Brachial plexus injuries: outcome following neurotization with intercostal nerve

ALIASGAR VAJHUDDIN MOYADI, M.Ch., BHAGAVATULA INDIRA DEVI, M.Ch., AND K. P. SIVARAMAN NAIR, D.M.

Departments of 1Neurosurgery and 2Psychiatric and Neurological Rehabilitation, National Institute of Mental Health and Neurosciences, Bangalore, India

Object. Brachial plexus root avulsion injuries, which are devastating, usually result from high-speed accidents. Nerve transfer provides hope for successful treatment of this difficult set of injuries. Nevertheless, the controversies regarding indications, techniques, and outcome of the various available surgical procedures continue.

Methods. A retrospective analysis was performed in 51 patients (43 male and eight female patients) with brachial plexus injuries who underwent neurotization at the authors’ institute between 1997 and 2003. Clinical, electrophysiological, and imaging data were used to identify the type and pattern of involvement of the various elements of the plexus. The mean duration of denervation was 6.4 months (range 2–24 months). Outcome was computed in terms of the overall improvement in power of the target muscle as well as the functional usefulness of such recovery.

Results. There were 50 supraclavicular injuries (25 preganglionic, eight postganglionic, and 17 mixed). One patient had an infracavicular (posterior spinal cord) injury. Pan–brachial plexus injury with a flail upper limb was the most common pattern. Overall, 55 nerves were neurotized—33 musculocutaneous, 18 axillary, and two each for ulnar and radial nerves (47 single and four double neurotizizations—by using intercostal nerve donors in the majority of cases. Adequate follow-up data were available in 36 patients (38 nerves) and these were used for the analysis of outcome. Overall, 58.3% of patients had improvement, and of these 62% achieved useful recovery. This accounted for 36% of overall useful recovery. The critical duration of denervation was 5.5 months.

Conclusions. Neurotization for brachial plexus root avulsion injuries is a viable option. Early detection and intervention (within 5.5 months) leads to a better overall recovery. (DOI: 10.3171/JNS-07/08/0308)

Key Words • brachial plexus injury • intercostal nerve • neurotization • outcome analysis • root avulsion

Abbreviations used in this paper: ICN = intercostal nerve; MR = magnetic resonance; ROC = receiver operating characteristic.
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formed. Evaluation consisted of a review of the records of these patients, including the operative notes and investigations. The Medical Research Council (British) system was used to assess the power of the muscle involved. Pain was graded into three categories by using the method of Bruxelle et al.4 Findings on x-ray films of the cervical spine, shoulder, and chest as well as computed tomography myelography or MR imaging (if available) were recorded. Electrophysiological testing was available in all patients preoperatively. This was performed more than 4 weeks after the injury in all cases. Besides evidence of denervation or regeneration, specific features that we looked for to identify root avulsion included paraspinal denervation and the presence of sensory nerve action potentials in anesthetized nerves. Electrophysiological indicators of root avulsion were supplemented with clinical clues (deafferentation pain, Horner syndrome, absent Tinel sign, and weakness of rhomboid and serratus muscles) to diagnose preganglionic injury.

Patient Characteristics

Of the 51 patients who underwent neurotization at our institution between 1997 and 2003, 43 were male and eight were female. Most were between 21 and 40 years of age (Table 1); the mean age was 28.7 years. There were two children younger than 10 years of age.

Inclusion Criteria

The 51 patients included in this study had undergone neurotization based on the following criteria.

Clinical Criteria. These included the following: 1) indicators of avulsion (traction injury, Horner syndrome, rhomboid and paraspinal weakness, and/or absent Tinel sign); and 2) failure of regeneration over a period of 4 to 6 months, even if the trauma was not an avulsion injury.

Electroneuromyography Findings. These included the following: 1) evidence of paraspinal denervation; and 2) normal sensory nerve action potentials in limb nerves in the presence of anesthesia.

