EVOLED SPINAL CORD POTENTIALS FOR DIAGNOSIS
DURING BRACHIAL PLEXUS SURGERY

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We used evoked spinal cord potentials (ESCP) for intraoperative diagnosis in 17 cases of traumatic brachial plexus palsy. Forty spinal nerves were directly stimulated during exploration of the brachial plexus and ESCP recorded from the cervical epidural space were compared with simultaneously observed somatosensory evoked potentials (SEP) and myelographic findings.

Both SEP and ESCP could be evoked in 21 spinal nerves but ESCP were always more distinct and five to ten times greater in amplitude than SEP. In four nerves, ESCP but no SEP were produced, suggesting that there was continuity from the nerves to the spinal cord. ESCP were obtained from two spinal nerves which appeared to be abnormal on the myelogram. The results show that intraoperative electrodagnosis by epidural ESCP recordings can provide useful information on the lesions of traumatic brachial plexus palsy.

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Interest in the early exploration of brachial plexus lesions has led to the use of various repair procedures such as nerve grafts and transfer of intercostal and spinal accessory nerves. The accurate diagnosis of the site and severity of the lesions is important in the choice of management: postganglionic lesions can be treated by neurolysis, neurorrhaphy or nerve grafts; preganglionic lesions require nerve transfer procedures. ESCP is often used for the diagnosis of root avulsion, but sometimes produces false-positive or false-negative results. CT and MRI can provide more detail, when they are available.

An alternative method is electrophysiological diagnosis during brachial plexus surgery. Somatosensory evoked potentials (SEP) can be recorded from the sensory area of the scalp after direct stimulation of the plexus nerves. We have investigated the use of evoked spinal cord potentials (ESCP) for the accurate diagnosis of brachial plexus nerve injuries.

PATIENTS AND METHODS

We report our experience with 17 patients having exploration of the brachial plexus for traumatic palsy (Table I); 16 had been involved in traffic accidents and one had a direct injury from glass. There were 15 men and two women, all with unilateral palsy; their ages ranged from 17 to 60 years (mean 23.4). The palsy was of the upper plexus in 11, the lower plexus in two and was total in four. Myelography with Isovist (Iatrolan; Schering Aktiengesellschaft, Berlin, Germany) by lumbar puncture was performed before surgery in all cases and an abnormal root pouch was shown in 12 cases. The repair procedures were: neurolysis in four patients; nerve grafts in one; intercostal or spinal accessory nerve transfer in eight; and intercostal nerve transfer combined with nerve grafts in the other four.

Before operation, a catheter electrode was introduced into the spinal canal using a 15-gauge Tuohy needle inserted percutaneously through the C6-C7 or C7-T1 interspinous space with the aid of an image intensifier. This was done with the patient in a sitting position before the induction of anaesthesia, placement of the needle tip in the epidural space being confirmed by the 'loss of resistance' method. A catheter, 1.2 mm in diameter, carrying four electrodes (Pisces Quad Model 3478A Lead Kit for Spinal Cord Stimulation; Medtronic, Minneapolis, USA) was then inserted through the needle and advanced to the epidural space at the level of C4-C5 (Fig. 1).

The median nerve on the unaffected, normal side was stimulated by bipolar surface electrodes at the wrist. The brachial plexus was then exposed and the nerves of the plexus were directly stimulated by a bipolar needle electrode (UK7005; Unique Medical Co, Tokyo, Japan),

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Table I. Details of 17 patients with traumatic brachial plexus palsy treated surgically

