Evaluation of intercostal to musculocutaneous nerve transfer in reconstructive brachial plexus surgery

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Object. Direct coaptation of intercostal nerves (ICNs) to the musculocutaneous (MC) nerve was performed to restore elbow flexion in 25 patients with brachial plexus root avulsions.

Methods. Seventy-five ICNs were transected as close as possible to the sternum to obtain sufficient length and then tunneled to the axilla and coapted to the MC nerve. Direct coaptation was achieved in 95% of ICNs, and functional elbow flexion was regained in 64% of the patients. The results were compared with several reported transfer techniques in which either an ICN or other donor nerves were used.

Conclusions. Direct coaptation was equally effective and more straightforward than transfers involving interposition of grafts. The use of alternative donors such as the accessory nerve carries inherent disadvantages compared with the use of ICNs, and the results are not substantially better. Direct ICN–MC nerve transfer is a valuable reconstructive procedure.

Key Words • nerve transfer • intercostal nerve • brachial plexus

Clinical Material and Methods

Patient Population

The ICN–MC nerve transfer was performed in a consecutive series of 25 adult patients (21 men and four women) with a brachial plexus traction/crush lesion who were followed for at least 2 years postoperatively (mean 931 days ± a standard deviation [SD] of 242.4 days). The nerve transfer was part of an extended brachial plexus reconstruction, including for example an accessory–suprascapular nerve transfer. The mean age of the patients at surgery was 22.1 ± 6.4 years (SD). All 25 patients had sustained their injuries in traffic accidents. A needle electromyographic (EMG) examination was performed prior to surgery. The absence of action potentials during attempts at maximum voluntary effort excluded the possibility of spontaneous recovery. A computerized tomography myelography study was obtained to detect root avulsions. Twenty patients were shown to have total avulsion of roots C-5 and C-6, with some sustaining avulsion of cervical roots C7–T1 as well. Four patients had a ruptured spinal nerve at C-5 combined with avulsion of C-6. Resection of these four C-5 stumps close to the intervertebral foramen showed fibrosis, as assessed by intraoperative frozen-section examination, and they were judged unsuitable for nerve grafting. A nerve grafting procedure from C-5 to reinnervate the biceps would otherwise have been preferred. One patient had axonotmesis of C-5 and avulsion of C6–T1. Three patients had also suffered a lesion of the phrenic nerve.

The right side was affected in 15 patients, and in all
cases it was the dominant side. The left affected side appeared to be dominant in two patients and nondominant in eight. The mean interval between trauma and referral to our outpatient department was 52.4 days (median 41 ± 45.6 days [SD]). The mean interval between trauma and operation was 100.6 days (median 75 ± 58.2 days [SD]).

The force exerted by the biceps muscle was assessed according to the Medical Research Council (MRC) scale. In evaluating the active elbow flexion, the function of the brachioradial muscle as well as a possible Steindler effect from lower arm muscles were taken into account. Repeated postoperative needle EMG studies of the biceps muscle were performed in all patients. Reinnervation of the biceps muscle was documented by EMG responses with characteristic features.