Imaging Studies. For a case to be included, there had to be evidence of pseudomeningoceles on neuroimaging studies.

Operative Details

The goal of surgery was to restore elbow flexion and/or shoulder abduction in the patients with upper-trunk (C-5 and C-6) or pan–brachial plexus palsy. All 51 patients in this study underwent neurotization without supraclavicular exploration. Of these, 47 had a single-nerve neurotization (musculocutaneous in 29, axillary in 15, radial in two, and ulnar in one), and three patients had a simultaneous two-nerve neurotization (musculocutaneous plus axillary nerve in two and musculocutaneous plus ulnar in the other). One more patient who had a good outcome with musculocutaneous nerve neurotization subsequently underwent axillary nerve neurotization.

Overall, 55 nerves were neurotized (33 musculocutaneous, 18 axillary, and two each for radial and ulnar). The ICNs were used in 49 patients. These were dissected up to the midaxillary or anterior axillary line as in the standard technique and then tunneled into the axilla to be anasto-

<table>
<thead>
<tr>
<th>Age Group (yrs)</th>
<th>Overall</th>
<th>w/ FU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1–10</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>11–20</td>
<td>9</td>
<td>6</td>
</tr>
<tr>
<td>21–30</td>
<td>21</td>
<td>13</td>
</tr>
<tr>
<td>31–40</td>
<td>14</td>
<td>11</td>
</tr>
<tr>
<td>41–50</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>&gt;50</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>total</td>
<td>51</td>
<td>36</td>
</tr>
</tbody>
</table>

* FU = follow-up.

Statistical Analysis

Statistical analysis was performed using the standard SPSS version 11.0 software. Data were expressed using descriptive statistics, namely the mean, standard deviation,
percentages, and so on. Univariate analysis was performed to ascertain the influence of variables on the outcome (both the overall and functionally useful outcome). The continuous variables (age, duration of denervation, and duration of follow-up) were compared among groups by using the Student independent-sample t-test. The categorical variables (sex, mechanism and mode of injury, and recipient nerve) were analyzed using the chi-square and Fisher exact tests. A probability value of less than 0.05 was considered significant. To find the best prognostic factor after adjusting for the confounding effect of other variables, multiple logistic regression analysis was used. The ROC curve was used to study the critical duration of denervation.

Results

Clinical Profile

Besides weakness, 22 patients reported numbness, and pain was significant in seven. The duration of denervation ranged from 2 to 28 months (mean 6.4 months). None of the patients were seen immediately after the injury; 25 were seen within 6 months, 21 within 1 year, and five patients were seen more than 1 year after the injury. Motor vehicle accidents accounted for 43 (84%) of the 51 injuries. Of the 51 patients, 23 (45%) had an associated major systemic injury, the most common being head injury; 16 had local bone injury, and one also had local vascular injury. Falls and assaults with weapons leading to irregular lacerations accounted for the rest of the brachial plexus injuries. Stretch–contusion (traction) injury occurred in 90% of the patients (Table 2), with open injuries occurring in the remaining five. These five patients had undergone supraclavicular exploration at other institutions before coming to us. Most (43) of the 51 patients had a power of 0/5 in the involved muscle. Eight had partial injuries with varying degrees (Scores 1/5–3/5) of residual power.

In 49 patients x-ray films of the limb involved were available. Sixteen patients had local bone injuries. Fifteen had been evaluated with computed tomography myelography and/or MR imaging; in six of these pseudomeningoceles were detected and in two others neuromas were revealed on MR imaging.

Pattern of Injury

Fifty patients had supraclavicular lesions. Of these, 42 had preganglionic injury (17 of whom had a combined preganglionic and postganglionic injury), and there were eight patients with only postganglionic injury. In addition to the 50 with supraclavicular injuries, one patient had an infraclavicular posterior spinal cord injury. Pan–brachial plexus injury with a flail limb was the most common pattern of involvement. The distribution of the pattern and level of injury for the supraclavicular lesions were as shown in Table 3. None of the patients had electrophysiological evidence of reinnervation prior to the surgical procedure.

