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Muscle and fascicle excursion in children with cerebral palsy

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ABSTRACT

Background: Fascicle length and fascicle excursion measurements in children with cerebral palsy have yielded inconsistent results. The purpose of this study was to measure *in vivo* passive fascicle lengths and fascicle excursions in the Medial Gastrocnemius muscle of children with cerebral palsy and typically developing controls.
Methods: We measured 11 children with spastic cerebral palsy and 14 controls between the ages of 9 and 16 years. Ultrasound imaging was used to measure fascicle lengths while a dynamometer moved the ankle joint through the range of motion. A common range of motion for all subjects was used for analysis of fascicle excursion.
Findings: Fascicle lengths in children with cerebral palsy were 43% smaller than those for control subjects throughout the range of motion. The relative fascicle excursion was 92% greater on average for the cerebral palsy compared to the control group children. The muscle excursion for the control group children was greater than for the cerebral palsy group children.
Interpretation: Since the fascicles in children with spastic cerebral palsy are shorter, but they go through the same excursion as fascicles in typically developing children, sarcomeres within the medial gastrocnemius muscle must be working over a larger range of sarcomere lengths. Combined with findings of overstretched sarcomeres in spastic muscles reported in the literature, our results suggest that the increased passive forces and the weakness found in spastic muscles may be caused by a decrease in contractile filament overlap as sarcomeres are pulled to extreme lengths in children with cerebral palsy.

1. Introduction

Cerebral palsy (CP) is a non-progressive condition that is caused by a static lesion in the brain that occurs before, during or shortly after birth. A common symptom of CP is spasticity, which is defined as an increased sensitivity to the normal stretch reflex in addition to a velocity-dependent increase in resistance to stretch (Miller, 2005). Joint contractures often form in children with CP when spastic muscles become taut and limit the range of motion (RoM) of joints. Studies have also shown that spastic muscles are weaker and have an increased passive joint stiffness compared to non-spastic muscles (Alhusaini et al., 2010; Herman and Schaumburg, 1967). As a result, individuals with CP often have severe functional impairments.

The detailed reasons for why spastic muscles become weak and taut remain unknown. Even though CP is neural in origin, distinct structural changes of muscles have been found. Muscles in children with spastic CP have been found to be smaller in volume, cross sectional area, and muscle thickness compared to typically developing (TD) children (Barrett and Lichtwark, 2010). These results are believed to be a factor in the muscle weakness often found in children with CP (Wiley and Damiano, 1998). The passive muscle stiffness and the joint contractures have been proven harder to explain. Sarcomere lengths have been studied, and have been reported to be longer in the flexor carpi ulnaris muscle in spastic CP patients compared to control (Lieber and Friden, 2002; Pontén et al., 2007), suggesting that sarcomeres were operating primarily on the descending limb of the force–length relationship (Gordon et al., 1966) for children with CP.

Ultrasound imaging has been used extensively to measure the structure of muscles *in vivo* (Barber et al., 2011; Fukunaga et al., 2002; Gao et al., 2011). Several studies have focused on passive fascicle length measurements in spastic muscles of CP patients using ultrasound imaging, but the results have been inconsistent. Some studies reported significantly shorter fascicle lengths in spastic compared to control muscles (Gao et al., 2011; Mohagheghi et al., 2008), while others reported no differences between patients with CP and appropriate control group subjects (Malaiya et al., 2007; Shortland et al., 2002). Measurements of fascicle lengths in the triceps surae group have typically been made with the ankle joint in the resting (relaxed) position, where the muscle tension between agonists and antagonists is the same and likely close to zero.

From a functional point of view, fascicle excursion, the measurement of passive fascicle length changes throughout the range of joint motion, is more important than individual static measurements because passive fascicle excursion directly relates to the changes in sarcomere lengths that need to be accommodated during movement. Fascicle excursions in the gastrocnemius muscle of young adults with spastic CP have

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been measured in a single study (Barber et al., 2011). They found that fascicle excursions were significantly smaller in patients with spastic CP compared to age- and sex-matched controls, and they concluded that this was the case because the fascicles in the CP group patients were stiffer than those in the control group subjects. However, fascicle excursions in the study by Barber et al. (2011) were defined from slack length to the maximal fascicle length, thus, the range of ankle joint motion was different for each subject, and comparisons of functional properties, such as stiffness across the patient and control group must be viewed with caution. Careful analysis of the Barber et al. (2011) data revealed that ankle excursions in the spastic CP group patients were consistently smaller than those of the control group patients, thus the differences in fascicle excursion might be simply a function of the smaller ankle joint excursion in the CP patients, rather than a difference in the stiffness properties.

Therefore, the purpose of this study was to measure *in vivo* passive fascicle lengths, fascicle excursions, and muscle excursions in the medial gastrocnemius (MG) muscle over a common range of motion in children with spastic CP and typically developing children. There is no consensus in the literature regarding fascicle lengths in children with CP. However, the majority of results seems to suggest that fascicle lengths in children with CP are shorter at a given joint configuration than fascicle lengths observed in age-matched typically developing children, therefore we hypothesized that absolute fascicle lengths were shorter in children with spastic CP and that absolute fascicle excursions and muscle excursions over a common range of motion were the same between groups. Relative fascicle excursions, and thus an estimate of sarcomere excursions, could then be calculated from the absolute fascicle excursions. Together with the passive ankle joint moment measurements (a surrogate for muscle force), estimates of fascicle and sarcomere stiffness could be made for the typically developing and CP group children. The significance of this study was to provide the first ever data of this nature over a common range of motion between typically developing and CP group children, and thus obtain further insight into the workings and function of spastic muscles in children with CP.

