Spasticity and strength changes as a function of selective dorsal rhizotomy

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This investigation quantified pre- and postsurgery (8 months) hamstring muscle spasticity and strength in children with cerebral palsy (CP) undergoing a selective dorsal rhizotomy. Nineteen children with CP (CP group) and six children with able bodies (AB group) underwent testing with a dynamometer. For the spasticity measure, the dynamometer measured the resistive torque of the hamstring muscles during passive knee extension at four different speeds. Torque angle data were processed to calculate the work done by the machine to extend the knee for each speed. Linear regression was used to calculate the slope of the line of best fit for the work velocity data. The slope simultaneously encompassed three key elements associated with spasticity (velocity, resistance, and stretch) and was considered the measure of spasticity. For the strength test, the dynamometer moved the leg from full knee extension to flexion while a maximum concentric contraction of the hamstring muscles was performed. Torque angle data were processed to calculate the work done on the machine by the child. Hamstring spasticity values for the CP group were significantly greater than similar values for AB group prior to surgery; however they were not significantly different after surgery. Hamstring strength values for the CP group remained significantly less than those for the AB group after surgery, but were significantly increased relative to their presurgery values. The results of spasticity testing in the present investigation agreed with previous studies indicating a reduction in spasticity for the CP group. The results of strength testing did not agree with those in the previous literature; a significant increase in strength was observed for the CP group.

Key Words * cerebral palsy * spasticity * rhizotomy * strength * dynamometer * hamstring

Selective dorsal rhizotomy (SDR) is a surgical procedure performed to treat children with cerebral palsy (CP) by selectively cutting the dorsal rootlets from L-1 to S-2 based on their response to electrical stimulation.[13,15,16,18,19,22] The surgery is intended to minimize or eliminate the influence of spasticity.[18] In previous investigations a reduction in spasticity after SDR has been reported;[3,13,15,16,20,22,23,25] however, in these investigations the modified Ashworth Scale has been used to quantify spasticity.[2] Even with this scale's widespread use in both clinical and research settings, it is a subjective measure recorded by using ordinal data and the results must therefore be evaluated in terms of these limitations. In one investigation in which an objective measure was used to quantify spasticity, a significant reduction as a result of SDR was indicated.[15] The method involved the use of a custom made dynamometer that is not readily available to hospitals and clinics. Furthermore, the results incorporated complex variables that are difficult to understand and interpret. Recently, an objective

measure in which spasticity is characterized as a velocity-dependent resistance to passive stretch[6,11] that can be measured by a dynamometer available to medical centers has been reported.[9]

In addition to spasticity, muscle weakness is another impairment associated with children who have CP. Weakness in the antigravity musculature has been reported to be a contraindication to the performance of SDR.[1,17,19,20] In addition, postoperative weakness is considered to be a limitation to a favorable outcome of the surgery.[1,17,19,20] Although these reports indicate the need for caution in performing a SDR in children with muscle weakness, a paucity of objective information is available to substantiate or refute the claim. Objective measures to quantify strength and weakness in children with CP have been described;[5,10,12] however, these measures have been used to investigate the abilities of children with CP to show gains in strength as a result of training. They have not been used in the clinical setting to aid in the selection of patients who are appropriate candidates to undergo SDR or in the evaluation of their outcome. Recently, an objective measure to quantify strength and weakness that can be used in conjunction with the spasticity measure cited above has been developed.[8] The purpose of this investigation was to quantify changes in spasticity and strength in children with CP as a function of their having undergone SDR surgery and the associated intensive physical therapy. It was hypothesized that a significant decrease in both spasticity and strength would occur as a result of the surgery and physical therapy.