<table>
<thead>
<tr>
<th>Case</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Type of palsy</th>
<th>Surgical procedure*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18</td>
<td>F</td>
<td>Lower</td>
<td>Neurolysis</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4,5)—MCN, SAN—SSN</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>F</td>
<td>Upper</td>
<td>Neurolysis</td>
</tr>
<tr>
<td>4</td>
<td>17</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4)→AXN, ICN (5,6)→MCN</td>
</tr>
<tr>
<td>5</td>
<td>21</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4)→AXN</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4)→MCN, Nerve graft (C5→SSN)</td>
</tr>
<tr>
<td>7</td>
<td>18</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4)→MCN, SAN—SSN</td>
</tr>
<tr>
<td>8</td>
<td>17</td>
<td>M</td>
<td>Total</td>
<td>ICN (3,4)→MCN, ICN (5,6)→TDN ICN (6LB,7)→MN</td>
</tr>
<tr>
<td>9</td>
<td>23</td>
<td>M</td>
<td>Lower</td>
<td>ICN (3)→TDN, ICN (4,5)→MN</td>
</tr>
<tr>
<td>10</td>
<td>19</td>
<td>M</td>
<td>Upper</td>
<td>Neurolysis</td>
</tr>
<tr>
<td>11</td>
<td>21</td>
<td>M</td>
<td>Upper</td>
<td>Nerve graft (AXN→AXN) SSN→Supraspinatus muscle (Direct nerve transfer)</td>
</tr>
<tr>
<td>12</td>
<td>33</td>
<td>M</td>
<td>Upper</td>
<td>Neurolysis</td>
</tr>
<tr>
<td>13</td>
<td>18</td>
<td>M</td>
<td>Upper</td>
<td>ICN (3,4,5)→MCN</td>
</tr>
<tr>
<td>14</td>
<td>17</td>
<td>M</td>
<td>Total</td>
<td>ICN (3,4,5)→MCN, ICN (2,5LB,6)→MN DSN→SN, Nerve graft (C5→UT)</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>M</td>
<td>Total</td>
<td>ICN (3,4,5)→MCN, ICN (3,4LB,5LB)→MN Nerve graft (C5→SSN, UT)</td>
</tr>
<tr>
<td>16</td>
<td>23</td>
<td>M</td>
<td>Upper</td>
<td>SAN→UT</td>
</tr>
<tr>
<td>17</td>
<td>22</td>
<td>M</td>
<td>Total</td>
<td>ICN (3,4,5)→MCN, Nerve graft (C5→PC)</td>
</tr>
</tbody>
</table>

* ICN, intercostal nerve; MCN, musculocutaneous nerve; SAN, spinal accessory nerve; SSN, suprascapular nerve; AXN, axillary nerve; TDN, thoracodorsal nerve; LB, lateral cutaneous nerve of intercostal nerve; MN, median nerve; DSN, dorsal scapular nerve; UT, upper trunk; PC, posterior cord; →, nerve graft or transposition

using a rectangular pulse, ranging from 1 to 5 mA with 0.2 ms duration. ESCP were recorded using two of the four epidural electrodes, the more cranial one as reference and the other as an active electrode. At the same time, SEP were recorded from surface electrodes (silver plate with silver chloride), attached to the scalp overlying the upper extremity region of the somatosensory cortex (C3 or C4, 10 to 20 system) and the mid-frontal position (Fz, reference electrode), with impedance adjusted to under 2 kΩ. Potentials were recorded by an electromyograph (MEB 5304; Nihon Kohden, Tokyo, Japan), averaging 300 to 500 responses from two stimulations per second. The latency for the first negative deflection and the amplitude of each evoked potential were measured.

RESULTS

Normal median nerve at the wrist. Data from the median nerve of the unaffected site were available for both ESCP and SEP in 13 cases (Fig. 2). For ESCP, the average latency was $11.0 \pm 0.9$ ms (SD) and the average amplitude was $4.6 \pm 3.3 \mu V$. The potential consisted of 6 to 10 waves. For SEP, the latency of the first negative peak was $21.1 \pm 1.4$ ms and the average amplitude was $1.1 \pm 0.8 \mu V$.

Brachial plexus. A total of 40 spinal nerves were stimulated in the 17 patients (Table II). When no response could be obtained from either the epidural space or the scalp at a sensitivity of $0.31 \mu V$/division, the nerve was diagnosed as having no potential. Both ESCP and SEP were recorded from 21 nerves, ESCP but no SEP from four, and neither ESCP nor SEP potentials in 15.

Of the 21 spinal nerves with both ESCP and SEP recordings, 18 were found to be intact on the basis of
preoperative neurological findings, normal appearances in myelograms and macroscopic findings at operation. From these 18 normal nerves, the average latency and amplitude of ESCP were $1.8 \pm 0.7$ ms and $15.0 \pm 8.8$ μV, while for SEP they were $11.1 \pm 1.6$ ms and $0.8 \pm 1.0$ μV. In each case, ESCP had a five to ten times greater amplitude and a more clearly recognisable configuration than SEP (Fig. 3). They showed an initial positive spike, followed by a sharp negative spike and a positive slow wave often with a subsequent negative slow wave.

In three cervical nerves suspected to be damaged from preoperative sensorimotor deficits (C5 in cases 11, 12 and 15), the amplitudes of ESCP were significantly decreased to $1.32 \mu V$, $2.35 \mu V$ and $1.69 \mu V$, respectively. Exploration of these three cases showed supra- or infraclavicular lesions.

