Changes in ankle spasticity and strength following selective dorsal rhizotomy and physical therapy for spastic cerebral palsy

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Object. In this investigation the authors quantified changes in ankle plantarflexor spasticity and strength following selective dorsal rhizotomy (SDR) and intensive physical therapy in patients with cerebral palsy (CP).

Methods. Twenty-five patients with cerebral palsy (CP group) and 12 able-bodied volunteers (AB controls) were tested with a dynamometer. For the spasticity measure, the dynamometer was used to measure the resistive torque of the plantarflexors during passive ankle dorsiflexion at five different speeds. Data were processed to yield a single value that simultaneously encompassed the three key elements associated with spasticity: velocity, resistance, and stretch. For the strength test, the dynamometer rotated the ankle from full dorsiflexion to full plantarflexion while a maximum concentric contraction of the plantarflexors was performed. Torque angle data were processed to include the work done by the patient or volunteer on the machine. Plantarflexor spasticity values for the CP group were significantly greater than similar values for the AB control group prior to surgery but not significantly different after surgery. Plantarflexor strength values of the CP group were significantly less than those of the AB control group pre- and post-surgery. Post-surgery strength values did not change relative to presurgery values.

Conclusions. The spasticity results of the present investigation agreed with those of previous studies indicating a reduction in spasticity for the CP group. The strength results did not agree with the findings of most previous related literature, which indicated that a decrease in strength should have occurred. The strength results agreed with a previous investigation in which knee flexor strength was objectively examined, indicating that strength did not decrease as a consequence of an SDR. The methods of this investigation could be used to improve SDR patient selection.

Key Words • cerebral palsy • spasticity • strength • dynamometer • rhizotomy • ankle

Selective dorsal rhizotomy (SDR) surgery is performed by selectively cutting dorsal rootlets from L-1 to S-2 in persons with cerebral palsy (CP). The selection is made according to lower-extremity muscular response to electrical stimulation of rootlets.13,15,17,18,21 The intent of the surgery is to minimize or eliminate the influence of spasticity.13 Previous investigators have reported a reduction in spasticity after SDR.3,13,15,19,21 However, these investigators have primarily used the modified Ashworth Scale13 to quantify spasticity. Despite its widespread use in both clinical and research settings, the modified Ashworth Scale is a subjective measure recorded using ordinal data. Results must therefore be evaluated in terms of these limitations. One group of investigators14 who did use an objective measure to quantify spasticity indicated a significant reduction in spasticity as a result of SDR. The method involved a custom-made dynamometer not readily available to hospitals and clinics. Investigators in another study in which a readily available dynamometer was used also reported a significant reduction in spasticity.8 Spasticity was characterized as a velocity-dependent resistance to passive stretch.6,8 However, the results of that study only covered the knee flexors, and it is unknown if the same results would exist for the ankle plantarflexors.

Muscle weakness is another impairment associated with CP and has been reported to be a contraindication to SDR.1,10,12 In addition, postoperative weakness is considered a limitation to a favorable outcome of the surgery.1,10,12 The authors of these reports indicated that caution should be used when performing an SDR in patients with muscle weakness; however, a paucity of objective information is available to support the claim. Objective measures designed to quantify strength and weakness in patients with CP have been described.6,10,12 However, these measures have been used to investigate the abilities of patients with CP to show gains in strength as a result of training. They have not been used in the clinical setting to aid in patient selection for SDR or in outcome evaluation. Only one group of investigators has reported on objective measures of strength as a consequence of SDR.6 Similar to the spasticity measure, the results were only reported for knee flexors. The purpose of the present investigation was to quantify changes in ankle spasticity and strength as a result of SDR surgery and an associated intensive physical therapy program in patients with CP. We hypothesized that a significant decrease in both ankle spasticity and strength would occur as a consequence of the surgery and physical therapy.
community or by word of mouth. In each volunteer, only

Groups (seven boys and five girls with a mean age of 11.9 kg) were recruited through parents within the hospital. The able-bodied volunteers (AB control group) were recruited. The able-bodied volunteers (seven boys and five girls with a mean age 5–18 years) and a mean mass standard deviation of 30.4 ± 11.9 kg) were recruited. The able-bodied volunteers (AB control group) were recruited through parents within the hospital community or by word of mouth. In each volunteer, only

Clinical Material and Methods

For this prospective investigation, a sample of 12 able-bodied volunteers (seven boys and five girls with a mean age ± standard deviation [SD] of 12 ± 3.6 years [range 5–18 years] and a mean mass ± SD of 30.4 ± 11.9 kg) were recruited. The able-bodied volunteers (AB control group) were recruited through parents within the hospital community or by word of mouth. In each volunteer, only

one leg was tested. The patients with CP (CP group) had been referred to the Human Performance Laboratory for testing and were scheduled to undergo SDR the following day. The CP group was tested again approximately 8 months after surgery. Both legs of patients in the CP group were tested. Each patient and/or parent was informed about the project and gave informed consent.

