ISOMETRIC MUSCLE STRENGTH IN ADOLESCENTS AND ADULTS WITH UNILATERAL CEREBRAL PALSY HEMIPLEGIA AND HEALTHY CONTROLS

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Abstract

Abnormal motor behaviour is the core feature in cerebral palsy (CP). It has been established that children with CP hemiplegia have muscle weakness in the lower limbs as compared to healthy controls. However few studies on muscle strength have been done on adolescents and young adults with CP hemiplegia. The purpose of this study was to examine muscle strength in adolescents and young adults with CP hemiplegia and to compare their muscle strength with healthy controls.

A group of 29 participants with CP hemiplegia, age 15-23 (14 females, 15 males) and 15 healthy participants (6 females, 9 males) participated. Isometric maximal voluntary contractions in plantarflexion, dorsiflexion and knee extension in the lower limbs were measured in a computerized dynamometer (Strength measuring chair, SMC). Mean peak torque values of three trials were statistically analyzed.

The participants with hemiplegia produced less torque in all muscle groups both in the dominant and non-dominant limb (involved hemiplegic side), as compared to healthy controls. In the group with hemiplegia, plantarflexion, dorsiflexion and knee extension strength in the non-dominant (involved hemiplegic) lower limb showed significantly lower strength values compared to the dominant lower limb in the same individual. In healthy controls there was no difference between the dominant and non-dominant lower limb.

Conclusion

This study shows that adolescents and young adults with CP hemiplegia, although reporting mild impairments, have significant muscle weakness as compared to peers in the same age span. Unlike healthy persons, persons with CP hemiplegia are significantly weaker in their non-dominant (involved hemiplegic) lower limb compared to their dominant lower limb.

Key words: Cerebral palsy, hemiplegia, muscle strength, muscle strength testing, isometric contraction
Sammanfattning

Avvikande motorik är kännetecknande för cerebral pares. Studier har visat att barn med hemiplegi har nedsatt muskelstyrka i de nedre extremiteterna. Studier om muskelstyrka hos ungdomar och unga vuxna med CP hemiplegi är få. Syftet med denna studie var att undersöka muskelstyrka hos ungdomar och unga vuxna med CP hemiplegi och jämföra med friska kontroller.

Försöksgruppen bestod av 29 personer med hemiplegi i åldern 15-23 år (14 flickor, 15 pojkar). Femton personer (6 flickor, 9 pojkar) i samma åldersspann utgjorde kontrollgrupp. Isometriska styrketester för fotledens plantarflexorer, dorsalflexorer och för knäextensorer utfördes i en datoriserad dynamometer (Muskelstyrkestolen, SMC). Deltagarna utförde tre försök varefter medelvärdet av deras maximala styrkevärde analyserades statistiskt. Försökspersonerna med CP hemiplegi var signifikant svagare i det icke-dominanta (hemiplegiska) benet i plantarflexion och dorsalflexion jämfört med friska kontroller. Även i knä extension i det icke-dominanta (hemiplegiska) benet och i plantarflexion, dorsalflexion och knäextension i det dominanta benet var muskelstyrkan lägre dock ej signifikant. Försökspersonerna med CP hemiplegi var signifikant svagare i plantarflexion, dorsalflexion och knä extension i deras icke-dominanta ben jämfört med deras dominanta ben. Hos de friska kontrollpesonerna var det ingen skillnad i muskelstyrka mellan icke-dominant och dominant ben.

Konklusion

Denna studie visar att ungdomar och unga vuxna med CP hemiplegi har en betydande muskelsvaghet jämfört med friska jämnåriga, trots att de ej beskriver sig begränsade av sin funktionsnedsättning. Personer med CP hemiplegi är signifikant svagare i sitt icke-dominanta ben jämfört med sitt dominanta ben vilket man ej ser hos friska personer.
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INTRODUCTION

Muscle strength

The measurement of muscle strength is an important component of the assessment of persons with neurological conditions. Muscle strength can be defined as the ability of a skeletal muscle to develop force for the purpose of providing stability and mobility within the musculoskeletal system, so that functional movements can take place. Muscle strength is the maximal force production a muscle can exert during one voluntary action. In order to fully describe the function of a muscle it is necessary to consider not only muscle strength but also muscular endurance and power. Muscle endurance refers to the ability to perform repetitive contractions or to maintain the magnitude of force for a period of time. Power is the product of muscle force and velocity of contraction. The ability to generate force is an interaction among anatomical and physiological components of a muscle, biomechanics and the central nervous system’s regulation of muscle contraction (1,2).

The skeletal muscle consists of muscle fibres arranged in bundles. The muscle fiber is built up by about 1000 strings of myofibrils which consist of two proteins, actin and myosin forming the sarcomere. The sarcomere is the basic contractile unit of the muscle fiber where myosinfilaments form cross-bridges with the actin filaments called the sliding-filament mechanism. The magnitude of the muscle force is affected by the number of cross-bridges formed in the contraction. There is a positive correlation between cross-sectional area of the muscle fiber and muscle strength (3). Two major categories of skeletal muscle are distinguished based on histological, biochemical and contractile characteristics: Type I, low fatigability and slow contracting, type II subdivided in IIA, relatively low fatigability and slow contracting, and IIB, high fatigability and fast contracting. (1,4).