In four cervical nerves in which ESCP but no SEP could be recorded (C6 in case 5 and C5 in cases 6, 14 and 17), the amplitudes of ESCP were greatly decreased, to $2.77 \mu V$, $1.47 \mu V$, $0.17 \mu V$ and $1.62 \mu V$, respectively (Fig. 4). These nerves were shown to be ruptured and attenuated at the neural foramina.

**Comparison with preoperative myelograms** (Table II). Myelographic appearances were classified according to our criteria into the following six categories (Kawai et al 1989):

- **N**, normal;
- **E + O**, slight abnormality of root pouch with rootlet;
- **E + C**, closed root pouch with rootlet;
- **E −**, closed root pouch with no rootlet;
- **D**, no root pouch; and
- **M**, pseudomeningocele.

Our experience has shown that the last four appearances strongly suggest root avulsion.

![Figure 3](image)

**Fig. 3**

Case 9. SEP (upper trace) and ESCP (lower trace) obtained by stimulating C5 nerve. SEP: latency 5.94 ms, amplitude 1.9 μV. ESCP: peak latency 1.74 ms, amplitude 12.2 μV. The cervical nerve was diagnosed as intact.

![Figure 4a](image)

**Fig. 4a**

Case 5. Figure 4a – The myelogram shows pseudomeningoceles at C5 and C6. Figure 4b – Stimulation of C5 evoked neither SEP nor ESCP. Stimulation of C6 evoked ESCP (lower trace) but no SEP (upper trace).
Case 6. Figure 5a - The preoperative myelogram shows slight abnormality at C5 (E+O), absent root pouch at C6 and C7 (D), a dural defect and normal appearances at C8 and T1. Figure 5b - The intraoperative SEP (upper trace) and ESCP (lower trace) from C5 nerve showed SEP to be absent and ESCP positive with a latency of 1.44 ms and an amplitude of 1.47 μV. Figure 5c - Shoulder abduction and elbow flexion two years after the operation.

Both ESCP and SEP were obtained from all 20 nerves with normal myelograms. Of the six spinal nerves rated as E+O, both SEP and ESCP were recorded in one case, ESCP but not SEP in two and neither ESCP nor SEP in three. In 12 of the 14 spinal nerves showing E+C, E- or M on the myelogram neither SEP nor ESCP could be recorded; in the remaining two ESCP but not SEP were recorded.

ILLUSTRATIVE CASES

Case 6. A 25-year-old man sustained an upper-type right brachial plexus palsy in a motor-cycle accident. The myelogram showed a slight abnormality at C5 rated as an E+O lesion and no root sheath at C6 or C7 indicating E+C lesions (Fig. 5a).

Case 7. An 18-year-old boy was injured in a motor-cycle accident, resulting in upper-type palsy of his right brachial plexus. The myelogram showed closed root sheaths at C5 and C6, indicating E+C lesions (Fig. 6a).
Case 7. Figure 6a – The preoperative myelogram shows a closed dural sac and leakage of contrast medium at C5 and C6 (E+C). C7, C8 and T1 roots are normal. Figure 6b – Intraoperative SEP (upper trace) and ESCP (lower trace). Neither SEP nor ESCP were recorded from C5 or C6 nerves; both are well evoked by stimulating C7 and C8.

Case 10. Intraoperative SEP (upper trace) and ESCP (lower trace). Both SEP and ESCP were evoked normally by stimulation of C5 to C8 nerves and the dorsal scapular nerve (DSN). Stimulation of the suprascapular nerve (SSN) gave ESCP with a low amplitude (2.53 μV) and polyphasic form, disclosing neural damage in continuity.
One month after the injury, at exploratory operation, ESCP and SEP were absent from C5 and C6 nerves, but were strongly evoked by stimulation of the C7 and C8 nerves, ESCP being recorded as spike waves with a high amplitude (Fig. 6b). The diagnosis was made of C5 and C6 root avulsion with normal C7 and C8 nerves. The third and fourth intercostal nerves were transferred to the musculocutaneous nerve and the spinal accessory nerve to the suprascapular nerve. At 18 months, biceps power was grade 4 and there was active shoulder abduction to 60°.

**Case 10.** A 19-year-old boy was also injured in a motorcycle accident and complained of difficulty in abducting his left shoulder. Examination showed considerable atrophy of the left supraspinatus and infraspinatus muscles and EMG showed fibrillation potentials in these muscles. A cervical myelogram was normal.

