Gastrocnemius Architecture in Patients with Spastic Cerebral Palsy

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Purpose: Gastrocnemius muscle spasticity is a common finding in children with cerebral palsy (CP). However, the differences between spastic hemiplegic CP (SHCP) and spastic diplegic CP (SDCP) have not been compared. The purpose of this study was to compare the gastrocnemius architecture between the two CP groups and a control group, by using ultrasonography.

Materials and Methods: We enrolled 18 children with CP and 10 healthy controls. Patients with CP were categorized into two groups: 10 patients with SHCP and eight patients with SDCP. Ultrasonography images of the gastrocnemius were acquired at rest and with the knee at 0° with full ankle dorsiflexion. Fascicle lengths, pennation angles, and muscle widths were compared.

Results: SHCP demonstrated the most limited ankle dorsiflexion, and there were no significant differences in joint positions between the two CP groups at rest. Compared to healthy controls, fascicle lengths were diverse, but pennation angles and muscle width were similar or decreased in the two CP groups. There were no significant differences between SHCP and SDCP in fascicle length, pennation angle, and muscle width with the knee at 0° with ankle full dorsiflexion. At rest, the fascicle length of SHCP was longer than SDCP and the lateral gastrocnemius muscle width of SDCP was smaller than SHCP.

Conclusions: A decreased pennation angle and muscle width are characteristic features of the gastrocnemius in patients with CP. There was little difference in the architecture of the gastrocnemius between SHCP and SDCP, despite different spasticity. A decreased pennation angle would be expected to decrease the excursion of the muscle during ankle dorsiflexion.

Key Words: Gastrocnemius muscle, Cerebral palsy, Ultrasonography
Introduction

Cerebral palsy (CP) is a disorder arising from non-progressive brain lesions, but patients also have progressive skeletal problems as a result of spastic muscle and skeletal deformities\(^\text{11}\). Equinus is one of the most common problems in patients with CP. The cause of equinus is spasticity of the triceps surae, composed of the medial and lateral gastrocnemius, and the soleus. Altered in vivo gastrocnemius muscle architecture in children with CP has been previously investigated by using ultrasonography, but the studies are difficult to compare because of the use of different methods and variability in the results\(^\text{3,12,13,16,17}\). Some of the studies did not differentiate between the clinical features, such as spastic diplegia and hemiplegia, or different gait patterns. The affected brain areas in spastic hemiplegic CP (SHCP) and spastic diplegic CP (SDCP) are different, and a recent study mentioned that the CP subtype (hemiplegia versus diplegia) is one of the important variables for determining the outcome of surgery for equinus deformity in CP\(^\text{11,15}\). Therefore, the muscle changes in both conditions are also suspected to be different from each other.

The muscle architecture of the gastrocnemius is changed according to the knee and ankle joint position\(^\text{10,19,20}\). Clinically, the Silverskiöld test that checks the passive full ankle dorsiflexion angle with knee extended and knee flexed is a common method to differentiate the spastic muscle between gastrocnemius and soleus\(^\text{18}\). If the patient has a positive result on the Silverskiöld test, the cause of limited ROM is only the spastic gastrocnemius. On the other hand if the result of the test is negative, the gastrocnemius and soleus are the cause of limited ROM and the surgical treatment of heel-cord lengthening is needed. Although the spasticity of the soleus also affects ankle dorsiflexion, the measurement of gastrocnemius architecture will be more important, considering the gastrocnemius spans both knee and ankle joint.

The purpose of this study was to compare gastrocnemius architecture in patients with CP by using ultrasonography. To evaluate the muscular architecture, the gastrocnemius architecture was compared (i) between patients with SDCP, patients with SHCP, and healthy controls (HC), and (ii) between a resting position and the knee held at 0° with full ankle dorsiflexion.

