Long-term functional outcome after selective posterior rhizotomy


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Object. Selective posterior rhizotomy (SPR) is a well-recognized treatment for children with spastic cerebral palsy (CP). Few investigators have used quantitative outcome measures to assess the surgical results beyond 3 years. The authors analyzed data obtained from the McGill Rhizotomy Database to determine the long-term functional outcome of children who had undergone selective dorsal rhizotomy accompanied by intraoperative electrophysiological monitoring.

Methods. The study population was composed of children with spastic CP who underwent SPR and were evaluated by a multidisciplinary team preoperatively, and at 6 months and 1 year postoperatively. Quantitative standardized assessments of lower-limb spasticity, passive range of motion, muscle strength, and ambulatory function were obtained. Of the 93 patients who met the entry criteria for the study, 71 completed the 3-year and 50 completed the 5-year assessments, respectively. Statistical analysis demonstrated significant improvements in spasticity, range of motion, and functional muscle strength at 1 year after SPR. The preoperative, 1-, 3-, and 5-year values for the global score of the Gross Motor Function Measure were 64.6, 70.8, 80, and 85.6, respectively. The greatest improvement occurred in the dimensions reflecting lower-extremity motor function, where the mean change was 10.1% at 1 year, 19.9% at 3 years, and 34.4% at the 5-year follow-up review in comparison with the baseline value. This was associated with a lasting improvement in alignment and postural stability during developmental positions, as well as increased ability to perform difficult transitional movements.

Conclusions. The results of this study support the presence of significant improvements in lower-limb functional motor outcome 1 year after SPR, and the improvements persist at 3 and 5 years. The authors conclude that SPR in conjunction with intraoperative stimulation is valuable for permanently alleviating lower-limb spasticity while augmenting motor function.

KEY WORDS • spasticity • cerebral palsy • rhizotomy • intraoperative electrophysiological monitoring • outcome

Cerebral palsy consists of a heterogeneous group of nonprogressive motor impairment syndromes caused by injury to the developing brain. The predominant types of CP are classified as spastic, athetoid, ataxic, hypotonic, or mixed. Lumbosacral SPR has become a standard neurosurgical procedure for the management of CP in carefully selected children with the spastic form of this disability. The intent of surgery is to eliminate lower-limb spasticity while improving motor function in ambulatory children. With renewed interest in the procedure over the last 15 years, several investigators have reported favorable results after SPR. Early follow-up evaluations showed considerable gains in sitting, standing, upper extremity use, range of motion, and walking, based on both qualitative and quantitative parameters. Only a handful of groups, however, have described the outcome of SPR beyond 3 years. Even fewer studies have involved statistical analysis of standardized functional assessment tools to determine long-term outcome. In this study, we report the effects of SPR at 3- and 5-year follow up by using rigorous analysis of quantitative functional outcome measures.

In addition, several authors have suggested that intraoperative stimulation during dorsal rhizotomy has no impact on the overall success of the operation. Even statistical analysis of standardized functional assessment tools to determine long-term outcome. In this study, we report the effects of SPR at 3- and 5-year follow up by using rigorous analysis of quantitative functional outcome measures.
The main purpose of this prospective investigation is to examine whether statistically significant improvement in lower-limb spasticity, passive range of motion, strength, and motor function occurs after the selective procedure, and to determine whether this effect is durable. Careful analysis of appropriate objective outcome scales, especially those used to assess enhancement of function rather than simple elimination of spasticity, is critical in establishing the true benefits of the EMG-guided procedure.

Clinical Material and Methods

Patient Population

Data were collected prospectively from the McGill Rhizotomy Database in a series of patients who had undergone SPR at the Montreal Children’s Hospital of the McGill University Health Centre since 1991. This continually updated database includes pre- and postoperative evaluations from the neurosurgery, neurology, orthopedic surgery, physiotherapy, and occupational therapy departments. The study population was composed of children with spastic CP who were evaluated by the multidisciplinary team preoperatively, and at 6 months and 1 year postoperatively. Patients selected for surgery had a typical perinatal history, a static disease process, and emerging locomotor functions. Patients with underlying low tone, dystonia, multiple prior orthopedic procedures, and double hemiplegia were excluded. Of 93 patients who met the entry criteria for the study, 71 completed the 3-year evaluations. Of these, 50 patients completed the 5-year assessments; the remaining 21 children had not yet reached the 5-year mark.

