Hip Spasticity and Strength in Children With Spastic Diplegia Cerebral Palsy

Jack R. Engsberg, Sandy A. Ross, Kevin W. Hollander, and T.S. Park

Hip spasticity and strength from 44 children with cerebral palsy (CP) and 44 children with able bodies (AB) were compared. For spasticity, a KinCom dynamometer abducted the passive hip at 4 different speeds and recorded the resistive adductor torques. Work values for the torque-angle data were calculated at each speed. Linear regression derived the slope for the line of best fit for the work-velocity data to determine the spasticity measure. For strength, the KinCom rotated the hip from maximum adduction to maximum abduction at a speed of 10°/s while the child performed a maximum abduction concentric contraction. Tests were reversed to record maximum adduction. Maximum torques and work by the abductors and adductors were calculated. Spasticity in the adductors for the CP group was significantly greater than values recorded for the AB group. All strength measures were significantly less than the AB group. Results provide objective information, quantifying hip spasticity and strength in children with CP.

Key Words: spasticity, strength, cerebral palsy, dynamometer

Introduction

Cerebral palsy (CP) is a non-progressive disorder characterized by impairment of motor function secondary to injury of the immature brain (Ingram, 1984). Spasticity and muscle weakness are two factors related to the impairment of motor function. Spasticity has been characterized in a variety of ways including: muscle hypertonia (Katz et al., 1989; Rymer et al., 1989), hyperactive deep tendon reflex, (Miglietta et al., 1962) clonus (Skinner, 1992), and velocity dependent resistance to passive stretch (Dimitrijevic, 1985; Engsberg et al., 1996; Jones et al., 1982; Lance, 1980). Recently, an objective measure characterizing spasticity as a velocity dependent resistance to passive stretch has been reported for the knee flexors and ankle plantarflexors (Engsberg et al., 1996, 1998, 1999, 2000). While subjective reports about spasticity in children with CP abound (e.g., Bohannon et al., 1987; Peacock et al., 1991; Sloan et al., 1992), few investigations have been found that objectively quantified spasticity (i.e., characterized as a velocity dependent resistance to passive stretch). No investigations have objectively quantified spasticity in the hip adductors.

The authors are with the Human Performance Laboratory at Barnes-Jewish Hospital, 4555 Forest Park Parkway, St. Louis, MO 63108, and the Center for Cerebral Palsy Spasticity at St. Louis Children’s Hospital, One Children’s Place, St. Louis, MO 63110.
Muscle weakness is often an interest for health care professionals as they try to determine the most appropriate treatment pathways for children with CP. Subjective reports of lower extremity muscle weakness have been reported to be a contraindication to performing a selective dorsal rhizotomy (McDonald, 1991; Oppenheim, 1990). Objective measures to quantify knee and ankle strength in children with CP have been reported (Damiano et al., 1995, 1998; Engsberg et al., 1998a, 1999, 2000; Kramer et al., 1994; MacPhail et al., 1995; Olney et al., 1990). Only one investigation has reported hip abductor/adductor strength in children with CP (Damiano et al., 1998). These investigators used a hand held dynamometer to record maximum force values.

The purpose of this investigation was to compare spasticity of the hip adductors and strength of the hip abductors/adductors in children with spastic diplegia CP and able bodies (AB). It was hypothesized that greater spasticity would exist in the hip adductors of the children with CP (CP group) compared to a group of children with able bodies (AB group). It was also hypothesized that the CP group would exhibit less hip abductor/adductor strength compared to the AB group.

**Methods**

For this prospective investigation, a sample of 44 children with spastic diplegia CP and 44 children with able bodies were recruited (Table 1). The children with CP were recruited from around North America as part of a study investigating the efficacy of the selective dorsal rhizotomy surgery. The children with able bodies (AB group) were recruited through parents within the hospital community and by word of mouth throughout the greater St. Louis area. The AB group and the children with CP (CP group) were part of a comprehensive investigation studying the effects of selective dorsal rhizotomy surgery. Testing was performed prior to any intervention related to the investigation. The majority of the children in the CP group were independent ambulators \((n = 30)\). The remaining children \((n = 14)\) ambulated using assistive devices (e.g., crutches, walkers). The clinical diagnosis of spastic diplegia was made by a neurosurgeon or neurologist. Participants were limited to children who were large enough to fit comfortably on the test equipment with minimal adaptations and would presumably cooperate. All parents and children (age >17) signed an informed consent. For each child with an able body, only one leg was tested, while both legs of all children in the CP group were tested.