Three months after the injury, brachial plexus exploration showed slight adhesions of the brachial plexus in the supraclavicular region. Normal ESCP and SEP were recorded on stimulating the C5 to C8 nerves and the dorsal scapular nerve. Suprascapular nerve stimulation, however, yielded only low-amplitude ESCP, with polyphasic components, suggesting neural injury in continuity which could be treated only by neurolysis (Fig. 7).

**DISCUSSION**

The preoperative evaluation of brachial plexus injury can be made by clinical observation of motor weakness, sensory deficit and Horner's sign, and by a series of electrodiagnostic and radiographic methods. These do not always give precise information on the site and extent of the injury. Even myelography, however, considered to be one of the most reliable preoperative methods, may lead to misdiagnosis in some cases (Davies, Sutton and Bligh 1966; Sunderland 1974). These difficulties in accurate diagnosis make early exploration of the brachial plexus and intraoperative electrodiagnosis essential before appropriate nerve repairs can be planned.

Intraoperative electrodiagnosis has included the use of SEP, nerve action potentials, and root potentials obtained by stimulating the cerebral cortex (Jones 1979; Matsuda et al 1981; Sugio et al 1982). Recording of SEP evoked by stimulating preserved spinal nerves has been well accepted because of its convenience, but the technique is difficult and SEP easily disappear as a result of electrical noise and anaesthetic effects. This prevents wider use in many hospitals in which brachial plexus surgery is carried out.

Our technique of using ESCP from the cervical epidural space as a new diagnostic method for brachial plexus surgery has proved to be more useful than SEP recording. ESCP have previously been used for diagnosis of spinal cord disorders and for monitoring during spinal surgery (Shimoji, Higashi and Kano 1971; Tamaki et al 1984; Anderson, Hetreed and Loughnan 1990). They can be recorded from the spinous processes, interspinous ligaments, ligamenta flava and intervertebral discs but none of these provides such a clear potential as ESCP recorded from the epidural space (Cracco 1973).

There are two categories of ESCP: segmental and ascending. Evoked potentials obtained from the C4-C5 epidural space by stimulating the brachial plexus are regarded as segmental ESCP; Shimoji et al (1972)
reported that the potential evoked by segmental peripheral nerve stimulation is made up of three waves. There is an initial positive spike wave (P1), followed by a sharp negative wave (N1) and then a slow positive (P2) wave. These waves reflect respectively the afferent volley from the root, the synchronised activity of dorsal horn neurones, and primary afferent depolarisation. When this potential is recorded from the epidural space very close to the spinal cord, it has quite a high amplitude and a clear configuration. These advantages make intraoperative diagnosis with ESCP more reliable, less time-consuming and more convenient than SEP, especially for the evaluation of root avulsion. ESCP can sometimes be obtained from a spinal nerve at a level at which myelography showed a traumatic pseudomeningocele. This suggests some preservation of continuity of the nerve to the spinal cord, that is, sheath tearing without root avulsion.

ESCP recording has other advantages. First, intraoperative ESCP can provide quantitative assessment of the function of the damaged nerve root by measurement of amplitude. In our series, four spinal nerves showed positive ESCP, although with a decreased amplitude, but no SEP. We concluded that these damaged nerve stumps had preserved some neural continuity to the spinal cord and were usable as proximal stumps for nerve repair. Further study will be needed to determine whether such a damaged stump could be a satisfactory donor nerve.

Secondly, analysis of the recorded configurations helps with understanding of the pathology of the nerve injury. Normal ESCP show a clear configuration of three to four waves, and even slight damage to the nerve trunk will result in recognisable disturbance of this configuration on the recorded ESCP. Thirdly, SEP reflect only the potential originating in the posterior column of the spinal cord, but segmental ESCP are considered to reflect nerve potentials from both sensory and motor tracts. Fourthly, although SEP are easily suppressed by anaesthesia, ESCP are enhanced by inhalation anaesthetics such as halothane, enflurane and isoflurane, and only slightly dimin-

ished by analgesics such as morphine and fentanyl (Shimoji et al 1971). This means that there is little risk that recordings will be diminished by anaesthesia.

The only serious disadvantages are the possible complications, and the difficulty of introducing the electrode into the spinal canal. We had no complications in our series, and therefore consider that ESCP recording is a safe procedure when it is done carefully under image-intensifier control.

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

REFERENCES