Patient Subgrouping

All patients were categorized preoperatively according to age-related severity of functional locomotive impairment by using a grading scale based on the NYU classification system.2 We considered independent ambulators (Group I) to have the best chance of improving the appearance and efficiency of their gait. We anticipate that patients requiring assistive mobility devices (Group II) would improve their quality of locomotion and decrease the level of assistance required for ambulation. Children classified in Group III (reciprocal and nonreciprocal quadruped crawlers) were expected to improve their functional ability, with the ultimate goal of walking with the aid of braces or other assistive devices. Generally, nonambulatory patients in Groups IV and V (severely limited mobility despite use of assistive devices) do not obtain functional motor gains despite elimination of spasticity with SPR. Consequently, these severely disabled children were offered alternative therapies, such as implantation of an intrathecal baclofen pump or tendon lengthening, to improve ease of caretaking and facilitate positioning.

Surgical Procedure and Postoperative Care

The SPR surgery has been described in detail elsewhere.40 Briefly, anesthesia was induced in all patients by a mixture of sufentanil (0.2–0.5 μg/kg/hr) and propofol (1–10 mg/kg/hr), which was infused along with nitrous oxide. A short-acting nondepolarizing neuromuscular blocking agent, rocuronium, was used only at induction of anesthesia. Lumbosacral dorsal roots were exposed through a narrow L1–S2 laminotomy flap, and stimulation of dorsal roots began after all infusions had reached a steady state. Once the electrophysiological monitoring protocol was completed, the roots were divided into rootlets. Both the neurophysiologist and the physical therapist assessed the motor responses to electrical stimulation of sensory roots and rootlets. Based on the evoked stimulation responses, rootlets were sectioned using predefined lesioning criteria outlined previously. Postoperative analgesia was provided by morphine infusion (4 μg/kg/hr) containing 0.125% bupivacaine. The infusion was continued for 72 hours through an epidural catheter that had been placed under direct vision at the time of surgery.

After undergoing rhizotomy, children were allowed to sit in a chair on the 4th postoperative day. The following day, the patients were transferred to the Shriners Hospital for Children, where they received 6 weeks (6 hours/day) of intensified inpatient rehabilitation devoted to muscle reeducation and strengthening. Thereafter, their rehabilitation continued with standard physiotherapy (3 hours/week) involving stretching and strengthening exercises for the lower extremities. Postoperative stability and control of lower limbs was further enhanced by judicious use of orthotic devices.

Adjunctive Orthopedic Procedures

Some of our patients, as in other reports, required adjuvant treatments during the follow-up period (Tables 1 and 2). These complementary therapies were taken into consideration in the outcome analyses. Of note, however, no additional surgical interventions were performed between the time the SPR was performed and the 1-year follow-up evaluation.

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**TABLE 1**

<p>| Adjunctive orthopedic procedures after SPR in 13 children with CP |</p>
<table>
<thead>
<tr>
<th>Factor</th>
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<td>female</td>
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<tr>
<td>quadriplegic</td>
<td>2</td>
</tr>
<tr>
<td>prehizotomy locomotive abilities*</td>
<td>3</td>
</tr>
<tr>
<td>Group I</td>
<td>3</td>
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<tr>
<td>Group II</td>
<td>7</td>
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<tr>
<td>Group III</td>
<td>3</td>
</tr>
<tr>
<td>Group IV</td>
<td>0</td>
</tr>
<tr>
<td>Group V</td>
<td>0</td>
</tr>
<tr>
<td>mean interval post-SPR (yrs)</td>
<td>3.7</td>
</tr>
<tr>
<td>range</td>
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<tr>
<td>procedure</td>
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<tr>
<td>heel cord release</td>
<td>4</td>
</tr>
<tr>
<td>hip adductor release</td>
<td>4</td>
</tr>
<tr>
<td>iliopsoas release</td>
<td>3</td>
</tr>
<tr>
<td>subtalar arthrodesis</td>
<td>3</td>
</tr>
<tr>
<td>femoral osteotomy</td>
<td>3</td>
</tr>
<tr>
<td>posterior tibial transfer</td>
<td>3</td>
</tr>
</tbody>
</table>

*See Patient Subgrouping for explanation of designations.

