SPINAL CORD MONITORING IN OPERATIONS FOR NEUROMUSCULAR SCOLIOSIS

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We reviewed retrospectively the role of monitoring of somatosensory spinal evoked potentials (SSEP) in 99 patients with neuromuscular scoliosis who had had operative correction with Luque-Galveston rods and sublaminar wiring.

Our findings showed that SSEP monitoring was useful and that a 50% decrease in the amplitude of the trace optimised both sensitivity and specificity. The detection of true-positive results was higher than in cases of idiopathic scoliosis, but the method was less sensitive and specific and there were more false-negative results. In contrast with the findings in idiopathic scoliosis, recovery of the trace was associated with a 50% to 60% risk of neurological impairment.

Only one permanent injury occurred during the use of this technique, and any temporary impairment resolved within two months.

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Intraoperative monitoring of the spinal cord is commonly used to help to diminish the risk of neurological injury. Somatosensory recording of the spinal evoked potential (SSEP) is a popular method which offers continuous surveillance and is generally used during operations for idiopathic scoliosis. Its role in neuromuscular scoliosis, however, is less well defined. We have therefore assessed the value of SSEP monitoring in a large series of patients with this condition.

PATIENTS AND METHODS

We retrospectively reviewed 99 consecutive patients who had reconstructive surgery of the spine for neuromuscular scoliosis between April 1983 and December 1994. The operations had all been performed by one surgeon in the same unit with the same anaesthetist. All the patients had a one-stage Luque-Galveston procedure with crossed rods and sublaminar wires. Of the 99 patients, 55 had Duchenne’s muscular dystrophy (DMD), 30 had spinal muscular atrophy (SMA), and 14 had miscellaneous conditions including congenital myopathies, spinal dysraphism and other rare syndromes. Table I gives the details of the groups.

We reviewed the records of each patient and recorded the age at operation, gender, diagnosis, the operative approach, the instrumentation and the levels fused. In addition, we noted the magnitude, flexibility, percentage correction and level of coronal and sagittal spinal curves fused, the anaesthetic details and intraoperative events, the neurological function after operation and any adverse postoperative symptoms.

Spinal cord monitoring. Measurement of the SSEP was used to monitor the function of the spinal cord throughout the operation. Stimulation of the posterior tibial nerve with supra-maximal constant-voltage single-pulse stimuli of 0.2 ms, at 20 per second, was applied alternately to both legs. The SSEP was recorded with a 4F bipolar electrode (Orthoexpress, Amersham, UK) from the epidural space at the level above the highest proposed level of fusion. The signals were amplified, conditioned and displayed on a Medelec MS91 (Medelec, Old Woking, UK) and a PA89 preamplifier. The filters were set to BER (200 to 2000 Hz) and sweeps were averaged to obtain clear recordings at intervals coinciding with steps in the operation or changes in the signal. Hard copies of the traces were made on calibrated paper.

The SSEP was measured as the maximum peak-to-peak value, and its amplitude related to different points in the operation. The amplitude at insertion of the electrode was taken as the control level and the amplitudes at the insertion of sublaminar wires, correction (tightening of the wires) and at closure of the skin were measured and expressed as a percentage of the control value.

Three levels of loss of signal, namely more than 25%, 50% or 75% of the control were used to judge the sig-
The SSEP traces were designated as false-positive, false-negative, true-positive or true-negative, defined as follows:

**False-positive.** A change in the trace unrelated to the position of the electrode or an anaesthetic event but with no neurological injury detected.

**False-negative.** No change in the trace but a neurological injury was produced.

**True-positive.** A change in the trace unrelated to the position of the electrode or an anaesthetic event with neurological injury detected.

**True-negative.** No change in the trace and no neurological injury detected.

The neurological injuries included change in muscle power in the lower limb, change in sensation in the trunk or in the lower limb, or a change in bladder control.

**Anaesthesia.** Similar techniques of anaesthesia were used. Induction was either by intravenous injection of thiopental or by inhalation of halothane and was followed by maintenance with enflurane and nitrous oxide in oxygen. Vecuronium or pancuronium was given for paralysis and doses of opioid were given peroperatively for analgesia. The systolic blood pressure was maintained at about 70 mmHg, and labetolol or trimetephan was occasionally given to facilitate this. All patients had intra-arterial monitoring, and most also had a central venous pressure transducer.