Candidates for SDR were children older than 2 years of age in whom a diagnosis of spastic diplegia or quadriplegia had been made and in whom the presence of spasticity determined by the Ashworth Scale, deep tendon reflex, and clonus were present. Determination by the neurosurgeon that spasticity hindered the patient’s motor activities and a history of premature birth were also factors. Selective dorsal rhizotomy was not considered for children with dystonia or rigidity, damage to the basal ganglia as revealed by magnetic resonance imaging, or severe fixed joint deformities.17

The SDR surgery has been described in detail elsewhere.17 Briefly, in preparation for intraoperative electromyographic (EMG) examinations, the patient was placed prone, general anesthesia was induced, and needle electrodes were placed bilaterally in six major muscles of the lower extremity. The lamina medial to the facet of L-2 was removed, and ultrasonography was used to determine the location of the conus medullaris in relation to the laminectomy. Depending on this location, the laminectomy was extended to L-1. The L-1 spinal roots were identified at the foraminal exit, and the dorsal root was separated from the ventral root. Next, individual dorsal roots were identified at the level of the cauda equina. Each root was then subdivided into four to seven smaller rootlets, and these rootlets were individually suspended over the rhizotomy probes. Electrical stimulation was used to grade a reflex response from the lower-extremity muscles. Rootlets were cut according to the response. This procedure was repeated on the remaining L-2 through S-2 dorsal roots, and the entire procedure was repeated on the contralateral side.

Fig. 1. Left: Graph showing a typical set of torque-angle curves for a patient with CP undergoing tests for spasticity of the plantarflexors in which spasticity was characterized as a velocity-dependent resistance to passive stretch. Passive dorsiflexion began at end-range plantarflexion. As the ankle was dorsiflexed, a small amount of dorsiflexor torque (that is, values above the horizontal zero axis) was present and almost immediately changed to a plantarflexor torque. This plantarflexor torque continued to increase until the end of dorsiflexion. In addition, as the speed of the test increased, the plantarflexor torque magnitudes became progressively larger. Results for volunteers with able bodies (right) did not display a velocity-dependent resistance to the stretch because, regardless of the speed, the path of the data remained the same (that is, the plantarflexor torque magnitudes did not increase with increased speeds). Right: Graph showing typical set of torque-angle curves for a volunteer with an able body undergoing tests for spasticity of the plantarflexors. Similar to the patient with CP (left), as the ankle was dorsiflexed, a small amount of dorsiflexor torque was present. It quickly changed to a plantarflexor torque that continued to increase until the end of dorsiflexion. However, unlike the patient with CP, regardless of speed, the plantarflexor torque remained essentially the same (no velocity-dependent resistance to passive stretch).

Work values, as illustrated by the hatched region for the 10°/second speed, were calculated for each speed and plotted against velocity (Fig. 2). Deg = degree; s = second.

Fig. 2. Graph depicting typical work-velocity data for a patient with CP and a volunteer with an able body. The work values calculated from Fig. 1 (for example, the hatched region for 10°/second) were plotted against velocity (10, 30, 60, 90, and 120°/second) for the patient with CP (Fig. 1 left) and the volunteer with an able body (Fig. 1 right). Linear regression was used to calculate a line of best fit for the work compared with the velocity data. The slope of the line (m) was used to measure the magnitude of the spasticity. This single value simultaneously quantified the three components often used to characterize spasticity (velocity, resistance, and range of motion). The slope of the regression line for a patient with CP (m = 0.029) was five times greater than the slope for the volunteer with an able body (m = 0.006).
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The number of rootlets cut varied depending on the EMG response. In general, approximately 75% of the rootlets were cut.

