Maximum Active Resultant Knee Joint Torques in Children With Cerebral Palsy

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This investigation quantified maximum active resultant joint torques in children with spastic diplegia cerebral palsy and nondisabled children. An isokinetic dynamometer rotated the limb (10°/s) while the resultant knee joint torques (both assistive and resistive) during knee extension and flexion in 6 nondisabled children and 26 children with cerebral palsy were recorded. Torque–angle data were processed to calculate maximum values during extension and flexion and work done during the movements. An independent t test determined if significant differences existed between groups (p < .05). Maximum extensor and maximum flexor torques and work during extension and flexion were significantly less for the children with cerebral palsy. Results supported previously published research indicating that children with spastic diplegia were weaker than nondisabled children. Additional information regarding the weakness of the children with spastic diplegia near the end range of extension motion is presented.

Key Words: strength, spastic diplegia, dynamometer, flexion, extension

Cerebral palsy is a nonprogressive disorder characterized by impairment of motor function secondary to injury of the immature brain (Ingram, 1984). Muscle weakness is a common problem in children with cerebral palsy (Damiano, Kelly, & Vaughn, 1995; Kramer & MacPhail, 1994; MacPhail & Kramer, 1995; MacPhail, Kramer, & Johnston, 1996; Olney, MacPhail, Hedden, & Boyce, 1990). Muscle weakness is often a concern when clinicians are considering procedures to improve the function of these children. For example, lower extremity weakness is a contraindication to performing a selective dorsal rhizotomy (McDonald, 1991; Oppenheim, 1990).

Mechanically, muscle weakness is related to the inability of the child with cerebral palsy to actively produce or control torque about a joint. One method of quantifying joint torque is to use an isokinetic dynamometer to measure the sum of all the individual torques that can occur about a joint. This sum is often called the resultant joint torque and includes individual torques produced by muscle–tendon complexes, ligaments, and other soft tissues crossing the joint (Andrews, 1974). With respect to the muscle–tendon complexes, this includes both agonist and antagonist muscles, which may be contracting at the same time. It also includes the torque under control of the child (which may be antagonistic) and that associated with spasticity or hypertonicity.
Recently, investigators have reported maximum lower extremity joint torques in adolescent children (n = 17, mean age 15.9 years, SD 3) with cerebral palsy having spastic diplegia (Kramer & MacPhail 1994; MacPhail & Kramer, 1995; MacPhail et al., 1996). Children with spastic diplegia have involvement primarily in the lower extremities with normal or minimal involvement in the upper extremities (Gage, 1991). The children were tested for maximum concentric and eccentric resultant knee joint torques in both flexion and extension at a speed of 90°/s with an isokinetic device. Results indicated greater strength deficits for both knee flexors and extensors during concentric contractions compared to nondisabled children. It was concluded that strength training programs could be implemented for these children to correct strength deficits about the knee. At least three limitations were noted from these investigations. The first was that only adolescents were tested and the applicability of results to younger children is unknown. A second limitation was that a speed of 90°/s was used in the protocol. It is possible that younger or more involved children would be unable to adequately perform the task at that speed. A third limitation was that only a 50° excursion of the knee in the middle range of motion was evaluated. End range of knee extension was not tested; hence, torque generation in the extension range used during normal gait was unknown. The purpose of the present investigation was to quantify maximum active resultant joint torques in children with spastic diplegia cerebral palsy.

Methods

For this prospective, descriptive investigation, a convenience sample of 6 nondisabled children (mean age 9 years, SD 4.5, range 4–17; 2 boys, 4 girls; mean mass 34.5 kg, SD 17.9) and 26 children with spastic diplegia cerebral palsy (mean age 9 years, SD 3.9, range 4–16; 13 boys, 13 girls; mean mass 30.3 kg, SD 14.3) were tested. The nondisabled children were recruited through parents within the hospital community or were siblings of children visiting the hospital. The children with spastic diplegia were ambulators and had been referred to the Human Performance Laboratory for other testing by an orthopedic surgeon or a neurosurgeon. The majority of the children were independent ambulators (n = 20) possibly requiring orthotics. The remaining children (n = 6) ambulated using assistive devices (e.g., crutches, walkers). The clinical diagnosis of spastic diplegia was made by the referring physician. Only children who were large enough to fit comfortably on the test equipment with minimal adaptations and who would presumably cooperate were approached for participation. All parents and children who were asked to participate consented. Each child and/or parent was informed about the project and signed an informed consent. In each nondisabled child only one leg was tested. Attempts were made to test both legs of the children with spastic diplegia, but if a child became tired or uncooperative, only one leg was tested.