Follow-Up Evaluation and Outcome

Demographic Features of the Follow-Up Group. Follow-up data were available in 36 of these patients (38 nerves), and the duration of follow-up ranged from 3 to 75 months (mean 22.3 months, median 17 months). Twenty-two patients had a follow-up duration of more than 1 year. There were 28 males and eight females in whom follow-up data were available; the age distribution in these individuals was as shown in Table 1. The mean age in this group was 28.5 years and the mean duration of denervation was 6.4 months. All but one of these patients had undergone neurotization in which the ICN was used as the donor.

Motor Outcome. Overall, improvement was seen in 21 patients (55.2%). Of these patients, eight had a muscle power of M2 or less, eight had a power of M3, and five had power of M4 or more. Thus, useful recovery (Score ≥ M3) occurred in 13 (62%) of the 21 patients. These represented 36% of the entire group of 36 patients.

The outcome in those with more than a 1-year follow-up duration (22 patients) and in those with less than 1-year follow-up periods (14 patients) are shown in Tables 4 and 5, respectively. With longer follow-up periods it was seen that the rates of useful recovery were better.

The outcome for each of the recipient nerves is shown in Table 6. The recovery and useful recovery rates for the musculocutaneous nerve were 54.5 and 58.3%, respectively, and for the axillary nerve the rates were both 66.7%.

Of the 36 patients available for follow-up review, 35 had ICN donors. Muscle power in the single patient with medialized–musculocutaneous nerve neurotization had improved to 2/5 at 4 months of follow-up. The follow-up data were not available for the patient with a median–musculocutaneous nerve neurotization.

Predictors of Outcome. The influence of various factors (age, sex, mechanism of injury; mode/type of injury, duration of denervation, and recipient nerve) on outcome was assessed using univariate analysis. This was computed between two sets of groups: between the improved (21) and the unchanged (15) patients; and between the useful (13) and the nonuseful (23) recovery groups. In both instances, there was no significant difference in the follow-up duration between the two groups in both the sets.

<table>
<thead>
<tr>
<th>Pattern</th>
<th>C-5 &amp; C-6 Roots</th>
<th>C-7 Roots</th>
<th>C-8–T1 Roots</th>
<th>PBPI</th>
<th>Upper Trunk</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>preganglionic</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>25</td>
</tr>
<tr>
<td>postganglionic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>combined</td>
<td>1</td>
<td>3</td>
<td>0</td>
<td>8</td>
<td>5</td>
<td>17</td>
</tr>
<tr>
<td>total</td>
<td>10</td>
<td>8</td>
<td>1</td>
<td>22</td>
<td>9</td>
<td>50</td>
</tr>
</tbody>
</table>

* One patient had an infraclavicular posterior spinal cord injury. Abbreviation: PBPI = pan–brachial plexus injury.
† Two patients had an additional middle trunk injury.
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### TABLE 4
Outcome in 22 patients with more than 1 year of follow-up

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>unchanged</td>
<td>9 (41)</td>
</tr>
<tr>
<td>improved*</td>
<td>13 (59)</td>
</tr>
<tr>
<td>poor</td>
<td>4</td>
</tr>
<tr>
<td>fair</td>
<td>5</td>
</tr>
<tr>
<td>good</td>
<td>4</td>
</tr>
</tbody>
</table>

* When fair and good outcomes are combined, nine (69%) of 13 patients had a useful recovery.

Multiple logistic regression analysis was performed to adjust for the confounding effect of other variables. It showed that the duration of denervation was the single most important predictor of improvement (p = 0.082). The model predicted the nonimprovement with 80% sensitivity and 71.45% specificity. Nevertheless, no variable was found to be able to predict useful functional recovery.

