Utility of neurophysiological monitoring using dorsal column mapping in intramedullary spinal cord surgery

Clinical article

Daniel S. Yanni, M.D.,1 Sedat Ulkatan, M.D.,2 Vedran Deletis, M.D.,2 Ignacio J. Barrenechea, M.D.,1 Chandranath Sen, M.D.,1 and Noel I. Perin, M.D., F.R.C.S.Ed.1

1 Department of Neurological Surgery and 2 Division of Neurophysiology, St. Luke’s–Roosevelt Hospital, New York, New York

Object. Intramedullary spinal cord tumors can displace the surrounding neural tissue, causing enlargement and distortion of the normal cord anatomy. Resection requires a midline myelotomy to avoid injury to the posterior columns. Locating the midline for myelotomy is often difficult because of the distorted anatomy. Standard anatomical landmarks may be misleading in patients with intramedullary spinal cord tumors due to cord rotation, edema, neovascularization, or local scar formation. Misplacement of the myelotomy places the posterior columns at risk of significant postoperative disability. The authors describe a technique for mapping the dorsal column to accurately locate the midline.

Methods. A group of 10 patients with cervical and thoracic intramedullary spinal cord lesions underwent dorsal column mapping in which a strip electrode was used to define the midline. After the laminectomy and durotomy, a custom-designed multielectrode grid was placed on the exposed dorsal surface of the spinal cord. The electrode is made up of 8 parallel Teflon-coated stainless-steel wires (76-µm diameter, spaced 1 mm apart) embedded in silastic with each of the wires stripped of its insulating coating along a length of 2 mm. This strip electrode maps the amplitude gradient of conducted spinal somatosensory evoked potentials elicited by bilateral tibial nerve stimulation. Using these recordings, the dorsal columns are topographically mapped as lying between two adjacent numbers.

Results. The authors conducted a retrospective analysis of the preoperative, immediate, and short-term postoperative neurological status, focusing especially on posterior column function. There were 8 women and 2 men whose mean age was 52 years. There were 4 ependymomas, 1 subependymoma, 1 gangliocytoma, 1 anaplastic astrocytoma, 1 cavernous malformation, and 2 symptomatic syringes requiring shunting. In all patients the authors attempted to identify the midline by using anatomical landmarks, and then proceeded with dorsal column mapping to identify the midline electrophysiologically. In the 2 patients with syringomyelia and in 5 of the patients with tumors, the authors were unable to identify the midline anatomically with any certainty. In 2 patients with intramedullary tumors, they were able to identify the midline anatomically with certainty. Dorsal column mapping allowed identification of the midline and to confirm the authors' anatomical localization. In 2 patients with intramedullary tumors, posterior column function was preserved only on 1 side. All other patients had intact posterior column function preoperatively.

Conclusions. Dorsal column mapping is a useful technique for guiding the surgeon in locating the midline for myelotomy in intramedullary spinal cord surgery. In conjunction with somatosensory evoked potential, motor evoked potential, and D-wave recordings, we have been able to reduce the surgical morbidity related to dorsal column dysfunction in this small group of patients. (DOI: 10.3171/2010.1.SPINE09112)

Key Words • intramedullary spinal tumor • neurophysiological monitoring • intraoperative mapping • somatosensory evoked potentials • motor evoked potentials • dorsal column mapping

Intramedullary spinal cord surgery poses significant risk for neurological impairment. Intramedullary spinal cord tumors are rare neoplasms accounting for approximately 2–4% of CNS tumors.10 They are primarily astrocytomas and ependymomas. Astrocytomas commonly occur in the pediatric population and ependymomas in the adult population. They are very slow growing and can reach significant proportions within the spinal cord before becoming symptomatic. They tend to expand the spinal cord and can distort the surface anatomy.

Resection is the definitive treatment for intramedullary spinal cord tumors.4,5,7,10 Resection of large, centrally located intramedullary spinal cord tumors is achieved via a midline myelotomy. The midline in a normal cord is the dorsal median sulcus, located between the elevated posterior columns (Fig. 1A). The midline can also be identified by following the dorsal median sulcal vein as it enters the midline raphe and also by locating a point midway between the root entry zones on either side.

However, this anatomy is frequently distorted in cases of tumor, due to edema, neovascularization, or scar formation. The distortion can be a combination of cord rotation and asymmetrical enlargement, making identi-
fication of the surface anatomy extremely difficult (Fig. 1B and C). Inadvertent dissection through the dorsal columns will cause postoperative sensory deficits, including the loss of proprioception, which can be disabling.2,5,7

Dorsal column dysfunction is the most common cause of postoperative morbidity following myelotomy for spinal cord tumors, reported in 43.6% of patients in one series.7 Many authors believe that the dysfunction following intramedullary spinal cord surgery is, at least in large part, a result of injury to the posterior columns.5,7 The standard microsurgical splitting of the dorsal columns from within the dorsal median sulcus is performed after identifying the midline via standard anatomical landmarks without any objective neurophysiological data. Injury to the dorsal columns during this dissection can result in dysfunction manifesting as numbness, tingling, painful dysesthesias, or ataxic gait. This can be significantly incapacitating to the patient’s functional status and the ability to rehabilitate. Decreasing the risk of dorsal column dysfunction remains a challenge in the treatment of intramedullary spinal cord lesions requiring a midline myelotomy.