The motor unit is the basic functional unit of the motor system, consisting of the motor neuron, the neuromuscular junction and the muscle fibers innervated by the motor neuron. The number of muscle fibers innervated by one motor neuron varies depending on the function of the muscle. In fine motor function the motor neuron innervate a small number of muscles fibers whereas in gross motor function a large number. The number of active motor units and their firing rates decide and regulate the force of the contraction (5). Two types of skeletal muscle contraction are described. In the isometric contraction the muscle force is equal to the externally applied force and no motion takes place. In the isotonic contraction motion will take place. If the external force is less than the force generated by the muscle, the muscle will shorten in concentric contraction. If the external force is larger than the force generated by the muscle, the muscle will lengthen in eccentric contraction. There is a
relationship between force and speed of contraction. A larger external force gives a decreased velocity of contraction (1,4).

**Muscle strength testing**

Physiotherapists use muscle strength tests to determine motor function. Baseline measurements of muscle strength are important both when choosing training method as well as evaluating the outcome of a strength training program. When choosing muscle function assessment it is important to take into account characteristics of the participant, the reason for testing, available equipment, level of specificity and required accuracy. Muscle function assessments are performed in isokinetic or isometric conditions. The method of testing should reflect the purpose of the assessment as closely as possible (2). The testing situations must be standardized with regard to the position of the participant, method used, instructions and direction of resistance (7). It is also crucial to consider the effect that changes in body proportions have on muscle strength. The lengths of the limbs affect the torque produced by the muscles. Muscle volume, in correlation with muscle strength, increases from childhood to adulthood (6). For girls, age and weight correlates best with muscle strength during childhood but by the onset of puberty the gains in muscle strength seems to level off (7). Even for boys, age and weight are best predictors for muscle strength. Their gains in muscle strength continue to increase though following puberty (6,7,8,9,10).

Manual muscle testing (MMT) is commonly used in clinic because of its adaptability as no equipment is required (7). MMT has a six-grade both numerical and qualitative score evaluating the ability of a muscle to move against gravity and against manual resistance, therefore testing isotonic strength. In MMT manual resistance is applied near the distal end of a limb or other body part. The scores range from 0, representing no activity, to 5, which represents a normal response. Score 3 represents activity towards gravity and 4 and 5 activity against a minimal and maximal resistance respectively (11). The reliability of the method, however has been discussed since the grades above fair; good and normal, requires an examiner-imposed force and distinction between these grades is sensitive (12).

The hand-held dynamometry (HHD) also requires an examiner-imposed force to measure isometric strength. The HHD is held perpendicular to the participant’s limb segment and the participant is encouraged to push as hard as possible, performing an isometric contraction. The HHD is reliable to measure within-session knee extension strength but has a lower reliability in between-session testing (13). There are restrictions when using the HHD because it can be difficult to stabilise the patient’s joint position. The measured value reflects
the resistance given by the examiner. This may cause an under-estimation of muscle strength (14).

The computerized isokinetic (constant-velocity) dynamometer is a device with highly reliable measures in both healthy and disease populations (15,16). The device has a resistance arm pivoting around an axis aligned with the segment tested. It provides a concentric or eccentric resistance throughout the whole range of movement (2).

The Strength Measuring Chair (SMC) is a computerized dynamometer measuring isometric muscle strength in seated persons. It is designed to measure isometric muscle strength in the lower extremities at restricted joint motion during testing. The reliability of isometric strength measurements in plantar flexors, knee extensors and knee flexors in the SMC has been shown to be good to excellent, with high Intra-class correlation coefficient (ICC) values (0.87-0.92). ICC between three repetitions for each muscle group during each session has shown a high reliability coefficient (0.88-0.98) for healthy adults. A Bland and Altman 95% limits of agreement test has shown no systematic variation between two different SMC test-sessions. A systematic variation was observed in all muscle groups tested except for plantarflexion when comparing the SMC to a kinematic dynamometer (17,18).

Cerebral palsy
Cerebral palsy is a collection of disorders characterized by an insult or lesion to the developing brain that produces a physical disability (19). The most recent definition of cerebral palsy (CP) is described as ”a group of disorders of the development of movement and posture, causing activity limitations that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of CP are often accompanied by disturbances of sensation, cognition, communication, perception and/or behaviour, and/or by a seizure disorder” (20, page 572).

Abnormal motor behaviour is the core feature in CP. It is characterized by abnormal patterns of movement and posture due to defective coordination of movements and/or regulation of muscle tone (20). Symptoms like muscle weakness, spasticity, muscle cocontraction and restriction in range of motion (ROM) are frequent (21).

CP can be classified in subgroups depending on the character of the neurological symptoms. The spastic subgroup includes spastic hemiplegia, spastic diplegia and spastic tetraplegia. Other subtypes are ataxia and dyskinesia (22). Bax et al (20) recommended the continuum of categorization by the dominant type of tone or movement abnormality, but with the addition of the anatomical distribution in unilateral or bilateral, and a description of gross
motor function abilities (20). In clinical practice the classification of CP in subgroups like spastic hemiplegia, diplegia, tetraplegia and in ataxia and dyskinesia is still in use.

