The validity of electrophysiological criteria used in selective functional posterior rhizotomy for treatment of spastic cerebral palsy

PAUL STEINBOK, M.B., B.S., F.R.C.S.(C), ROBERT KEYES, M.D., F.R.C.P.(C), LISA LANGILL, R.E.T., R.T.(EMG), R.EPT., AND D. DOUGLAS COCHRANE, M.D., F.R.C.S.(C)

Department of Surgery and Department of Medicine (Faculty of Medicine), University of British Columbia, and Division of Neurosurgery, Section of Surgery, Division of Neurology, and Department of Diagnostic Neurophysiology, B.C.'s Children's Hospital, Vancouver, British Columbia, Canada

Although selective functional posterior rhizotomy (SFPR) is an established procedure for the treatment of spasticity, the electrophysiological criteria used to define which posterior rootlets should be cut have not been standardized. The purpose of this study was to determine the validity of the intraoperative electrophysiological criteria used to select posterior rootlets for sectioning in SFPR.

Intraoperative stimulation of posterior lumbosacral nerve roots and rootlets, using a 50-Hz stimulus at threshold intensity, was performed in five nonspastic children (controls) undergoing laminectomy for spinal cord untethering and in 32 spastic patients undergoing SFPR. Electromyographic responses were recorded in the upper and lower limbs, the neck, and the face. The pattern of sustained responses was assessed in detail in 17 additional patients who had previously undergone SFPR and in the five controls. Sustained responses with ipsilateral lower limb extrasegmental spread occurred in both spastic patients and the control group. Contralateral lower limb spread and suprasegmental spread to the upper limbs, neck, and face were found only in spastic children. Sustained responses with an incremental pattern were restricted to the spastic population and correlated well with the extent of contralateral and suprasegmental spread, whereas decremental patterns were not associated with contralateral spread.

It is concluded that contralateral and suprasegmental spread into the upper limbs, neck, and face, and incremental responses are probably valid criteria of abnormality.

KEY WORDS • posterior rhizotomy • electrophysiological criteria • spasticity • cerebral palsy

SELECTIVE functional posterior rhizotomy (SFPR) is based on the concept that one can define, by the responses to intraoperative electrical stimulation, populations of rootlets within the posterior roots that are maximally involved in the maintenance of spasticity. If so, then one should be able to selectively cut these involved fibers to produce optimum relief of spasticity with the least disturbance of sensory or motor function. Although the procedure has been adopted in many centers and the results have been favorable,1,4,6,10,11,13,15 the electrophysiological criteria used to define which posterior rootlets should be cut have not been standardized, and the validity of any of the criteria used has not been established.

The electrophysiological criteria originally used to define a posterior rootlet that should be divided in SFPR included: 1) a low threshold to single stimulus; 2) a sustained response to a 50-Hz tetanic stimulation; and 3) diffusion of the response to muscle groups not involved with the rootlet's segmental distribution.4,10 In this report, we compare the electrophysiological responses to posterior root and rootlet stimulation in spastic children having an SFPR procedure with those seen in a control group of nonspastic children undergoing lumbosacral laminectomy for a tethered spinal cord. The purpose was to determine whether the presence of a sustained response or spread of the response was valid as an electrophysiological criterion in SFPR.

More recently, attention has been given to using a detailed analysis of the patterns of the sustained response or the H2/H1 ratio to guide the selection of posterior nerve rootlets to be saved or cut.13,14 In this report, we also examine the pattern of the sustained responses in both spastic and nonspastic patients to determine the validity of such an analysis in identifying posterior rootlets to be sectioned during SFPR.
Electrophysiological criteria in posterior rhizotomy

![Graph showing examples of unsustained and sustained responses](image)

**Clinical Material and Methods**

**Comparison of Electrophysiological Responses**

Electromyographic (EMG) responses to a 1-second 50-Hz electrical stimulation of posterior lumbosacral nerve roots were analyzed retrospectively in two groups of children: one group consisted of 32 consecutively treated patients who had undergone SFPF for treatment of spastic diplegia or quadriplegia associated with cerebral palsy, and the other included five children without lower limb spasticity or hyperreflexia who underwent laminectomy in the lumbosacral area with intradural exploration for untethering of the spinal cord. We examined whether the response was sustained (Fig. 1) and the extent of spread of the response to muscle groups outside the segmental distribution of the nerve root. A sustained response was defined as one in which electrical activity continued for at least the total duration of the 50-Hz stimulus.

