ELSEVIER

Brain & Development 36 (2014) 294–300

BRAIN & DEVELOPMENT
Official Journal of the Japanese Society of Child Neurology

www.elsevier.com/locate/braindev

Original article

Lower limb muscle volumes in bilateral spastic cerebral palsy

Jonathan J. Noble [a,*], Nicola R. Fry [b], Andrew P. Lewis [a], Stephen F. Keevil [c], Martin Gough [b], Adam P Shortland [b]

[a] *Division of Imaging Sciences and Biomedical Engineering, King's College London, The Rayne Institute, 4th Floor, Lambeth Wing, St. Thomas' Hospital, London SE1 7EH, United Kingdom*
[b] *One Small Step Gait Laboratory, Guy's and St. Thomas' NHS Foundation Trust, Guy's Hospital, London SE1 9RT, United Kingdom*
[c] *Department of Medical Physics, Guy's and St. Thomas' NHS Foundation Trust, The Rayne Institute, 4th Floor, Lambeth Wing, St. Thomas' Hospital, London SE1 7EH, United Kingdom*

Received 26 November 2012; received in revised form 15 April 2013; accepted 21 May 2013

Abstract

Aim: Muscle weakness is a feature of individuals with spastic cerebral palsy (SCP) but there are few reports in the literature of muscle volume in this group. This study compares muscle volumes in adolescents and young adults with SCP with those of their typically developing (TD) peers. *Design:* Measurements of the volumes of nine major lower limb muscles in 19 independently ambulant subjects with SCP (mean age 14.2 years (sd 2.7), 11 male, GMFCS I ($n = 5$); GMFCS II ($n = 14$)), 19 TD subjects (mean age 16.5 years (sd 3.0), 11 male) were made using magnetic resonance imaging. *Results:* Lower limb muscles were smaller in the SCP group ($p \leqslant 0.023$ in all muscles) than the TD group with the exception of the vastii (lateralis + intermedius; $p = 0.868$) and gluteus maximus ($p = 0.056$). Average muscle volume deficit was 27.9%. Muscle volume deficits were significantly greater for distal muscles than proximal muscles ($p < 0.001$). *Conclusions:* Reduced muscle size in adolescence and the natural history of sarcopenia in adulthood may contribute to the early loss of mobility of adults with SCP.

Keywords: Cerebral palsy; Independently ambulant; Lower limb; Muscle volume; Magnetic resonance imaging

Muscle weakness in individuals with spastic cerebral palsy (SCP) is well documented [1] and is in part attributable to reduced activation of the muscles in SCP [2–4] and to co-activation of agonists and antagonists [2,3]. Wiley and Damiano [1] demonstrated that during maximum voluntary contractions the muscle groups of children with SCP may produce only between 30% and 75% of the force of their typically-developing (TD) peers. Stackhouse et al. [2] compared forces from the quadriceps and plantarflexors during maximum voluntary contraction and augmented voluntary activation using electrical stimulation in groups of children with SCP and TD children. In both groups muscles could produce substantially greater forces when electrically stimulated. However, data from the subjects with SCP implied that lack of voluntary activation of the musculature alone could not explain muscle weakness. Elder et al. [4] attempted to quantify the agonist–antagonist co-activation and cross-sectional area of the triceps surae in children with SCP and found that both contributed significantly to weakness during voluntary activation. Their study investigated the triceps surae only and was limited to a small number of children.

Investigations of gross muscle morphology in SCP have largely been confined to the medial gastrocnemius. Volume deficits have been reported in children and young adults of between 22% and more than 50% [5–

* Corresponding author. Address: One Small Step Gait Laboratory, Guy's Hospital, Great Maze Pond, London SE1 9RT, United Kingdom. Fax: +44 (0) 20 7188 2477.
E-mail address: jonathan.noble@gstt.nhs.uk (J.J. Noble).