<table>
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<th>Females</th>
<th>Mass (kg)</th>
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<td>14–85</td>
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<td>19.4</td>
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<tr>
<td>Range</td>
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<td>14–108</td>
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**Table 1** Descriptive Characteristic of Children With Cerebral Palsy and Able Bodies
The general methods used in this investigation to measure spasticity and strength have been described elsewhere for the knee and ankle (Engsberg et al. 1996, 1998a, 1998b, 1999, 2000; Ross et al., 2000). They will be described briefly for the hip. Each child lay supine on the KinCom dynamometer bench and had his/her hip joint abduction/adduction axis aligned with the center of the KinCom lever arm (Figure 1). The pelvis was stabilized with a belt and with the aid of a research assistant. End range hip abduction/adduction limits were established by the physical therapist with a slight amount of hip flexion to permit the heel to clear the bench during the movement. Range of motion limits were set at the point where further movement in a direction resulted in lateral pelvic tilt. Caution was taken to maintain the lower extremity in resting knee extension and neutral rotation within the child’s bony alignment limits. For the spasticity tests, the child was instructed not to help the lever arm move and remain as relaxed as possible as the passive hip was rotated from maximum adduction to maximum abduction, thereby stretching the hip adductors. The amount of adductor resistance to the stretch was recorded by the KinCom. Spasticity tests were conducted at speeds of 10, 30, 60, and 90°/s. While a number of trials were performed, only one trial at each speed was actually used in the analysis. A feature of the KinCom is that it automatically overlays the results from the current trial with the

Figure 1 — A subject with her left hip placed in the KinCom dynamometer. The hip abductor/adductor axis was aligned with the axis of the KinCom lever arm, and the pelvis was secured with a belt. End range adduction and abduction were determined, and tests were conducted over the entire range of motion.
previous trial. These results were viewed in “real time” by a physical therapist and the child. It was thus straightforward to determine the variation between successive trials. The therapist saved the trial when variation between trials was minimal or nonexistent for a given speed. A previous investigation reporting reliability for the knee and ankle using the Pearson Product Moment Correlation Coefficient indicated a value of $r = 0.98$ (Engsberg et al., 2000).

The strength tests were similar to the spasticity tests except that they were designed to measure the maximum active resultant torque that each child could produce. The active assist test was developed, because some children were unable to produce sufficient active torque to initiate movement of the lever arm without assistance. In contrast to an isometric contraction, it provided joint torque information throughout an entire range of motion. For the tests, the hip rotated from end range adduction to end range abduction at 10°/s while the child performed a maximum concentric contraction of the adductors. Next, the hip rotated from end range abduction to end range adduction at 10°/s while the child performed a maximum concentric contraction of the adductors. One practice trial was generally sufficient to acquaint the child to the procedure. Three to five trials were conducted to permit the child to achieve his/her best performance. Only the trial indicating the greatest amount of torque was used in the analysis. Similar to the spasticity measure, the overlay feature on the KinCom permitted rapid determination of the best trial. The therapist used verbal and visual encouragement to enhance performance by asking the subject to exceed the results from the previous trial.

Torque-angle data were processed to minimize acceleration and machine dynamic responses. Areas within the torque-angle curves were calculated for each speed of each child using the trapezoidal rule, yielding work values (i.e., $\Sigma T^*\Delta\theta$, $T =$ torque and $\Delta\theta$ is a small angular displacement measured in radians; Figure 2). For the spasticity measure, each child’s work values were determined for each speed (i.e., 10, 30, 60, and 90°/s). These values represented the amount of work required by the KinCom to move the passive hip throughout its entire abduction range of motion. Linear regression was then used to determine the line of best fit for these four work values as a function of speed (Figure 3). The slope of the linear regression line was considered to measure the magnitude of the spasticity. A slope close to zero represented no spasticity, while increasing slopes represented increasing amounts of spasticity (i.e., increased velocity dependent resistance to passive stretch). For the strength measures, the maximum torque values for both abduction and adduction were recorded (Figure 4). Next, the trapezoidal rule was used to determine the area bounded by the curve, the zero torque line, and the beginning and ending range of motion for each abduction/adduction torque-angle curve. The values were subtracted when areas existed both above and below the zero torque line. All values were normalized by dividing by subject mass to permit intersubject comparison (Engsberg et al., 1998; 1999a, 1999b; 2000; Kramer et al., 1994; MacPhail et al., 1995; Ross et al., 2000).