**Stimulation Technique.** In the 32 patients undergoing SFPF, the posterior nerve root was separated from the anterior nerve root and each posterior root was stimulated individually. Each posterior nerve root was then divided into multiple bundles, termed “rootlets,” which were stimulated individually in an attempt to identify which rootlets should be divided. This was repeated at every level from L-2 through S-2 bilaterally. In the five children without spasticity, posterior roots were identified and stimulated as above, but the posterior roots were not subdivided into rootlets.

All intraoperative stimulation was given via two modified nerve hooks* which served as unipolar electrodes. The electrodes were positioned on the nerve approximately 1 cm apart. A single stimulus was given with increasing intensity until the threshold of response was reached. A Grass SD9 constant-voltage square-wave stimulator was used with a stimulus intensity varying from 10 to 100 mV, a stimulation duration of 0.1 msec, and a delay time of 0.01 msec; a biphasic stimulus output was used. The threshold of response was defined as the stimulus intensity at which the first muscle contraction was noted visibly in the segmental distribution of the posterior rootlet or root being stimulated. Tetanic stimulation at 50 Hz was then applied for a duration of 1 second at the threshold level of stimulation.

**Recording Technique.** The EMG recordings were made from silver chloride surface electrodes applied to the muscles of both lower limbs including the hip adductor, quadriceps, tibialis anterior, and gastrocnemius muscles. In 16 spastic patients and two nonspastic control patients, surface electrodes were also placed on the extensor digitorum communis and deltoid muscles in both upper limbs and the sternocleidomastoid and masseter muscles on one side depending on the position of the head. All responses were recorded using a 17-channel electromyograph machine.

**Anesthesia.** All 37 patients were anesthetized in the same manner. Following intravenous induction and intubation with succinylcholine, light general anesthesia was maintained with a volatile agent and a narcotic drug. No neuromuscular blocking agents were used after intubation.

**Analysis of the Pattern of Sustained Responses**

In 17 additional children who had previously undergone SFPF and in the five nonspastic children described above, the pattern of each sustained response was analyzed retrospectively and categorized into either decremental, incremental, flat (square wave), or clonic (multiphasic) patterns (Fig. 2). In the spastic pa-

---

* Hook electrodes manufactured by Aesculap Surgical Instruments, Burlingame, California.
tients the pattern of the sustained responses was correlated with the extent of spread of the response and whether the rootlet had been divided.

**Recording and Stimulation Techniques.** The technique of nerve root stimulation was identical to that described above. Electrical recordings were made from surface electrodes placed over the muscles of both lower limbs, upper limbs, and sternocleidomastoid and masseter muscles in the 17 patients who had undergone SFPR.

**Process of Nerve Rootlet Selection.** In the 17 patients who had previously undergone SFPR the only electrophysiological criterion used to select which rootlets to cut was the extent of contralateral and suprasegmental spread in response to 50-Hz tetanic stimulation of posterior nerve rootlets. The nerve rootlets were considered to be involved in the spastic process if there was spread to the contralateral lower limb, particularly if the spread also included the upper limbs or the sternocleidomastoid or masseter muscles.

**Results**

**Comparison of Electrophysiological Responses**

**Patients with Spastic Quadriplegia.** The 32 patients undergoing SFPR ranged in age from 3 to 17 years with a median age of 4.6 years. Twelve children were quadriplegic, seven triplegic, and 13 diplegic. A total of 384 posterior roots were stimulated, comprising four L-1 roots, 64 each of L-2, L-3, L-4, L-5, and S-1 roots, and 60 S-2 roots. Of these stimulated posterior roots 383 (99.7%) showed a sustained response to 50-Hz stimulation. In response to stimulation at threshold level intensity, 92 posterior nerve roots (24%) exhibited ipsilateral spread only, which involved all muscle groups in the lower limbs (Fig. 3a). In the remaining 292 roots (76%) spread involved both the ipsilateral and contralateral lower limbs (Fig. 3b and c). Spread to the upper limbs, neck, and face could be assessed in 192 posterior roots in 16 children, and such spread was noted in 124 posterior roots (64.6%) (Fig. 4).

