Dorsal selective rhizotomy through a limited exposure of the cauda equina at L-1

Technical note

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The technique of the dorsal selective rhizotomy as originally developed by Professor Fasano and by the author is described. The rhizotomy is performed through a one-level laminectomy at L-1. Exposure of the conus medullaris and the cauda equina at this level is adequate to thoroughly assess the reflex electrical response to stimulation of the lumbosacral roots and to section the selected roots/rootlets. This approach, based on over 100 surgical procedures, obviates the need for an extensive laminectomy in a growing child without compromising the clinical results.

KEY WORDS • cerebral palsy • spasticity • rhizotomy • cauda equina • operative technique

**Dorsal root rhizotomy** is an accepted procedure for the management of spasticity in a variety of conditions such as cerebral palsy, spinal cord injuries, and multiple sclerosis. Functional dorsal selective rhizotomy, as introduced in the mid-1970's at the University of Torino by Fasano, was performed through an L-1 laminectomy and with a strict intraoperative protocol. The procedure was subsequently popularized in the United States by Peacock, et al., and was performed through a L2-5 lumbar laminectomy. The intraoperative protocol was also different because the nerve roots were sectioned sequentially immediately after being stimulated.

The present article clarifies the original operative protocol as developed by Professor Fasano and the author. The author's experience is based upon 80 rhizotomies performed at the University of Torino and 40 rhizotomies performed at Thomas Jefferson University. The protocol is the one currently followed by the author when performing the dorsal selective rhizotomy.

The goal of the procedure is to produce long-lasting, meaningful reduction of the spasticity with minimal bone disruption and by sectioning the minimum number of dorsal roots necessary to accomplish the results. Minimal bone disruption is obtained by limiting the laminectomy to L-1. Minimization of the number of nerve roots sectioned is based on intraoperative electrical stimulation of the L1-S1 dorsal roots and systematic analysis of the reflex responses.

Limited exposure of the cauda equina at the level of the conus medullaris allows the procedure to be performed thoroughly and completely with minimal complications.

**Operative Procedure**

**Laminectomy**

The patient is placed on the operating table in the prone position on chest rolls. The L-1 spinous process is identified by x-ray film. An incision is made over the spinous process and an L-1 laminectomy is performed. After completion of the laminectomy the dura is opened longitudinally and the operating microscope is brought into the operative field.

**Identification of Anatomical Landmarks**

The intradural contents are evaluated. To properly perform the procedure, the following structures have to be in the operative field and must be clearly identified: 1) the conus medullaris; 2) both S-1 dorsal nerve roots and their entry zone; and 3) both L-1 nerve roots. Identification of the conus is usually straightforward. The dorsal S-1 nerve roots are the largest and most medial dorsal roots. They often come in contact in midline and almost completely cover the conus medullaris. They usually consist of 10 to 15 rootlets. When they are lifted upward and medially, one can readily visualize the conus medullaris and the smaller S2-4.
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Fig. 1. Operative view of the conus medullaris and cauda equina as seen after L-1 laminectomy and dural opening.

Fig. 2. Schematic drawing of the area visualized during the dorsal selective rhizotomy at L-1. The view is that obtained after an L-1 laminectomy and longitudinal opening of the dura. Only the dorsal roots are represented, since the ventral roots can only be visualized by retracting the dorsal roots. * = spinal cord; ** = S-1 dorsal root entry zone.

rootlets as they enter the cord (Fig. 1). The L-1 nerve root, at this level, is the most lateral one and can be traced to its exit into the foramen. The L-2 nerve root lies just medial to L-1, and becomes closer to the lateral wall of the spinal canal after the L-1 root has exited. The L-1 and L-2 dorsal roots usually consist of only two to three rootlets. The L3-5 dorsal roots are seen as a group of rootlets and cannot be individually identified with this exposure (Fig. 2). The ventral roots can be visualized if the dorsal roots are lifted up. The L-1 and L-2 ventral roots can be identified as they run laterally and increasingly closer to the corresponding dorsal roots.

It is extremely important to promptly identify the above-mentioned structures before proceeding to any further manipulations of the cauda equina (Fig. 1). Even minor manipulation of the cauda equina leads to disruption of the identifiability of the S-1 nerve roots as well as the distinction of the dorsal from the ventral roots. Initial clear establishment of the anatomical landmarks is of paramount importance. In the rare instance where the conus medullaris does not lie exactly at the L-1 level (no more than 5% to 10% in our series), the laminectomy can be extended in a cephalad or caudal direction as necessary. In our series, this has never resulted in an extension of the laminectomy of more than one level and most commonly consists of removing the caudal half of the T-12 or the upper half of the L-2 lamina.