Activity limitations are presumed to be a consequence of the motor disorder in CP. It is of interest to describe the activity limitations and functional mobility in CP (20). The Gross Motor Function Classification System (GMFCS) (23) is a standardized classification system for CP, focusing on self-initiated movement with emphasis on sitting, transfers and movement of the child and youth from 0-18 years. The GMFCS is used complementary to CP category. The GMFCS comprises five levels of gross motor function: from Level I (most able) to Level V (most limited) (23,24).

In Sweden the prevalence of CP is 2,4 per 1000 (25). Spastic hemiplegia, with a prevalence of 0,8 per 1000, is one of the most frequent form of CP (22,25). The physical impairment is usually milder than other CP subgroups and located to one side of the body (22). Gross motor function in children with hemiplegia is most often classified as GMFCS, level I, indicating walking without restrictions and performing more advanced gross motor skills such as climbing stairs and cycling (26). Youth with hemiplegia perform gross motor skills like running and jumping but speed, balance and coordination is limited (24).

**Muscle strength in cerebral palsy**

Several authors have reported muscle weakness in children with CP including all subgroups (14,27,28). Distal muscles in the lower limbs have been found to be relatively weaker than proximal muscles in CP as compared to healthy controls (14,29,30). Stackhouse (31) reported that isometric knee extension and plantarflexion strength were 56 percent and 73 percent less respectively in children with CP, aged 7-13 years, than in controls, aged 8-13 years (31). Studies indicate that muscle weakness persists in adults with CP. In a study where 256 adults were examined, a majority showed a moderate muscle weakness (score 3 and 4) and 25 percent had severe muscle weakness (score < 2) as measured with MMT (32).

For children with hemiplegia, studies indicate a decrease in strength in lower limb muscle groups on the involved side compared with the non-involved side of age-matched peers. They show lower strength values even in plantarflexors and dorsiflexors in the non-involved side. The children with hemiplegia were also significantly weaker in soleus, gastrocnemius and tibialis anterior in the involved side compared to the non-involved side in the same individual (14).

The relationship between lower limb spasticity, muscle strength and functional measures of gait and gross motor function in children with spastic diplegia has been studied
The results showed that strength was highly related to function and explained more of the variance among the participants than spasticity. Strength values for knee extensors and flexors and ankle dorsiflexors and plantarflexors related highly to motor function as measured with Gross Motor Function Measurement-66 (GMFM) (23), an valid and reliable clinical assessment evaluating change in gross motor function in children with CP. Items of the GMFM span the spectrum of activities in lying and rolling (dimension A) sitting (dimension B), crawling (dimension C), standing (dimension D) and walking and running (dimension E) (34). Muscle strength has been shown to relate particularly to dimension D and E (30,33). Strength was also highly related to stride length, moderately to gait speed and mildly to cadence (29,33). For stride length, 47 percent of the variance was explained by the strength of the ankle dorsiflexors followed by knee extensors (33).

The effectiveness of strength training for children, adolescents and adults with CP, mainly spastic diplegia and hemiplegia, and its effect on gross motor function and gait parameters has been studied. Strength training increases muscle strength in this group as in healthy population. Increased muscle strength improves gross motor function measured with GMFM and also particularly gait velocity and cadence (30,35,36,37). Gains made in gross motor ability as a result of strength training were found to be maintained over the three-month period following the training (36).

**Problem definition**

In several studies of muscle strength in CP, using MMT or HHD, only the force (in Newton) has been measured (14,29,32,36,38,39). To be able to compare muscle strength within or between participants, however, it is necessary to measure torque which is the product of force and lever arm. The SMC is designed to measure torque. Muscle strength values of healthy children and adults have been presented (17,18), leaving a need for strength values in CP. A number of authors have examined muscle strength in children with CP hemiplegia reporting lower values compared to healthy children (14,27,28). For adolescents and adults, however, only a limited number of studies have been found (32,36). Muscle strength increases with age, healthy boys make greater gains in strength than healthy girls in the onset of puberty (7,8). If the same relationship exists between boys and girls with CP has been little studied(14).

The subgroup hemiplegia represents a major part of the CP syndrome. Information about possible decrease in muscle strength in adolescents and adults in this group, is therefore of interest.
Purpose and research questions
The purpose of this study was to examine the muscle strength in the lower limbs in female and male adolescents and adults with CP, hemiplegia. The purpose was further to compare their strength values with those of female and male control persons and in addition with respect to gender.

The research questions were:
1. What isometric muscle strength did female and male adolescents and young adults with CP, hemiplegia exhibit in a) ankle plantarflexion, b) ankle dorsiflexion and c) knee extension in both lower limbs compared with that in a healthy female and male control group measured in the SMC?
2. Was there a difference in isometric muscle strength in ankle plantarflexion, ankle dorsiflexion and knee extension between the involved lower limb and the non-involved lower limb in female and male adolescents and young adults with CP, hemiplegia measured in the SMC?
3. Was there a difference in isometric muscle strength in ankle plantarflexion, ankle dorsiflexion and knee extension, between the more used and less used lower limb in female and male controls measured in the SMC?
4. Was the discrepancy in isometric muscle strength measured in the SMC between the lower limbs different in CP hemiplegia than in healthy controls?