All patients in the CP group participated in a home exercise program and had concomitant physical therapy both before and following the SDR. After surgery and while still in the hospital, each child received physical therapy twice daily starting on the 3rd day postsurgery. After discharge the child underwent physical therapy four or five times per week for 6 months. Subsequently, the treatments were reduced to three or four times per week after 6 months and continued beyond the 8-month postsurgery testing.

The methods used in this investigation to measure spasticity and strength have been described elsewhere. Briefly, each child sat on the KinCom and had their ankle joint axis aligned with the center of the KinCom lever arm. Ankle dorsiflexion and plantarflexion range-of-motion limits were established. For the spasticity tests, the patient was instructed not to help the lever arm move, but to remain as relaxed as possible while the passive ankle joint was rotated from a plantarflexed to dorsiflexed position, and repeatable resistive torques were recorded. Tests were conducted at speeds of 10, 30, 60, 90, and 120°/second.

The strength test was similar to the spasticity tests except that it was designed to measure the maximum, active, resultant ankle plantarflexion torque—generating capacity that each child could produce as the foot moved from maximum ankle dorsiflexion to maximum ankle plantarflexion. The movement speed was 10°/second. Each child was instructed to plantarflex the ankle as the machine went from maximum dorsiflexion to maximum plantarflexion (concentric contraction of the plantarflexors). One practice trial was generally adequate to acquaint the child with the procedure. Three to five tests were conducted to permit the child to achieve his or her best performance, and the test indicating the greatest amount of torque was used in the analysis.

Torque-angle data were processed to parcel out the effects of gravity and to minimize acceleration and machine dynamic responses. Areas within the torque-angle curves were calculated for each speed and child, yielding work values (that is, $\Sigma T \Delta \Theta$, where $T$ is torque and $\Delta \Theta$ is a small angular displacement measured in radians). For the spasticity measure, work values were determined from each speed for each patient (Fig. 1 left). The data from these tests can be contrasted with similar data obtained in a volunteer with an able body (Fig. 1 right). Linear regression was then used to determine the line of best fit for the five work values as a function of speed (Fig. 2). The slope of the linear regression line was considered to measure the magnitude of the spasticity. A slope close to zero represented no spasticity, whereas slopes greater than zero represented increasing amounts of spasticity (that is, increased velocity-dependent resistance to passive stretch). The slope of the work–velocity data obtained in the patient with CP can be contrasted with similar results obtained in a volunteer with an able body (Fig. 2). Similarly, for the strength measure, work values were calculated at 10°/second (Fig. 3).

Because data were collected from both ankles of patients in the CP group, the values for the right and left sides were averaged. An independent t-test was used to determine if significant differences existed between groups ($p < 0.05$). A dependent t-test was used to compare between pre- and postsurgery values ($p < 0.05$).

Results

Results indicated that presurgery plantarflexor spasticity values in the CP group were significantly greater than those in the AB group (Fig. 4 left and Table 1). In the CP group, postsurgery spasticity values were significantly less than presurgery values and not significantly different from the AB group. Thus, the hypothesis that spasticity would be reduced was supported. Results for strength indicated that presurgery values in the CP group for maximum work of the plantarflexors were significantly less than those of the AB group (Fig. 4 right). Postsurgery strength values remained significantly less than those in the AB group. Postsurgery values in the CP group were not significantly changed from presurgery values, indicating that no loss of strength occurred. Thus, the hypothesis that active joint torques would be reduced was supported because no changes in strength were made.

Despite the significant differences found between groups and conditions, the SDs were quite large (Table 1). To gain a greater understanding of this variation, individual pre- and postsurgery spasticity and strength data were plotted (Fig. 5). As a basis for comparison the individual data for the AB group were also plotted. As would be
expected, the individual data for the CP group show a general shift to the left, indicating a reduction in spasticity, but no shift upward or downward, indicating no change in strength (that is, work). However, the diversity of the patient sample in the CP group is apparent. As a result, lines that seemed to indicate natural breaks in data were placed in Fig. 5 to separate the presurgery results into three different subgroups:8 SDR Subgroup I consisted of 12 patients with CP with presurgery spasticity equal to or greater than 0.02 J/(°/second) and varying amounts of strength; SDR Subgroup II consisted of 10 patients with CP with spasticity less than 0.02 J/(°/second) and strength values greater than zero; and SDR Subgroup III consisted of three patients with CP with spasticity less than 0.02 J/(°/second) and strength values less than zero.

