tr>
<tr>
<td>biceps</td>
<td>51</td>
<td>29 (57) of 51</td>
<td>23 (67) of 43</td>
</tr>
<tr>
<td>triceps</td>
<td>20</td>
<td>7 (35) of 20</td>
<td>6 (38) of 16</td>
</tr>
</tbody>
</table>

* Motor function Grades M3 to M5 are based on the MRC scale.

### Discussion

#### Time of Operation

After injury to the brachial plexus most patients suffer from loss of function. It is generally accepted that spontaneous recovery should be awaited before surgery is considered. It could be shown, for example, that two thirds of patients with stretch injury and dysfunction confined to the C-5 and C-6 nerve roots will recover biceps muscle function. Some authors nevertheless favor an aggressive approach as early as possible, even with replantation of avulsed roots.

After a baseline evaluation of a patient’s clinical and electrophysiological status, follow-up examinations are required. During this time, physiotherapy is essential to prevent contractures. Two weeks after trauma, EMG studies can show signs of denervation as reduced insertional activity or spontaneous firing, followed by electrical signs of reinnervation. The optimal time to decide for or against surgery has been the subject of much controversy: the period between incurring the trauma and the time of operation has varied from 1 to 6 months.

Long denervation leads to degenerative changes such as shrinkage and deformation of muscle fibers, atrophy of muscle end plates and spindles, and replacement of fat and fibrous tissue. In the present series, waiting periods longer than 5 months clearly led to worse results in later function. We propose an interval be-
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Among 3 and 6 months after trauma. If there is no clinical or electrophysiological sign of recovery, surgical exploration should not be delayed any longer. We recommend the algorithm in Fig. 5 for this purpose.

External/Internal Neurolysis

External neurolysis is a frequent and widely accepted procedure in peripheral nerve surgery. Results are satisfactory if the causative agents can be removed. If the interval between the onset of symptoms and neurolysis is too long, however, irreversible changes in the target organs can occur and functions will not recover. Complications arise because the nerve remains in a hostile environment after neurolysis. Note, however, that apparently good results following neurolysis can be brought about by spontaneous recovery and could be unrelated to neurolysis.

In our opinion, external neurolysis or nerve repair should be performed according to the local microscopic findings of the nerve and the results of intraoperative electrophysiological monitoring. Kline et al.14 asserted that nerve lesions in continuity with reproducible NAPs must be treated using either external neurolysis if the lesions are not associated with pain or internal neurolysis if severe and neuritic pain is a problem. In contrast, nerve lesions in continuity without recordable NAPs must be resected and repaired. Kim, et al.,12 reported that the nature of the repair depended on the lesion type and the presence or absence of positive NAP recordings. Injuries that result in a lesion in continuity and positive NAP recordings have the most favorable outcomes.12,27

This opinion contradicts Millesi and associates,21 who claimed that spontaneous recovery is hindered by scar tissue in different nerve compartments and had recommended epineurotomy or internal neurolysis. These authors differentiated between the following situations. In the event of simple compression with a certain loss of function but no further reaction of the connective tissue framework, simple decompression is the treatment of choice (Grade I). In the case of compression and/or traction, the necessary passive motion of the nerve is reduced and external neurolysis is indicated (Grades IIa and IIb). Long-distance damage to the gliding tissue requires external neurolysis and transposition (Grade IIc). If the epifascicular epineurium is fibrotic, external neurolysis is recommended (Grade IIIa), as in Sunderland Grades I and II. If the interfascicular epineurium is fibrotic, internal neurolysis can be considered (Grade IIIb) and coincides with Sunderland Grade I, II, or III. If the endoneurium becomes fibrotic, regeneration is unlikely and can be compared with Sunderland Grade III. Millesi and colleagues called this condition Grade IIIc and recommended resection and grafting as the treatment of choice. In the event of the loss of fascicular pattern, resection and grafting are required (Grade IV).21,37

Internal neurolysis has been the cause of continuing controversy. In Seddon’s opinion, internal neurolysis cannot solve the problem of intrafascicular collagenization. He did not see a place for internal neurolysis: the blood supply might be decreased, but fibrous tissue build up might be induced, thus resulting in functional deterioration after initial improvement. Painful neuromas and paresthesia might be additional untoward sequelae. On the other hand, results of internal neurolysis in an experimental rat model have been good, as judged on the basis of morphological and electrophysiological characteristics.19 In a study on the human ulnar nerve, Rath, et al.,31 showed that the risk of inducing a pain syndrome following internal neurolysis is not increased, compared with the risk after external neurolysis.

Graft Quality and Length

In lesions with the loss of continuity, nerve grafting is indicated. Shorter nerve grafts yield better results than longer ones.9 In our study, however, the length of the nerve graft

<table>
<thead>
<tr>
<th>Muscle Graft</th>
<th>LSUHSC Grade (no. of patients)</th>
<th>No. of Patients w/ Grades LSUHSC (no. of patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>supra/infraspi-natus ≤6 cm</td>
<td>25</td>
<td>7</td>
</tr>
<tr>
<td>&gt;6 cm</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td>deltoid ≤6 cm</td>
<td>16</td>
<td>4</td>
</tr>
<tr>
<td>&gt;6 cm</td>
<td>17</td>
<td>11</td>
</tr>
<tr>
<td>biceps ≤6 cm</td>
<td>21</td>
<td>3</td>
</tr>
<tr>
<td>&gt;6 cm</td>
<td>29</td>
<td>6</td>
</tr>
<tr>
<td>triceps ≤6 cm</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>&gt;6 cm</td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>
did not have a convincing effect on the surgical results. Ochiai and colleagues\textsuperscript{23,25} also found no relation between graft length and functional results: even 25-cm long transplants could be restored to a functional grade of better than M3. Vascularized nerve grafts also showed no better results than a free sural nerve, which most surgeons prefer.\textsuperscript{2}

We did find one interesting point, however: neurotization of either the suprascapular nerve or the axillary nerve can be used to achieve shoulder stability. Interventions with the suprascapular nerve demonstrated better results, because often they could be restricted to end-to-end-sutures.

