Utility of Direct Stimulation of Roots in Spinal Surgery

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Abstract
Prevention of postoperative neurological deficits is a major concern of spinal surgeons and has led to the introduction and current development of intraoperative neurophysiological monitoring. We have used motor evoked potentials and somatosensory evoked potentials as routine monitoring techniques and, in some cases, added optional methods such as direct stimulation of nerve roots and spinal evoked potentials. We report our experience of direct nerve root stimulation as an optional monitoring method during spinal surgeries in 7 patients with lesions affecting the proximal nerve roots aged from 1 day to 78 years (mean 23.5 years). Four patients had anomalous lesions, two had spinal nerve root schwannomas, and one had a far-lateral lumbar disc herniation. Direct stimulation was used for detection of motor nerve roots in the anomalous lesions and schwannomas, and to distinguish the nerve root from the paraspinal soft tissues in the case of a far-lateral herniated disc at the L5-S1 level. Although some patients had slight transient neurological symptoms such as motor weakness and sensory disturbance, none developed severe permanent neurological impairment. Direct stimulation allows detection of the motor nerve during spinal surgery in real time. Our limited experience suggests that the direct stimulation technique could reduce the risk of motor or vesicorectal disturbance after surgery of lesions affecting or involving the spinal nerve roots.

Key words: intraoperative neurophysiological monitoring, direct stimulation, compound muscle action potential, spinal surgery, spinal nerve root

Introduction
The use of intraoperative neurophysiological monitoring has become widespread, and its utility is well recognized in neurosurgical procedures.12) Motor evoked potential and somatosensory evoked potential have been applied as a basic modality to every procedure in our institute, but combined application of optional protocols such as direct stimulation of the nerve roots, spine evoked potential, and others have been utilized in spinal surgeries depending on the case. The purpose of intraoperative monitoring can be roughly divided into monitoring and mapping. Monitoring is intended to supply the function of the region of interest in real time. Mapping by direct stimulation has mainly been used for the identification of a nerve nuclei or pathway in skull base lesions.3) We report seven cases in which nerve root direct stimulation was useful to prevent spinal lesion.

Materials and Methods
Intraoperative neurophysiological monitoring was performed in 46 cases of spinal surgery between January 2006 and January 2009. Direct nerve root stimulation, in which the compound muscle action potential (CMAP) of the target muscles was recorded, was performed in seven patients, five men and two women, aged 1 day to 78 years (mean 23.5 years) with four congenital malformations, two nerve sheath tumors, and one herniated disc (Table 1).

The region of interest was stimulated with a Slim Press Flush-Tip Monopolar Stimulator Probe® (Medtronic Xomed, Inc., Rochester, Minnesota, USA). The stimulation intensity ranged from 0.1 to 10.0 mA (Fig. 1). The observer watched the surgical procedure via a 3 CCD camera on the operating microscope, and recorded the CMAP waveform with a Viking IV® (Nicolet Biomedical, Inc., Madison, Wisconsin, USA). In patients with congenital...
Table 1 Clinical characteristics of the patients

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age</th>
<th>Sex</th>
<th>Disease type</th>
<th>Purpose of direct stimulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 yr</td>
<td>F</td>
<td>lipomyelomeningocele</td>
<td>identify motor rootlets</td>
</tr>
<tr>
<td>2</td>
<td>35 yrs</td>
<td>M</td>
<td>lt L5 root extraforaminal schwannoma</td>
<td>distinguish between motor and sensory roots</td>
</tr>
<tr>
<td>3</td>
<td>49 yrs</td>
<td>M</td>
<td>rt L5-S1 far lateral disc</td>
<td>distinguish nerve root from soft tissue</td>
</tr>
<tr>
<td>4</td>
<td>6 mos</td>
<td>M</td>
<td>dermal sinus</td>
<td>identify motor rootlets</td>
</tr>
<tr>
<td>5</td>
<td>1 yr</td>
<td>M</td>
<td>spina bifida, terminal filum lipoma</td>
<td>identify motor rootlets</td>
</tr>
<tr>
<td>6</td>
<td>1 day</td>
<td>F</td>
<td>myeloschisis</td>
<td>identify non-functional placode and rootlets</td>
</tr>
<tr>
<td>7</td>
<td>78 yrs</td>
<td>M</td>
<td>rt C4 root intradural extramedullary schwannoma</td>
<td>distinguish between motor and sensory roots</td>
</tr>
</tbody>
</table>

F: female, M: male.

malformations and nerve sheath tumors, mapping by direct stimulation of the cauda equina or parent nerves of the tumors was applied to establish whether the relevant nerve roots could be sectioned or not. In patients with far-lateral type disc herniation at the L5-S1 level, direct stimulation was used to distinguish between herniated disc tissue and the L5 nerve root.