Operative Technique for ICN–MC Nerve Transfer

In all cases, the entire trajectory of the brachial plexus was exposed and root avulsions were confirmed by the emptiness of the intervertebral foramen. The third through the fifth ICNs were dissected free by means of an undulating, lateral skin incision, starting at the inferior border of the major pectoral muscle, continuing beneath the nipple (or breast in women) and extending medially up to the costosternal junction (Fig. 1A). The inferior part of the major pectoral muscle was shifted upward, sometimes necessitating partial cutting of its sternal insertion. The main branch of the ICN was identified halfway through its course at the bone groove of the lower costal border and dissected free over its entire anterior course (Fig. 1B). Motor responses were assessed by using electrical nerve stimulation. If feasible, sensory branches were identified by their course toward the skin and left intact after they had been dissected interfascicularly from the main nerve. The ICNs were then transected as close as possible to the sternum to obtain sufficient length for direct coaptation to the MC nerve and were tunnelled to the axilla. The infraclavicular and intercostal wounds remained separated from each other by an area of intact skin at the anterior axilla, facilitating later wound closure. In women, if the anatomical localization of sensory innervation to the nipple was uncertain, the third ICN was left untouched to preserve this important area of sensibility at least partially. In the latter cases, the sixth ICN was taken instead. The MC nerve was cut as proximally as possible after freeing it of the major pectoral muscle, continuing beneath the nipple (or breast in women) and extending medially up to the costosternal junction (Fig. 1A). The inferior part of the major pectoral muscle was shifted upward, sometimes necessitating partial cutting of its sternal insertion. The main branch of the ICN was identified halfway through its course at the bone groove of the lower costal border and dissected free over its entire anterior course (Fig. 1B). Motor responses were assessed by using electrical nerve stimulation. If feasible, sensory branches were identified by their course toward the skin and left intact after they had been dissected interfascicularly from the main nerve. The ICNs were then transected as close as possible to the sternum to obtain sufficient length for direct coaptation to the MC nerve and were tunnelled to the axilla. The infraclavicular and intercostal wounds remained separated from each other by an area of intact skin at the anterior axilla, facilitating later wound closure. In women, if the anatomical localization of sensory innervation to the nipple was uncertain, the third ICN was left untouched to preserve this important area of sensibility at least partially. In the latter cases, the sixth ICN was taken instead. The MC nerve was cut as proximally as possible after freeing it
from the lateral cord until fascicular intermingling was encountered (Fig. 1C). A concomitant rupture of the MC nerve at the entrance to the biceps muscle was excluded by means of visual inspection. No attempt was made to identify the motor branches within the MC nerve. Before coaptation, the patient’s arm was abducted 90° and proximal and distal stump fascicles were carefully trimmed. The ICNs were coapted to the centrally located MC nerve fascicles by means of 10-0 sutures and/or fibrin glue (Fig. 1D).

**Statistical Analysis**

The statistical analysis was performed using a linear regression model. The dependent variable (outcome) was the “biceps force.” The model was used to analyze the simultaneous association of the following factors: “age on day of operation,” “interval between trauma and operation,” and “affected side.” All statistical tests were performed within the framework of these linear regression models, testing the significance of the association of each independent variable with the outcome, and always adjusting for possible confounding effects of the other independent variables. The significance level of 0.05 was applied.

**Results**

Three ICNs were transferred in 21 patients, two in two patients, and four in two patients. In 71 (95%) of 75 ICNs direct coaptation to the MC nerve was achieved. In four patients, direct coaptation of one of three ICNs to the MC nerve did not succeed because it was anatomically too short; the other two ICNs could be directly connected. In-nerve did not succeed because it was anatomically too proximal and distal stump fascicles were carefully trimmed. The ICNs were coapted to the centrally located MC nerve fascicles by means of 10-0 sutures and/or fibrin glue (Fig. 1D).

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>No. of Cases</th>
<th>MRC Grade ≥3 (%)</th>
<th>Mean Age (yrs)</th>
<th>Mean Interval (mos)†</th>
<th>No. of ICNs Transferred</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minami &amp; Ishii, 1987</td>
<td>17</td>
<td>17 (100)</td>
<td>23</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Kawai, et al., 1988</td>
<td>24</td>
<td>17 (71)</td>
<td>22</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Friedman, et al., 1990</td>
<td>14</td>
<td>7 (50)</td>
<td>22</td>
<td>7</td>
<td>2 or 3</td>
</tr>
<tr>
<td>Chuang, et al., 1992</td>
<td>66</td>
<td>49 (74)</td>
<td>27</td>
<td>4</td>
<td>2 or 3</td>
</tr>
<tr>
<td>Nagano, et al., 1992</td>
<td>64</td>
<td>56 (88)</td>
<td>21</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Songcharoen, 1995</td>
<td>17</td>
<td>11 (65)</td>
<td>23</td>
<td>NR</td>
<td>2</td>
</tr>
</tbody>
</table>

* NR = not reported.
† Mean interval between trauma and operation.

The brachioradial muscle was paralytic in all patients and subsequent spontaneous recovery did not occur.

In the statistical analysis, the relation between biceps force and age of the patient, interval between injury and operation, and handedness was analyzed. None of those factors seemed to show a significant association with the biceps force (Table 3).

**Postoperative Complications**

There were no peri- or postoperative deaths and no significant morbidity. Three patients developed restricted pneumothorax as a result of parietal pleural lesions. These resolved in a few days with no intervention. Regardless of diaphragm function, no patient displayed clinical symptoms of pulmonary function impairment, and no patient was jeopardized neurologically by the surgical intervention.