**Tagging the Dorsal Root Bundles**

At this stage, bundles of the dorsal rootlets are tagged with threads of different colors, starting medially and proceeding laterally. The rootlet bundles are lifted up, the thread is passed under the rootlets, and the loop is held together by a small bulldog clamp. An effort is made to have about five or six rootlets in each bundle. Usually, L-2 and L-1 are individually tagged in separate bundles since they only consist of two to four rootlets. The color of each thread, the estimated tagged nerve root, and the number of rootlets tagged is entered sequentially in an intraoperative form. This allows identification of each group of rootlets later in the procedure. The same procedure is performed bilaterally. Care must be taken to keep the right and left tagged rootlets separated and clearly identified. Once this part of the procedure is finished, it is very difficult to recognize the dorsal apart from the ventral roots and even separating the right from the left S-1 nerve roots could pose a problem. Careful initial tagging and identification is therefore mandatory. Usually five or six groups of rootlets are tagged on each side, resulting in a total of 25 to 30 rootlets being tagged on each side (because rootlets can be still further subdivided into smaller filaments, the number of rootlets reported may vary among different reported series).

**Electrical Stimulation of Dorsal Roots**

At this stage each of the rootlet bundles is individually lifted up and stimulated with uni- or bipolar electrical stimulation. Initially, stimulation is performed at 1 Hz and the reflex motor contraction threshold is established. The voltage is then increased until well-defined strong muscle contractions are obtained. The contracting muscle groups are identified and charted. Then 50 Hz stimulation is given and the contracting muscles and contraction pattern (continuous or short-lasting) are observed and charted. The same procedure
is performed for each rootlet bundle bilaterally. Visual observation and palpation of the contracting muscles is usually sufficient to provide the necessary information for the rhizotomy. Electromyographic recordings, although not necessary, can be added for more precise localization and data analysis.

**Decision as to Extent of Rhizotomy**

After stimulation of all the dorsal roots bilaterally, the responses obtained are reviewed and analyzed. Decisions are made as to which rootlets should be sectioned or spared. Decision making is based on the preoperative picture, the goals of the procedure as established preoperatively, and the intraoperative mapping of the reflex responses.

**Section of the Selected Roots/Rootlets**

By this stage of the procedure, visual identification of the dorsal/ventral roots or subgroups of rootlets has become impossible, and one has to rely on the identification of the bundles by the colored threads. The selected rootlets are coagulated and divided. The incision is then closed in the standard fashion.

The basic criterion for selection of the roots/rootlets to be sectioned is that only the nerve roots which display a pathological reflex activity should be sectioned. Most of the intraoperative calculations and assessments are made based not on the roots but on the rootlets. In the small percentage of cases where only a limited number of roots/rootlets exhibit abnormal behavior, the selection is straightforward. However, in most children with spastic cerebral palsy, the majority of the stimulated dorsal rootlets exhibit abnormal behavior. The issue then becomes what percentage of stimulated roots/rootlets should be sectioned to obtain positive long-lasting results and which roots/rootlets should be sectioned?

The percentage of roots/rootlets to be sectioned depends on the severity of the neurological picture, the desire to obtain supraspinal sensorial effects and the pre-established goals of the procedure in the individual patient. The exact percentage that has to be sectioned in order to obtain long-lasting results remains to be established and varies from case to case. As a general rule, limited sections are more liable to allow earlier recurrence of the hypertonia. If ambulation is a goal, the author does not section more than 70% of the stimulated rootlets. A larger percentage can be sacrificed if the patient has extreme hypertonia and ambulation is not a reasonable goal. If one wants to achieve improvement of the upper extremities or to reduce drooling with a lumbar rhizotomy, at least 60% to 70% of the stimulated roots/rootlets should be divided.

Which roots/rootlets should be sectioned? The following criteria are employed by our team at Thomas Jefferson University. The rationale for these criteria are extensively discussed elsewhere. Even though physiological explanations for these criteria exist, no conclusive statistical evidence has been collected to prove their individual relative weight in the intraoperative decision-making process. The criteria are listed in order of proposed decreasing significance: 1) bilateral muscle contractions at 1 Hz stimulation; 2) bilateral muscle contractions at 50 Hz stimulation; 3) contractions of the upper extremities/trunk muscles; 4) contraction patterns that mimic the abnormal clinical pattern; and 5) continuous contractions at 50 Hz stimulation.