Together with the standard preoperative radiographic studies and intraoperative ultrasound to identify the exact location of the tumor within the spinal cord, we used an intraoperative functional technique of mapping the dorsal columns to help locate the midline for the myelotomy.6,8 This is accomplished by defining the amplitude gradient of conducted SSEPs using a miniature multielectrode grid. These signals are interpreted intraoperatively by the neurophysiology team correlating the surgical anatomy with the functional anatomy. We have found this tech-
Dorsal column mapping

Technique particularly useful in patients with large intramedullary spinal cord tumors and syringomyelia.

Methods

We performed a retrospective evaluation of patients who had undergone dorsal column mapping for identification of the midline for myelotomy (Table 1). There were 8 women and 2 men whose mean age was 52 years (range 30–76 years). Of the patients with intramedullary spinal cord tumors, there were 4 ependymomas, 1 subependymoma, 1 anaplastic astrocytoma, 1 gangliocytoma, and 1 cavernous malformation. Two patients had symptomatic syringomyelia requiring a syringopleural shunt. In all patients a myelotomy was performed after definitively identifying the midline, using the dorsal column mapping technique (Table 1).

In patients undergoing intramedullary spinal cord surgery, total anesthesia was induced using a continuous intravenous infusion of propofol and fentanyl to enable continuous monitoring of the MEPs and SSEPs.

All patients underwent a standard laminectomy performed with the patient in the prone position. After the dura mater was exposed, ultrasound was used to localize the tumor within the cord. The dura was subsequently opened in the midline and the dural edges were sutured to the adjacent muscle. In all cases the dorsal surface of the cord showed some distortion and raised doubts as to the exact location of the midline.

We have used an electrophysiological technique to accurately define the midline for the myelotomy, rather than depend solely on anatomical landmarks. The strip electrode used in our cases is a custom-designed miniature multi electrode grid, consisting of 8 parallel Teflon-coated stainless-steel wires (numbered 1–8), diameter 76 μm and the wires are spaced 1 mm apart and embedded in silastic. Each of the 8 wires was stripped of its insulation coating along a length of 2 mm. These recording wires run parallel to the long axis of the spinal cord, with a reference needle electrode placed in a nearby muscle.

The impedance for all recording surfaces is approximately 20 kΩ, the filter settings are 50–1700 Hz, and the epoch length is 50 msec. To ensure reproducibility, 2 sets of 100–200 sweeps are averaged from each of the 8 parallel recording surfaces after stimulation of each tibial nerve at the ankle. The grid is placed over the dorsal surface of the cord; to ensure good contact with the cord, a small paty is laid on the grid and gentle pressure is applied. To ensure reproducibility, 2 sets of 100–200 sweeps are averaged from each of the 8 parallel recording surfaces, after stimulation of the right and left tibial nerves at the ankle.

The stimulus intensity is 40 mA, duration is 0.2 msec, and the repetition rate is 13.3 Hz. This multielectrode grid is able to record conducted SSEPs from the dorsal surface of the exposed spinal cord with the amplitude gradient corresponding to the topographic anatomy of the dorsal column.

After obtaining the traces, the neurophysiologist notes the locations of the maximal amplitudes on the traces. Maximum amplitudes occur where there is a dense collection of dorsal column fibers. The midline is determined as the point lying between 2 maximum-amplitude recordings obtained after stimulation of the right and left tibial nerves.

We did not measure the distance between the surgeon’s anatomical midline and the physiological midline obtained with mapping. However, in 3 of the cases the anatomical midline corresponded to the determined physiological midline.