A total of 1208 posterior rootlets were stimulated in 32 children, and a sustained response to 50-Hz stimulation was noted in all. Ipsilateral lower limb spread following 50-Hz stimulation was present in all rootlets, with mild contralateral spread in 634 (52.5%) and marked contralateral spread in 234 (19.4%). When contralateral spread in the lower limbs occurred, there was usually spread to all muscle groups in the opposite limb; when the response did not spread to all contralateral lower limb muscles, there was no discernible pattern. Spread did not occur preferentially to antagonist muscle groups or to muscles below or above the segmental level. Spread to the upper limbs, neck, and face could be studied in 764 rootlets in 16 patients, and was noted in 245 rootlets (32%).

**Nonspastic Patients.** The five nonspastic patients ranged in age from 1.4 to 7.8 years with a median of 6.0 years. None had any upper motor neuron findings in the lower limbs and four had a normal neurological examination; one child had weakness and decreased reflexes in one lower limb (Table 1). In these nonspastic children, only L-5, S-1, and S-2 nerve roots were stimulated and recordings were made from 20 posterior roots.

In 14 posterior roots there was a sustained response to 50-Hz stimulation at the threshold level of stimulus intensity with spread to all muscles of the ipsilateral lower limb, whereas in six posterior roots there was no sustained response. In one root there was minimal spread to the contralateral lower limb. In the two children in whom recordings were monitored from the upper limbs, face, and neck, there was minimal spread to the ipsilateral upper limb in two of 10 roots with 50-Hz stimulation. Spread did not occur contralaterally or to the neck and face.

**Analysis of the Pattern of Sustained Responses**

**Children With Spasticity.** The 17 patients who had previously undergone SFPR ranged in age from 2.5 to 10 years, with a median age of 5.3 years. Eight children
Electrophysiological criteria in posterior rhizotomy

![Electrophysiological criteria in posterior rhizotomy](image)

**FIG. 4.** Pattern of response to 50-Hz stimulation of the left L-5 posterior root in a spastic child. There is contralateral lower limb spread and spread into both upper limbs and the sternocleidomastoid and masseter muscles. EDC = extensor digitorum communis.

**TABLE 1**

<table>
<thead>
<tr>
<th>Age at Surgery (yrs)</th>
<th>Clinical Presentation</th>
<th>Neurological Examination</th>
<th>Pathology</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>weak rt leg</td>
<td>decreased strength &amp; reflexes in rt leg.</td>
<td>diastematomyelia</td>
</tr>
<tr>
<td>1.7</td>
<td>scoliosis</td>
<td>1 foot turn in when walking</td>
<td>tight filum</td>
</tr>
<tr>
<td>7.8</td>
<td>enuresis</td>
<td>normal</td>
<td>tight filum</td>
</tr>
<tr>
<td>7.8</td>
<td>encoparesis, urinary incontinence</td>
<td>normal</td>
<td>tight filum</td>
</tr>
<tr>
<td>1.4</td>
<td>hairy patch</td>
<td>normal</td>
<td>tight filum</td>
</tr>
</tbody>
</table>

had spastic quadriplegia, three spastic triplegia, and six spastic diplegia. A total of 725 rootlets were analyzed, comprising 102 S-2, 142 S-1, 142 L-5, 117 L-4, 115 L-3, 99 L-2, and eight L-1 rootlets. Of these rootlets, 49% were cut during the procedure.

The extent of spread and the relationship between this and the number of rootlets cut are shown in Table 2. The patterns of the sustained responses are documented in Table 3. The relationship between the pattern of the sustained responses and the extent of spread was analyzed (Fig. 5). In the nerve rootlets that demonstrated unilateral lower limb spread there was a preponderance of decremental responses, whereas in the rootlets that demonstrated suprasegmental spread (such as to the upper limbs, neck, and face) there was a preponderance of incremental responses. Flat responses occurred in similar percentages in rootlets that demonstrated ipsilateral spread, contralateral lower limb spread, or suprasegmental spread; clonic responses tended to occur more in patients showing the greatest extent of spread. The relationship between the pattern of the response and whether the nerve rootlet was cut or saved was analyzed (Fig. 6). Almost every nerve rootlet that had a decremental response was

![Electrophysiological criteria in posterior rhizotomy](image)