**Discussion**

Direct coaptation of ICNs to neurotize the MC nerve is one of the technical options for treating biceps muscle paralysis resulting from brachial plexus root avulsions. In this series, direct coaptation, usually of a total of three ICNs to an MC nerve, succeeded in the vast majority of cases (95%), although some authors claim that this is rarely feasible from a technical point of view. Elbow flexion selectively exerted by the biceps muscle and rated MRC Grades 3 and 4 was obtained in 8% and 56% of patients, respectively. Sensory deprivation of the nipple was prevented by the sparing of either a major sensory branch or the entire third ICN. No clinical symptoms of pulmonary function impairment were observed even in the presence of homolateral diaphragm paralysis.

Prior to 1978, the entire course of the brachial plexus was not routinely explored by every surgeon treating biceps muscle paralysis. Reported surgical results may not be reliable because spontaneous recovery of elbow flexors may have occurred. We traced six reports comprising a total of 202 patients in whom direct ICN–MC nerve coaptation was performed (Table 1). According to these reports, successful results, that is, elbow flexion to MRC 3 or more, have been achieved in between 50% and 100% of cases. Comparison of the results is hampered by differences in composition of the patient populations. Surgical experience with the technique may account at least in part for the wide variation in results. However, in our series, the first half of the patients treated fared just as well as the second. Furthermore, a 100% score seems extremely high in view of the large discrepancy in the number of fibers; three ICNs contain approximately half the number of fibers of the MC nerve.

Different factors have to be taken into account when judging the pros and cons of the various ICN transfer techniques. Direct coaptation causes loss of outgrowing axons at only one coaptation site, whereas this occurs at two sites with graft interposition. Direct coaptation can be achieved if the donor nerve is sufficiently long. Intercostal nerves transected parasternally meet this requirement, but contain fewer motor axons than ICNs obtained proximally. On the other hand, a proximally transected acceptor yields greater length than a distally transected one, but because of dis-
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persian, there is more of a chance that axons will not arrive at the biceps muscle in the former case than in the latter.

Coaptation of ICNs to spinal nerves or the superior trunk, either directly or by means of short grafts, did not result in useful elbow flexion.26,33 This technique has, therefore, been abandoned. In the series reported by Kline and Hudson,26 57% of the patients attained a useful level of elbow flexion after paravertebral sectioning of three or four ICNs and coaptation to the MC nerve by means of interposed sural grafts. Another technique was proposed by Millesi:25 the ICNs are cut in the midaxillary line and grafts are interposed to the acceptor site. The acceptor site has changed twice in a period of 20 years. Initially, the MC nerve was chosen, and 10 (53%) of 19 patients attained a functional result. Later, both biceps and triceps muscles were neurotized. After triceps reinervation, tendon transfer of this muscle was performed and 75% of patients attained functional elbow flexion. Although comparison of results between these techniques26,25 and direct ICN–MC nerve coaptation is hardly warranted because of the small number of cases per series and differences in patient characteristics, the results do not differ greatly. An advantage of the ICN–MC nerve coaptation technique is its relative simplicity.

Some technical adjustments have been proposed to improve the results. The ICN can be dissected in continuity with the accompanying intercostal artery and vein to maintain the nerve’s vascular supply. Although a high success rate has been demonstrated in dogs treated with the vascularized ICN–MC nerve transfer,41 this technique did not improve the results in humans.25 The value of transposing an entire bundle of intercostal nerves, arteries, veins, and muscles seems questionable.44 The number of ICNs transferred may also play a role. In the series reported by Chuang et al.,11 the results did not differ significantly when the use of two or three ICNs was compared. Although the use of only two ICNs does not exclude a good result, as also shown by one of our cases, we agree with these authors in favoring the transfer of three ICNs. Selective coaptation to the motor branches of the MC nerve can be performed to prevent misrouting of motor axons toward the lateral antebrachial cutaneous nerve.25 However, because direct coaptation is not possible using this technique, the graft interposition required probably nullifies any advantage. Another method dealing with the mixed composition of the MC nerve is redirection of the lateral antebrachial cutaneous nerve into the biceps muscle, called neuromuscular neurotization.7 In our series, the suture technique proposed by Ochiai et al.32 for nerves of unequal diameter was not used. We more or less selectively coapted to the central part of the MC nerve, which is reported to be motoric.14 The value of these and other refinements in the technique is difficult to assess. In our opinion, gentle handling of the thin ICN is a prerequisite for recovery of function. In our patients, 40 to 80% of the cross-sectional area of the MC nerve could be covered by three ICNs.