CLINICAL MATERIAL AND METHODS

For this prospective investigation, a sample of six children with able bodies (mean age 9 years: standard deviation [SD] 4.5 years, range 4-17 years; two boys and four girls: mean mass 34.5 kg, SD 17.9 kg, range 17-61 kg) and 19 children with spastic diplegic CP (mean age 9 years: SD 4.2 years, range 4-16 years; nine boys and 10 girls: mean mass 32.7 kg, SD 14.6 kg, range 15-58 kg) were recruited. The children with able bodies (AB group) were recruited through parents within the hospital community or were siblings of children admitted to the hospital. In each child in the AB group, only one leg was tested. The children with CP (CP group) had been referred to the Human Performance Laboratory for testing by a neurosurgeon and were scheduled to undergo SDR the following day. The CP group was tested again approximately 8 months after surgery. Attempts were made to test both legs of the children with CP presurgery, but if a child became tired or uncooperative, only one leg was tested. In the 13 children in whom both legs were tested, a single leg from each child was randomly selected for analysis and formed the basis for both pre- and postsurgery values. We did not use the data from both legs because they were taken from the same subject and could not be considered to be independent measurements.[21] Each child and/or parent was informed about the project and gave informed consent.

The SDR surgery has been described in detail elsewhere.[18] Briefly, in preparation for intraoperative electromyographic (EMG) examination and with the patient prone and receiving general anesthesia, 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 ultrasound was used to determine the location of the conus medullaris in relation to the laminectomy. Depending on the location of L-2, 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. The 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 rhizotomy probes. Electrical stimulation was used to grade a reflex response from the lower-extremity muscles; rootlets were then cut according to the response. This procedure was repeated on the remaining L2-S2 dorsal roots and the entire procedure was repeated on the contralateral

side. The number of rootlets cut varied depending on the EMG response. In general approximately 60 to 80% of the rootlets were cut.

All children participated in a home exercise program and received concomitant physical therapy both before and after the SDR surgery. Six weeks before the surgery, a daily home exercise program and physical therapy treatments were initiated twice per week. After the surgery, each child received physical therapy twice daily starting on the 3rd day postsurgery. A home exercise program was taught to the patient and family during the hospital stay. After discharge the child received physical therapy four to five times per week for 6 months. Subsequently, treatments were reduced to three to four times per week after 6 months and continued well beyond the 8-month postsurgery testing.

The methods used in this investigation to measure spasticity and strength have been described elsewhere.[8,9] Briefly, each child sat on the KinCom and their knee joint axis was aligned with the center of the KinCom lever arm (Fig. 1). Knee extension range of motion limits were established. For the spasticity tests, the child was instructed not to help the lever arm move and to remain as relaxed as possible while the passive knee joint was rotated from a flexed to an extended position. Tests were conducted at speeds of 10š, 30š, 60š, and 90š per second. Although a number of trials were performed for the tests, only one trial at each speed was actually used in the analysis. A unique feature of the KinCom is that it automatically overlays the results from of the current trial with the previous trial. These results were viewed in real time by the therapist and patient. Thus, it was straightforward to determine the variation between successive trials. The therapist recorded and saved the trial when variation between trials was minimal or nonexistent for a given speed.

Fig. 1. Photograph of a child with his right leg placed in the KinCom dynamometer and his knee flexed. The knee axis was aligned with the axis of the KinCom lever arm. End range knee extension was determined. Tests were conducted covering a range from approximately

60° below the horizontal axis to full knee extension.

The reliability of obtaining consistent results for patients during a single session was evaluated by saving two consecutive test results for 13 patients. A Pearson product moment correlation coefficient test gave a value of 0.98 between tests, indicating very high intratest reliability.

The strength test was similar to the spasticity tests except that it was designed to measure the maximum active resultant knee flexion torque-generating capacity produced by each child as the leg moved from maximum knee extension to approximately 60° below the horizontal level. The movement speed was 10° per second. This type of active assist test was developed because in some cases children were unable to produce sufficient torque to initiate movement of the lever arm without assistance, and in contrast to an isometric contraction, it provided joint torque information for a broad range of motion. Each child was instructed to flex the knee as the machine went from maximum knee extension to knee flexion (that is, concentric contraction of the hamstring muscles). One practice trial was sufficient to acquaint the child with the procedure. Three to five tests were conducted to permit each child to achieve their best performance. Only the test indicating the greatest amount of torque was used in the analysis. Similar to the spasticity measure, the overlay feature of the KinCom permitted rapid determination of the best trial. The therapist used verbal and visual encouragement to enhance performance by asking the child to exceed the results from the previous trial.