The midline was noted as the point located between 2 maximum amplitudes recorded between the determined numbers (from 1 to 8) and a midline myelotomy was carried out. Sutures were then placed in the pial layer and attached to the adjacent dural edges; these sutures allowed for gentle retraction as the planes were established. Epidural electrodes were placed above and below the levels of the durotomy to monitor D-waves. Central debulking of the tumor was performed to further develop the plane between the tumor and normal white matter. A gross-total resection was achieved in patients with the ependymomas, ganglioglioma, and subependymoma, and

<table>
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<th>Case No.</th>
<th>Age (yrs)</th>
<th>Diagnosis</th>
<th>Syrinx</th>
<th>Location of Lesion</th>
<th>Dorsal Column Function Preop</th>
<th>Postop</th>
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<tr>
<td>1</td>
<td>35</td>
<td>ependymoma (tanycytic)</td>
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<td>C2–4</td>
<td>mild</td>
<td>intact</td>
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<td>2</td>
<td>68</td>
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<td>no</td>
<td>T7–8</td>
<td>rt LE proprioception</td>
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<td>3</td>
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<td>yes</td>
<td>C1–T6</td>
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<td>mild</td>
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</tr>
</tbody>
</table>

* LE = lower-extremity; Oc = occipital.
in the patient with the anaplastic astrocytoma, a subtotal resection was achieved.

**Results**

In all patients a strip electrode with antidromically elicited SSEPs was used to identify the site for myelotomy. All patients also underwent SSEPs, MEPs, and D-wave monitoring throughout the operation. Gross-total resection of the tumors was achieved in the 3 patients with ependymomas, the 2 patients with subependymomas, and the patient with the intramedullary cavernous malformation. The patient with the anaplastic astrocytoma had a small residual tumor. In 2 patients a syringopleural shunt was placed with dorsal column mapping guidance.

**Illustrative Cases**

*Case 1*

This 35-year-old woman presented with a 3-month history of intractable neck pain radiating to both shoulders and associated with bilateral upper-extremity numbness and tingling. Neurological examination revealed motor weakness in both triceps muscles (Grade 3+/5), and sensory examination revealed diminution to pinprick sensation over the tips of all the fingers. Deep tendon reflexes were Grade 3+/5, brisk in all 4 extremities, with a positive Hoffman sign, without up-going toes or clonus. Joint-position sense was preserved in the right hand and both lower extremities but impaired in the left hand. Cervical MR imaging revealed a large, partially cystic, enhancing intramedullary tumor at C2–3 (Fig. 2). On MR imaging edema was noted to extend up the cervical cord and down to the upper thoracic cord. Intraoperatively, the spinal cord was noted to be edematous and enlarged, distorting the normal anatomical landmarks. The dorsal median sulcus was not well visualized. Dorsal column mapping with the grid electrode established the physiological midline as lying between electrode Numbers 1 and 2. This location was to the right of the selected anatomical midline, which was at electrode Number 4. The longitudinal myelotomy was made between electrodes Numbers 1 and 2.

A gross-total removal of the tumor was achieved. Histological inspection showed a tancytic ependymoma. Postoperatively, the patient had some weakness in both hands but maintained good lower-extremity strength and preservation of joint-position sense. She had a month of inpatient rehabilitation prior to being discharged home. At 3-month follow-up, the patient had some difficulty, weakness, and numbness in the left leg. Neurological examination revealed diffuse weakness in the left leg (3+/5) with more proximal weakness than distal. She had sensory loss and loss of joint position sense in the left lower extremity. She was also myelopathic, but this myelopathy was residual from her prior cord injury. Magnetic resonance imaging revealed a large syrinx expanding the cord and extending up from the site of the posterior surgery up to the cervicothoracic junction (Fig. 3).

The patient's prior thoracotomy incision was reopened. There was extensive scarring, and we were unable to determine the midline or the root entry zone anatomically. The grid electrode was used to identify the midline, allowing us to avoid injury to the posterior columns and place our myelotomy more laterally at the root entry zone.

*Case 2*

This 63-year-old woman had undergone a thoracoscopic discectomy 2 years previously for a large calcified thoracic disc and spinal cord compression; at that time, an adjacent-level ventral thoracic spinal cord hernia was also noted. The latter was addressed via a posterior approach 3 months later. After reducing the herniated spinal cord a sling was placed intradurally to close the ventral dural defect.

The patient returned 2 years later with increasing gait difficulty, weakness, and numbness in the left leg. Neurological examination revealed diffuse weakness in the left leg (3+/5) with more proximal weakness than distal. She had sensory loss and loss of joint position sense in the left lower extremity. She was also myelopathic, but this myelopathy was residual from her prior cord injury. Magnetic resonance imaging revealed a large syrinx expanding the cord and extending up from the site of the posterior surgery up to the cervicothoracic junction (Fig. 3).

The patient's prior thoracotomy incision was reopened. There was extensive scarring, and we were unable to determine the midline or the root entry zone anatomically. The grid electrode was used to identify the midline, allowing us to avoid injury to the posterior columns and place our myelotomy more laterally at the root entry zone.

**Discussion**

The preferred treatment for primary intramedullary spinal cord tumors is resection. Ependymomas and astrocytomas are the 2 most prevalent intramedullary tumors encountered. Most series show a predominance of ependymomas in the adult population with astrocytomas accounting for roughly 30% of those reported.