Apart from the ICN, a variety of extraplexal nerves has been used to neurotize the MC nerve (Table 2).3,5,7,12,16,17,19,29,31,34,38,45 These techniques are not irrefutably superior to the ICN–MC nerve transfer. The results in 216 patients who underwent an accessory–MC nerve transfer with graft interposition have been reported.3,5,19,35,36 In the series reported by Songcharoen38 (by far the largest), elbow flexion of MRC Grade 3 or more was achieved in 75% of cases, whereas results obtained in the smaller series were the same or worse.3,5,19,35 The appeal of this technique is that the donor nerve lies in the same surgical area as the brachial plexus, obviating additional exposures.24 A disadvantage is that transfer of the suprascapular nerve cannot be accomplished. In one series, a phrenic–MC nerve transfer was performed and 80% of patients attained a biceps muscle force of MRC Grade 3 or more.15 This technique inevitably results in diaphragm paralysis. Results of a transfer of trapezius and levator scapulae muscle branches of C-3 and C-4 to the MC nerve by means of graft interposition8 were poor at best in 84% of cases.29 Bridge–graft coaptation of the entire anterior primary rami C-3 and C-4 to the upper trunk in all three cases yielded MRC grades of 3 or more.45 The value of this technique seems promising but lacks a solid basis until reports of larger series with comparable results become available. Following C-7 nerve root transfer from the contralateral healthy side to the MC nerve, two patients attained a biceps muscle force of MRC Grade 4.17 The impact of this type of transfer on function on the healthy side must be established with more certainty before application is warranted.10,18 This is particularly true in severe brachial plexus injuries, because these patients are fully dependent on their healthy arm. It has been reported that severance of C-7 causes no notable functional damage.13 In two cases of surgically documented selective sharp transection of the C-7 spinal nerve (not included in the present series), we observed clinically normal function of the upper limb, although its overall strength was definitely impaired in both cases.

Obviously, in upper nerve root avulsions, intraplexal nerve transfers can only be applied if the function of C-7, C-8, and T-1 is maintained. Direct coaptation of one or two fascicles of the ulnar nerve (± 10% of the cross-sectional area) to the MC nerve yielded a biceps force of

<table>
<thead>
<tr>
<th>Authors &amp; Year</th>
<th>Donor Nerve*</th>
<th>No. of Cases</th>
<th>MRC Grade ≥3 (%)</th>
</tr>
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<tbody>
<tr>
<td>Samardzic et al., 1986</td>
<td>pectoral</td>
<td>2</td>
<td>1 (50)</td>
</tr>
<tr>
<td>Allieu &amp; Cenac, 1988</td>
<td>thoracodorsal</td>
<td>10</td>
<td>3 (30)</td>
</tr>
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<td>Kawai et al., 1988</td>
<td>CN XI</td>
<td>18</td>
<td>3 (17)</td>
</tr>
<tr>
<td>Dai et al., 1990</td>
<td>thoracodorsal</td>
<td>1</td>
<td>1 (100)</td>
</tr>
<tr>
<td>Gu et al., 1990</td>
<td>phrenic</td>
<td>40</td>
<td>32 (80)</td>
</tr>
<tr>
<td>Samardzic et al., 1990</td>
<td>CN XI</td>
<td>6</td>
<td>3 (50)</td>
</tr>
<tr>
<td>Yamada et al., 1991</td>
<td>C-3 &amp; C-4†</td>
<td>3</td>
<td>3 (100)</td>
</tr>
<tr>
<td>Gu et al., 1992</td>
<td>healthy C-7</td>
<td>2</td>
<td>66</td>
</tr>
<tr>
<td>Brandt &amp; Mackinmon, 1993</td>
<td>pectoral</td>
<td>5</td>
<td>4 (80)</td>
</tr>
<tr>
<td>Oberlin et al., 1994</td>
<td>ulnar</td>
<td>9</td>
<td>6 (66)</td>
</tr>
<tr>
<td>Bonnard &amp; Narakas, 1995</td>
<td>CN XI</td>
<td>4</td>
<td>3 (75)</td>
</tr>
<tr>
<td>Songcharoen, 1995</td>
<td>CN XI</td>
<td>182</td>
<td>136 (75)</td>
</tr>
</tbody>
</table>

