THE ROLE OF SOMATOSENSORY EVOKED POTENTIALS AND NERVE CONDUCTION STUDIES IN THE SURGICAL MANAGEMENT OF BRACHIAL PLEXUS INJURIES

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In 15 patients who underwent open exploration of the brachial plexus, the somatosensory evoked potentials and nerve action potentials recorded at the time of operation were useful as guides to the most appropriate surgical procedure, and also in predicting the outcome in certain lesions. In three patients the apparent normality of the upper trunk of the plexus was concealing a more proximal lesion which was irrecoverable. The presence of a somatosensory evoked potential showed functional continuity in three patients in whom the C7 root was clinically involved and who recovered after operation. In five patients proximal stumps of ruptured C5 roots showed functional central continuity; this indicated their suitability for grafting. These patients recovered except one who suffered from co-existing disease. The electrophysiological studies also confirmed the clinical diagnosis of avulsion of the C8 and T1 roots and therefore prevented unnecessary dissection.

Surgical repair of traction lesions of the brachial plexus produces poor results. However, the lack of success may be partly due to incorrect diagnosis of the lesion. Surgical investigation for intraspinal lesions can be misleading since only the apparent continuity of the plexus is analysed unless extensive laminecтомy is undertaken. There may also be a more distal co-existing lesion in the limb, which can only be revealed by extensive exploration. Electrophysiological tests help delineate the damage in the plexus before operation (Bonney and Gilliatt 1958; Zalis, Oester and Rodriguez 1970; Zvěřina and Kredba 1977; Jones 1979). These tests can also be misleading when there is a double lesion since all the investigations show the more distal site of injury. Normal sensory conduction in an anaesthetic area indicates a lesion proximal to the posterior root ganglia. If an additional double lesion exists conduction will be absent, suggesting a distal lesion.

In the past, very little attention has been paid to electrophysiological tests during operations for brachial plexus injuries. We have investigated the use of recordings of intra-operative somatosensory evoked potentials over the scalp and nerve action potentials using direct nerve stimulation and recording at a more-distal point over the nerve. Recordings of somatosensory evoked potentials at operation confirm that the nerve stumps are centrally connected and consequently amenable to grafting.

CLINICAL MATERIAL AND METHODS

Between January 1977 and December 1978 120 patients with injuries to the brachial plexus were seen in the peripheral nerve injuries clinic at the Royal National Orthopaedic Hospital under the care of Mr Donal Brooks. Twenty-nine were considered for exploration of the plexus which was carried out on 17 patients aged between 14 and 25 years and on one six-year-old girl. Three of these 18 patients were excluded because of incomplete intra-operative recordings caused by technical failure. The results for the remaining 15 patients who presented between 2 and 17 months (average eight months) after injury, were reviewed.

The plexus was explored by making an S-shaped incision extending from the mastoid process to the junction of the medial and middle thirds of the clavicle, then laterally along the clavicle to the line of the deltopectoral groove and then distally. Care was taken to maintain haemostasis, using bipolar coagulation to avoid interference with the conduction volume during the electrophysiological studies.

Nerve action potentials were made by direct stimulation during the operation (Fig. 1) using a standard Medelec stimulating electrode. Recordings were made with a similar electrode placed at 90 degrees to the long axis of the nerve (R1) to obtain a monopolar response. The action potentials were displayed on an oscilloscope (Medelec S6). The somatosensory evoked potential was obtained by direct stimulation of the root and recorded using a silver-silver chloride disc electrode placed over the contralateral parietal lobe on the midline 12 centimetres above the nasion (R1). The evoked potential was amplified from 32.0 hertz to 1.6 kilohertz and displayed on an

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oscilloscope, after averaging up to 128 responses, at one or two hertz using an averager module with 256 sample points spaced over the first 30 milliseconds after the stimulus. Biopsies of the resected nerves or roots were taken and sent for routine histological analysis.

RESULTS
This study was confined to the surgical implications of electrophysiological studies performed at the time of operation and correlated with the clinical findings and subsequent recovery of the patient. A comparison between the pre-operative sensory action potential, the electromyogram, and the intra-operative somatosensory evoked potentials will be reported elsewhere.

From the results shown in Table I it can be seen that the patients fall into four main groups: Group I (Patients 1 to 7). Lesions involved all the nerve roots (C5–T1), but with partial obvious avulsion. This group was the most severely affected. The somatosensory evoked potential was useful to determine if the C5 root was centrally connected and consequently suitable for grafting. The C5 root was found to be suitable for grafting in Patients 1, 2, 3, 6 and 7.

In spite of the presence of somatosensory evoked potentials in Patient 1 there was no recovery 12 months later. This may have been caused by a mild intraspinal lesion indicated by the increased latency of the somatosensory evoked potential. The patient also had neurofibromatosis which affected the histological character of the sural nerve used for grafting. The somatosensory evoked potential was present in Patient 2 which indicated a good proximal stump. However, the length of the graft needed would not have been feasible and 11 months had elapsed from the time of injury. The musculocutaneous nerve and median nerve were neurotised with intercostal nerves and the intercostobrachial nerve. Similar results were found with Patient 3 who was re-neurotised, but the good C5 stump was anastomosed to the suprascapular nerve which resulted in a good clinical recovery.