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Functional Outcome Measures

All patients underwent a comprehensive standardized assessment protocol preoperatively, at 6 and 12 months postoperatively, and at yearly intervals thereafter. Functional outcome measures consisted of quantitative determinations of lower-extremity spasticity, passive range of motion, functional strength, and gross motor function. A pediatric physiotherapist, who was previously trained in the use of the standardized evaluation tools, took measurements with a consistent technique. The children were examined without braces, orthoses, or walking aids in place. All developmental motor skill assessments were videotaped for analysis of the performance and scoring.

Evaluation of Spasticity and Range of Motion

The spasticity of the hip adductors, hamstrings, and ankle plantar flexors was assessed using a modification of the Ashworth Scale that contained a five-point grading system based on the NYU Tone Scale. A muscle that offered normal resistance to passive limb movement was assigned 0; Grade –1 was given if the limb was floppy with less than normal tone. Grades 1, 2, and 3 were designated as mildly, moderately, and severely increased tone, respectively, corresponding to the severity of resistance to passive movement and impairment of function. Passive range of motion was measured for hip abduction from midline with the hip and knee extended (normal 45°). Knee extension was measured with the patient supine (normal 0°), and ankle dorsiflexion was assessed with the knee in extension and the subtalar joint of the foot in the neutral position (normal 20°). The joint angle was measured at the maximal range of motion by using a protractor goniometer. The means of measurements taken from the left and right sides were used in the analysis.

Evaluation of Developmental Motor Skills

The method we used to assess developmental positions and transitional movements was taken in part from the functional assessment section of the Rusk Institute of Rehabilitation/NYU Rhizotomy Evaluation Form. The specific developmental positions and transitional movements analyzed in this study were previously identified as functional skills that young ambulatory children with spastic CP have difficulty executing. In addition, analysis of the quality of alignment in each static developmental position was added to the assessment to quantify qualitative changes in posture after SPR.

Five developmental positions were used to determine the effect of SPR on the child’s stability and the quality of alignment in the static positions. These included long sitting, bench sitting, side sitting (right and left), half kneeling (right and left), and standing. During the assessment, each position was first demonstrated for the child by a clinician. The patient was then asked to assume the position and verbal cues were given to elicit the best performance. The ability to maintain the position independently was graded on a scale of 1 to 5: Grade 1 was given if the child could not be maintained in position, Grade 2 was assigned when the child required full external support from the therapist to maintain the position, Grades 3 and 4 were given if the patient required bilateral (Grade 3) or unilateral upper-extremity support (Grade 4) to maintain position, and children who could maintain the position independently were assigned Grade 5. To quantify changes in the quality of alignment, the position of relevant body segments (head, trunk, elbows, hips, knees, ankles, and feet) was assessed in each developmental position. An extensive grading system was used to measure the quality of alignment of each of the body segments, as appropriate, in the five developmental positions. The segmental scores for each static position were summed for a total alignment score. A mean score was used for the developmental positions in which both the right and left sides were assessed.

Five developmentally based transitional movements were evaluated to assess the gains in the level of performance following SPR. These included transition from supine to long sitting, supine to side sitting, floor to bench sitting, floor to standing, and tall kneeling to half kneeling. During the assessment, each movement was first demonstrated for the child by a clinician. The patient was then asked to perform the movement and verbal cues were given to elicit the best performance. All transitional movements were graded on a five-point scale: Grade 1 was assigned to a child who could not be placed in position, Grade 2 to a child who could not observably participate in transition but with whom the therapist could complete the entire movement, Grade 3 was given to patients who required assistance to complete the limb movement and used furniture to assist themselves into position, Grade 4 was given when the child completed the movement but required assistance from the therapist or furniture, and Grade 5 was assigned if the patient was able to complete the transitional movement independently.

Evaluation of Motor Function

The GMFM is a criterion-referenced observational mea-
sue that was developed and validated to assess children with CP.\textsuperscript{52} The 88 items of the GMFM are assessed after observation of the child and are scored on a four-point ordinal scale. The items are weighted equally and grouped into five dimensions: A, lying and rolling (17 items); B, sitting (20 items); C, crawling and kneeling (14 items); D, standing (13 items); and E, walking, running, and jumping (24 items). Scores for each dimension are expressed as a percentage of the maximum score for that dimension. The total score is obtained by averaging the percentage scores across the five dimensions. As indicated by Russell and colleagues,\textsuperscript{52} a change of 6% in the total score or within a dimension of the GMFM is considered to be clinically important in children with CP who have undergone a neurosurgical intervention.