METHOD
The study was part of a larger ongoing study of adolescents and young adults with cerebral palsy, hemiplegia, which aimed to investigate correlation between muscle strength, gait and muscle thickness.

Design
The study was a non-experimental study. It had a descriptive and comparative design.

Participants
A consecutive series of adolescents and young adults in age from 15-23 years, with CP, hemiplegia, from Stockholm and Skaraborg area were invited to participate in the study during the period of February to December 2008. The participants were recruited from the senior research leader in the larger ongoing study. Inclusion criteria were independent ambulation and ability to understand instructions. The participants were neither allowed to be
under spasticity reduction treatment prior to six months before test, nor having an orthopaedic operation closer than one year prior to the test. Twenty-nine adolescents and young adults, 15 men and 14 women, mean age 18.2 years (SD 2.48) range 15.0-22.5 participated in the study. A control group in approximately the same age span as the participants was recruited from colleagues, friends and acquaintances. The control group consisted of 14 healthy adolescents and adults, 9 men and 6 women, mean age 19.2 years (SD 2.66) range 15.4-24.4, with no known history of orthopaedic surgery in the lower limbs or neurological signs. The number of controls was limited because of difficulty in recruiting volunteers. An inquiry of participation was given both in written and verbal form to all participants within the larger ongoing study, while the controls were contacted by telephone. The participation was voluntary and could be interrupted at any time. Ethical approval for the study was obtained by the Ethical Committee in Karolinska University Hospital.

There was no significant difference between the entire groups or between gender with respect to age, weight and height. Male controls were significantly heavier and taller than female controls while in the hemiplegia group, there was no difference in weight between genders.

Characteristics for participants with hemiplegia and controls with respect to gender are presented in Table I.

Table 1: Characteristics for participants with hemiplegia and controls with respect to gender.

<table>
<thead>
<tr>
<th>Gender</th>
<th>N</th>
<th>Age</th>
<th>Weight</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
<td>Mean</td>
<td>Mean</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SD</td>
<td>SD</td>
<td>SD</td>
</tr>
<tr>
<td>Hemiplegia Female</td>
<td>14</td>
<td>17.5</td>
<td>2.29</td>
<td>62.2</td>
</tr>
<tr>
<td>Hemiplegia Male</td>
<td>15</td>
<td>18.9</td>
<td>2.53</td>
<td>68.6</td>
</tr>
<tr>
<td>Control Female</td>
<td>6</td>
<td>19.4</td>
<td>2.26</td>
<td>57.3</td>
</tr>
<tr>
<td>Control Male</td>
<td>9</td>
<td>19.1</td>
<td>3.02</td>
<td>73.3</td>
</tr>
</tbody>
</table>

**Data collection**

**Clinical examination**

Passive range of motion (ROM) measurements were performed. Popliteal angle was measured in supine with 90 degrees hip flexion. Restriction in the knee extension motion was defined as popliteal angle more than 50 degrees. ROM in ankle dorsiflexion was measured in supine both with 90 degrees knee flexion angle and with 0 degree knee flexion angle. Restriction in ROM in ankle dorsiflexion was defined when a neutral joint position was not achieved passively. ROM was measured with an universal Goniometer a reliable and valid tool for measuring ROM (40,41). Spasticity in the ankle plantarflexors were estimated according to
the modified Ashworth scale, a six-level scale grading resistance of the muscle to passive stretching through the ROM. Zero level corresponds to normal muscle tone and level four corresponds to rigidity in joint movement (42). Spasticity examination was performed bilaterally, in supine with extended hip and knee joint. The reliability of the modified Ashworth scale has been questioned. Interrater and intrarater reliability have shown to be good for hamstrings muscles and poor to moderate for other muscles in the lower limbs (42,43).

In the group with hemiplegia a restriction in ROM in knee extension was apparent in 14 participants, of which 3 bilaterally. All participants in the group with hemiplegia achieved a neutral position of the ankle dorsiflexion with the knee in 90 degrees of flexion though three participants did not achieve neutral position with knee extended. Among the participants with hemiplegia, spasticity in the plantarflexors, corresponding to level 1 or more, were estimated unilaterally in all but two participants and bilaterally in 20 participants.

**Muscle strength testing**

Isometric muscle strength was measured in the Strength Measuring Chair (SMC), which is designed for seated persons and adjustable in size for participants from approximately five years of age to adulthood (17). The SMC has levers to measure movement arm of lower extremities in ankle plantarflexion, ankle dorsiflexion and knee extension and flexion. A mechanical joint at knee level makes it possible to adjust the levers in 30-90° of knee flexion (0°=straight leg). During tests the participants were seated in the SMC in an upright position with the back supported and the hip and ankle in 90° angle. Straps over the pelvis, the distal part of the thigh and around the ankle and the forefoot were applied to maintain the position and restrict motion. The knee extension was tested in 60° knee flexion angle and plantar- and dorsiflexion of the ankle in 30° knee flexion (17,18).