A good somatosensory evoked potential was demonstrated in Patient 7 and subsequently the C5 stump was grafted to the musculocutaneous nerve and the median nerve neurotised with intercostal grafts. In Patient 5, the C5 root was in pseudo-continuity, although the somatosensory evoked potential was absent. Histological evidence of this root later showed that the somatosensory evoked potential correctly predicted the absence of nerve bundles. This stump was not used in the operation and the musculocutaneous nerve was re-neurotised with four intercostal nerves.

The absence of the somatosensory evoked potential in C8 and T1 in the presence of a nerve action potential of the median and ulnar nerves provided evidence of a preganglionic lesion and hence valuable dissection time was saved in Patients 1 and 3. An attempt was made to provide some sensation to the hand with Patients 2 and 3, where C8 and T1 were avulsed. The median nerve was separated into three main fascicles and using distal stimulation the two fascicles with the largest potentials were selected and anastomosed to the intercostobrachial nerve. Group II (Patients 10 to 12). The upper trunk was in apparent continuity and normal to the naked eye. In this group, the electrophysiological tests were extremely helpful in demonstrating proximal lesions in the nerve roots which would not recover spontaneously. In Patient 10, the pre-operative investigations were conflicting. The myelogram showed a meningocele at C5, and the Tinel sign was absent (Landi and Copeland 1979) but electromyography showed signs of re-innervation of the biceps. The patient was explored, and the somatosensory evoked potential found to be absent for C5, C6 and C7, so the upper trunk was neurotised with the accessory nerve. Biopsies of these roots showed only scar tissue on the proximal part. The distal biopsies revealed a few myelinated fibres in the upper trunk, but these fibres could have come from any of the surrounding tissues. This could explain why the re-innervation potentials disappeared after operation.

In Patient 12, the upper trunk appeared normal, but the somatosensory evoked potential of both nerve roots were absent whereas the nerve action potentials of the musculocutaneous nerve were of a high amplitude. This
<table>
<thead>
<tr>
<th>Patient</th>
<th>Surgical findings</th>
<th>Somatosensory evoked potentials</th>
<th>Nerve action potentials</th>
<th>Procedure</th>
<th>Recovery</th>
<th>Follow-up (months)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Amplitude (µV)</td>
<td>Latency (msecs)</td>
<td>Nerve tested</td>
<td>Amplitude (µV)</td>
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<td>C5 Rupture</td>
<td>-0.3</td>
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<td>Musculocutaneous</td>
<td>25</td>
<td>C5 grafted to musculocutaneous nerve</td>
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<tr>
<td></td>
<td>C6 Avulsed</td>
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<td></td>
<td>Median</td>
<td>10</td>
<td>Median nerve neuritised with intercostal nerves</td>
</tr>
<tr>
<td></td>
<td>C7 Avulsed</td>
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<tr>
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<tr>
<td></td>
<td>T1 Avulsed</td>
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<tr>
<td>2</td>
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<tr>
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<td>10</td>
<td>C5 grafted to suprascapular nerve</td>
</tr>
<tr>
<td></td>
<td>C6 Avulsed</td>
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<td>Median</td>
<td>30</td>
<td>Musculocutaneous nerve neuritised with intercostal nerves</td>
</tr>
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<td>4</td>
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<td>Absent</td>
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<td>5</td>
<td>C5 Pseudo-continuity</td>
<td>Absent</td>
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<td>Clinical recovery in musculocutaneous nerve and T1</td>
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<td>T1 In continuity</td>
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<tr>
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<td></td>
<td>Median Ulnar</td>
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</tr>
<tr>
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<tr>
<td>7</td>
<td>C5 Ruptured</td>
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<td>None in median nerve</td>
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<tr>
<td></td>
<td>C7 Pseudo-continuity</td>
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</tr>
<tr>
<td></td>
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<td></td>
<td></td>
<td>Absent</td>
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<tr>
<td></td>
<td>T1 Not explored</td>
<td></td>
<td></td>
<td>Absent</td>
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</tr>
</tbody>
</table>
| 8 | C5 Ruptured  
   C6 Ruptured  
   C7 Continuity  
   C8 Not explored  
   T1 Not explored | C5 graft to primary trunk  
   Clinical recovery in C5 and C7 | 17 |
|---|---|---|
| 9 | C5 Ruptured  
   C6 Ruptured  
   C7 Scarred  
   C8 Normal  
   T1 Not explored | −0.5  
   −0.5  
   Absent  
   −0.4 | 11.5  
   11.5  
   10.5 | Primary trunk graft to lateral cord  
   Clinical recovery in C5 and C6 | 9 |
| 10 | C5 Pseudo-continuity  
   C6 Pseudo-continuity  
   C7 Normal  
   C8 Normal  
   T1 Normal | Absent  
   Absent  
   Absent  
   −0.5  
   −0.5 | 12.0  
   13.0 | Musculocutaneous  
   Accessory nerve neurotised to musculocutaneous nerve  
   Too early to be assessed | 2 |
| 11 | C5 Apparently normal  
   C6 Apparently normal  
   C7 Avulsed  
   C8 Not explored  
   T1 Not explored | Absent  
   Absent  
   Absent  | Radial  
   Present†  
   Present† | Accessory nerve neurotised to musculocutaneous nerve in a second operation  
   Median nerve re-neurotised with intercostal nerves at first operation  
   Clinical recovery | 7 |
| 12 | C5 Apparent continuity  
   C6 Apparent continuity  
   C7 Apparent continuity  
   C8 Apparent continuity  
   T1 Not explored | Absent  
   Absent  
   Absent  
   0.8  
   0.6 | 10.0  
   9.0 | Musculocutaneous  
   50  
   None | None  
   None | None | 11 |
| 13 | C5 Normal but kinked suprascapular nerve  
   C6 Normal  
   C7 Normal  
   C8 Normal  
   T1 Normal | In suprascapular nerve, small but present | Neurolysis of suprascapular nerve at suprascapular notch  
   Full clinical recovery | 10 |
| 14 | C5 Infraclavicular lesion  
   C6 in continuity of musculocutaneous nerve and posterior cord  
   C7 musculocutaneous nerve  
   C8 Normal  
   T1 Normal | −0.5  
   −0.8 | 11.0  
   10.0 | Musculocutaneous  
   (potential across lesion)  
   Present† | Neurolysis of posterior cord and musculocutaneous nerve  
   Clinical recovery in posterior cord | 1 |
| 15 | C5 Musculocutaneous  
   C6 nerve ruptured  
   C7 Radial nerve in continuity  
   C8 Median nerve ruptured  
   T1 Ulnar nerve one fascicle in continuity | Musculocutaneous  
   Radial  
   Medial cord | Absent  
   Present†  
   Absent | Musculocutaneous nerve graft to lateral cord  
   Radial nerve epineurotomy  
   Median nerve grafted | Recovering median and radial nerve | 5 |