Materials and Methods

This study was approved by the institutional review board of our hospital and was conducted according to the Declaration of Helsinki (2012-11-01, entry no. 2012-112). Eighteen children with CP (11 boys, seven girls: mean age 8 years±3 months) who were able to walk without assistive devices were recruited. All patients in our study have a level II functional mobility, measured by the Gross Motor Function Classification System\(^\text{14}\).

The exclusion criteria were: (i) previously having the treatments including selective posterior rhizotomy, surgical intervention or botulinum toxin injection, and (ii) presence of excessive varus or valgus ankle deformity (>10°), excessive internal (>10°) or external (>40°) tibia rotational deformity, or a fixed flexion contracture.
of the knee joint confirmed by a physician.

The subjects were divided into two groups. Group I (SHCP) consisted of 10 patients with SHCP (six boys, four girls: mean age 6 years±1 month; five with right hemiplegia and five with left hemiplegia), and group II (SDCP) comprised 8 patients with SDCP (five boys, three girls: mean age 7 years±5 months). All patients in Group I had a negative Silverskiold test and all patients in Group II had a positive Silverskiold test. Ten age-matched, normally developing children (6 boys, 4 girls: mean age 7 years±8 months) were recruited as HC.

Ultrasonography examinations were performed on the legs while the child was in the prone position, by using a linear phased array transducer (12 MHz) and a high-resolution scanner (Z-one; Zonare Inc., Vernon, CA, USA) with a linear 12 MHz probe. In the SHCP group, the paretic leg was examined and one of the both leg was randomly selected in the SDCP group. Longitudinal ultrasonography images of the medial and lateral gastrocnemius were acquired from the midbelly of the muscles. Each measurement was taken at the maximum anatomical cross-sectional area of the respective muscle, specifically, at the proximal level at 30% of the distance between the popliteal crease and the center of the lateral malleolus. Ultrasonography images of the lateral and medial gastrocnemius were acquired at rest and with the knee at 0° with full ankle dorsiflexion. The resting position was defined as a comfortable prone position with the feet hanging from the edge of the table. The ankle and knee joint angles were measured at each position.

Using the ultrasonography images, the fascicle lengths, pennation angles, and muscle widths were measured and compared. By visualizing the fascicles along their lengths, from the superficial to the deep aponeurosis, it is possible to ensure that the plane of the ultrasonography scan is parallel to the fascicles. Based on a simple planimetric muscle model, the pennation angle was defined as the angle formed between the fascicular path and the deep aponeurosis of the muscle (Fig. 1). Muscle thickness was defined as the shortest distance between the superficial and deep aponeuroses, and fascicle length was defined as the distance between the origin (the point where the fascicle and the superficial aponeurosis meet) and the insertion (the point where the fascicle and the deep aponeurosis meet).

All parameters were measured twice and the average was taken. Statistical analyses were performed by using SAS software package (version 9.1: SAS Institute, Cary, NC, USA). The obtained architecture...
atural variables were compared between the two study groups (group I (SHCP) and group II (SDCP)) and the HC. Differences between groups were examined by using the Kruskal-Wallis test. The Post hoc tests were performed with a Bonferroni correction. P-values were adjusted for multiple comparisons, and the adjusted p-value was Punadj · k, where k is the number of comparisons. Values are presented as mean±SD, and the level of significance was set at p<0.05. The intraclass correlation coefficient values were found to be between 0.784 and 0.990.

**Results**

**Clinical presentation**

Patients in the SHCP group demonstrated the most significant limitation in ankle dorsiflexion angles at rest compared to the SDCP group (p<0.001) and the HC group (p=0.026). With the knee at 0°, patients in the SHCP and SDCP group showed decrease in ankle dorsiflexion than the HC group (p<0.001). The knee angle at rest in the SDCP group was more flexed compared with the HC group (p=0.017). There were no significant differences in the ankle (p=0.056) or knee (p=0.106) position between the SHCP and SDCP groups at rest (Table 1).