The KinCom isokinetic dynamometer can move the leg through a range of motion at a specified speed, measuring the assistive or resistive force that the subject applies to a support arm during the motion. Each child sat on the KinCom seat with the trunk and pelvis supported in the upright position. Stabilization straps were placed across the distal aspect of the thigh and pelvis. The mechanical axis of the KinCom was aligned with the anatomical knee axis of the child. A fixed laboratory coordinate system was established by moving the lever arm to a horizontal position (0°). The leg of the child was attached to the support arm with Velcro straps. For safety, a technician not conducting the test or a parent was given a button to press that would immediately terminate the test.

Before conducting the resultant joint torque tests and to accommodate the individual variation in range of motion, range of motion limits for knee extension or ham-
string length were established for each child (Engsberg, Olree, Ross, & Park, 1996). The resultant joint torque tests were then conducted. A movement speed of 10°/s in the passive mode was selected on the KinCom since previous experimentation had indicated that some young children could not produce enough torque to initiate movement of the stationary support arm and others could not keep up with the machine at faster speeds. Isometric contractions were not used since they did not quantify torque over an entire range of motion.

Each child was instructed to push the leg straight (i.e., perform a concentric contraction of the quadriceps) as the lever arm went up, extending the knee, and to pull the leg bent as much as possible (i.e., perform a concentric contraction of the hamstrings) as the lever arm went down, flexing the knee. If the child was able to assist with the motion, for example, knee extension, then an extensor torque was recorded. However, if the child resisted the knee extension motion, then a flexor torque was recorded. One practice trial was generally sufficient to instruct the child in the procedure. One to three tests were then conducted to permit the child to achieve his or her best performance. The number of repetitions was not standardized, since experience indicated that the therapist in communication with the child could determine if a maximum effort was achieved. Since maximum torques were desired, only the test indicating the greatest amount of torque was used in the analysis.

Force as a function of KinCom angle and moment arm length for each child were downloaded to a personal computer. The weight of the leg and foot due to gravity, estimated to be 5.8% of total body weight (Clauser, McConville, & Young, 1969) and a function of KinCom angle, was then subtracted from the recorded force in a custom computer program. This was done since some of the unique attributes of the children with cerebral palsy (e.g., knee joint contractures or hamstring tightness) prevented the gravity correction capabilities in the KinCom software from being used. Torque values were then calculated as the product of the “gravity-corrected” force times the moment arm length. It should be noted that estimating the weight of the leg and foot is different for adults and children (Jensen, 1989). An analysis evaluating the potential error associated with this measure indicated less than a 2% error when using the adult values. This potential source of error was deemed acceptable considering the simplicity associated with the single value, in contrast to the use of regression equations (Jensen, 1989).

The angular range of motion for each child was determined (Figure 1). The maximum torque values for both extension and flexion were recorded and normalized by dividing by subject mass (Figure 1). Next, for each extension and flexion curve, the area bounded by the curve and the beginning and ending range of motion were determined using the trapezoid rule. When areas existed above and below the zero torque line (e.g., Figure 1), the values were subtracted. The areas quantified the work done by the child on the machine in both knee extension and flexion and were also normalized by dividing by subject mass (MacPhail & Kramer, 1995).

In the cases where both legs were tested, a single leg from each child was randomly selected for analysis (n = 13). Both legs were not used since they were taken from the same subject and could not be considered to be independent measurements (Rosner, 1982). A chi-square test was performed to determine if distribution of the variables for the children with spastic diplegia was significantly different from a normal distribution. Since no significant difference was found (p < .01), an independent t test was used to determine if significant differences existed between groups (p < .05).