**Statistical Analysis**

Sensitivity of the functional parameters was measured to change over time with the Friedman test. To determine more specifically at what time during the follow-up period any significant changes in function appeared, the differences in scores between preoperative, 1-, 3-, and 5-year assessments were evaluated using Wilcoxon matched-pairs signed-ranks tests. Five primary outcome measures were considered most relevant for this analysis. For spasticity, hip adductor muscle spasticity was chosen, because it is functionally significant and representative of global lower-extremity spasticity. For range of motion, hip abduction was selected, because it is also functionally important and is intimately associated with hip adductor spasticity. For the developmental positions and transitional movements of the Rusk/NYU motor function evaluation, the total alignment score was the primary outcome measure because it reflects overall spasticity and range of motion, and is associated with the ability to engage in functional activities such as eating, dressing, and grooming. For the GMFM score, dimensions D and E were chosen because they relate more specifically to lower-limb function. The remaining measures for spasticity, range of motion, and gross motor function were regarded as secondary outcomes. Because each primary outcome measure was analyzed at four different time points (preoperatively and at 1, 3, and 5 years postsurgery), six different paired comparisons were possible. Thus, probability values were adjusted for multiple paired comparisons according to the Bonferroni method. Accordingly, an α-error probability not exceeding 0.008 (0.05 ÷ six samples) was considered significant.

**Results**

**Demographic Factors**

The final study population was composed of 71 of the 93 eligible patients who had completed the 1-year assessment. There were 43 boys and 28 girls whose age at surgery ranged from 3 to 10.7 years, with a mean age of 5.2 years (Table 3). There were 57 patients with diplegia, four with triplegia, and 10 with quadriplegia. Forty-nine children (69%) were classified as having mild functional disabilities (Groups I and II; ambulatory with or without assistive devices), whereas patients with moderate locomotor limitations (Group III; quadruped crawlers) comprised 25.4% of the patients. Only four patients with severe functional restrictions preoperatively (Groups IV and V) underwent SPR in this series.

**Spasticity Scores**

Hip adductor spasticity, which is generally representative of the overall degree of lower-limb spasticity, was significantly reduced at 1 year postoperatively compared with baseline spasticity before SPR (Fig. 1 *upper left* and *right*, Friedman test, \( p < 0.001 \)). Paired comparisons failed to reveal any further significant reduction in spasticity at the 3- and 5-year follow up, however (Table 4). As shown in Fig. 1 *lower left* and *right*, a similar pattern was observed for hamstring and ankle plantar flexor spasticity values.

**TABLE 3**

Demographic factors in 71 patients in the study population

<table>
<thead>
<tr>
<th>Factor</th>
<th>Value</th>
</tr>
</thead>
<tbody>
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<td>female</td>
<td>28</td>
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<td>prehizotomy locomotive abilities</td>
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<tr>
<td>Group I</td>
<td>22</td>
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<td>Group II</td>
<td>27</td>
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<td>Group III</td>
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<tr>
<td>Group IV</td>
<td>3</td>
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<tr>
<td>Group V</td>
<td>1</td>
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<tr>
<td>age at surgery (yrs)</td>
<td></td>
</tr>
<tr>
<td>minimum</td>
<td>3</td>
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<td>maximum</td>
<td>10.7</td>
</tr>
<tr>
<td>mean</td>
<td>5.2</td>
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</table>

**TABLE 4**

Statistical analysis of results of the five primary outcome measures compared at various intervals

<table>
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<tr>
<th>Outcome Measure</th>
<th>Preop/1 Yr</th>
<th>Preop/3 Yrs</th>
<th>Preop/5 Yrs</th>
<th>1 Yr/3 Yrs</th>
<th>1 Yr/5 Yrs</th>
<th>3 Yrs/5 Yrs</th>
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</thead>
<tbody>
<tr>
<td>hip adductor spasticity</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>0.323</td>
<td>0.579</td>
<td>0.641</td>
</tr>
<tr>
<td>hip abduction range of motion</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>0.241</td>
<td>0.608</td>
<td>0.671</td>
</tr>
<tr>
<td>alignment score</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>0.303</td>
<td>0.293</td>
<td>0.601</td>
</tr>
<tr>
<td>GMFM, dimension D</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>0.001</td>
<td>0.005</td>
<td>0.004</td>
<td>0.018</td>
</tr>
<tr>
<td>GMFM, dimension E</td>
<td>( &lt;0.001 )</td>
<td>( &lt;0.001 )</td>
<td>0.001</td>
<td>( &lt;0.001 )</td>
<td>0.003</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Range of Motion Scores