**Table 1. Comparison of clinical presentation between groups (degree)**

<table>
<thead>
<tr>
<th></th>
<th>Group I (SHCP)</th>
<th>Group II (SDCP)</th>
<th>Healthy controls (HC)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>SHCP vs SDCP</td>
</tr>
<tr>
<td>Ankle dorsiflexion at knee 0°</td>
<td>-9±2.1</td>
<td>-3.9±4</td>
<td>24±4.5</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Ankle at rest</td>
<td>-14.5±4.4</td>
<td>-10.3±2.3</td>
<td>-6.5±2.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Knee at rest</td>
<td>0.5±1.6</td>
<td>2.1±2.6</td>
<td>0±0</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Values are means±standard deviation.
The P was the minimum value of Punadj · k or 1, where Punadj was the unadjusted value and k was the number of comparisons (k=3).

Gastrocnemius architecture at rest and with the knee at 0° with full ankle dorsiflexion

There were no significant differences between the SHCP and SDCP groups in fascicle length, pennation angle, and muscle width with the knee at 0° with full ankle dorsiflexion. With the knee at 0°, the pennation angles of the lateral gastrocnemius in the SHCP and SDCP groups were smaller (p=0.006 and p<0.001, respectively), and the muscle width of the lateral gastrocnemius in the SDCP group was smaller (p<0.001) than the HC group (Table 2).

At rest, there was no significant difference in the medial gastrocnemius between the three groups. Compared with the HC group, the lateral gastrocnemius fascicle length was longest in SHCP (p=0.007). Pennation angles of the lateral gastrocnemius were decreased in both SHCP (p<0.001) and SDCP (p<0.001) compared to the HC group, while there was no difference between SHCP and SDCP (p=0.736). The lateral gastrocnemius muscle width was significantly smaller in
SDCP than the SHCP or HC groups (p<0.001) (Table 3).

**Discussion**

Equinus is a common abnormality of gait in patients with CP. Using a musculoskeletal model, patients with equinus were shown to have a short gastrocnemius muscle-tendon length\(^1\). The musculoskeletal model reflects multiple joint motions, but this system does not demonstrate the differences in the muscular portions of muscles. Ultrasonography has been used to evaluate the different gastrocnemius architecture in patients with CP, but the findings were diverse. One study reported shorter gastrocnemius fascicle lengths in patients with spastic diplegia, but another study reported no significant difference compared to normal controls\(^12,17\). Diverse results were also found in patients with
spastic hemiplegia. The results can be affected by various clinical features and joint status. Furthermore, a review article on equinus deformity in children with CP revealed a different outcome between hemiplegia and diplegia patients after surgery for equinus deformity. We compared the gastrocnemius architecture of an SHCP and an SDCP group in the resting position and with the knee at 0° with full ankle dorsiflexion, considering the different triceps surae spasticity and Silverskiöld test.

Skeletal muscle growth appears to be influenced by neuronal, endocrine, nutritional, and mechanical factors, and muscle deformity in children with spastic CP may represent an impairment of muscle growth. Benard et al found that longitudinal muscle fiber growth accounts for only 20% of the longitudinal growth of the gastrocnemius medialis belly, with the remaining 80% being related to an increase in the diameter of the muscle fibers. If muscle growth is impaired, the diameter of the muscle fiber would therefore be more affected than the fiber length in patients with CP. Gough and Shortland stated that a reduction in the medial gastrocnemius volume and physiological cross-sectional area occurred without significant changes in muscle fiber length, but was associated with a reduction in passive dorsiflexion, thus suggesting a reduction in muscle fiber diameter, leading to reduced longitudinal growth of the muscle belly. In our study, fascicle lengths of the patients with CP were similar to the HC group, except for the lateral gastrocnemius fascicle length at rest in the SHCP group, which showed the greatest limitation in ankle dorsiflexion.

Changes in the gastrocnemius fascicle length may vary depending on the limitation in dorsiflexion and would not directly correlate to the CP.