**TABLE 2**

<table>
<thead>
<tr>
<th>Extent of Spread</th>
<th>Involved Rootlets</th>
<th>Rootlets Cut</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>Percent</td>
</tr>
<tr>
<td>unilat leg</td>
<td>199</td>
<td>27</td>
</tr>
<tr>
<td>bilat leg</td>
<td>187</td>
<td>26</td>
</tr>
<tr>
<td>bilat lower &amp; upper limbs</td>
<td>56</td>
<td>8</td>
</tr>
<tr>
<td>bilat lower limb, upper limb, sternocleidomastoid &amp; masseter muscles</td>
<td>283</td>
<td>39</td>
</tr>
</tbody>
</table>

**TABLE 3**

<table>
<thead>
<tr>
<th>Response Pattern</th>
<th>Rootlets with Sustained Response</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
</tr>
<tr>
<td>decremental</td>
<td>152</td>
</tr>
<tr>
<td>flat</td>
<td>267</td>
</tr>
<tr>
<td>clonic</td>
<td>81</td>
</tr>
<tr>
<td>incremental</td>
<td>225</td>
</tr>
</tbody>
</table>

![Electrophysiological criteria in posterior rhizotomy](image)

**FIG. 5.** Bar graph demonstrating the relationship of the pattern of sustained response to the extent of spread of the response (number of rootlets). "Suprasegmental" indicates spread to the upper limbs, the sternocleidomastoid muscle, and/or the masseter muscle.
was related to neurons posterior to the rootlet. It was demonstrated that repetitive stimulation of the nerve rootlet at frequencies of 30 to 50 Hz was a sustained response to 50-Hz stimulation. Of these, none had an incremental response, three showed a decremental response, nine had flat responses, and two exhibited clonic responses.

Discussion

Concept Underlying Posterior Rhizotomy

The concept underlying the procedure of SFPR for treatment of spasticity in the lower limbs was derived from experimental work in cats, in which it was demonstrated that repetitive orthodromic stimulation of posterior roots caused reflex depression of spinal motor neurons as the rate of stimulation increased from 10 to 50 Hz. It was postulated that this inhibitory activity was related to normal presynaptic inhibition. Fasano, et al., suggested that similar responses might be normal in humans and that lack of inhibition in spastic patients might lead to different, less inhibited, responses to posterior root stimulation. If indeed this was the case, then it might be possible to differentiate, based on the results of intraoperative stimulation, between those rootlets involved in the spastic process and those not so involved. By cutting the former rootlets and preserving the latter, spasticity might be relieved while preserving sensory function.

Electrophysiological Criteria

Fasano, et al., reviewed their results of electrical stimulation of posterior rootlets in children with spastic diplegia and subdivided the responses into three distinct groups. In the first situation, repetitive stimulation of the nerve rootlet at frequencies of 30 to 50 Hz produced muscle contraction only with the first stimulus; during the remainder of the stimulation period, there was relaxation. Stimulation of these nerve rootlets caused contraction only in one or two muscle groups in the ipsilateral limb. These rootlets were believed to be inserted in spinal circuits having normal inhibitory activity and thus it was believed that they were normal. A second population of nerve rootlets could be identified where the response to repetitive stimulation at 30 to 50 Hz was a sustained and synchronous activation of muscles. There was often abnormal activation of other circuits, such that there was spread of the muscle response to affect the contralateral lower limb, the upper limbs, or even the trunk and neck muscles. It was believed that these nerve rootlets were inserted in spinal circuits in which the normal inhibitory processes were lacking and were therefore involved in the maintenance of spasticity. This latter group of nerve rootlets would then be cut in an attempt to relieve the spasticity. A third group of responses that was observed in some cases was an excess of inhibition, often corrected by sectioning an adjacent root in which this inhibition was lacking.

Peacock, et al., who modified the procedure of selective functional rhizotomy as described by Fasano, et al., indicated that the posterior rootlet being stimulated was divided if it had "a low threshold, was associated with a sustained muscular contraction or with diffusion of contraction to muscle groups not belonging to that rootlet's segmental distribution. If the rootlet had a high threshold, if the muscle's duration of contraction was brief and diffusion of contraction did not occur, that rootlet was left intact."