In the SMC four sensor plates, which are placed at the levers in adjustable distances from joint centres, register force when pushing the foot on the sensor plate in plantarflexion. In dorsiflexion and knee extension the pulling of the strap wrapped around the foot or distal part of the shank, creates a tensile force in the sensor. The voltage signal from the force sensors is converted into a digital signal and sent to a computer (Pc). A data acquisition software (Lab View, National Instruments, Austin, Texas, USA) was used to collect, convert, save and present the data. The data acquisition software converts the data from V to kg and implements the moment arms and displays the generated force to torque (Nm). Collected data is then exported to Ms Excel® format.
Before testing taring was done with the purpose of subtracting the limb weight from the actively generated force (43). The moment arm from the joint centre to the centre of the sensor was measured allowing the force signal to be transformed to a moment/torque (Nm). Torque is defined as the product of force in Newton (N) and lever arm (moment arm) in metres (m) (19).

Procedure
All data collection was gathered by two experienced physiotherapists familiar with the SMC. Each participant and control person attended a single trial session that lasted about one hour. The session was commenced with an examination of ROM followed by the strength measurement. Isometric maximal voluntary contraction (MVC) in ankle movements and knee extension were tested bilaterally in a random order for all participants and controls. Strength testing of the ankle was initiated by plantarflexion followed by dorsiflexion. Mean peak strength values of three trials per muscle group were performed and registered. To avoid muscle fatigue the participants and controls were given a resting period of 45 seconds between the contractions.

Before testing and before each trial, the participants and controls were given both verbal and visual instructions to push or pull as hard as possible for 5 seconds. The participants and control were previous to each trial, reminded of the intended movement. A practical trial was provided to ensure that the participants had understood the instructions and to control position maintenance or reinstruct the participants.

Similar and strong verbal encouragement was used during all tests to produce maximal effort. Visual or verbal information about the results were not provided during the tests.

Data and statistical analysis
Peak values of MVC in each trial, and mean peak of three trials for each muscle group for each participant were calculated in Microsoft Excel. Plantarflexor torque was defined as negative values and dorsiflexor and knee extensor torque as positive values. In the group with hemiplegia the non-involved limb was categorized as dominant and the involved limb as the non-dominant limb. In controls the preferred leg when kicking football was categorized as the more used, thus categorized as the dominant lower limb. The contra lateral leg was categorized as the non-dominant lower limb.

One male participant was unable to perform isometric strength tests in dorsiflexion and plantarflexion due to pain after tests of knee extension. Only the knee extension values for
this participant are included when calculating the statistics. Two participants with hemiplegia performed plantarflexion movements in one of the three trials, when instructed to perform a dorsiflexion. A male participant with hemiplegia had a missing value in knee extension (dominant lower limb). Mean peak values in dorsiflexion and knee extension respectively for these participants, were calculated for two trials.

Descriptive statistics were used to calculate mean and standard deviation. To compare means in age, height and weight between participants and controls, and females and males Independent-Samples T test was used. The differences in muscle strength between genders, between participants and controls, between female participants and female controls and between male participants and male controls were calculated with non-parametric Mann-Whitney U test.

Non-parametric Wilcoxon Signed Rank test was used to compare muscle strength in the dominant limb and the non-dominant limb in each subgroup.

The lower limb symmetry index (LSI) was calculated to determine whether a side-to-side leg difference could be classified as normal or abnormal. The LSI was defined as the ratio in muscle strength between non-dominant lower limb and the dominant lower limb expressed in per cent (non-dominant/dominant X 100). An LSI greater than or equal to 90% was classified as normal (45).

Data was analysed in the statistical program, SPSS version 17. Statistical significance level was set at p=0.05.

RESULTS
Entire group with CP hemiplegia compared to entire control group
The group with hemiplegia presented lower mean strength values in all muscle groups compared to healthy controls. Significantly lower strength values were found in plantarflexion and dorsiflexion in the non-dominant limb in the group with hemiplegia compared to the non-dominant limb in the control group. In knee extension the group with hemiplegia presented lower strength values (32%) in the non-dominant lower limb although not significantly lower.

In the dominant lower limb, the group with hemiplegia presented 24% lower strength values in plantarflexion, 9% lower strength values in dorsiflexion and 22% lower strength values in knee extension than corresponding values in the control group. None of these values was significantly lower. Muscle strength with respect to the entire group is presented in Table II.
Table II: Muscle strength values (Nm) in three different muscle groups in the dominant lower and non-dominant lower limb (mean±SD). Results presented for the group with hemiplegia and the control group.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Hemi (n)</th>
<th>Control (n)</th>
<th>Hemi (Nm)</th>
<th>Control (Nm)</th>
<th>p value</th>
</tr>
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<tbody>
<tr>
<td>Plantarflexion dom</td>
<td>28</td>
<td>15</td>
<td>-110.47±</td>
<td>47.37</td>
<td>-146.20±</td>
</tr>
<tr>
<td>Plantarflexion non-dom</td>
<td>28</td>
<td>15</td>
<td>-71.14±</td>
<td>41.37</td>
<td>-135.42±</td>
</tr>
<tr>
<td>Dorsiflexion dom</td>
<td>27</td>
<td>15</td>
<td>28.28±</td>
<td>9.53</td>
<td>30.95±</td>
</tr>
<tr>
<td>Dorsiflexion non-dom</td>
<td>27</td>
<td>15</td>
<td>9.01±</td>
<td>6.69</td>
<td>29.54±</td>
</tr>
<tr>
<td>Knee extension dom</td>
<td>29</td>
<td>15</td>
<td>111.34±</td>
<td>50.60</td>
<td>142.32±</td>
</tr>
<tr>
<td>Knee extension non-dom</td>
<td>29</td>
<td>15</td>
<td>96.79±</td>
<td>51.22</td>
<td>141.54±</td>
</tr>
</tbody>
</table>