0387-7604/$ - see front matter © 2013 The Japanese Society of Child Neurology. Published by Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.braindev.2013.05.008

7]. Fewer studies include measurements of muscle size for the whole lower limb. Lampe et al. [8] studied muscle volumes and lengths in a group of young adults with unilateral SCP using MRI. They found significant reductions in muscle volumes for nearly all the muscles in the lower limb when compared to the non-paretic limb and noted that the proximal musculature was less affected than the distal musculature. Riad et al. [9] also reported significantly reduced muscle volume for the majority of the muscles in the lower limb compared to the non-paretic limb in adolescents and young adults with unilateral SCP. However, these studies did not include TD adults as controls and was limited to unilateral subjects. Oberhofer et al. [10] published MRI data from a young group of six children with SCP (four bilaterally affected) and a matched group of TD children. They found significant differences in muscle volumes (normalised to body mass) for the quadriceps and the hamstrings in the children with CP, but not for the calf muscles. Their results are in contrast to Fry et al. [7] who found very large differences in muscle volume in the gastrocnemius muscles, and to Lampe et al. [8] who found the distal muscles to be more affected. A recent review of muscle morphology in SCP by Barret and Lichtwark [11] highlights the limited volume data studies published to date.

In this paper we measured the volume of nine major muscles of the lower limbs in adolescent and young adult subjects with bilateral SCP and in TD subjects. We hypothesised that we would find large reductions in muscle volumes in the individuals with SCP, and that the distal muscles would be more affected than the proximal ones due to increased distal motor impairment in this group [12].

1. Materials and methods

1.1. Participants

The local research ethics committee granted ethical approval for this study. SCP group inclusion criteria: age 10–24 years, diagnosis of bilateral SCP, Gross Motor Function Classification System (GMFCS) levels I–III and met the safety requirements of MRI. Patients were excluded from the study that had undergone surgery, serial casting or botulinum toxin injections to the lower limbs within the previous year. This is a convenience sample of individuals attending our hospital department, with consecutive patients that met the inclusion criteria were invited to participate in the study. Nineteen participants with bilateral SCP were recruited to the study (mean age: 14.4 years; age range: 10.2–19.7 years, GMFCS level I: $n = 5$, level II: $n = 14$, 11 male) from clinics in our university hospital. Nineteen TD subjects were included in this study (mean age: 16.5 years; age range: 10.6–22.3 years, 11 male, 8 female). The TD subjects had not had no previous surgery to their lower limbs and had no known neurological or musculoskeletal condition.

1.2. Data collection and analysis

Both lower limbs of all subjects were acquired with contiguous transverse slices from above the iliac crest to below the calcaneum. All subjects lay supine on the scanner bed and went feet first into the scanner with their feet resting against a wooden footplate giving an approximate plantarflexion angle of 25°.

All MRI data was collected on a 1.5 T Phillips Achieva system (Philips Medical Systems, Best, The Netherlands). Seven SCP and nine TD subjects were scanned using a T1 weighted turbo spin echo sequence (TE/TR = 18/1104.4 ms, number of averages = 2, echo train length = 3, 1.8 × 1.8 mm in-plane voxel size) with a quadrature body coil. Slices were collected contiguously with a slice thickness of 2 mm over the hip, knee and ankle joints and every 4 mm over the remainder of the lower limb. Image acquisition took approximately 20 min for each subject. Data was also collected from twelve SCP and ten TD subjects using a three point Dixon sequence (TE/TR = 4.6/13 ms, echo time shift = 1.53 ms (120° echo phase shift), 20° flip angle, 0.9 × 0.9 mm in-plane voxel size, number of averages = 2, 5 mm slice thickness) with a quadrature body coil. Each scan took approximately 30 min.

Volume measurements were performed using Osirix [13] (version 3.7.1). Visually, the proximal and distal endpoints of each muscle belly were identified and regions of interest were outlined on every image slice with the exception of T1 weighted scans with 2 mm slice thickness where regions were drawn on every other slice (effective slice thickness = 4 mm). The total volume was calculated within the software as the sum of the outlined cross sectional areas multiplied by slice thickness. The volumes of the medial gastrocnemius (MG), lateral gastrocnemius (LG), soleus (SOL), tibialis anterior (TA), rectus femoris (RF), vastus intermedius and lateralis composite (VI + VL), semimembranosus (SM), semtiendinosus (ST), and gluteus maximus (GMax) were measured. Sections of the boundary between VL and VI are difficult to identify in MRI. Therefore, to remove potential boundary inaccuracies, VL and VI were measured as a group VL + VI.

Individuals with SCP tend to be shorter and lighter than TD children of similar age [14]. To account for differences in body size across the age range and between groups, muscle volumes were normalised to body mass [6,7]. In general, the volumes of each muscle were averaged across legs of individual subjects prior to statistical analysis of normalised muscle volume between the two groups. When data was not available from a particular muscle due to image artefacts or subject compliance,