**Neurotization or Nerve Transfer**

In the case of root avulsion, neurotization or nerve transfer is required. Neurotization was first attempted by Le-viant in 1873. Other early attempts at neurotization were described by Tuttle in 1913,\textsuperscript{40} who used intact elements of the cervical plexus. Nerve transfers using the cervical plexus risk the development of an unstable scapula. Brunelli and Monini\textsuperscript{1} demonstrated recovery of shoulder and elbow movement by means of anterior nerves of the cervical plexus. Other surgeons performed a successful bridge-graft co-optation with anterior primary rami of C-3 and C-4 as donor material and the entire upper trunk as recipient matter in three patients with C-5 and C-6 root avulsion.\textsuperscript{42}

Kotani and colleagues\textsuperscript{36} first described the use of intercostal nerves for neurotization of the musculocutaneous nerve in 1973, with one good and one fair result. This experiment was soon followed by many other studies with disparate results. According to Solonen and associates,\textsuperscript{35} useful elbow flexion was regained in three of nine patients; for Chuang, et al.,\textsuperscript{1} in 49 of 66 (third and fourth intercostal nerve); for Narakas and Hentz,\textsuperscript{28} in nine of 24 patients; for Samardzic, et al.,\textsuperscript{32} in three of seven; for Sedel,\textsuperscript{34} in five of 10; for Friedman and coworkers,\textsuperscript{8} in seven of 16 (using vascularized grafts and third to fifth intercostal nerves); and for Nagano, et al.,\textsuperscript{39} in 56 of 64. Intercostal nerves can also function as donor nerves for the axillary nerve.\textsuperscript{16,26}

One point of criticism is the synkinesis of muscle contraction and respiration.\textsuperscript{22,28} It is difficult for patients to control elbow flexion independently of respiration. Moreover, intercostal nerves could not be used in patients with several rib fractures. For these reasons, we preferred the use of the cervical plexus and the accessory nerve as donors.

Authors of many studies have demonstrated good results with accessory nerve transfer to the musculocutaneous nerve.\textsuperscript{11,26,36} For example, 10 of 15 patients regained strength graded M3 or better.\textsuperscript{1} If neurotization of the suprascapular nerve is performed using the spinal accessory nerve, there is a risk of scapular instability, especially if parts of the trapezius muscle are paralyzed by the procedure. Investigators using this method have noted more disappointing results, that is, useful recovery in 36\%\textsuperscript{26} or 50\%\textsuperscript{35} of patients. The phrenic nerve has also been used, with maintenance of good pulmonary function postoperatively.\textsuperscript{28,61}

Other nerves that have been used as donors include the contralateral C-7 root,\textsuperscript{4} the ulnar nerve,\textsuperscript{28} and of course a variety of combinations. Narakas and Hentz\textsuperscript{28} described a combination using the intercostal, long thoracic, and spinal accessory nerves, which was successful in nine of 25 cases. Samardzic and colleagues\textsuperscript{32} analyzed results of nerve transfers to the musculocutaneous and axillary nerves using branches of the plexus, intercostal nerves, and the accessory nerve. The rates of recovery were best when the plexus branches were used (90\% musculocutaneous nerve and 87\% axillary nerve), rather than the accessory nerve (65 and 75\%, respectively) or intercostal nerves (50 and 63\%, respectively).

Many authors are convinced that better results can be achieved through anastomosis to the terminal nerves, such as the musculocutaneous nerve, in contrast to coaptations to further proximally located plexus elements. Neurotization of musculocutaneous nerve with intercostal nerves or the accessory nerve resulted in satisfactory elbow flexion in 64\% of patients (21 of 33).\textsuperscript{18} Songchaoren\textsuperscript{36} reported good results with neurotizations using the accessory nerve, intercostal and phrenic nerves, and plexo-plexal methods.

Independent of the donor nerve used, neurotization of the suprascapular nerve was more effective in obtaining useful shoulder abduction than was neurotization of the axillary nerve.

In agreement with our results, Songchaoren\textsuperscript{36} compared motor function recovery by using different methods and demonstrated better results with grafting (82\%) compared with those obtained using neurotization (69\%).

**Conclusions**

In summary, neurosurgical treatment of traumatic lesions of the brachial plexus rendered satisfactory results, especially operations undertaken between 3 and 5 months after trauma. Preconditions include detailed preoperative clinical, radiological, and electrophysiological examinations. The type, location, and degree of injury are important factors in determining the right procedure. The different surgical techniques such as external neurolysis, nerve grafting, and neurotization must be individually adapted for each patient. Technical advances in microsurgical techniques for nerve grafting and repair combined with intraoperative electrophysiological monitoring have changed the prognosis of brachial plexus injuries considerably in recent years. Intensive postoperative physiotherapy is essential for success.

When neurosurgical intervention is not indicated or its results are poor, function can be restored by tendon transfers, transposition of intact muscles, or arthrodesis.

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