Female participants with hemiplegia compared to male participants with hemiplegia

There was no significant difference in plantarflexion (dominant p=0.15, non-dominant p=0.34) between genders. Male participants were significantly stronger than the female participants in dorsiflexion in both the dominant limb (p<0.01) and non-dominant limb (p<0.05). In knee extension males were stronger compared to females in the dominant (p<0.01) and in the non-dominant lower limb (p<0.03). Muscle strength for female and male participants with hemiplegia is illustrated in figure 1-3.

Female controls compared to male controls

In the group of healthy controls male participants were stronger in all muscle groups in comparison with female participants (plantarflexion p<0.01, p<0.01, dorsiflexion p<0.01, p<0.01, knee extension p<01, p<0.01). Muscle strength for female and male controls is illustrated in figure 1-3.

Female group with hemiplegia compared to female control group.

In female participants with hemiplegia there was no significant difference in plantarflexion (p=0.08) in the non-dominant lower limb compared with female controls. Strength values in dorsiflexion of the non-dominant limb were significantly lower compared with strength values in dorsiflexion in female controls (p=0.01). In knee extension (p=0.74) there was no significant difference between the groups. In the dominant lower limb female participants with hemiplegia, presented higher strength values in plantarflexion, dorsiflexion and knee extension compared to female controls, although the differences were not significant (plantarflexion p=0.62, dorsiflexion p=0.1, knee extension p=0.41). Muscle strength for female participants with hemiplegia and female controls is illustrated in figure 1-3.
Male group with hemiplegia compared to male control group.
In male participants with hemiplegia compared to male controls, significantly lower muscle strength values were found in plantarflexion (p<0.01), dorsiflexion (p<0.01) and knee extension (p<0.01) in the non-dominant limb. In the dominant lower limb the male participants with hemiplegia presented significantly lower muscle strength values in plantarflexion (p<0.04) and knee extension (p<0.04). In dorsiflexion there was no significant difference between the groups. Muscle strength for male participants with hemiplegia and male controls is illustrated in figure 1-3.

Figure 1. Muscle strength (Nm) for plantarflexion in the dominant and non-dominant lower limb, presented separately for female (n=14) and male (n=14) subjects with hemiplegia and for female (n=6) and male (n=9) controls.
Figure 2. Muscle strength (Nm) in dorsiflexion in the dominant and non-dominant lower limb, presented separately for female (n=14) and male (n=13) subjects with hemiplegia and for female (n=6) and male controls (n=9).

Figure 3. Muscle strength (Nm) in knee extension in the dominant and the non-dominant lower limb, presented separately for female (n=14) and male (n=15) subjects with hemiplegia and for female (n=6) and male (n=9) controls.
Comparison between the dominant lower limb and non-dominant lower limb in participants with CP hemiplegia and control participants

Muscle strength in the non-dominant lower limb showed significantly lower strength values in plantarflexion \((p<0.01)\), dorsiflexion \((p<0.01)\) and knee extension \((p<0.01)\) as compared to the dominant lower limb, for the entire group with hemiplegia.

The strength values were significantly lower in the non-dominant lower limb compared to the dominant lower limb among females (plantarflexion \(p<0.01\), dorsiflexion \(p<0.01\), knee extension \(p<0.01\)) as well as among males (plantarflexion \(p<0.01\), dorsiflexion \(p<0.01\), knee extension \(p<0.01\)) in the group with hemiplegia. Muscle strength in the non-dominant and the dominant lower limb in the group with hemiplegia are presented in Table III.

Comparison of muscle strength for the entire control group showed no differences between the dominant and the non-dominant lower limb (plantarflexion \(p=0.92\), dorsiflexion \(p=0.75\), knee extension \(p=0.25\)) (Table III)

Among males solely in the control group, the plantarflexors in the non-dominant lower limb showed significantly lower values as compared to the dominant lower limb \((p=0.04)\). Among females there were no difference between the non-dominant and the dominant lower limb. Results are presented in table III.

Table III. : Muscle strength values (Nm) in three different muscle groups in the dominant and non-dominant lower limb (mean±SD). Results presented for females and males in the group with hemiplegia and for females and males in the control group.