NA = Not available for follow-up.
* Where no results are given the potential was not tested.
† Variable but unmeasurable potential.
demonstrated an intramedullary avulsion of the rootlets with a good preservation of the ganglia.

**Group III** (Patients 8 and 9). Partial lesions of the upper and middle trunks occurred in this group and the somatosensory evoked potential helped to predict the eventual recovery of undivided roots in continuity. In Patient 9, the absence of the somatosensory evoked potential in C7 whilst in continuity predicted that there would be no clinical recovery in this root. In both Patients 8 and 9, the presence of the somatosensory evoked potential in roots C5 and C6 showed it was possible for these roots to be grafted. Both patients showed signs of recovery.

**Group IV** (Patients 13 to 15). Infraclavicular lesions occurred in these patients. The presence or absence of somatosensory evoked potentials below the lesion, and nerve action potentials through the lesion, enabled us to predict the eventual results of the operation.

Patient 13 had a lesion of the upper trunk, but at presentation he had partially recovered and regained full elbow flexion, although there was no abduction or lateral rotation at the shoulder. We suspected an isolated lesion of the suprascapular nerve. Exploration was performed with the aim of re-neurotising using the accessory nerve. However, at operation, the nerve was found to be kinked at the suprascapular notch. Electrical stimulation of the nerve did not elicit a response in the muscles, but a consistent somatosensory evoked potential was recorded. Neurotisation was abandoned and simple neurolysis performed. Forty-eight hours after operation, the patient partially regained abduction at the shoulder and eventually made a full recovery. A neurapraxic lesion at the suprascapular notch could possibly explain why no response could be elicited by direct stimulation above the lesion whilst a somatosensory evoked potential was obtainable.

**DISCUSSION**

The anatomical appearance of the plexus at operation can be very misleading. The application of electrophysiological tests greatly helped us to decide the suitability of ruptured root stumps for grafting and to test if trunks in apparent continuity also had functional continuity. We were able to check before neurotisation that the intercostal nerves were in physiological continuity, and that they had not been damaged in the accident by direct trauma or fracture of a rib. The electrophysiological tests we used were only qualitative and not quantitative. The values quoted for somatosensory evoked potential amplitude and latency were of the first cortically generated negative peak which was seen consistently at 10 to 12 milliseconds latency and occurred at approximately 20 milliseconds (Jones 1979), when the stimulus was given at the wrist. This was succeeded by a larger positive potential with a broader latency distribution. Both components were attenuated by anaesthesia, which accounts for the very small values of amplitude.

At exploration, we carried out the electrophysiological studies when the roots had been exposed and prepared for normal repair. If possible disrupted stumps were excised back to the level of good fascicular bundles. Surprisingly, no correlation was found between the visual assessment of the stumps and the electrophysiological assessment. These findings are consistent with the extensive retrograde damage that occurs in traction lesions, and would explain the disappointing results of operations based on anatomical morphology alone.

We would like to thank Mr Donal Brooks for his helpful advice and for allowing us to study the patients under his care.

**REFERENCES**