2. Methods

2.1. Inclusion criteria

The inclusion criteria for the CP children were that they had been clinically diagnosed with spastic gastrocnemius muscles on at least one leg, while exclusion criteria were recent (<6 months) orthopedic surgery or botulinum toxin type-A injections on the lower leg.

2.2. Participants

The experimental group included 11 children with CP (6 males, 5 females) between the ages of 9 and 16 years (mean 13.3, SD 1.5). The control group included 14 typically developing (TD) children (6 males, 8 females) between the ages of 9 and 15 years (mean 11.8, SD 2.6). Six of the eleven experimental group children had a sex-matched twin sibling that was used for the control group. Furthermore, one child's unaffected side was used as a control. Children with CP were recruited from the Calgary Cerebral Palsy Association, the Cerebral Palsy Association of Alberta, Calgary Youth Physiotherapy and the Alberta Children's Hospital. The control group children were recruited from twin siblings of the CP patients whenever possible and from the Calgary community. The study was approved by the Conjoint Health Research Ethics Board of the University of Calgary and informed parental consent was obtained from all participants.

The experimental group children were comprised of 6 children with spastic diplegia, 1 child with spastic hemiplegia, and 4 children with spastic quadriplegia. The children were level I ($n = 2$), level II ($n = 1$), level III ($n = 4$), level IV ($n = 4$) on the Gross Motor Function Classification System (GMFCS) for cerebral palsy (Palisano et al., 2007).

2.3. Experimental protocol

Height, weight, leg length and medial gastrocnemius length were measured for each participant. The length of the leg was measured from the center of the medial condyle of the femur to the bottom of the heel. Medial gastrocnemius length was measured as the length from the medial condyle of the femur to the top of the calcaneus with the ankle in a neutral position (90°).

Children were seated in the chair of a Biodex™ System III dynamometer (Biodex Medical Systems Inc., New York, USA). The resting ankle joint angle was measured with a hand held goniometer with the foot hanging and the ankle completely slack in a seated position. After that, the rotation axis of the dynamometer was aligned with the participant's center of rotation of the ankle joint and the foot securely strapped to a footplate. The anterior distal end of the lateral malleolus was defined as the skin landmark of the ankle joint rotation axis. The seat was adjusted and the leg positioned so that the knee angle was at 45° of flexion. An ankle angle of 90° was defined as neutral, was measured with a goniometer, and was set for a common reference in the Biodex system. Supportive straps were placed over the subjects' hips and shoulders to minimize upper body displacements during testing. The maximum dorsiflexion and maximum plantarflexion ranges were then quantified by applying manual pressure on the footplate in each direction until the comfort limits of the participants were reached.

Surface bipolar electromyographic (EMG) electrodes were placed on the medial gastrocnemius (MG) and the tibialis anterior (TA) muscles (Biovision, Germany). Trials in which MG activity was observed were not saved and were immediately repeated. EMGs of MG and TA were recorded to ensure that agonist and antagonist muscles were not active, thus providing measurements of passive muscle and fascicle excursions. If EMG activity was detected at the analysis stage, the trial was not included in the final analysis. An ultrasound scanner (Koninklijke Philips Electronics N.V., The Netherlands) was used to record ultrasound images at 13 Hz. The ultrasound transducer was fixed to the lower leg with elastic bandages to visualize first the myotendinous junction, then the mid-belly fascicles of the MG muscle. The Biodex system moved the foot from maximum dorsiflexion to maximum plantarflexion and back at an angular speed of 4°/s. Four trials were performed, two for measuring the muscle excursion and two for measuring the excursion of mid-belly MG fascicles. Torque, ankle angle and EMG data were collected simultaneously with the muscle and fascicle excursions for all trials covering the full range of motion (RoM) of the ankle joint. Absolute fascicle excursion was defined as the total length change of fascicles through the RoM. Relative fascicle excursion was defined as the percentage of absolute fascicle excursion relative to the fascicle length at 90° of ankle flexion. Muscle excursion was defined as the displacement of the myotendinous junction throughout the range of motion.

Prior to analysis of muscle and fascicle excursion, a common RoM for all subjects (patients and controls) was defined as the range between the lowest maximum dorsiflexion to the lowest maximum plantarflexion angle found for any of the subjects. Fascicle lengths from the ultrasound images were measured with Image J image processing software. The ultrasound provided 12 frames per second (that is one frame for every 0.33° of ankle excursion), and fascicle lengths were measured from the mid-belly of the muscle for every second frame throughout the full range of motion for each subject. Fascicle lengths and myotendinous junction displacements were measured for the dorsi and the plantarflexion movements. All fascicle length measurements were synchronized with the corresponding ankle joint angle. Fascicle lengths were analyzed for the full range of motion for each participant, but for comparison of groups, fascicle lengths corresponding to the joint angles within the common range of motion were used. Fascicle excursions for the common range of motion were calculated as the difference in fascicle length between the two ankle angles corresponding to the beginning and the end of the common