**Statistical methods.** We analysed the relationship between reduction of the trace to less than 50% of the control value and the neurological injury, the flexibility of the curves, the Cobb angle before operation and the percentage correction obtained using the Mann-Whitney U test. Comparison of the systolic blood pressures and the temperatures were made by Student’s two-tailed t-tests.

### RESULTS

Traces could not be obtained in two of the 99 patients; one had DMD and the other was paraplegic due to meningomyelocele.

**DMD group.** There were 51 sets of traces for the 55 patients available for analysis (Fig. 1); 40 (79%) had lost trace amplitude by more than 25% of the control, 35 (69%) by more than 50% and 30 (59%) by more than 75% of the control. The results were as follows: 25% loss of amplitude showed a 90% sensitivity with 29% specificity and two false-negative results; 50% loss of amplitude had 87% sensitivity with 44% specificity and three false-negative results; and 75% loss of amplitude had a 70% sensitivity with 52% specificity and seven false-negative results.

Neurological injury was detected in 22 cases (43%) (Fig. 2)
but was temporary in all of them. There were three false-negative results at 50% amplitude loss: one patient had hyperaesthesia on the abdomen for one week and in the legs and feet for three weeks, one had hyperaesthesia in a leg for two weeks and another had hyperaesthesia of the lower abdomen for two days.

Of the 35 patients with SSEP loss of over 50%, this occurred during wire tightening and correction in 34 and during passage of the wire in one. In 13 patients although the SSEP amplitude improved between correction and skin closure, six of these had neurological impairment.

**SMA group.** Examination of 30 sets of traces available for the patients with spinal muscular atrophy (Fig. 3) showed that 26 (87%) had a loss of amplitude of more than 25%, 22 (73%) of more than 50% and 20 (67%) of more than 75%. The results were as follows: 25% loss of amplitude had a sensitivity of 93% with specificity of 19% and one false-negative result, 50% loss of amplitude had a sensitivity of 93% with specificity of 42% and one false-negative result, and 75% loss of amplitude had a sensitivity of 82% with a specificity of 52% and three false-negative results.

There were 14 cases of neurological injury (47%) (Fig. 4), but all except one resolved. Loss of amplitude of 50% occurred on wire tightening and correction in 24 (81%) and on passing wires in four (14%). Of the 22 patients with loss of amplitude greater than 50%, 15 had some degree of neurological impairment.

**Miscellaneous group.** The miscellaneous group consisted of patients with a variety of syndromes and congenital myopathies. There were 13 traces available for analysis in the 14 patients; nine had lost amplitude by more than 50%, giving a sensitivity of 86% and a specificity of 54% (Fig. 5). There was one false-negative result. The pattern of neurological damage is shown in Figure 6, but there were no cases of permanent injury.
In all three groups of patients there was a 100% correlation between the side on which the amplitude decreased and the side of the neurological deficit.

In both the DMD and SMA groups, the Mann-Whitney U test showed no significant correlation between amplitude loss of greater than 50% or neurological injury and the preoperative Cobb angles, the flexibility curve or the percentage correction of the curve obtained during the operation (Table II).

Most patients with bladder dysfunction had retention of urine; those with permanent damage had intermittent retention.

Physiological details were available for 73 (74%) of the patients. Those who had neurological impairment were compared with those who did not, using Student’s two-tailed t-test (Table III). No significant difference was obtained when comparing the highest or the lowest systolic blood pressures or the core temperatures at skin closure.

### DISCUSSION

Segmental instrumentation of the spine carries a high risk of neurological injury. Intraoperative monitoring of the function of the spinal cord includes wake-up techniques and the recording of evoked potentials. Some patients, however, continue to suffer neurological complications despite monitoring.

A study of SSEP monitoring of the spinal cord in 1168 consecutive patients with idiopathic scoliosis using techniques identical to those in our series showed an inability to obtain adequate tracings in 26 patients (2.2%) which compares well with our figure of 2.1%. The incidence of technical failure was 28% using cortical somatosensory evoked potentials in a series of patients with neuromuscular scoliosis.

In the series of Forbes et al, 119 patients (10.2%) with an amplitude loss greater than 50% of the control value had detectable neurological injury with a sensitivity of 100% and a specificity of 57.8% (Table IV). In 35 (29.4%) of these, however, the SSEP improved spontaneously to more than 50% of the control level and none had neurological injury. There were no false-negative results. In our series there was a high rate of trace loss, temporary neurological injury and some false-negative results, as shown by the reduced sensitivity. Forbes et al, however, used broader categories than in our study and the results of neurological impairment are therefore difficult to compare directly.