Hip abduction was considerably increased at 1, 3, and 5 years compared with the preoperative assessment (Fig. 2 upper left and right, Table 4; Friedman test, p < 0.001). The patterns of change were similar for ankle dorsiflexion, whereas for knee extension, there was a tendency for further augmentation in the range of motion at 3 and 5 years compared with 1 year after rhizotomy (Fig. 2 lower left and right).

Alignment, Transition, and Stability Scores

A decrease in spasticity is associated with an increase in range of motion that enables children to improve their alignment in different developmental positions, thereby achieving greater postural stability in a given position. Theoretically, improved postural stability is associated with increased functional ability by freeing the upper extremities to engage in functional activities such as eating, dressing, and grooming. The total alignment score, the primary outcome measure of the Rusk/NYU motor function evaluation scale, was significantly improved 1 year after SPR (Fig. 3 upper left and right, Table 4; Friedman test, p < 0.001). Follow-up assessments at 3 and 5 years also showed a marked increase in quality of postural alignment. Significant improvements in the ability to assume and maintain specific developmental positions and perform transitional movements were seen at the 1-, 3-, and 5-year assessments compared with baseline values (Fig. 3 lower left and right).

Gross Motor Function Measure Scores

Presurgical and postsurgical means for GMFM scores were determined. The global score on the GMFM was statistically improved, including the five partial dimensions (Fig. 4). The preoperative, 1-, 3-, and 5-year values for the overall GMFM were 64.6, 70.8, 80.0, and 85.6, respectively. The greatest improvement, however, occurred in dimensions D (standing) and E (walking, running, and jumping) of the GMFM (Fig. 4, Table 4; Friedman test, p < 0.001). These two dimensions distinctively reflect lower-extremity motor skills. The mean change in dimension D was 10.1% at 1 year, 19.9% at 3 years, and 34.4% at 5 years, compared with the baseline score. Similarly, in the walking, running, and jumping section of the GMFM (dimension E), the mean change was 6.1% at the 1-year, 17.6% at the 3-year, and 39.9% at the 5-year follow-up review, in comparison with the baseline value. Moreover, when GMFM scores were compared according to patient subgroups (prehizotomy locomotive function), a more pronounced difference was seen. Indeed, as shown in Fig. 5, a greater benefit from SPR was noted in children with milder motor disabilities (Groups I and II; independent and dependent locomotors, respectively) compared with their less ambulatory counterparts (Group III). This was true for both the total score and

Fig. 1. Upper Left: Box-and-whisker plot showing degree of hip adductor muscle spasticity, the primary outcome measure for spasticity. Each box defines the interquartile range, and the vertical bars represent the 5th and 95th percentile values. The decrease in adductor spasticity between the baseline values and 1, 3, and 5 years after rhizotomy was found to be statistically significant (Friedman test, p < 0.001). Asterisks represent outliers above the 95th percentile or below the 5th percentile values. Upper Right and Lower: Line plots showing the degree of muscle spasticity in the hip adductors (upper right), ankle plantar flexors (lower left), and hamstrings (lower right). Assessments of muscle spasticity were made using the five-point NYU Tone Scale before rhizotomy, and at 1, 3, and 5 years after rhizotomy.

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for dimensions D and E of the GMFM (Table 4). In all patient subgroups, the increase in GMFM values was clinically significant as defined by Russell, et al.52

Functional Outcome of Patients not in the Valid Study Group

Outcomes were also analyzed in patients in whom formal baseline and 1-year assessments were obtained, but were excluded from the valid study group because they did not have 3-year assessments. Of the 22 patients in this category, follow-up information at more than 18 months after rhizotomy was available in 15 patients. At a mean follow-up duration of 25.5 months after SPR, all children had significantly improved lower-limb motor spasticity and range of motion compared with prerhizotomy values. Considerable enhancement in locomotive and transitional movements was also noted in these patients after SPR. Similarly, GMFM scores demonstrated clinically important gains in motor function.