In adult patients, muscle relaxant was exclusively administered at the induction of general anesthesia and then total intravenous anesthesia (TIVA) was performed with remifentanil and propofol. In the newborn and infants, since TIVA is not suitable for children, it was replaced with sevoflurane during anesthesia maintenance and fentanyl was intermit-tently infused if necessary.

Fig. 1 A: Photograph of the Viking IV equipment with dual display of waveform and microscope field. B: Photograph of the monopolar electrode.

Fig. 2 A, B: Preoperative coronal (A) and axial (B) T2-weighted magnetic resonance images showing the right far-lateral disc at L5-S1. C: Intraoperative photograph showing stimulation of the reddened and oppressed right L5 nerve root (asterisk).

Fig. 3 A: Photograph of the myeloschisis with large cyst and placed electrodes. B: Preoperative sagittal T2-weighted magnetic resonance image showing a large cystic sacral myeloschisis. C: Compound muscle action potential response from the right anterior tibialis and gastrocnemius after monopolar stimulation of the functional root.
Results

The clinical characteristics of the seven patients undergoing direct stimulation of roots during operation are presented in Table 1. In cases of schwannomas, direct stimulation was applied to identify the motor rootlets during operation. If CMAPs were induced from the target muscle with stimulus intensity up to 1.5 mA, the stimulated root was judged to be the motor root. The parent root was the right L5 anterior root in Case 2 and the patient had two anterior right L5 rootlets. After confirming the same waveform by direct stimulation from both anterior right L5 rootlets, the tumor was removed with the parent root. Only transient postoperative mild grade motor weakness was observed. Case 7 was a schwannoma originating from the C4 dorsal root. No electrophysiological reaction was detected from the target muscles with stimulus intensity of 10.0 mA. Total removal of the tumor, including the parent root, was performed without postoperative sensory disturbance. In the case of right L5-S1 far lateral disc (Case 3), the herniated disc and right L5 nerve root were easily distinguished by direct stimulation (Fig. 2). In cases of congenital malformation, direct stimulation was used to identify the motor nerve. All these patients were pediatric and anesthesia was maintained as previously mentioned. CMAPs were successfully obtained by direct stimulation in all patients under anesthesia. The placode or dermal sinus was primarily closed in Cases 1, 4, and 5. Direct stimulation was useful to identify the anatomical structure in those cases. On the other hand, the placode and attached root needed to be cut for closing because of the size in Case 6.

Representative Case 6: This female infant was born with myeloschisis and a large meningeal cyst. Spontaneous hip joint movement with paraparesis below the knee level suggested a diagnosis of dysfunction below the bilateral L5 nerve roots, and neurogenic bladder was also suspected. The repair of the myeloschisis was performed on the day after birth. Anesthesia was maintained with sevoflurane and fentanyl. Vecuronium bromide was only used at the induction of anesthesia. Surgical findings showed no cerebrospinal fluid leakage from the cyst, and nerve roots coupled to the placode were observed translucently through the cyst wall. The placode was disconnected from the surrounding skin and we tried to place the placode in the subarachnoid space. However, the placode was too large, so we had to remove a part of the placode and nerve roots. Direct stimulation was applied to find out if the part of the placode and nerve roots were responsive to the stimuli. Direct stimulation of the circumference of the placode induced no CMAPs of the lower extremities or anal sphincter muscle. Some nerve roots also showed no response to direct stimulation (Fig. 3). Therefore, the circumference of the placode and nonreactive roots were cut and the placode was reduced in size. Finally, the placode was successfully placed in the subarachnoid space. No postoperative deterioration from the baseline neurological status was observed.