Fig. 2. Graph showing a typical set of torque-angle curves for a child with CP who is undergoing tests for spasticity of the hamstring muscles, in which spasticity was characterized as a velocity-dependent resistance to passive stretch. Passive knee extension began in a flexed position (Fig. 1). As the knee was extended, a small amount of extensor torque (values above the horizontal zero axis) was present until approximately -30°. The extensor torque then passed below the horizontal zero axis and became a flexor torque. This

flexor torque continued to increase until the end of knee extension. In addition, as the speed of the test increased, the flexor torque magnitudes became progressively larger. The results for children with able bodies (Fig. 3) did not show a velocity-dependent resistance to the stretch because regardless of the speed, the path of the data remained the same (the flexor torque magnitudes did not increase with increased speeds). Work values, as illustrated by the shaded region for the 10š per second speed, were calculated for each speed and plotted against velocity (Fig. 4).

Torque angle data were processed to partial 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, $(\text{sum})T \cdot \text{change in } \theta$, T = torque and change in θ is a small angular displacement measured in radians). For the spasticity measure, work values were determined from each speed (that is, 10š, 30š, 60š, and 90š per second) for each child (Fig. 2). The data from these tests can be compared with similar data from a child in the AB group (Fig. 3).

Fig. 3. Graph showing a typical set of torque-angle curves for a child with an able body who was undergoing tests for spasticity of the hamstring muscles. Similar to the child with CP (Fig. 2), as the knee was extended, a small amount of extensor torque (values above the horizontal zero axis) was present until approximately -30š. The extensor torque then passed below the horizontal zero axis and became a flexor torque. This flexor torque continued to increase until the end of knee extension. However, unlike in the child with CP, regardless of the speed, the extensor torque remained essentially the same (no velocity-dependent resistance to passive stretch). Work values, as illustrated by the shaded region for the 30š per second speed, were calculated for each speed and plotted against velocity (Fig. 4).

Linear regression was used to determine the line of best fit for the four work values as a function of speed (Fig. 4). 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 increasing slopes represented increasing amounts of spasticity (that is, increased velocity-dependent resistance to passive stretch). The slope of the work-velocity data from a child in the CP group can be compared with similar results from a child in the AB group (Fig. 4).

Fig. 4. Graph showing typical work-velocity data in a child with CP and in an able bodied child. The work values calculated from Fig. 2 (shaded region for 10š per second in Fig. 2) were plotted against velocity (10š, 30š, 60š, 90š per second) for the child with CP, and for the child with an able body (Fig. 3). Linear regression was used to calculate a line of best fit for the work versus 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, range of motion). The slope of the regression line for a child with CP ($m = 0.030$) was 10 times greater than the slope for the able-bodied child ($m = 0.003$).

Similarly, for the strength measure, work values were calculated at 10š per second (Fig. 5). The extensor work (that work above the zero torque line) during the flexion motion was subtracted from the flexor work (that work falling below the zero torque line) recorded during the flexion motion.

Fig. 5. Graph showing a typical torque-angle curve for a child with CP who is undergoing the strength test. The test was designed to measure the maximum effort achieved during a concentric contraction of the hamstring muscles. The results of the test begin on the right side of the figure (see Start) when the knee was in an extended position and move to the left when the knee rests in a flexed position. The child could produce a flexor torque (values below the horizontal zero line) during the first two-thirds of the test. The child produced an extensor torque during the final one-third of the test (values above the horizontal zero line). These results are in contrast to able-bodied children who could achieve a flexor torque (values below the horizontal zero line) throughout the entire range of motion. The work done by the child on the machine was determined by calculating the area highlighted by shaded region. When both flexor and extensor work was performed by the children with CP, the values were subtracted.

A chi-square test was performed to determine whether the distribution of the variables for the children in the CP group were significantly different from a normal distribution. Because no significant difference was found ($p < 0.01$) an independent t-test was used to determine whether significant differences existed between groups ($p < 0.05$). A dependent t-test was used to compare values between pre- and postsurgery testing ($p < 0.05$).