The KinCom angles presented in the Results section quantify the angular orientation of the KinCom lever arm and not the actual knee joint angle of the child. An offset
between the lever arm and the leg existed. The lever arm–leg angular relationship did not influence the variables quantified in the investigation and did not interfere with comparisons from previous investigations; therefore, it was not determined for all children. However, the offset has been estimated to be between 10° and 15°. This information may be helpful when viewing the individual results.

Results

Peak extensor torques for a typical nondisabled child were generated at approximately 50° below the horizontal and near the most flexed position (Figure 2). This torque decreased as maximum extension was reached. For flexion, peak torques were reached near maximum extension and then tapered off with increasing flexion. Peak extensor torque for a single child with spastic diplegia was slightly less, and, in a manner similar to the nondisabled child, occurred near the most flexed position (Figure 3). In contrast to the results for the nondisabled child, at the end range of motion for the child with spastic diplegia, the torque changed from extensor to flexor. Flexor torques displayed similar characteristics, with maximum torques being generated near the maximally extended position and torque changing from flexor to extensor near the most flexed position.

The range of motion of the nondisabled children (79.5°, SD 4.9°) was significantly greater than that of the children with spastic diplegia (66.3°, SD 13.2°). The maximum extensor and flexor torques were significantly smaller for the children with spastic diplegia than corresponding values for nondisabled children (Figure 4).
The measurements of total work done by the children on the machine for both extension and flexion were significantly different between the two groups (Figure 4). The nondisabled children could perform significantly more work than the children with spastic diplegia. A major difference between the two groups was that while none of the nondisabled children exhibited a flexor torque during extension or an extensor torque during flexion (Figure 2), over 70% of the children with spastic diplegia did (Figure 3). In over 40% of the cases, the children with spastic diplegia produced an extensor torque during the majority of the flexion movement.

**Discussion**

The purpose of the present investigation was to quantify maximum active resultant joint torques in children with spastic diplegia cerebral palsy. A number of limitations are associated with this investigation. The resultant joint torques measured in this investigation quantified the sum of all the individual torques that can occur about the knee joint, including any agonistic and antagonistic muscle activity. No electromyographic (EMG) data were collected during this investigation; hence, it is unknown if any antagonistic muscles were active during the movements. Antagonistic muscle activity would, for example, reduce the recorded resultant extensor torque during the extension motion since the hamstrings (the antagonistic muscle group in this case) would be producing a flexor torque. It would also provide some indication of the cause of the change of extensor torque to flexor torque near end-range extension and from flexor torque to extension during end-range movement.

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**Figure 2** — Typical normalized torque–KinCom angle plots for a nondisabled child (female, age 7 years, mass 26 kg). The values were normalized by dividing by subject mass. The extension (top) curve began at approximately –60° (left side of figure), while the flexion curve began at approximately 10° (right side of figure). The maximum torques were produced shortly after movements began and tapered off as full extension or flexion was reached. For each test, the nondisabled child produced an extensor torque or flexor torque during the entire respective extension or flexion components of the test.
Figure 3 — Typical normalized torque–KinCom angle plots for a child with spastic diplegia (female, age 12 years, mass 39 kg). The values were normalized by dividing by subject mass. The extension (top) curve began at approximately $-60^\circ$ (left side of figure), while the flexion curve began at approximately $10^\circ$ (right side of figure). The maximum torques were produced shortly after movements began and tapered off as full extension or flexion was reached. In contrast to the nondisabled child (Figure 2), the child with cerebral palsy produced a flexor torque during the extension test and an extensor torque during the flexion test.

Figure 4 — Means and standard deviations (normalized by dividing by subject mass) for maximum extension and flexion values and work done during extension and flexion movements for nondisabled children ($n = 6$) and children with cerebral palsy ($n = 26$). *Peak extension and flexion values and work during extension and flexion were significantly different for the two groups of children.
flexion. If activation in the hamstrings was not present, then the flexor torque during extension, for example, could be primarily due to the passive elements of the musculotendinous complex. However, knowing the absence or presence of EMG would not alter the values reported in the present investigation. Until a relationship between EMG and torque (force) is determined for use in a clinical setting, EMG cannot be used to parcel out the torque due to antagonistic muscle activity.