The electrophysiological criteria that we used initially were those described by Peacock, et al.. A sustained response with ipsilateral lower limb spread outside the immediate segmental distribution of the nerve root being stimulated was noted in almost every nerve root or posterior rootlet stimulated. Thus, according to the criteria described, almost every rootlet could be considered abnormal (that is, involved in the maintenance of spasticity). The decision to cut certain posterior rootlets was based not on the finding that some rootlets were "normal" while others were "abnormal," but that some rootlets were more abnormal than others.

Normal Electrophysiological Responses

In order to determine what the so-called "normal" response might be in the human situation, dorsal root stimulation was carried out in five children who had no spasticity in the limbs. Although these children were not normal since they were undergoing operation for a tethered spinal cord, they had no spasticity or upper motor neuron findings and four of the five were normal on neurological examination. A so-called "normal" response with inhibition of the anterior motor neuron output at 50-Hz stimulation was noted in six of 20 posterior roots stimulated. In the other 14 roots, a sustained response to 50-Hz stimulation occurred. It was clear that, in the human child, the presence of a sustained response to 50-Hz stimulation of the posterior root could not be taken as evidence of an abnormality related to the maintenance of spasticity. Similar findings were documented by Cohen and Webster in one other nonspastic child.
Electrophysiological criteria in posterior rhizotomy

Pattern of Response Spread

Since recordings were made simultaneously from multiple muscles in both lower limbs, and more recently also from the muscles in the upper limbs, neck, and face, it was possible to look at the patterns of spread of the response to 50-Hz stimulation of posterior roots and rootlets in spastic versus nonspastic children. In nonspastic children 50-Hz stimulation produced minimal spread to the muscles of the contralateral lower limb in only one of 20 roots, whereas in spastic children significant contralateral spread was common (76%). In the two nonspastic children in whom monitoring was obtained on the upper limbs, neck, and face, there was minimal spread into the ipsilateral upper limb in two of the 10 roots stimulated; in the spastic children, spread often occurred into both upper limbs, neck, and face, as described also by Fasano, et al.8 These findings suggest that the presence of contralateral lower limb and suprasegmental spread might be a valid criterion to define a posterior nerve rootlet that feeds into a dis-inhibited spinal circuit and that may be involved in the maintenance of spasticity.

Modification of Electrophysiological Criteria

The results of posterior root stimulation in nonspastic children resulted in a change in the criteria used in our unit to define which posterior rootlets should be cut.13 The threshold level, the presence of a sustained response to 50-Hz stimulation, and the presence of ipsilateral spread to other muscles in the lower limb were not considered. The only electrophysiological criterion used to define an abnormality was the presence of spread to the contralateral lower limb and into the upper limbs and above. Using this criterion, approximately one-quarter of the stimulated posterior rootlets were considered normal (with no contralateral spread). All other rootlets could be considered abnormal but not all of these were cut. In general, nerve rootlets that showed only a mild amount of contralateral spread were spared, whereas rootlets that showed marked spread to the opposite lower limb and particularly those that showed spread into the upper limbs, neck, and face were divided (Table 2). The final decision about the amount of any particular posterior root that was going to be divided was based on knowledge of the clinical status of the patient and the extent of abnormality noted on electrical stimulation. Thus, there was subjectivity involved in choosing the rootlets that were finally divided. The end result was that fewer nerve rootlets were being cut based on the new criteria compared to the previous protocol, but this could not be attributed completely to the change in electrophysiological criteria.

Other workers have modified the electrophysiological criteria used in SFPR, but along different lines. Vaughan, et al.,15 examined in detail the pattern of the "sustained" response to a 50-Hz stimulation and considered decremental responses to be normal (even if the response was sustained) and incremental responses to be abnormal. Storrs and Nishida16 utilized a different approach during rhizotomy for the identification of rootlets involved in the spastic process. They assessed the "H" reflex recovery curve in response to intraoperative bipolar stimulation of posterior rootlets. Previously, Mayer and Mosser,9 using posterior tibial nerve stimulation, showed a reduction in amplitude from H1 to H2 of 70% to 91% at a 100-msec interstimulus interval in normal children; this reduction was 30% to 70% in adults. In a study by Futagi, et al.,78 of children with spastic cerebral palsy, the decrease from H1 to H2 was smaller, with a corresponding increase in the ratio of H2:H1. Storrs and Nishida arbitrarily selected a value of more than 50% in the H2:H1 ratio as the criterion of abnormality, and sectioned rootlets with ratios above this level. Neither Vaughan, et al., nor Storrs and Nishida attempted to validate these newer electrophysiological criteria by comparing the findings in nonspastic controls with those in the spastic patients.