Pre- and postsurgery means for spasticity and strength were determined for each subgroup (Fig. 6). Additional statistical procedures were not applied because the size of the subgroups was small. In a comparison of subgroups, SDR Subgroup I (high spasticity and variable strength) demonstrated a dramatic reduction in spasticity, whereas SDR Subgroups II (low spasticity and some strength) and III (low spasticity and little strength) displayed little or no change in spasticity (Fig. 6 left). For the strength variable, it can be observed that SDR Subgroup III manifested a large increase in strength, whereas SDR Subgroups I and II displayed little change (Fig. 6 right).

**Discussion**

The purpose of this investigation was to quantify changes in ankle spasticity and strength in patients with CP as a function of SDR surgery and intensive physical therapy. This investigation did not attempt to determine the individual effects of SDR surgery or intensive physical therapy. Assessment of function also was not a purpose of this investigation.

**Previous Investigations**

Authors of earlier investigations reported reduction in spasticity after SDR.3,13–15,19–22 Using the modified Ashworth Scale,7 these studies reported a significant, one- or two-point reduction in spasticity. The results of the present investigation agree with those of previous studies, indicating a reduction in spasticity. However, comparisons with previous studies are difficult because relationships between the modified Ashworth Scale and the measure used in the present investigation do not exist.

On the other hand, we previously reported on data identical to those presented in the current investigation except that the data were taken from knee flexors rather than ankle plantarflexors (Fig. 4 left and Table 1). The data were also collected from a different cohort of patients. A comparison between these spasticity values indicated no significant differences between ankle plantarflexors and knee flexors both pre- and postsurgery. Furthermore, because the slopes of lines for the two joints are approximately parallel, the data seemed to indicate natural breaks in data were placed in Fig. 5 to separate the presurgery results into three different subgroups: SDR Subgroup I (high spasticity and variable strength) demonstrated a dramatic reduction in spasticity, whereas SDR Subgroups II (low spasticity and some strength) and III (low spasticity and little strength) displayed little or no change in spasticity (Fig. 6 left). For the strength variable, it can be observed that SDR Subgroup III manifested a large increase in strength, whereas SDR Subgroups I and II displayed little change (Fig. 6 right).

**TABLE 1**

<table>
<thead>
<tr>
<th>Group</th>
<th>Ankle</th>
<th>Knee</th>
</tr>
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<tbody>
<tr>
<td>CP group</td>
<td></td>
<td></td>
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<tr>
<td>pre-SDR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spasticity</td>
<td>0.028 ± 0.028†</td>
<td>0.024 ± 0.024†</td>
</tr>
<tr>
<td>strength</td>
<td>0.20 ± 0.22†</td>
<td>0.12 ± 0.20†</td>
</tr>
<tr>
<td>post-SDR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spasticity</td>
<td>0.012 ± 0.14‡</td>
<td>0.009 ± 0.011‡</td>
</tr>
<tr>
<td>strength</td>
<td>0.26 ± 0.19‡</td>
<td>0.30 ± 0.28‡</td>
</tr>
<tr>
<td>AB group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>spasticity</td>
<td>0.006 ± 0.004</td>
<td>0.003 ± 0.008</td>
</tr>
<tr>
<td>strength</td>
<td>0.92 ± 0.42</td>
<td>0.62 ± 0.17</td>
</tr>
</tbody>
</table>

* The CP group tested for ankle values was composed of 25 patients, whereas the CP group tested for knee values consisted of 19 patients. The AB group tested for ankle values was composed of 12 volunteers, and those tested for knee values consisted of six volunteers. Large SDs existed for most variables. Abbreviation: s = second.
† Significantly different from AB group (p < 0.05).
‡ Significantly different from pre-SDR group (p < 0.05).
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parallel, the reductions in spasticity are approximately the same. These results add to the body of knowledge in at least two areas. The first is that there does not appear to be a significant difference in spasticity between ankle plantarflexors and knee flexors. These results seem to conflict with reports stating that the distal areas of the lower extremity are often more affected in children with spastic diplegia CP than the proximal areas.4,9 The implication of this statement is that greater spasticity should exist at the ankles compared with the knees. The second area is that changes in spasticity as a result of the SDR seem to be uniform across the two joints. Whether this is due to uniform cutting of rootlets or another factor is currently unknown; however, it leads to ideas relating to testing other methods of selecting the rootlets to be sectioned. For example, if greater spasticity existed in the knees compared with the ankles, then it may be more effective to section more rootlets associated with knee musculature than ankle musculature. It should be noted that the spasticity values for ankles and knees were not obtained in the same patients. Although our patient selection process has not changed over the years of collecting these data and it would be expected that one sample of patients would be the same as another, it would be prudent to confirm these ankle–knee results in the same group of patients.