* CN XI = accessory nerve, graft interposition; healthy C-7 = C-7 from contralateral healthy side, graft interposition; pectoral = medial pectoral nerve.
† C-3 & C-4 = deep motor branches of C-3 & C-4, graft interposition.
‡ C-3 & C-4 = entire anterior primary rami of C-3 & C-4, graft interposition.
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MRC Grade 3 or more in 66% of patients. The recovery of useful function within 1 year postoperatively is one of the advantages of this technique. Ulnar deficit at the hand was not observed, but remains a risk of this procedure. Biceps muscle function recovered to MRC Grade 3 or more in 71% of cases after direct coaptation of the medial pectoral nerve to the MC nerve. We disapprove of the use of the medial pectoral nerve as a donor, because denervation of the lower part of the pectoral major muscle jeopardizes the important thoracobrachial grip. Transfer of the thoracodorsal to the MC nerve resulted in a biceps force of MRC Grade 3 or more in all cases. The drawback of this method is the denervation of the latissimus dorsi muscle, which becomes unsuitable for a tendon transfer (for example, to restore exorotation).

In our series, the extent of recovery in older patients could not be distinguished statistically from that in younger patients (Table 3), which is in accordance with other reports. The length of the interval between trauma and operation (mean 100 ± 58.2 days [SD]), also did not correlate significantly with results (Table 3). We can rule out with a 95% probability that a clinically substantial difference of 50 days will result in an actual difference of more than 0.5 points in MRC grading. This difference can hardly be considered of practical clinical importance. Others report intervals ranging from 3 months to 5 months after which results decline, unfortunately without any statistical foundation. In the series of Minami and Ishii, patients with excellent results had experienced a delay of 20 weeks; those with good results, a delay of 30 weeks, suggesting a positive effect of a shorter time between injury and surgery. Akasaka et al. used the factor “interval” in their treatment strategy. In their series, results were good or fair in 50% of cases when the ICN–MC nerve transfer was performed within 6 months postinjury. The result became progressively worse as time increased past 6 months.

Therefore, in cases in which surgery was delayed for more than 6 months, these investigators opted for free muscle transfer reinnervated by the ICN. This procedure yielded elbow flexion of MRC Grade 3 in 72% of cases. There was no significant relationship between surgical outcomes and affected side: patients affected on the left or right side recovered equally well (Table 3). The biceps muscle in normal subjects is more strongly represented in the right hemisphere. However, it is not known whether this difference in side also implies a different potential for plasticity between hemispheres. This might be of interest because cortical plastic changes occur following transfer.

In one patient with root avulsions, successful results have been reported for repair by direct insertion of the ventral roots into the spinal cord. In our opinion, however, the efficacy of this innovative technique has not yet been documented convincingly. The outcome of ongoing experiments in animal models must be evaluated before application in humans can be justified. This is even more important, because the risk of lesioning long tracts in the hemiatrophied spinal cord may be considerable; 10% of patients experience permanent sequelae after dorsal root entry zone coagulation.

### TABLE 3

<table>
<thead>
<tr>
<th>Factor</th>
<th>Estimated Effect</th>
<th>95% Confidence Interval</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (yrs)</td>
<td>−0.04</td>
<td>−0.15 to 0.07</td>
<td>0.47</td>
</tr>
<tr>
<td>injury–op interval (days)</td>
<td>0</td>
<td>−0.01 to 0.01</td>
<td>0.86</td>
</tr>
<tr>
<td>handedness</td>
<td>0.12</td>
<td>−1.14 to 1.38</td>
<td>0.85</td>
</tr>
</tbody>
</table>

* Regression coefficient (estimated difference in biceps force between two individuals who are equal with regard to all other factors and differ by 1 U on the factor itself). None of the factors appeared to show a significant association with the biceps force.

### Conclusions

With the ICN–MC nerve transfer, functional elbow flexion can be obtained in the majority of cases. Contrary to results with other donor nerves, the use of the ICN does not entail drawbacks of any importance. The ICN–MC nerve transfer with direct coaptation is a straightforward and relatively simple procedure to cope with the devastating consequences of root avulsions.

### References


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J. Neurosurg. / Volume 88 / February, 1998
Intercostal to musculocutaneous nerve transfer


Manuscript received March 7, 1997.
Accepted in final form September 8, 1997.
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