RESULTS

The results indicated that the presurgery hamstring spasticity values in the CP group were significantly greater than those for the AB group (Fig. 6). In the CP group, postsurgery spasticity values were significantly less than presurgery values and not significantly different from those of the AB group. Thus, the hypothesis that spasticity would be reduced was supported. The results of strength testing

indicated that the CP group presurgery values for maximum flexion work of the hamstring muscles were significantly less than those of the AB group (Fig. 6). Postsurgery strength values remained significantly less than those for the AB group. However, the postsurgery values were significantly greater than the presurgery values, indicating that gains in strength were made. Thus, the hypothesis that active joint torques would be reduced was not supported; significant increases in strength were made.

Fig. 6. Graph showing the mean values for spasticity (horizontal axis) and strength (vertical axis) for the CP (pre- and postsurgery) and AB groups of children. Horizontal SD bars for spasticity and vertical SD bars for strength indicate the variations from the means. The asterisk symbol indicates that the variable was significantly different from the AB group ($p < 0.05$), while the carrot symbol indicates that the variable was significantly different from the presurgery values of the CP group ($p < 0.05$). Spasticity values for the CP group were significantly greater than for the AB group prior to surgery, but not significantly different after surgery. Strength values for the CP group were significantly less than for the AB group both before and 8 months after surgery; however, the postsurgery values were significantly greater than presurgery values for the CP group.

Despite the significant differences found among groups and conditions, the SDs, particularly for the presurgery spasticity and postsurgery strength measures, were quite large (Fig. 6). To gain a greater understanding of this variation, individual pre- and postsurgery spasticity and strength data were plotted (Fig. 7).

Fig. 7. Graphs showing individual spasticity (horizontal axis) and strength (vertical axis) data for CP (pre- and postsurgery) and AB groups of the children. The large variation in values prompted us to divide the CP group into three subgroups. The dashed lines represent the dividing points and the Roman numerals indicate the subgroup names. The 10 children in the SDR subgroup I had spasticity equal to or greater than the group mean and varying amounts of strength. The six children in the SDR subgroup II had low spasticity and some strength (work values > 0), and the three children in the SDR subgroup III had low spasticity and low strength (work values < 0).

As a basis for comparison, the individual data for the AB group were also plotted. Similar to the mean value, the results for the individual data for the CP group show a general shift to the left, indicating a reduction in spasticity, and a shift upward, indicating an increase in strength (that is, work). However, the diversity of the patient sample for the CP group is apparent. As a result of this diversity, lines that seemed to indicate natural breaks in the data were placed in Fig. 7 to separate the presurgery results into three different subgroups. The SDR subgroup I consisted of 10 CP patients with presurgery spasticity values equal to or greater than the entire group's mean value and varying amounts of strength. The SDR subgroup II consisted of six CP patients with spasticity values less than the entire presurgery group mean and strength values greater than zero. The SDR subgroup III consisted of three CP patients with spasticity values less than the entire presurgery group mean and strength values less than zero.

Fig. 8. Graph showing pre- and postsurgery means and SDs for spasticity in SDR subgroups I, II, and III. The SDR subgroup I showed a substantial decrease in spasticity as a function of the SDR, whereas SDR subgroups II and III showed only minor changes.

Pre- and postsurgery means and SDs for spasticity and strength were determined for each subgroup (Figs. 8 and 9). Additional statistical procedures were not applied because the size of the subgroups was small. The SDR subgroup I (high spasticity and variable strength) showed a dramatic reduction in spasticity, whereas SDR subgroups II (no spasticity and some strength) and III (no spasticity and little strength) displayed little or no change in spasticity values (Fig. 8). For the strength variable, it can be observed that SDR subgroup II showed a large increase in strength, whereas SDR subgroups I and III displayed only small increases (Fig. 9).

Fig. 9. Graph showing pre- and postsurgery means and SDs for strength in SDR subgroups I, II, and III. The SDR subgroup II displayed a substantial increase in strength, whereas SDR

subgroups I and III displayed only minor changes.