The ROC curve was used to study the critical denervation time that distinguished overall improvement from nonimprovement. The area under the curve was 0.743 with a standard error of 0.09, which is significant at probability values of 0.014, corresponding to a 5.5-month denervation time. Sensitivity for this value was 80% and specificity was 71.4%, which maximizes both sensitivity and specificity. The same curve was applied to determine the critical denervation time between the functionally improved (useful improvement) and functionally nonimproved groups. Although the same duration of 5.5 months was obtained, it was not significant. The curves are as shown in Fig. 1.

### Discussion

Our experience reflected the pattern of referral to a tertiary neurosurgical care facility. Most patients were referred a long time after the initial injury, some of them after failed surgical attempts had been made elsewhere. Male patients predominated in this study, with most of them in the third and fourth decades of life. The male/female ratio was 5:4:1, with a mean age of 28.7 years, reflecting the high incidence of such injuries in young adult males.\(^6,22,24,25\)

Motor vehicle accidents (85%) were the most common mechanism of injury in our patients. In an epidemiological review in 1997, Midha\(^4\) noted that road accidents account for more than half of such injuries. This has been the case in many other reports.\(^6,22,24,25\) Most of our patients had stretch–contusion (traction) types of injuries necessitating a neurotization procedure. We also had five patients with nontraction injuries. These patients had undergone a supraclavicular exploration in an attempt at reinnervation elsewhere, and when that procedure failed they had been referred to our institution. Neurotization was offered to these as a salvage procedure.

All but one of our patients had a supraclavicular injury. Midha\(^4\) noted that patients with supraclavicular lesions had more severe injuries than those in the infraclavicular group. That could be the reason for our cases being predominantly supraclavicular, assuming that only the more severe injuries were referred to us. The predominant pattern that we encountered was a pan–brachial plexus injury with involvement of all roots. Most of the patients undergoing neurotization (42 of 51) had a preganglionic component of injury, which precluded any other type of reinnervation procedure. Eight patients had a postganglionic injury; of these, three had presented within 6 months postinjury. The injury was an irregular laceration in each of these three cases in which previous local exploration had been attempted elsewhere. The other five had presented more than 6 months postinjury with no evidence of regeneration in the upper trunk innervated muscles. Hence, these eight patients also underwent neurotization, as did the only patient with a partial posterior spinal cord injury, who presented 17 months postinjury after a failed attempt at local nerve repair.

### Outcome After Neurotization

The clinical profile (age, duration of denervation, and mechanism of injury) of the 36 patients available for follow-up evaluation was similar to the entire group of 51 patients. Overall recovery and useful recovery rates for the follow-up group were 55.2 and 62%, respectively. There was no statistically significant difference between the outcomes for the axillary and musculocutaneous nerves.

Comparing these results with other series is very difficult because different authors use different criteria. The complicating factors include heterogeneity of the patient population; variability in the grading systems used to assess the extent and severity of the injuries; differing management strategies, including the indications for surgical intervention; availability of a large number of procedures, with numerous modifications of basic techniques; variability in

### TABLE 5
Outcome in 14 patients with less than 1 year of follow-up

<table>
<thead>
<tr>
<th>Outcome</th>
<th>No. of Patients (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>unchanged</td>
<td>6 (43)</td>
</tr>
<tr>
<td>improved*</td>
<td>8 (57)</td>
</tr>
<tr>
<td>poor</td>
<td>4</td>
</tr>
<tr>
<td>fair</td>
<td>3</td>
</tr>
<tr>
<td>good</td>
<td>1</td>
</tr>
</tbody>
</table>

* When fair and good outcomes are combined, four (50%) of eight patients had a useful recovery.