Adjunctive Procedures Between 1 and 5 Years After SPR

Orthopedic Surgery. Children with CP frequently require orthopedic surgery on the lower extremities, for example, tendon lengthening and osteotomies for contractures and bone deformities that complicate spasticity.15 In this series, 13 (18.3%) of 71 patients required a total of 21 orthopedic interventions (Table 1). No orthopedic procedure was performed in the 1st year post-SPR. Six patients (8.5%) required soft-tissue correction within 3 years postrhizotomy and were included in the 3-year outcome analyses. The remaining seven patients underwent their adjunctive orthopedic surgery 4 or more years after SPR.

Botulinum Toxin Injection. Botulinum toxin type A is a potent neurotoxin that causes profound, transient chemodenervation and muscle relaxation by disrupting acetylcholine release into the presynaptic cleft of the neuromuscular junction. It offers a targeted antispasticity treatment and has been used successfully in children with CP.15,67 Twenty-five (35.3%) of 71 children required adjunctive botulinum toxin A injections after SPR, as outlined in Table 2. None of them received the intramuscular injections within 1 year following rhizotomy, whereas 12 of the 25 patients received botulinum toxin within 3 years postrhizotomy. Only nine of the 12 children had injections in the lower extremities, and the lower limb outcome measures at 3 years included data from these nine patients (12.7% of study population).

Surgical Complications

The perioperative complications were minor, transitory, and similar to those described in the literature.1,61 Three cases (4.2%) of urinary retention that required intermittent catheterization for up to 14 days were documented. This
avoidable complication has been minimized by cutting no more than two thirds of dorsal S-2 rootlets and by leaving the indwelling urinary catheter for an additional 24 hours after discontinuation of intrathecal morphine. No cerebrospinal fluid leak, wound infection, or kyphosis was encountered. No patient required orthopedic correction or trunk bracing of scoliotic deformity following SPR.

Discussion

Historical Background

Cerebral palsy is the most common cause of severe physical disability in childhood. Selective dorsal rhizotomy was originally conceived in Europe as a treatment option for the spastic form of CP.\textsuperscript{20,22,23,26} The procedure has undergone considerable modifications in an effort to improve the motor outcome and limit complications,\textsuperscript{45} and has been used increasingly in many centers for the past 15 years.\textsuperscript{63} The goal of SPR is to relieve the velocity-dependent hypertonicity, which is predominantly seen in the lower limbs, and to improve muscle strength, and hence motor function. In fact, numerous studies have shown that, in children with debilitating spasticity, SPR can effectively increase range of movement in the lower limbs\textsuperscript{29,31,27,56,73} and improve ambulation.\textsuperscript{30,34,37,43,62} The operative procedure consists of selectively cutting dorsal rootlets from L-2 to S-2, thereby eliminating the aberrant myotatic reflex impulse. The selection is made according to the extent of lower-extremity muscular response to electrical stimulation of sensory rootlets. Some authors have questioned the reproducibility of EMG-guided rootlet sectioning. Nonetheless, most surgeons continue to use direct dorsal rootlet stimulation with intraoperative EMG response monitoring as an adjunct to clinical

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evaluation. We have recently shown the reliability of intraoperative stimulation during SPR.40

Rationale Underlying Selectivity of Posterior Rhizotomy

Lumbosacral dorsal rootlets that evoke abnormal reflex activity in lower-extremity muscles on direct, repetitive, high-frequency stimulation are involved in a dysfunctional spinal reflex. Abnormalities in these reflex circuits are believed to produce spasticity, which in turn impairs ambulation. These abnormal rootlets should therefore be selected for sectioning. Similarly, dorsal rootlets with normal reflex responses must be spared because they presumably do not participate in the abnormal circuitry. In our experience, in addition to identifying abnormal reflex circuits for interruption, EMG-guided rhizotomy also enables accurate identification of sacral nerve roots involved in bowel and bladder control.31,40 Whereas the results after sectioning of abnormal rootlets in both selective and nonselective rhizotomy can likely be evaluated by considering the simple change in spasticity scores, more rigorous and validated outcome tools to assess functional motor gains may be better suited to measure the outcome in selective rhizotomy with preservation of normal rootlets.