A $\chi^2$ test was performed to determine if the distribution of the variables for the CP group was significantly different from a normal distribution. No significant difference was found ($p > .05$). Since both hips were tested for the CP group, bilateral hip spasticity and strength asymmetry were evaluated. A paired $t$ test was used to determine if a significant difference existed between the right and left hips ($p < .05$) for the measures. No significant differences were found for any of the measures. For the comparison with the AB group, the values for the right and left sides of the CP group were averaged. An unpaired $t$ test was used to compare abduction to adduction strength values (i.e., max and work) within groups.
Figure 2 — Typical torque-angle curve (10°/s) for a child with an able body undergoing tests for spasticity of the adductors, where spasticity was characterized as a velocity dependent resistance to passive stretch. The work (i.e., \( \Sigma T^*\Delta\theta \), \( T = \) torque and \( \Delta\theta \) is a small angular displacement measured in radians) was quantified by measuring the area in the shaded region. The boundaries for the area were: the torque-angle curve, the zero torque line, and the end range of motion (about 55°). A work value was calculated for each of the four speeds (i.e., 10, 30, 60, and 90°/s) for each child. Inertial and gravitational effects were removed from the data. It should be noted that children with CP produced similar curves.

Figure 3 — Typical work-velocity data for a child with cerebral palsy and an able body. The work values calculated as depicted in Figure 2 (e.g., shaded region for 10°/s in Figure 2) were plotted against velocity (i.e., 10, 30, 60, and 90°/s) for a child with cerebral palsy, and for a child with an able body. 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 cerebral palsy (m = 0.0117) was about seven times greater than the slope for the child with an able body (m = 0.0016).
Figure 4 — Resultant joint torque variables used to quantify strength. Maximum abduction and adduction values in addition to the abduction and adduction work were calculated. The boundaries for the work during adduction (i.e., shaded region) were the adduction torque-angle curve and the end ranges of motion. The values were normalized by dividing by subject mass.

**Results**

Torque-angle data for the hip adductor spasticity test in a typical child with an able body indicated very little change in resistive torque as a function of speed since all curves were essentially the same (Figure 5). In contrast, similar data for a typical child with CP indicated larger resistive torques with an increase in speed (Figure 6). The individual spasticity values, or slopes for the child with CP was about seven times greater than that of the child with an able body (Figure 3). The child with CP had less hip abduction/adduction range of motion than the child with an able body. This reduced range was observed in the majority of children with CP.

The slope [Joules/(°/s)] of the linear regression line for work values as a function of velocity (i.e., the measure for spasticity) for the hip adductors in the AB group was very close to zero [0.0018 Joules/(°/s), SD = 0.0048]. The corresponding slope for the CP group was over 10 times greater [0.0216 Joules/(°/s), SD = 0.0289; Figure 7]. Despite the large standard deviations, the values were significantly different.

Peak abductor torque for a typical child with an able body (upper curve in Figure 8) was generated at about 15% (~ –10° of KinCom angle) of the range of motion starting from end range adduction. The torque gradually decreased as the end range of abduction motion was achieved. For adduction (lower curve in Figure 8), peak torque was reached at about 25% range of motion from the starting abducted position, and then gradually tapered off with increasing adduction. Peak abductor torque for a single child with CP (upper curve in Figure 9) was less than the child with an able body and was achieved earlier in the range of motion. Similar to the child with an able body, the normalized torque decreased as the hip became more abducted. However, unlike the child with an able body, the torque transitioned from an abductor torque to an adductor torque at ~10° of KinCom angle. Such a transition did not occur in the child with an able body (upper curve in Figure 8). The maximum adductor torque for this child with CP (lower curve in Figure 9) was about the same as the child with an able body.
Figure 5 — Typical set of torque-angle curves (four speeds) for a child with an able body undergoing tests for spasticity of the adductors (— 10°/s; --- 30°/s; – – 60°/s; – · – · 90°/s). Passive hip abduction began in an adducted position (see Start). As the hip was abducted a small amount of abductor torque (i.e., values above the horizontal zero axis) was present until approximately 5°. The abductor torque then passed below the horizontal zero axis and became an adductor torque. This adductor torque continued to increase until the end of hip abduction. It should be noted that regardless of the speed, the adductor torque remained essentially the same, indicating no velocity dependent resistance to passive stretch (i.e., spasticity).