Patient Subgrouping

In our previous investigation in which we examined knee spasticity and strength, the substantial variation prompted us to divide our cohort of patients into three subgroups.8 Similarly, the substantial variation in our present data warranted a similar subgrouping (Fig. 6). The subgrouping of patients for the spasticity measure at the ankle produced the same results as previously reported for the spasticity measure at the knee. Those patients in SDR Subgroup I (spasticity and variable strength) indicated a substantial decrease in spasticity (Fig. 6 left). Those patients in Subgroups II (low spasticity and some strength) and III (low spasticity and minimal strength) showed little change as a consequence of the surgery. If the objective of performing the SDR is to reduce spasticity, as characterized in this investigation (that is, velocity-dependent resistance to passive stretch), and the spasticity results at the ankle are characteristic of both the knee and hip, then the value of performing the rhizotomy on patients in SDR Subgroups II and III must be called into question. However, it should be noted that spasticity data for the knees and hips were not collected from these patients. It is therefore inappropriate to conclude that patients in SDR Subgroups II and III were not candidates for rhizotomy. Further insight into this concept will be gained when data are collected for ankles, knees, and hips in the same patients.

The subgrouping of patients for strength measure at the ankle produced mixed results compared with strength data previously reported at the knee.8 Similar to the knee, the results for SDR Subgroup I (spasticity and variable strength) indicated little change in strength (Fig. 6 right). However, a comparison of the results of SDR Subgroups II and III for the knee with similar results at the ankle produced different results. At the knee, SDR Subgroup II (low spasticity and some strength) displayed a substantial increase in strength. At the ankle, SDR Subgroup II dis-
played little change. At the knee, SDR Subgroup III (low spasticity and minimal strength) had little change in strength as a consequence of the rhizotomy, yet at the ankle Subgroup III had a substantial increase in strength. Although the objective of the SDR is to reduce spasticity, the results for Subgroup III indicated an increase in strength (Note: only three patients were in SDR Subgroup III). Based on these results, it is possible that an SDR and combined intensive physical therapy could be used to increase ankle plantarflexor strength in these patients. The benefits or detriments associated with this objective have yet to be determined but warrant additional consideration.

Although data on the hip have not yet been collected, data on the knee and ankle provide more information about the effects of the SDR on spasticity and strength. At least three items are worth noting. The first is that the SDR appears to reduce spasticity by the same amount in both knees and ankles. Whether this is due to uniform sectioning of the rootlets or other factors is currently unknown. The second item is that strength is not being altered by the rhizotomy in a consistent manner, and in a way this agrees with that shown in the previous literature. The inconsistent changes may simply be a result of our lack of understanding in this area, in which case, with additional knowledge we can use the strength information to develop better treatment pathways for these patients. It is also possible that the patient’s ability to control these joints is a major factor in changes in strength. Unfortunately, a simple objective measure to assess this strength control does not presently exist. The third item is that the process of selecting patients undergoing the SDR is important. The methods described in our present and previous work may become a valuable tool not only in helping with patient selection but also in understanding the mechanisms associated the changes in spasticity and strength changes as a consequence of the SDR.

Conclusions

The spasticity results of the present investigation agreed with those of previous studies indicating a reduction in spasticity for the CP group. The strength results did not agree with those of most previous studies, which indicated that a decrease in strength should have occurred. The strength results did agree with a previous investigation in which knee flexor strength was objectively examined, in which case, with additional knowledge we can use the strength information to develop better treatment pathways for these patients. It is also possible that the patient’s ability to control these joints is a major factor in changes in strength. Unfortunately, a simple objective measure to assess this strength control does not presently exist. The third item is that the process of selecting patients undergoing the SDR is important. The methods described in our present and previous work may become a valuable tool not only in helping with patient selection but also in understanding the mechanisms associated the changes in spasticity and strength changes as a consequence of the SDR.

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