Long-Term Functional Outcome Measure

The methods used in several previous studies were not consistently delineated, making it difficult to ascertain the distinct effects of SPR. In this clinical follow-up investigation, the results of selective dorsal rhizotomy were studied in orthopedic and functional fields by using standardized assessment tools. Among the different objective measures used, we identified five primary outcome measures that were considered to be the most relevant to examine appropriately the long-term effects of SPR (Table 4). Reduction of spasticity has predictable benefits, but does not automatically lead to functional improvements. Decreased spasticity has been demonstrated qualitatively up to 12 years after SPR.4,14,21,24,50,54 Quantitative assessments of spasticity, in which myometry, dynamometry, the Ashworth Scale, or some variation of this scale, were used in 15 studies to date.2,11,18,25,30,33,34,38,39,53,57,59,60,62,73 This includes three randomized controlled trials in which a significant reduction of spasticity was shown after SPR and physiotherapy, compared with a control group of patients treated with physiotherapy alone.39,62,73 Only one study contained quantitative assessments performed at 5 years after rhizotomy.27 In agreement with these earlier studies, our results demonstrate that lower-limb spasticity is significantly reduced at 1 year postrhizotomy (Fig. 1). This beneficial effect is maintained at 3 and 5 years postsurgery.

Range of motion in the lower limbs has been previously examined quantitatively by using goniometry in nine prospective case series2,9,11,25,27,43,56,57,59 and two randomized controlled studies.62,73 All studies have indicated greater range of motion in the lower-extremity joints tested between 9 months and 2 years after SPR. Only one other study27 demonstrated an increase in range at 1 year postsurgery, which was maintained up to 5 years after rhizotomy. In addition to improved range of motion, several authors have also shown increased stride length and velocity by using instrumented gait analysis in ambulatory patients.3,9,15,47,53,65,66,68,72,73 Among these studies, in only one was the follow-up duration longer than 2 years.65 In the present study, we found that passive range of motion is significantly improved up to 5 years after SPR (Fig. 2, Table 4).

Quantitative examination of lower-limb strength has been reported in only five studies.18,19,27,57,62 One long-term study showed a tendency for further strengthening between 1 and 5 years after SPR.27 We have used five static developmental positions and five transitional movements taken from the Rusk Institute of Rehabilitation/NYU Rhizotomy Evaluation Form27 which is a nonvalidated tool for assessing motor function, to measure the postural stability, transition, and quality of alignment. As noted in Fig. 3 and Table 4, significant improvement in the total alignment score, a primary outcome measure, is seen up to 5 years postsurgery. Because a large proportion of children in this study were able to maintain the sitting positions and perform the transitional movements independently before undergoing SPR, the transition and stability scores, although they improved postsurgery, did not increase as much as the alignment score (Fig. 3). Given the foregoing results, we believe that the children were able to use the decrease in spasticity following SPR effectively to improve their performance of developmental motor skills.

Several investigators have reported beneficial effects of SPR on quantitative parameters used to assess functional limitations involving sitting ability.63,74 ambulation,20,53,57,59,62 and motor function.27,28,61 Almost all these studies,
however, used nonvalidated outcome assessment measures. The validated tool most widely used to assess motor function has been the GMFM, which measures independent functional skills. It is also an indirect reflection of the ability of spasticity to interfere with normal motor activity. In five studies, including two randomized controlled trials, statistically significant increases have been reported in GMFM scores following rhizotomy. None of these studies used nonvalidated measures to establish the true effects of dorsal rhizotomy. In this report, we have clearly demonstrated that SPR, accompanied by intraoperative electrophysiological monitoring, results in a clinically significant and lasting reduction in lower limb spasticity by using a specific test method and grading scale that have been proven to be reliable, we recognize that these evaluations remain somewhat subjective. Results therefore are subject to the shortcomings of such an investigation. Randomized controlled trials featuring the quantitative measures used in this study, as well as more detailed objective measures, such as instrumented gait analysis, are necessary to make conclusive statements regarding outcomes after SPR.