Figure 6 — Typical set of torque-angle curves (four speeds) for a child with cerebral palsy undergoing tests for spasticity of the adductors (— 10°/s; --- 30°/s; – – 60°/s; – · – · 90°/s). Similar to the child with an able-body (Figure 5), as the hip was rotated from an adducted to an abducted position, the adductor torque increased in magnitude until end range abduction. However, unlike the child with an able body, the child with cerebral palsy displayed an increased resistance as a function of the increased speed (i.e., a velocity dependent resistance to passive stretch). It can be noted that the child with cerebral palsy had a decreased range of motion compared to the child with an able body.
The group results for the strength measures indicated significantly greater strength by the AB group compared to the CP group for all variables (Figure 10). The maximum abductor torque for the AB group (1.06 Nm/kg; $SD = 0.32$) was significantly greater than the value for the CP group (0.41 Nm/kg, $SD = 0.25$). The maximum adductor torque for the AB group (1.16 Nm/kg; $SD = 0.41$) was significantly greater than the value for the CP group (0.63 Nm/kg, $SD = 0.28$). The maximum abductor/adductor torque ratio for the able-bodied group was 0.96 ($SD = 0.24$), while the same percent for the CP group was 0.66 ($SD = 0.30$). The ratios were significantly different between the two groups.
Figure 9— Typical normalized torque-KinCom angle strength curves for a child with cerebral palsy for both abduction and adduction. The values were normalized by dividing by subject mass. The abduction (top) curve began at approximately 20°, while the adduction (bottom) curve began at approximately 20°. The maximum torques were produced shortly after movements began and decreased as full abduction or adduction was reached. It should be noted that the abduction torque changed from an abductor torque to an adductor torque shortly after 10°.

Figure 10— Means and standard deviations (normalized by dividing by subject mass) for maximum abduction and adduction torque values (left side of figure) and work values (right side of figure) done during the abduction and adduction movements for the CP and AB groups. The maximum abduction and adduction values, and abduction and adduction work values were significantly different for the two groups of children ($p < .05$).
abductor work for the AB group (0.63 J/kg; $SD = 0.25$) was significantly greater than the value for the CP group (0.11 J/kg; $SD = 0.19$). The adductor work for the AB group (0.76 J/kg; $SD = 0.35$) was significantly greater than the value for the CP group (0.27 J/kg; $SD = 0.19$). The abductor/adductor work ratio for the able-bodied group was 0.93 ($SD = 0.33$), while the same ratio for the CP group was 0.48 ($SD = 1.10$). These ratios were significantly different from one another. Finally, adductor max and work values were significantly greater than the abductor values for both AB and CP groups.

**Discussion**

The purpose of this investigation was to objectively compare spasticity of the hip adductors and strength at the hip abductors/adductors in children with spastic diplegia CP and able bodies. There are a number of limitations associated with this investigation and previous reports have described them in detail (Engsberg et al., 1996, 1998, 1999, 2000; Ross et al., 2000; Wagner et al., 2000). Three limitations will be included here: (a) quantification of spasticity, (b) lack of electromyographic (EMG) data to evaluate abduction/adduction muscle activation, and (c) relationship to function.

We chose to quantify spasticity as a velocity dependent resistance to passive stretch (Dimitrijevic, 1985; Engsberg et al., 1996; Jones et al., 1982; Lance, 1980), since this characterization was clinically relevant and contained three elements that were fundamental basic engineering principles (stretch, resistance, and velocity). The stretch was related to an angular joint range of motion, the resistance was related to the torque about the joint, and the velocity was related to the rate of angular change of the joint. Further, the torque and angular range of motion values could be combined into another common engineering term, work. Incorporating these measures into the technique of linear regression permitted the creation of the single variable, slope, for quantifying spasticity. Being able to relate the variables to fundamental principals was very important, since no “gold standard” exists from which to make a comparison (Davidoff, 1985). It was reasoned that the measure would be valid if it quantified the elements of its characterization.