DISCUSSION

The purpose of this investigation was to quantify changes in spasticity and strength values as a function of SDR surgery and intensive physical therapy in children with CP. We did not attempt to determine the individual affects of the SDR surgery or the intensive physical therapy. Assessment of function was also not a purpose of this investigation. Although some functional measures, not part of the investigation, were obtained in most of the children in the study, they were obtained by numerous testers whose measurement reliability was not assessed. Thus, functional results are not presented here. Similarly, the modified Ashworth Scale data were also obtained in most of the patients, but because of the lack of rigor in the ways in which these data were collected, the results were not included. The cohort of children with CP in this investigation was relatively small (19 patients). The results must be interpreted based on this sample size. It should be noted, however, that randomized clinical studies in which the effects of SDR and physical therapy were investigated had comparable group numbers. The investigations by McLaughlin, et al.,[14] and Steinbok, et al.,[23] involved 19 and 15 patients per group, respectively.

A number of limitations can be associated with the spasticity and strength tests used in this investigation.[8,9] The resultant joint torque assessed in this investigation is the sum of all the individual torques that can occur around a joint (such as those caused by agonist and antagonistic muscles). In the present investigation these individual contributions to the resultant joint torque were not determined. In fact, the ability to distribute the resultant joint torque to the load carrying structures (such as that resulting from quadriceps and hamstring muscles) has not been reported in children with CP, and it would be a very difficult task because the muscle modeling techniques required have not yet reached the necessary level of sophistication. This lack of information limits to some degree the interpretation of the results. For example, if during the hamstring concentric contraction tests, torque was being generated by the quadriceps, then the resultant joint torque, our measure of hamstring strength, would be underestimated. Furthermore, if after the SDR was performed, this quadriceps muscle activity were reduced or eliminated, then regardless of any change in hamstring muscle strength, our reported values would be increased. The EMG activity of the quadriceps muscle during testing might be helpful in this regard, but these data were not collected in this investigation. It should be noted, however, that it has been reported that EMG activity during gait was not altered as a result of the SDR.[4]

KinCom angles are offset 10 to 15° from the actual knee joint angle of the child (Fig. 1). Knowledge of this offset is helpful in relating the KinCom angles (Figs. 2 and 4) to the anatomical position but are not required to calculate spasticity or strength values. Only the hamstring muscles of the knee joints were tested. The lack of spasticity and strength data for the ankles and hips prevents general conclusionary statements about the effects of SDR on lower-extremity spasticity and strength. Future work will focus on the study of these joints. Although the reliability of the measures for a single data collection session have been tested, the reliability of the measure between test sessions has not been fully evaluated. The logistics of arranging multiple pre- and postsurgery visits to the laboratory have made this evaluation quite difficult. However, repeated testing of a few patients has been encouraging.[9] Finally, fatigue, learning, and motor control were factors considered as possibly preventing the children in the CP group from achieving strength results more similar to those in the AB group. Fatigue was considered to play a minor role in the magnitude of force because many children put forth their best maximum efforts on the third trial. On the other hand, it is possible that learning and motor control may have had a major influence on the ability of the children with CP to produce the desired torque. Research efforts along

these lines appear warranted.

Earlier investigations have reported on a reduction in spasticity after SDR.[3,13,15,16,20,22,23,25] In three of these investigations numerical information on spasticity in the knee flexors was reported.[15,22,23,25] Based on the modified Ashworth Scale a significant one to two point reduction in spasticity was reported.[2]

The results of the present investigation agree with those of the previous studies in which a reduction in spasticity was indicated. However, it should be noted that the results of the present investigation are unique for at least three reasons. We used an objective measure that detected resistance via a force transducer in the KinCom. This force transducer is not susceptible to variations associated with human assessment. In contrast, previous reports have been based on the modified Ashworth Scale, which is a subjective measure based on one or more clinicians' ability to sense a resistance uniformly over a range of motion.[2] The second reason is that the present investigation produced ratio scale data.[7] Ratio scale data can be subjected to the most sophisticated types of statistical treatment.[7] Thus, direct comparisons in which the extent or degree of differences in measurements is examined are possible. On the other hand, the numbers derived from the modified Ashworth Scale are of ordinal scale.[24] Ordinal data reveal whether a score is larger or smaller than another, but cannot be used to determine the extent or degree of differences.[7] As a result, less powerful nonparametric statistical procedures should be used to evaluate these types of data.[7] The third reason is that we used a measure that incorporates the three key elements often associated with spasticity[8] (velocity, resistance, and stretch[6,11]). The slope of the work-velocity curve simultaneously includes the resistance and range of motion in the work value (Fig. 2), and the velocity component is represented by multiple speeds that were tested (Fig. 4). The modified Ashworth Scale does not measure the three key elements often used to characterize spasticity: only the resistance associated with a stretch is examined. It does not explicitly include velocity in the measure.