Discussion

Intraoperative neurophysiological monitoring including direct stimulation of the cranial nerves has become a routine procedure in surgeries to the skull base or brainstem lesions. However, direct stimulation methods are not necessarily used often in the treatment of spinal lesions. In spinal surgeries, direct stimulation of the nerve root is mainly used to identify structures at the level of the cauda equina and to assess the integrity of nervous structures in spinal tumor surgery. The method is sometimes applied to detect a medial pedicle wall breach in the pedicle screw placement. We applied this method to seven spinal lesion cases and found it useful for surgical decision making.

Total removal of spinal schwannoma requires resection of the parent nerve root. Schwannomas typically originate from the dorsally situated sensory nerve root and rarely from the ventral motor root. In cases of tumors derived from the motor root, direct stimulation can be applied to judge whether that nerve root is functional or not (Case 2). Even if the nerve was damaged, increased intensity to 5–6 mA usually suffices. In our Case 2, CMAP responses from the parent root were obtained with stimulus intensity of 1.5 mA or less. For this reason, we judged that the schwannoma had originated from the motor root. The spinal nerve root usually consists of two or more anterior and posterior roots, and each skeletal muscle is innervated by two or more nerve roots. Cutting of the parent root in which the motor function is already lost is unlikely to result in postoperative motor deficit. If the CMAP responses are recorded by direct stimulation of the parent root or the tumor, and similar CMAP responses can be obtained from other motor rootlets near the lesion, postoperative paralysis will probably be slight. In our Case 2, the schwannoma had originated from one of two anterior right L5 roots, and almost the same waveform was evoked by direct stimulation of both roots. Only transient postoperative mild grade motor weakness was observed in the right L5 anterior root, which was the original site.
and was cut at tumor removal, probably due to functional compensation by the other motor roots. The judgment of the ventral and dorsal roots is possible with intensity change in direct stimulation. The stimulation threshold of the dorsal sensory root is 3.6 mA or higher.\(^7\) Since no electrophysiological reaction was observed from target muscles with stimulus intensity of 10.0 mA, we judged that the parent root was the sensory root. Although no postoperative new sensory or motor disturbance was observed in our Case 2, sensory disturbance arises in about 3.5% of cases of nerve sheath tumors requiring cutting of the dorsal root at resection.\(^8\)

Far-lateral disc herniation is a rare entity that accounts for approximately 0.7% to 11.7% of all lumbar disc hernias,\(^1,5,10,14,15\) and has recently been treated via the paraspinal approach in many cases.\(^2\) The paraspinal approach has advantages over the conventional midline approach in that the operating time is relatively short, and preservation of the facet joint is possible. However, this approach may lead to disorientation because of the deep surgical field and less familiar anatomy.\(^3\) If the nerve root is oppressed posteriorly and thinned by the herniated disc as in our Case 3, it may be misidentified as a disc fragment. In such cases, direct stimulation of the motor fibers can distinguish the nerve root from the surrounding soft tissues. Since additional equipment other than a stimulation probe is not needed, direct stimulation is very useful and should be considered as a main modality of intraoperative neurophysiological monitoring.

Cauda equina lesions account for a comparatively large number of pediatric neurosurgery procedures and monitoring the function of the sacral neuromuscular system during surgery is often needed.\(^17\) On the other hand, general application of TIVA is difficult to neonates and younger infants because propofol clearance is decreased due to the immaturity of the hepatic enzyme system.\(^11\) Direct stimulation has been used to identify the recurrent laryngeal nerve during patent ductus arteriosus ligation in newborn infants under TIVA.\(^10\) However, TIVA for a newborn infant has not been reported in spinal surgery. CMAP monitoring using spinal or nerve root stimulation has been used for patients more than 7 months old. Ketamine is recommended for the anesthesia of infants aged 6 years or below.\(^6,19\) In our Case 6, CMAP monitoring of the lower extremities by direct stimulation of a nerve root or placode was possible in a newborn patient. Although the anesthesiologist’s cooperation is required, this monitoring method is considered to be indispensable for manipulation of cauda equina lesion.

Direct stimulation of the nerve root in the surgical field can provide the surgeon with the information needed to safely cut the nerve root without postoperative sequelae. This method can reduce the risk of severe motor disturbance or vesicorectal impairment.

References


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