An amplitude loss greater than 25% diminished the rate of false-negative results but increased the false-positives, diminishing specificity. The use of loss of amplitude greater than 75% resulted in an unacceptable number of false-negatives. We therefore suggest that a loss of amplitude of 50% or more should be used to define abnormality in neuromuscular scoliosis.

The incidence of neurological injury in neuromuscular

### Table II. Characteristics of the curves in degrees (mean, range) in the DMD and SMA groups

<table>
<thead>
<tr>
<th>Group</th>
<th>Preoperative Cobb angle</th>
<th>Flexibility</th>
<th>% correction obtained</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMD (n = 51)</td>
<td>69.3 (10 to 122)</td>
<td>24.8 (0 to 70)</td>
<td>57.2 (15 to 100)</td>
</tr>
<tr>
<td>SMA (n = 30)</td>
<td>93 (40 to 100)</td>
<td>20 (5 to 70)</td>
<td>48.4 (18 to 80)</td>
</tr>
</tbody>
</table>

### Table III. Physiological measurements (mean, SEM) in patients with neurological injury compared with those with no injury

<table>
<thead>
<tr>
<th></th>
<th>Systolic blood pressure (mmHg)</th>
<th>Core temperature at skin closure (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>Lowest</td>
<td>Highest</td>
</tr>
<tr>
<td>No neurological injury</td>
<td>71.7 (2.1)</td>
<td>112.4 (3.3)</td>
</tr>
<tr>
<td>(n = 28)</td>
<td></td>
<td></td>
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<tr>
<td>Neurological injury</td>
<td>68.5 (1.4)</td>
<td>107.6 (1.9)</td>
</tr>
<tr>
<td>(n = 45)</td>
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### Table IV. Comparison of idiopathic and neuromuscular scoliosis

<table>
<thead>
<tr>
<th>Group</th>
<th>Number of patients</th>
<th>Loss of trace &gt;50%</th>
<th>Recovery of this degree of loss (%)</th>
<th>Neurological complication</th>
<th>Long-term neurological impairment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forbes et al¹</td>
<td>1168 (26 failures; 2.2%)</td>
<td>119 (10.2%)</td>
<td>29.4 (of which none had neurological complications)</td>
<td>32 (2.8%)</td>
<td>6 (0.5%)</td>
</tr>
<tr>
<td>DMD</td>
<td>55</td>
<td>35 (69%)</td>
<td>37 (of which 46% had neurological complications)</td>
<td>22 (43%)</td>
<td>37.0</td>
</tr>
<tr>
<td>SMA</td>
<td>30 (2 failures for all three groups; 2.1%)</td>
<td>22 (73%)</td>
<td>36 (of which 68% had neurological complications)</td>
<td>14 (47%)</td>
<td>44.0</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>14</td>
<td>9 (69%)</td>
<td>33 (of which 66% had neurological complications)</td>
<td>6 (46%)</td>
<td>46.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>True-positive results (%)</th>
<th>False-negative results (%)</th>
<th>Sensitivity (%)</th>
<th>Specificity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forbes et al¹</td>
<td>26.9</td>
<td>0.0</td>
<td>100.0</td>
<td>57.8</td>
</tr>
<tr>
<td>DMD</td>
<td>37.0</td>
<td>6.0</td>
<td>80.0</td>
<td>52.8</td>
</tr>
<tr>
<td>SMA</td>
<td>44.0</td>
<td>3.0</td>
<td>88.5</td>
<td>59.5</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>46.0</td>
<td>7.0</td>
<td>77.0</td>
<td>66.0</td>
</tr>
</tbody>
</table>
scoliosis seems to be much higher than in idiopathic scoliosis. In the former group an amplitude recovery above 50% may still be associated with significant, although temporary, neurological sequelae which may be due to an increased sensitivity of the spinal cord to injury, caused by the segmental wiring or to both. Luque-Galveston instrumentation using sublaminar wires has been associated with a significantly higher incidence of trace changes.\(^6\)

We conclude that SSEP monitoring in neuromuscular scoliosis is useful for the detection of neurological injury in contrast to the use of somatosensory cortical evoked potentials which have been found to be unreliable and non-specific. Although the detection of true-positive results is higher in neuromuscular scoliosis when compared with idiopathic scoliosis, the method is, however, less sensitive and specific.

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