Analysis of the Pattern of Sustained Responses

Since a permanent record of responses to the rootlet stimulation had been obtained in our patients, a detailed analysis of the pattern of the sustained responses both in normal and in spastic children was performed to determine how valid the pattern analysis might be in selecting the posterior rootlets involved in the spastic process. Our analysis of the nonspastic children indicated that decremental, flat, and clonic patterns occurred in the spastic situation, but incremental patterns were not seen, suggesting that an incremental pattern might well be one that was abnormal and could indicate involvement of that particular posterior rootlet in the maintenance of spasticity. In the spastic children, the relationship between the pattern of sustained response and the extent of spread was analyzed and it was shown that, in patients with the least amount of spread (ipsilateral lower limb spread only), decremental and flat responses were common and clonic and incremental responses were rare. As the extent of spread increased, the percentage of rootlets showing an incremental response and a clonic response also increased, whereas decremental responses became less frequent. Thus, in the rootlets that exhibited the most spread, with spread to both lower limbs and to the upper limbs, the sternocleidomastoid muscle, and/or the face, there was a high proportion of incremental responses with a very small number of decremental responses. Flat responses occurred across all groups of spread. It could be concluded from this that a decremental response should be considered normal and an incremental response abnormal, whereas a flat response might or might not be associated with a posterior rootlet involving the spastic process and a clonic response tended to be more abnormal, although not as definitively abnormal as an incremental response.

Analysis of the response type was done retrospectively, and in the 17 previous patients analyzed, the only electrophysiological criterion on which a decision to cut or save a particular posterior rootlet had been based was the extent of contralateral and suprasegmental spread that had been noted in response to 50-Hz stimulation. Thus, it was interesting to go back and deter-
mine how the number of rootlets cut or saved solely on the basis of extent of spread might correlate with the pattern type of that electrical response. It was noted that almost every rootlet demonstrating a decremental response was saved, whereas almost every rootlet displaying an incremental response was cut (Fig. 2). On the other hand, the presence of a flat or a clonic response did not predict very accurately whether that nerve rootlet would have been cut based on the electrophysiological criterion of the extent of spread.

Relationship of Electrophysiological Criteria to Outcome

If the underlying concept of SFPR is correct, it should be possible by using more valid electrophysiological criteria to identify the posterior rootlets to be sectioned to achieve optimum results while sparing the maximum percentage of posterior root fibers. With the introduction of the new electrophysiological criteria based on the extent of contralateral or suprasegmental spread only, the percentage of posterior roots being cut during SFPR decreased compared to previous procedures. In an analysis of the first 50 patients undergoing SFPR at our institution (only six patients were included in whom the new electrophysiological criteria had been used), reduction of spasticity, improvement in range of motion, and functional improvement appeared similar to the results that had been obtained in the previous 44 patients using the original electrophysiological criteria. A more detailed analysis of a larger number of patients undergoing SFPR using the new electrophysiological criteria and followed for a longer period of time is currently being performed.

Study Findings

The comparisons of electrophysiological responses between the nonspastic children and the spastic children have indicated that many of the original electrophysiological criteria proposed for use in the SFPR procedure are not valid. The presence of a sustained response to 50-Hz tetanic stimulation for 1 second is definitely not useful as a discriminator of posterior rootlets that might be maintaining the spastic process. Among the criteria that appear to be valid are the excessive spread of the response, either contralaterally to the other lower limb or particularly suprasegmentally to the upper limb, cervical musculature, or facial musculature, and the presence of an incremental pattern of the sustained response to 50-Hz tetanic stimulation.