The resultant joint torques quantified in the present investigation also do not distinguish between torque resulting from muscular contractions under voluntary control of the child and torque resulting from muscular contractions due to spasticity or muscle hypertonia. Such a distribution process would be quite valuable since it could help determine the appropriateness of some surgical procedures that alter torque generation from spasticity or muscle hypertonia (e.g., selective dorsal rhizotomy). Distributing the resultant joint torques to the various load-carrying structures is possible by using a variety of modeling techniques (Crowninshield, Pope, & Johnson, 1976; Hefzy & Grood, 1988; Herzog & Leonard, 1991; Seireg & Arvikar, 1975). However, these models only distribute the resultant joint torque to a given structure, such as the rectus femoris or the biceps femoris muscles. They are presently not capable of distributing the force within the muscle to a spasticity component or to that under control of the child. While the separation of this force within a particular muscle is a worthy endeavor, it is highly unlikely that enough will be known about spasticity to make this a reality in the near future. Hence, resultant joint torques or a distribution process to individual muscles is the best that is presently possible.

The torque values of the present investigation were normalized by dividing by subject mass (MacPhail & Kramer, 1995). While this method of normalization attempts to account for variation in size, many factors such as gender, age, height, weight, and specific muscle properties all contribute to variation in torque values (Molnar, Alexander, & Gutfeld, 1979). Like previous investigators (MacPhail & Kramer, 1995; MacPhail et al., 1996), we attempted to account for these differences by the normalization process. However, no attempt was made to determine the contribution of individual factors to the effectiveness of the normalization.

Reliability of the measurement is an important factor in determining its utility. A detailed assessment of the reliability of the measures used in the present study has not yet been completed. Most of the children tested for this investigation were not from the surrounding area and could not be expected to bear the expense of multiple visits. However, previous investigations have indicated acceptable reliability for nondisabled children as well as those with mild retardation and spastic diplegia (Kramer & MacPhail, 1994; Molnar et al., 1979). Strategies for determining reliability for this group are currently under consideration.

Fatigue, learning, and motor control were factors considered as possibly preventing the children with spastic diplegia from achieving results more similar to those of the nondisabled children. Fatigue was considered to have a minor role in the magnitude of force, as many children had 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 spastic diplegia to produce the desired torque. Research efforts along these lines appear warranted.

The range of motion recorded in this investigation may not be the total range of motion possible by all the children. While the end range of extension motion was determined for each child, the KinCom would not permit determination of a complete end range of flexion motion from the seated position. This was due to the lack of open space
underneath the KinCom chair. If the child’s flexibility permitted, the KinCom lever arm was generally brought to 60° below the horizontal. The limitation probably meant that nondisabled children may not have reached their knee flexion limits. Thus, the range of motion results presented here may be an underestimation of their total possible range. Some children with spastic diplegia also may not have reached their knee flexion limits. However, many children with spastic diplegia could not achieve the desired 60° position, indicating that the results presented are probably not an underestimation of their capabilities. The reduced range for the children with spastic diplegia indicates that it was a factor in their smaller work values (Figure 4).

Peak concentric extension torques for the two groups of the present investigation were less than those reported by Mohtadi, Kiefer, Tedford, and Watters (1990) for nondisabled boys (Table 1). Differences in the methods between that investigation and the present one could account for the disparity. The boys of the Mohtadi et al. (1990) investigation were slightly older (mean age 11 years) than the boys and girls of the present investigation. In addition, the speeds used in the two investigations differed. Further work with more children at varied speeds could clarify this situation.

MacPhail et al. (1996) reported maximum extension and flexion values (at 90°/s) for children with spastic diplegia cerebral palsy greater than those found in the present investigation (Table 1). The work done by the children on the machine for both movements was also greater than those of the present investigation (Table 1). The differing results could be attributed to the older sample of children (mean 15.8 years, SD 3.0), the fact that all children were independent ambulators (no orthotics), and that data were collected over a midrange of motion (an excursion of 50°). The smaller range of motion reduced the possibility that the torque would change direction (i.e., from extensor to flexor).