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over the years, with improvement found that duration of denervation of in their 
J. Neurosurg. / Volume 107 / August, 2007 and proposed direct coaptation of the ICN to the reported overall and useful recovery rates of 50 and to suggest that the supported the also support early repair. They report good re-
Our results showed that overall improvement and use- graft inter-
and Dubuisson and Kline reported signif-
tained. in microsurgical techniques, better results have been ob-
resultant loss of available motor axons. Hence, Narakas 
positioning, achieving 50 and 56.7% recovery rates, re-
ference was noted between supra- and infraclavicular le-
pharmacological interventions. In the former group, no dif-
reporting a 78% rate of good recovery in cases of open bra-
Kline6 found that postganglionic lesions recovered significantly better than preganglionic avulsions. Within the former group, no dif-
ences. These authors also found a positive correlation with 
their severity score (that is, the more severe the injury, the 
our results, except for the quality of recovery for the axil-
nerve, which was significantly higher in our patients. We 
adopted the same intermediate technique of neurotiza-

groups, and therefore we could compare the influence of other variables on the outcome. We also applied the multi-
ple logistic regression model to adjust for the confounding 
effect of other variables.

Pattern and Severity of Injury. Dubuisson and Kline6 re-
ported a 78% rate of good recovery in cases of open bra-
chial plexus injuries and a significantly lower (58%) rate of 
good recovery in closed injuries. Terzis et al.25 found that 

Duration of Denervation. Yamada et al.26 reported sig-
ificantly better outcomes for various coaptation procedures 
done within 6 weeks postinjury. Narakas and Hentz28 and 
Millesi15 also support early repair. They report good re-
sults, however, even with repairs done up to 9 months after 
denervation. Samii et al.29 report improvement with pro-
dcedures done within 7 months of injury. In their series of 204 
patients, Terzis et al.29 found that duration of denervation of 
less than 6 months was important for biceps reinnervation 
and not for other muscles. (Their results, however, were 
expressed not as a percentage of the total number of pa-
tients improved but as a percentage increase of power in 
each muscle reinnervated.) Other authors have found no 
correlation.25 Our results showed that overall improvement 
was better with early surgery, but even with early surgery 
not all patients may achieve a functional recovery. We also 
were able to calculate that the critical duration of denerva-
tion influencing overall improvement was 5.5 months.

Recipient Nerves. Variability in the techniques used does 
not permit an accurate comparison between various targets of 
the neurotization procedure. In general, however, rates 
of recovery for the musculocutaneous and axillary nerves are 
comparable. There is evidence30,31 to suggest that the 
quality of recovery may be better for the musculocutaneous 
nerve. We found that both the overall and the useful recov-
ery were marginally better with the axillary nerve, but this 
difference was not significant across the groups.

Fifteen of our patients were not available for follow-up 
evaluation. Some patients were unable to attend the clinic 
due to socioeconomic problems, and in some the addresses 
provided were incorrect or changed. Moreover, a signif-
ificant number of patients in the early part of the study had 
been referred late following the injury, sometimes after fail-
ure of other reinnervation procedures. In these patients neu-
rotization was therefore offered as a last resort, and the 
improbability of improvement was emphasized preopera-
tively. It is possible that these patients may not have been 
motivated enough to participate in the follow-up review. 
Hence not all patients could be assessed. Some of those 
who were lost to follow-up may have improved. Further-
more, as we have seen in our own results, better outcomes 
are seen in patients whose cases are followed longer. In 
those who had adequate follow-up in our study, the out-
come status was said to have been evaluated on the day 
when the last follow-up review was recorded. Longer fol-
low-up of these patients may yield better outcomes. How-

Fig. 1. Graphs showing the ROC curve for overall (left) and functional (right) improvement. AUC = area under curve.
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ever, limited by the 30% loss of patients to follow-up, the results may be a best-case computation of outcome.

Conclusions

Reinnervation following brachial plexus injuries is very challenging. Neurotization of the musculocutaneous and axillary nerves for reanimation of a flail limb is a viable and useful alternative. Outcomes are better when procedures are done within 6 months of injury. Normalization of function, however, remains a challenge.

References


Address reprint requests to: Bhagavatula Indira Devi, M.Ch., Department of Neurosurgery, National Institute of Mental Health and Neurosciences, Bangalore 560029, India. email: bindira@nimhans.kar.nic.in.