No EMG data were collected during this investigation; hence, it is unknown if any antagonistic muscles were active during the movements for these children. However, EMG data collected for similar tests at the knee and ankle from other children with CP and with able bodies have indicated no antagonistic muscle activity in either group (Engsberg, 1997). In addition, while children with able bodies indicated no activity in the agonist (muscle being stretched), children with CP had increased EMG activity in the agonists with increased speed.

The spasticity and strength measures associated with this investigation are impairment measures and do not quantify function. Nevertheless, these impairment variables should not be considered unworthy of study. In fact, in a research plan presented by the National Center for Medical Rehabilitation Research (NCMRR) at the National Institutes of Health (NIH), five domains of equal importance have been described (NIH, 1993). It was stated that attempts should be made to quantify information in all five domains in the research process to gain a broad understanding of a patient. The spasticity and strength measures are included in the impairment domain. We are currently collecting data on children with CP from multiple domains, including function.

Our hypothesis testing produced consistent results. The hypothesis that greater spasticity would exist in the hip adductors of the children with CP compared to similar values obtained from a group of children with able bodies was confirmed. The values for the children with CP were over 10 times greater than similar values for children with able
bodies. This is not a unusual result, as it would be expected that the children with CP would have a greater spasticity value than the children with able bodies. However, the large standard deviations associated with the variables should be noted, since some children with CP recorded spasticity values that were the same as those of the children with able bodies. The implications of the results could be related to global attempts to reduce spasticity (e.g., baclofen pumps or selective dorsal rhizotomy). For example, if spasticity does not exist at the hip but does exist at the knee and/or ankle, then when planning a selective dorsal rhizotomy, afferent nerve rootlets innervating the knee and/or ankle musculature may need to be viewed in a different context than those innervating the hip musculature.

The hypothesis that the children with CP would exhibit less abduction/adduction strength compared to a group of children with able bodies was also confirmed. The children with CP could not generally produce a maximum value for abduction or adduction that was the same as children with able bodies. Similarly, the abduction/adduction work values were also not as great as those generated by the children with able bodies. Key factors contributing to these results include: range of motion, torque magnitude, and inability to produce the desired torque. For example, it is quite apparent that the range of motion for the child with CP (~40°; Figure 9) is less than that of the child with an able body (~60°; Figure 8). The abduction torque magnitude of the child with CP (top curve in Figure 9) is substantially less than that of the child with an able body (top curve in Figure 8). It is also possible to observe the transition from an abductor torque to an adductor torque for the abduction motion (top curve in Figure 9). Such a transition did not exist in the children with able bodies (top curve in Figure 8). The mechanism behind this transition is presently unknown but could be related to weakness, lack of motor control, activation of the antagonistic musculature, and/or passive joint tension due to contractures or capsular constraints. Further work is necessary to understand these relationships.

Damiano et al. (1998) reported strength values collected from a handheld dynamometer for the hip abduction/adduction in 15 children with spastic diplegia and 16 children with able bodies. Their primary results were reported as a force value, preventing a direct comparison with the primary results (torque) from the present investigation. However, they also reported an abduction/adduction strength ratio, permitting a comparison. Their abduction/adduction maximum strength ratios indicated that the abductors were stronger than the adductors for the children with able bodies and about the same for the children with CP (1.28 for AB group and 1.02 for CP group). These results contrasted with the present investigation, which found that the adductors were stronger than the abductors (maximum torque ratio, 0.96) in the able-bodied group, and in the CP group (maximum torque ratio, 0.66). An explanation for the contradictory results is unknown but could be related to sample size (Damiano et al., n = ~15; present investigation, n = 44), method of measurement (Damiano et al., isometric contraction with handheld dynamometer in a single joint position; present investigation, dynamic contraction on KinCom dynamometer over the entire joint range of motion), and ambulation status (Damiano et al., all independent ambulators; present investigation, 30 independent ambulators and 14 dependent ambulators). It should be noted that the ratios were not substantially altered when only the 30 independent ambulators were evaluated.

The results of this investigation build upon previous reports of similar measures at the knee and ankle providing objective data regarding the spasticity and strength of children with CP and able bodies (Engsberg et al., 1996, 1998a, 1998b, 1999, 2000; Ross et al., 2000; Wagner et al., 2000). The goal of this work has been to develop a comprehensive objective assessment of spasticity and strength at the ankles, knees, and hips in children
with CP. These data should permit clinicians to make more informed decisions about the treatment pathways for their patients, as well as assess the efficacy of various procedures.

References


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