<table>
<thead>
<tr>
<th></th>
<th>n</th>
<th>Plantarflex</th>
<th>Dorsiflex</th>
<th>Knee ext</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dom</td>
<td>Non-dom</td>
<td>Dom</td>
<td>Non-dom</td>
</tr>
<tr>
<td>Female Hemi</td>
<td>14</td>
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<td>-62,7±36,0</td>
<td>22,9±5,8</td>
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<tr>
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<td>-79,6±45,9</td>
<td>34,1±9,5</td>
</tr>
<tr>
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<td>19,0±4,9</td>
</tr>
<tr>
<td>Male control</td>
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<td>-183,1±51,8</td>
<td>-163,5±43,0</td>
<td>38,9±6,8</td>
</tr>
</tbody>
</table>

Limb symmetry index

The ratio in mean peak muscle strength values between the non-dominant lower limb and the dominant lower limb is presented as limb symmetry index (LSI). LSI for participants with hemiplegia was classified as abnormal, in plantarflexion 64%, in dorsiflexion 32% and in knee extension 87%.
In the control group LSI for plantarflexion was 92%, for dorsiflexion 96% and for knee extension 99% thus classified as normal.

**DISCUSSION**

**Summery of results**
The aim of this study was to examine isometric muscle strength in adolescents and young adults with hemiplegia. This study indicates that adolescents and young adults with CP hemiplegia are weaker in the lower limbs as compared to healthy controls. The muscle weakness is significant in the non-dominant (involved) lower limb but also the dominant (non-involved) lower limb shows muscle weakness as compared to healthy controls. When comparing muscle strength in the non-dominant (involved) and the dominant (non-involved) lower limb, the group with hemiplegia presented significantly lower muscle strength values in the non-dominant lower limb in plantarflexion, dorsiflexion and knee extension compared to the same muscle groups in the dominant lower limb.

**Discussion of results**
The recognition of muscle weakness as a component in CP has been increasingly highlighted. Several studies have indicated muscle weakness even in children with mild impairment as seen in bilateral spastic CP and in CP hemiplegia (14,28,30). The results in this study are in accordance with those results, and indicate that the muscle weakness remains with increased age.

In a study of fourteen children with CP hemiplegia, the hemiplegia non-dominant leg was found to be more than 50% weaker in plantarflexion compared to the non-dominant leg in healthy participants (28). In dorsiflexion the children with hemiplegia produced significantly about 50% less torque in the non-dominant lower limb and about 40% less in the dominant lower limb (28). In this study the group with hemiplegia was 48% weaker in plantarflexion in the non-dominant leg and 70% weaker in dorsiflexion as compared to healthy controls. In dorsiflexion in the dominant leg the group with hemiplegia in this study, produced however, only 7% less torque in comparison with controls.

When examine adolescents it is necessary to consider the effect of age, weight and height on muscle strength. Since there was no significant difference between the participants with CP hemiplegia and healthy controls in this study regarding age, weight or height, a comparison between groups was therefore possible.
In this study a difference between genders was found. Male participants with hemiplegia were significantly weaker in all muscle groups in the non-dominant limb and in plantarflexion and knee extension in the dominant limb compared to male controls while female participants with hemiplegia were only weaker in dorsiflexion of the non-dominant leg compared to female controls.

The relationship between muscle strength, gait parameters and gross motor function has been studied (33). Several studies indicate the benefit of strength training regarding gait velocity and cadence, gross motor function in dimension D and E (standing, running and jumping) in GMFM (29,30,35,36). Even adults with CP make improvements in gait velocity and GMFM dimension D and E after strength training (37). Gage (46) has described the roll of the plantarflexors as a major factor in the propulsion of walking and the roll of the dorsiflexors for foot-clearance in swing (46). The group with hemiplegia in this study produced decreased torque in plantarflexion and especially in dorsiflexion in the non-dominant leg as compared to controls. A number of the participants with hemiplegia showed furthermore a decrease in ROM in dorsiflexion. A decrease in propulsion and in foot-clearance may therefore be presumed, perhaps causing decreased gait velocity, though further studies are warranted.

In the group with hemiplegia muscle strength values in all muscle groups in the non-dominant lower limb were significantly lower than in the dominant lower limb. The difference between limbs is also presented with the LSI. The control group produced muscle strength values less than 8% lower in their non-dominant lower limb compared to their dominant lower limb, 92% expressed in LSI. In knee extension the difference in muscle strength between lower limbs presented with LSI was low also in the group with hemiplegia (87%). In the distal muscles the difference in muscle strength between non-dominant and the dominant limbs becomes obvious. The LSI in plantarflexion for group with hemiplegia was 64% and 32% in dorsiflexion. Earlier studies have shown, a muscle weakness more pronounced in distal muscles, plantarflexors and dorsiflexors, as compared to proximal muscles (14). This corresponds to the description of CP hemiplegia with symptoms like spasticity and decreased selective motor control also affecting more distally than proximally.