Previous investigators have reported that muscle weakness is a contraindication to and a limitation of SDR.[1,17,19,20] However, it was not reported how muscle weakness was evaluated either pre- or postsurgery to arrive at these conclusions. It should be noted that despite not reporting their method of evaluating weakness, investigators realized the importance of developing an objective measure for strength, as it was stated as a recommendation for future work.[19,20]

We used an objective measure to quantify weakness in the present investigation.[8] The results indicated that children with CP were weaker than able-bodied children both pre- and postsurgery. However, despite the fact that the children with CP remained weaker than the children with able bodies after surgery, a significant increase in strength was achieved compared to presurgery values. These results are new to the literature and do not agree with previous reports.[1,17,19,20]

It is essential to note that although a significant increase in strength was achieved by the entire group of children with CP, not all children displayed the same amount of change. It is apparent from Fig. 9 that the children in SDR subgroup III (no spasticity and low strength) achieved minimal changes in strength. Furthermore, children in SDR subgroup I (high spasticity and variable strength) showed a slightly greater increase in strength compared with those in SDR subgroup III, and children in SDR subgroup II (no spasticity and some strength) achieved the greatest increase in strength. All children underwent an aggressive strengthening program consisting of physical therapy approximately four to five times per week. Thus, the results of a strengthening program in combination with the SDR may not affect children with CP in the same way. These results must be considered carefully when appraising the general overall

strength gains reported for children with CP undergoing a strength training program.[5,10,12]

Similarly, when viewing the changes in spasticity for the subgroups (Fig. 8), it is possible to observe that not all subgroups changed in the same manner. In this case SDR subgroup I showed the greatest reduction in spasticity, whereas SDR subgroups II and III indicated little change. Additional work is required in these areas to determine the contribution of physical therapy and SDR to the strength and spasticity changes associated with the procedures.

The results of grouping the children with CP support at least three considerations. The first supports the literature in which it stated that selecting patients for SDR surgery is critical. Although the spasticity and strength for the plantar flexors at the ankles and adductors at the hip for the children in SDR subgroup III were not measured, the presurgery results for the knee indicate little spasticity and substantial weakness. The spasticity and weakness were not altered as a result of the SDR surgery. Based only on the results for the knee, it can be speculated that these children may not have been the most appropriate candidates for the SDR surgery. The second consideration is that SDR subgroup II displayed little spasticity in the knee and some strength in the hamstring muscles before surgery. After surgery spasticity was unchanged, but a substantial increase in strength was achieved. The objective of SDR surgery is to reduce spasticity. However, the results presented here indicate that the SDR surgery may be a procedure that permits an increase in strength in some children with CP. This consideration would require substantial investigation delving into such things as pre- and postsurgery quadriceps muscle activity, pre- and postsurgery physical therapy, the strategy for nerve rootlet cutting, and potential changes in voluntary motor control as a result of the surgery. The third consideration is that the results of this investigation only measure impairment. We did not examine how function is altered as a result of the surgery. Hence, although the specific objective of SDR surgery is to reduce spasticity, it is implied that this will produce an improvement in function. Thus, it is possible, for example, that despite low spasticity and strength values both pre- and postsurgery, children in SDR subgroup III may demonstrate substantial improvement in function. If it can be established that good correlations exist between the presurgery spasticity and strength in SDR subgroups I, II, and III and postsurgery function, the measures described in the present investigation could become valuable tools in the selection process of SDR patients.

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