According to this list, we initially choose the roots/rootlets with the most pathological responses. If further roots/rootlets are to be sectioned, we then move down the list and select the rootlets that qualify for the next group of criteria. We stop the selection once we have reached the pre-established percentage of rootlets to be sectioned. This usually leaves some pathological rootlets undivided.

If ambulation is a goal, we avoid complete section of S-1 or L-5. Even with extensive sections, we try to spare at least one out of six to seven adjacent rootlets.

**Discussion**

**Historical Perspective**

Dorsal selective rhizotomy is an accepted procedure for the management of severe spasticity refractory to medical management and physical therapy. The procedure, initially introduced by Foerster for the treatment of tabetic pain, was then applied by Gros, et al., for the treatment of spasticity. Several surgical techniques were subsequently developed to allow a more selective section of the dorsal roots to minimize postoperative hypesthesia. In the mid-1970's Fasano and coworkers developed criteria based on intraoperative stimulation of the dorsal roots to select roots/rootlets for section. Further analysis of the intraoperative electrophysiological findings was carried out and the procedure was then modified and popularized in the United States by Peacock, et al.

**Operative Technique**

As currently performed by most neurosurgeons across the country, the procedure consists of an L-2-5 laminectomy followed by individual stimulation of the dorsal roots identified at their exit point. Each nerve root is sequentially stimulated and sectioned according to the reflex response. The advantages of this approach include the fact that the dorsal and ventral roots can easily be identified and that each nerve root can be recognized with certainty. The major drawback lies in performing an extensive laminectomy in a growing child.

Our strategy is based on the following principles: 1) Limited exposure of the cauda equina at L-1 allows access to all the roots from L-1 to S-4. 2) Separation of the dorsal from the ventral roots is possible without much difficulty, since at this level the ventral roots are grouped together in the ventral part of the spinal canal. 3) It is mandatory to identify the S-1 and the L-1 nerve roots, since they constitute the lower and upper limits
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of the roots to be tested. Exact identification, within the rootlets, of the L2–5 dorsal roots is not necessary and does not add any meaningful information to the procedure. The selection is based on the reflex responses of individual or groups of rootlets, regardless of which dorsal roots they belong to. This obviates the need for an extensive laminectomy. 4) In that the vast majority of the reflex responses are abnormal, usually the selection is not based on normal versus abnormal responses; the goal is to select the rootlets that generate the most pathological responses. 5) Since most of the responses are abnormal and since the results are related to the amount of deafferentation produced (as well as intraoperative selection), an approximate estimate of the predicted percentage of rootlets to be sectioned is formulated preoperatively. In most cases, depending on the severity of the clinical involvement, the percentage of stimulated rootlets that are actually sectioned varies between 90% and 90%. In most patients whose goal is ambulation (or improvement of their gait), we do not section more than 70% of the stimulated rootlets. Particular attention is given not to section L-5 or S-1 completely. If the patient is severely incapacitated, mentally retarded, or with severe hypertonia, up to 95% of the rootlets can be sacrificed in order to provide significant and long-lasting results. If less than 70% of the rootlets are sectioned in these severely affected patients, the spasticity will most likely recur within 1 or 2 years following the procedure.

Limited Laminectomy

A limited approach through an L-5 laminectomy with section limited to the L-5 and S-1 roots has recently been proposed. Unfortunately, particularly in ambulatory children, these are precisely the roots that one tries to preserve to avoid creating handicapping hyposthesia in the feet. Exposure of the cauda equina at the conus medullaris allows a more complete assessment of the lumbar roots while still maintaining the advantages of a limited bone removal.

The safety of this approach is proven by the fact that none of the patients undergoing this procedure sustained paralysis due to section of the ventral roots or suffered any deficit of bowel and bladder function secondary to damage to the lower sacral roots. Significant hyposthesia consistently occurred whenever L-5 and S-1 dorsal roots were completely sectioned.

Conclusions

Selective dorsal rhizotomy can be safely and effectively performed through a limited exposure of the cauda equina at the L-1 vertebral level. In the rare instances where the conus ends slightly cephalad or caudal, the exposure can easily be extended as needed. Preoperative evaluation by magnetic resonance imaging might eliminate the rare instances where this extension of the laminectomy is required. This exposure allows complete electrical evaluation of the L1–S1 nerve roots with minimal manipulation of the nervous structures.

References


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