In the group with hemiplegia, compared to healthy controls, lower muscle strength values were found in the dominant lower limb, as well as in the non-dominant lower limb, though not significantly. CP hemiplegia is described as impairment in one-side of the body. This study indicates that also the dominant (non-involved) side might be influenced by muscle weakness.
Method discussion

Reliable and valid measurements of strength in a clinical setting are of importance. The Manual muscle testing (MMT) has been commonly used in clinic because it is user-friendly and no special equipment is required. The reliability of the MMT has been questioned partly because it is difficult to distinguish between grades 4 and 5 and partly because it requires a resistance imposed by the examiner (12). The Hand held dynamometer (HHD) has shown high test-retest reliability; however difficulties in stabilizing patient’s joint position and control the demand for resistance imposed by the examiner. For healthy controls and for participants with CP hemiplegia strength values measured with the HHD for plantarflexors are limited after the age of nine, since the muscles produce torques values impossible to impose as measured with the HHD (30). The HHD has in addition a value limitation that can be exceeded (28). The Strength measuring chair (SMC), used in this study, has shown high plantarflexion and knee extension reliability and slightly lower reliability for dorsiflexion (18). The SMC is not dependent on the strength of the test leader as the examiner-imposed device HHD and MMT. The seated position in the SMC makes it easy to instruct the participant and the participant has the possibility to see his/her own muscle activation. A number of participants in the group with hemiplegia in this study had restriction in ROM in knee extension which may have caused discomfort in sitting position and thereby effected maximal contraction in plantarflexion and dorsiflexion. The muscle strength testing did not, however, require full knee extension.

A male participant in the group with hemiplegia could not complete the test. A few males in both the group with hemiplegia and the control group were 180 cm or taller. The footplates of the SMC were in these cases set in the widest position on the lever arms and there may have been a deviation from the intended seated position. Some of the participants reported discomfort caused by the straps placed over the ankle and forefoot although there was a pad in between the foot and the strap. The discomfort did not restrain the participants from performing a maximal voluntary contraction as reported by the participants.

When comparing torque values it is notable that female controls in this study produced even less muscle strength values in knee extension in the non-dominant leg and in all muscle groups in the dominant leg compared to female hemiplegia. Örquist et al (17) examined peak torque values in healthy adults with the SMC. The females in that study produced higher torque than females in the present study. In plantarflexion 99,6 Nm, in dorsiflexion 30,7 Nm and in knee extension 115,0 Nm. Nyström-Eek (9) presented isometric muscle torque measured with Hand held dynamometer. The torque values for healthy 15 years old girls were
in dorsiflexion 34.8 Nm and in knee extension 98.0 Nm. The female controls in this study was 9% weaker in plantarflexion in the dominant lower limb as compared to results presented by Örtquist (17). In dorsiflexion the female controls produced 63% less and in knee extension 70% weaker as compared to the strength values presented by Örtquist (17). The number of female controls in this study was small and may have influenced the results. It is therefore doubtful whether these results can be considered representative for a female population in this age span and needs to be taken into account when comparing strength values with the female group with hemiplegia.

When analysing muscle strength values in dorsiflexion we found that two female participants with hemiplegia produced plantarflexion torque in one of three trials, when instructed to perform a dorsiflexion movement. One male participant in the group with hemiplegia performed a plantarflexion in all tree trials instead of performing a dorsiflexion movement. The female participants had a dorsiflexion ROM to neutral position with both flexed and extended knee joint. The male participant had a decreased dorsiflexion ROM -10 degrees with knee extended and spasticity level 1 measured with the modified Ashworth scale. Poor selective motor control can interfere with the ability to produce an ankle dorsiflexion (14). It is probable that these participants were unable to produce a dorsiflexion in the non-dominant lower limb because of decreased ROM, spasticity in plantarflexion or poor selective motor control. The muscle strength values in dorsiflexion in the non-dominant and the dominant lower limb were therefore excluded from statistical analysis.

Verbal encouragement has been shown to increase voluntary muscle action (47). In this study verbal encouragement was given in a standardised form during muscle activation and words like “good” and “well done” were given directly after muscle activation.

Clinical relevance
Torque values for muscle strength in the lower limbs for persons with CP hemiplegia in an age group earlier not largely investigated are here presented. Torque values for plantarflexion are presented measured with a reliable strength measuring device, the Strength Measuring Chair (SMC), showing significantly lower torque values in plantarflexion and dorsiflexion in the non-dominant lower limb in persons with CP hemiplegia. Also in knee extension in the non-dominant lower limb and in all three examined muscle groups in the dominant lower limb the group with CP hemiplegia presented lower torque values. This study indicates that the decrease in muscle strength remains from childhood through adolescence, why muscle
strength, both testing and training, should be well taken into account by physiotherapists addressing adolescents and young adults with CP hemiplegia.

Muscle strength training in persons with CP spastic diplegia has shown positive results (29,30,36,37). Is it possible that muscle strength training would decrease even the small activity limitations in the group with CP hemiplegia? Is it possible that the asymmetry in muscle strength between the lower limbs would decrease with muscle strength training or would it rather increase because of the relatively enhanced motor control in the dominant lower limb as compared with the non-dominant lower limb?

Since the number of participants in this study is rather small an examination including a larger number of participants is wanted.

**Conclusion**

This study shows that adolescents and young adults with CP hemiplegia, although mild motor impairments have significantly less muscle strength in plantarflexion and dorsiflexion in their non-dominant (involved) lower limb as compared with peers in the same age span. Persons with CP hemiplegia are also significantly weaker in their non-dominant (hemiplegic) lower limb compared to their dominant lower limb unlike healthy persons. The muscle weakness is more pronounced in the distal muscles.
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