Radiographically, ependymomas are more centrally situated with more distinct margins. They enhance homogeneously and generally have large associated cystic cavities. Early resection of these tumors, prior to onset of significant neurological deficits, offers better overall outcomes. Needle biopsy is unreliable and therefore not recommended in patients with intramedullary spinal cord tumors.

The surgical approach to these intramedullary tumors is through a midline myelotomy between the dorsal columns. The midline in the normal spinal cord is the sulcus between the elevated posterior columns, midway between the root entry zones. However, in the presence of intramedullary tumors the surface anatomy can be significantly altered, from cord edema, capillary neo-
vascularization, arachnoid scarring, and rotation of the cord. Injury to the posterior columns due to inaccurate placement of the myelotomy incision and the retraction of the posterior columns to access the tumor can produce changes in the SSEPs with decreased amplitude and/or increased latencies.

During resection of intramedullary lesions, intraoperative neurophysiological monitoring has become a standard of care. In addition to dorsal column mapping, we routinely monitor MEPs, SSEPs, and D-waves in all of our cases (Fig. 4).1,2,9

Motor evoked potentials are elicited by transcranial electrical motor cortex stimulation. The “multipulse” stimulation technique induces electromyographic responses in the peripheral muscles. The single stimulus technique evokes D-waves, which are recorded from an epidural electrode placed caudal to the lesion. Monitoring of D-waves primarily allows evaluation of the peak-to-peak amplitude. Loss of muscle MEPs and/or a decrease in the D-wave amplitude should serve as a warning to the surgeon of impending injury to the motor pathways.3 In situations as this, we wait for the potentials to recover, irrigate with warm saline, and elevate the mean arterial blood pressure to optimize spinal cord perfusion. Intraoperative neurophysiological monitoring combined with improved microsurgical techniques can help reduce the incidence of postoperative sensory and motor deficits following intramedullary spinal cord tumor surgery.

The importance of dorsal column dysfunction following intramedullary spinal cord surgery has not been adequately emphasized in the literature. The myriad symptoms falling under the category “dorsal column dysfunction” include generalized numbness, painful dysesthesias below the surgical level, proprioceptive loss, and gait dysfunction. These deficits can be very disabling even with good postoperative motor function.

More recently, we have been able to monitor the dorsal columns to accurately localize the midline for myelotomy using a miniature microelectrode grid made up of 8 parallel Teflon-coated stainless-steel wires numbered from 1 to 8. After stimulation of both tibial nerves at the ankle, the grid placed on the exposed spinal cord can re-
cord the conducted SEPs, with the amplitude gradients corresponding to the topographic anatomy of the dorsal columns.\textsuperscript{3,4,11} The neurophysiology monitoring team thus is able to guide the surgical team to the location of the midline as lying between 2 numbers on the grid. By moving the grid rostrally or caudally on the exposed spinal cord, the surgeon and neurophysiology team are able to identify and track the midline along a segment of cord enlargement or rotation. Thus, we have been able to place the myelotomy at the selected site with good postoperative results with respect to new “dorsal column dysfunction.”

We also have taken other precautions to avoid over-manipulation of the dorsal columns intraoperatively. We used pial sutures with gentle steady retraction to stabilize the dorsal columns during the case. Additionally, we debulk the center of the tumor early to develop the tumor/spinal cord plane before retracting the dorsal columns.

This technique has also proven useful in other cases of intramedullary pathology, including syringomyelia. In one of the patients in our series with syringomyelia, the cord was rotated and the midline was moved to the right lateral recess of the spinal canal. By using the dorsal column mapping technique, we were able to appropriately place the myelotomy for drainage and shunting of the syrinx.

Overall, dorsal column mapping is a relatively new application and therefore the number of patients in this group is small, making it difficult to draw definitive conclusions. However, these early data are reassuring that this technique may be another tool to help minimize postoperative dorsal column dysfunction. We hope to recruit more patients prospectively for dorsal column mapping and compare with historical retrospective cohorts to achieve statistical significance.

Conclusions

Dorsal column dysfunction following intramedullary spinal cord surgery often causes significant neurological deficits that can include generalized numbness, painful paresthesias, loss of proprioception, and gait imbalance. The inability to definitively identify the midline in these patients because of cord edema and cord rotation can contribute to injuries to the dorsal columns. Dorsal column mapping has proven to be a safe and effective method for identifying the functional midline of the spinal cord in intramedullary spinal cord surgery. Using an electrode array, we were able to locate the physiological midline and place the myelotomy safely, thus reducing injury to the posterior columns.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

References


Address correspondence to: Noel I. Perin, M.D., Department of Neurological Surgery, Suite 5G-80, St. Luke’s–Roosevelt Hospital, 1000 Tenth Avenue, New York, New York 10019. email: nperin@chpnet.org.