In our study, pennation angles and muscle widths in the patient groups were similar or decreased compared to the HC group. Barrett and Lichtwark reviewed studies on muscle morphology and structure in children with CP, and noted that the most consistent change was the size reduction of the muscle. A decreased muscle volume of the medial gastrocnemius in children with CP was also reported. Binzoni et al noted a continued increase in the pennation angle of the medial gastrocnemius during growth, which they considered to reflect muscle fiber hypertrophy. We can hypothesize that the impairment of muscle growth in patients with CP might slow or even stop the increase in the gastrocnemius pennation angle in both groups. After surgical recession of the gastrocnemius, an increase in the pennation angle was noted. Increased muscle volume after a Vulpius procedure was also reported. In our opinion, the pennation angle and muscle width of the gastrocnemius will be lesser in patients with CP than in healthy children, but the fascicle length can differ and may vary according to the ankle joint contracture.

The fascicle behavior of the medial gastrocnemius in healthy people has been shown to be affected by the knee joint angle, and because the gastrocnemius is a biarticular muscle, knee extension increased on foot contact after isolated mid-calf lengthening of the gastrocnemius and soleus in patients with spastic diplegia. In the current study, the joint configuration was controlled with the...
knee at 0° with full ankle dorsiflexion to make maximal stretching of gastrocnemius muscle considering the effect of knee and ankle joint. There were no significant differences in terms of fascicle length, pennation angle, or muscle width between the SHCP and the SDCP groups. Barber et al\(^2\) reported no differences in fascicle length and pennation angle at maximal ankle dorsiflexion angle between typically developing children and those with CP, and a reduced ankle dorsiflexion angle in patients with CP. If the ankle position were the causative factor, it would be better to compare the muscle architecture with the joint in the same position.

With the joint configuration set at rest, the joint position did not differ significantly between the SHCP and SDCP groups, but there was a significant difference in the lateral gastrocnemius. From our results, a simulated model of the lateral gastrocnemius at rest could be built (Fig. 2). Both the SHCP and SDCP groups had a decreased pennation angle compared to the HC group. Because of the similar muscle width in SHCP, the fascicle length in this group is longer than in the HC group, whereas the fascicle length in the SDCP group was similar to that of the HC group, because of the decreased muscle width and pennation angle. Normally, the pennation angle is decreased and the fascicle length is elongated with ankle dorsiflexion. Smaller pennation angles contributed to a smaller ankle dorsiflexion angle in both patient groups, which was reduced even more by the already elongated fascicle length in SHCP.

There are several limitations to our study. The simulation model was developed based only on the findings for the lateral gastrocnemius in the resting position. The Achilles tendon length and the length of the muscle belly were not compared. A relatively increased Achilles tendon length in patients with CP was reported in previous studies\(^8,21\). To compare the muscular architecture, the length of the Achilles tendon and muscle belly should also be compared in future studies. Although we controlled for skeletal deformity, functional level, and age in this study, we did not control for leg length, and normalization of the fascicle length to the fibula or leg length was not used. The method of standardization is not yet established, thus further studies

Fig. 2. The white line indicates the aponeurosis. Characters (a) demonstrate that similar pennation angles were seen between SHCP and SDCP. The dashed black lines demonstrate that similar fascicle lengths were seen between the patients with SDCP and the HC.
Conclusions

Our study compared the muscular architecture between SDCP and SHCP considering the different spasticity of the gastrocnemius. A decreased pennation angle and muscle width are characteristic features of the gastrocnemius in patients with CP. A decreased pennation angle would be expected to decrease the excursion of the muscle during ankle dorsiflexion, and the decreased muscle width would reduce the force that the muscle is able to generate. There was little difference in the gastrocnemius architecture between SHCP and SDCP, despite different spasticity. The limitation of ankle dorsiflexion seems to depend on the different architecture of the gastrocnemius. Further studies in SHCP only or SDCP only with positive result of the Silverskiöld test or comparison of SHCP and SDCP with the same result of the Silverskiöld test will increase our understanding of the gastrocnemius architecture.

REFERENCES