Conclusions

In earlier studies, the methods used to quantify outcome measures were not consistently defined, making it difficult to establish the true effects of dorsal rhizotomy. In this report, we have clearly demonstrated that SPR, accompanied by intraoperative electrophysiological monitoring, results in a clinically significant and lasting reduction in lower limb function despite adequate elimination of lower-extremity spasticity. This is in agreement with Russell, et al., who determined that, when controlled for age, the amount of change in GMFM scores is dependent on the severity of the child’s CP. Unfortunately, children with better ambulatory function (Group I) are often not referred for an evaluation, or it is deferred, because of the misconception that their potential for significant gains is low. Indeed, in our own group of patients, the total GMFM baseline score for independent ambulators was 84.3%. We noted a mean change, however, in patients in Group I of 13% and 25.8% in dimensions D and E, respectively, at the 5-year follow-up review compared with preoperative values (Fig. 5). Furthermore, we have found that the greatest degree of family satisfaction with respect to outcome is seen in the independently ambulating patient subgroup (unpublished data).

Adjuvant Orthopedic Procedures

The management of spasticity in CP is complex and is best handled by a multidisciplinary team. Neurosurgical and orthopedic treatment options for spastic CP are diverse and are complementary rather than mutually exclusive. This study was not designed to determine precisely the effects of botox injections or orthopedic interventions in children with spastic CP. These therapies are only mentioned in this analysis to help eliminate any potential contribution they could have on long-term functional outcome. We (unpublished data) and others have noted stabilization of progressive hip deformity after SPR, provided that the pre-rhizotomy Reimer index does not exceed 50%.

Analysis of outcome measures does not indicate that adjuvant orthopedic procedures during the follow-up period have a significant impact on spasticity, range of motion, or motor function. Indeed, as outlined earlier, statistically and clinically significant durable gains in all functional measures were identified at the 1-year assessment, before any orthopedic intervention (Tables 1 and 2). Also, one could argue that the significant ongoing improvements seen in dimensions D and E of the GMFM at 3 and 5 years post-rhizotomy (Fig. 4) could be partly influenced by orthopedic interventions. We note, however, that only six (8.5%) of 71 patients underwent an orthopedic procedure before the 3-year assessment and that only nine children (12.7%) needed lower-extremity botulinum toxin injections before the 3-year assessment. Even when these patients are excluded from analysis of dimensions D and E, a significant gain remains at the 3- and 5-year follow-up compared with baseline and 1-year values. In fact, the mean change in dimension D is 24.5% at the 3-year and 31.3% at the 5-year assessment compared with preoperative scores. For dimension E of the GMFM, the mean increase is 21.4 and 33.9% at the 3- and 5-year follow-up review, respectively.

Areas of Criticism and Concern

Monitoring motor function over time in patients with CP can be quite complex. The child’s development will inevitably change with maturity, because of intensive treatment and enhanced motivation, or with environmental adaptation. The concept of function must therefore remain central to proper assessment of surgical outcomes in SPR.

Although we have attempted to quantify the measure of spasticity by using a specific test method and grading scale that have been proven to be reliable, we recognize that these evaluations remain somewhat subjective. Results must therefore be evaluated in terms of these limitations. More objective measurements, as described by Engsberg and coworkers, are needed to provide more reliable and sensitive measures of spasticity and strength. Conversely, subjective improvements in motor function may not be quantifiable with standardized assessment scales (for example, quality of movement). Nevertheless, as pointed out by Siegfried, et al., such qualitative improvements must also be taken into account when examining the benefits that can be achieved with SPR.

We have demonstrated, using statistical analysis of standardized functional assessment tools, that excellent long-term outcomes can be achieved after EMG-guided SPR. This study, however, was a prospective case series and therefore is subject to the shortcomings of such an investigation. Randomized controlled trials featuring the quantitative measures used in this study, as well as more detailed objective measures, are necessary to make conclusive statements regarding outcomes after SPR.
spasticity, improvement in range of motion, and enhancement of overall motor function. One should be very cautious, however, when extrapolating the results of this study, in which patient selection was biased toward higher functioning individuals and intraoperative discrimination of rootlet response was weighed heavily, to other children who undergo nonselective rhizotomies. Continued reevaluation and critical appraisal of functional outcome should lead to further improvements in the procedure, with a decrease in patient morbidity and better overall outcome.

Acknowledgments

The authors thank Ms. Luisa Birri and Ms. Caterina Parretta for administrative assistance, and Ms. Isabelle Morin from the Department of Biostatistics, McGill University Health Centre, for help with statistical analysis.

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Long-term outcome after selective posterior rhizotomy


Manuscript received September 20, 2001.
Accepted in final form April 22, 2002.
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