### Table 1  Comparison of Results From the Present Investigation With Other Investigations

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mohtadi et al. (nondisabled)</th>
<th>Present investigation (nondisabled)</th>
<th>MacPhail et al. (spastic diplegia)</th>
<th>Present investigation (spastic diplegia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum extension knee torque (Nm/kg)</td>
<td>2.17</td>
<td>1.57</td>
<td>1.58</td>
<td>0.99</td>
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<tr>
<td>SD</td>
<td>0.36</td>
<td>0.23</td>
<td>0.56</td>
<td>0.66</td>
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<tr>
<td>Maximum flexion knee torque (Nm/kg)</td>
<td>0.79</td>
<td>1.04</td>
<td>0.36</td>
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<tr>
<td>SD</td>
<td>0.15</td>
<td>0.29</td>
<td>0.31</td>
<td></td>
</tr>
<tr>
<td>Knee extension work (J/kg)</td>
<td>1.10</td>
<td>1.00</td>
<td>0.47</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.22</td>
<td>0.37</td>
<td>0.41</td>
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</tr>
<tr>
<td>Knee flexion work (J/kg)</td>
<td>0.62</td>
<td>0.63</td>
<td>0.14</td>
<td></td>
</tr>
<tr>
<td>SD</td>
<td>0.17</td>
<td>0.20</td>
<td>0.23</td>
<td></td>
</tr>
</tbody>
</table>

Note. Values from other investigations were greater than those of the present investigation; the differences could be due to differences in subject age, gender, test speed, and variable calculations.
during the extension exercise and from flexor to extensor during the flexion exercise) (Figure 3). On the other hand, the speed of movement was greater (10°/s vs. 90°/s), which would imply a smaller torque production when compared to a slower speed (Winter, 1979). Additional work in this area is necessary.

The results of the present investigation indicate that the children with spastic diplegia could not achieve the same maximum extensor or flexor torques as nondisabled children. These results are comparable to previously reported results (MacPhail et al., 1996). The children with spastic diplegia from the present investigation could also not perform the same amount of extension and flexion work as nondisabled children. Similarly, results concur with those previously reported (MacPhail et al., 1996). These decreased abilities may reduce the children’s functional potential. Significant relationships have been reported between knee extensor strength and walking efficiency and gross motor ability (Kramer & MacPhail, 1994). It has been suggested that knee extensor muscle strength may be a key factor in limiting standing, walking, running, and jumping in children with spastic diplegia.

By quantifying a larger range of motion than was previously reported (MacPhail & Kramer, 1995; MacPhail et al., 1996), it was possible to observe a change in torque direction (e.g., change from extensor to flexor torque during end-range knee extension). While the cause of this direction change is unknown, it could be related to antagonistic muscle activity (spasticity or hypertonicity), lack of muscle control, or passive structures. Understanding more about this issue is important, since during many functional activities (e.g., gait), the knee performs near full extension.

From a clinical perspective, the results provide additional support regarding the weakness of children with cerebral palsy related to nondisabled children. However, the key clinical result is that the methods described in this investigation can be used to understand more about the strength characteristics of an individual patient. For example, if a hamstring lengthening was under consideration for a patient, and a strength test showed extreme hamstring weakness relative to the results for the nondisabled children reported in this investigation, then the lengthening may be contraindicated. Another example would be with respect to determining if a selective dorsal rhizotomy was an appropriate procedure for a child. Presurgery weakness has been reported to be a contraindication to the rhizotomy, and postsurgery weakness has been reported to be a limitation of the surgery (Cahan, Kundi, McPherson, Starr, & Peacock, 1987; Oppenheim, 1990). However, objective measures for assessing the weakness of children are not generally used in surgical decision making. Thus, the objective quantification of the weakness of the child as described here, and the ultimate correlation with function, would be a valuable tool in deciding if the surgery is warranted.

This investigation quantified maximum torques in nondisabled children and children with spastic diplegic cerebral palsy. Results supported previously published research indicating that children with spastic diplegia were weaker than nondisabled children. Additional information regarding the weakness of the children with spastic diplegia near the end range of extension motion was presented. The relationship between this end-range weakness and function (e.g., gait) requires additional research.

References
Knee Joint Torques


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