If it is believed that the results of a partial posterior rhizotomy are enhanced by selection of the posterior rootlets to be cut based on the functional results of intraoperative electrical stimulation, it is important that the electrophysiological criteria have some validity. Currently, it is our practice to use as electrophysiological criteria, first, the extent of contralateral and suprasegmental spread, and then a modification of this by also examining the pattern of the sustained response as a secondary discriminator. The clinical situation of each patient is also taken into consideration, and the actual percentage of any divided posterior root is based to a large extent on the patient's clinical condition. Having decided the desirable percentage of a posterior root to cut, the electrophysiological criteria are then used to determine which rootlets to cut to achieve that end result. If the electrophysiological responses are especially abnormal in a particular posterior root, then slightly more may be cut than would have been cut based on the clinical picture; if the electrophysiological responses are relatively normal, then slightly less of that posterior root may be cut than otherwise. The decision of whether to cut a root is not simply based on the electrophysiological criteria, but involves a certain amount of judgment.

Areas of Criticism and Concern

The conclusions of this study are dependent on acceptance of the results from the nonspastic controls as indicators of what might occur in a normal child. It is recognized that the five control children in this study were not normal, having undergone an operation to untether the spinal cord. However, they had no evidence of an upper motor neuron lesion and qualify perhaps as the best controls available in the human situation for this type of study. In these patients (who had no upper motor neuron findings and no spasticity) it is important to recognize that there were sustained responses to posterior root stimulation and that such sustained responses were said previously to be indicative of a posterior root or rootlet that was involved with the spastic process. Although these nonspastic patients are not ideal controls, there is no doubt from analysis of the data obtained in these children that a sustained response does not indicate involvement of a posterior root in spasticity.

Another concern is that the responses to electrical stimulation noted in this study are not identical to those found in every institution in which the procedure is performed. Other neurosurgeons performing the SFPR procedure have indicated that the responses differ, and in some institutions the amount of spread is not as dramatic as reported or as found in our unit. The reasons for these differences are not clear, but could be related to the actual surgical portion of the procedure, the type of anesthesia, or the parameters of electrical stimulation and the recording of responses. One of the most obvious potential differences between our institution and some others may be the definition of the threshold during electrical stimulation; however, the threshold is not defined in most reports\textsuperscript{1,11,12} and in one report where it is defined it is similar to our definition.\textsuperscript{14} The threshold as we have defined it is the intensity at which a visible muscle contraction occurred in the segmental distribution of the posterior root or rootlet being stimulated. In our experience this has occurred at a stimulus intensity of 2 to 5 mV more than the intensity at which an electrophysiological response was noted. It can be argued that, by using as the threshold the point at which an actual visible muscle contraction occurs, the type of responses obtained and the spread of those responses are exaggerated compared to results obtained when an electrophysiological threshold is used. We doubt that
Electrophysiological criteria in posterior rhizotomy

this actually occurs since we have previously studied the responses to 50-Hz stimulation carried out at 25%, 50%, 75%, and 100% of threshold intensity and found that there were no responses at a level of 50% or below and at the level of 75% a response occurred in one-half of the patients; when a response did occur, the pattern and extent of spread were similar to those noted using threshold intensity, although the amplitude of the response was generally less than when an intensity of 75% of threshold was used as opposed to 100% of threshold. It has also been argued that perhaps some responses being noted are secondary effects related to the visible muscle contraction in the lower limb. The electrophysiologist involved in this study did not agree with this explanation; it is his opinion that the spread of the response, particularly to the contralateral lower limb and suprasegmentally, is a direct result of the electrical stimulation of the posterior root or rootlets. Whatever the cause, there is certainly variability in the responses to electrical stimulation between different institutions performing SFPR and one must be cautious about extrapolating the electrophysiological findings from any one center to others. It may be useful and important for each neurosurgical center performing SFPR to obtain internal nonspastic control information in order to validate the electrophysiological criteria being used in that particular unit.

It has not been proven whether refinement of the rhizotomy procedure by intraoperative electrical stimulation to assess function improves the outcome compared to a simpler partial posterior rhizotomy procedure, but if we are going to continue to perform the SFPR procedure, it is important that the criteria used as indicators of abnormality do in fact indicate such abnormality.

Acknowledgment

We wish to thank Sharon Gaschnitz for typing the manuscript.

References


Manuscript received March 2, 1993.
Accepted in final form November 24, 1993.
Address reprint requests to: Paul Steinbok, M.B.,B.S., F.R.C.S.(C), Division of Pediatric Neurosurgery, B.C.'s Children's Hospital, 4480 Oak Street, Vancouver, British Columbia V6H 3V4, Canada.