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Effects of backward-downhill treadmill training versus manual static plantarflexor stretching on muscle-joint pathology and function in children with spastic Cerebral Palsy

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ABSTRACT

Background: Patients with spastic Cerebral Palsy are prone to equinus deformities, likely affected by short and inextensible plantarflexor muscles. Manual stretching is a popular treatment but its effectiveness concerning joint mobility, muscle-tendon morphometrics and walking function is debated. Eccentric exercise by backward-downhill treadmill training could be a therapeutic alternative for ambulatory patients improving gait and muscle function.

Research question: What are the effects of eccentric training by backward-downhill treadmill training and plantarflexor stretching concerning gait and muscle function in patients with spastic Cerebral Palsy?

Methods: 10 independent ambulators with spastic Cerebral Palsy (12 [SD 4] years old, 2 uni- and 8 bilaterally affected) participated in a randomized crossover-study. One group started with manual static stretching, the other one with backward-downhill treadmill training. Each treatment period lasted 9 weeks (3 sessions per week). Pre and post treatments, 3D gait was assessed during comfortable and during fastest possible walking. Ultrasonography and dynamometry were used to test plantarflexor strength, passive joint flexibility, as well as gastrocnemius morphometrics, stiffness and strain on muscle-tendon and joint level.

Results: When comparing both treatments, backward-downhill treadmill training lead to larger single stance dorsiflexion at comfortable walking speed (+2.9°, P = 0.041) and faster maximally achievable walking velocities (+ 0.10 m/s, P = 0.017). Stretching reduced knee flexion in swing, particularly at faster walking velocities (-5.4°, P = 0.003). Strength, ankle joint flexibility, as well as stiffness on muscle-tendon and joint level were not altered, despite similar increases in passive muscle and fascicle strain with both treatments (P ≤ 0.023).

Significance: Backward-downhill treadmill training can be an effective gait treatment, probably improving co-ordination or reducing dynamic stretch sensitivity. More intense BDTT might be necessary to further alter muscle-tendon properties. Manual static plantarflexor stretching may not be optimal in Cerebral Palsy patients with high ambulatory status.

1. Introduction

Children with spastic Cerebral Palsy (SCP) are constrained by weakness and contractures. The ankle is usually severely affected, showing equinus with progressive loss in passive dorsiflexion [1] and pathologically increased stiffness [2]. This may be neurally mediated [3], but also altered muscle architecture appears influential. For the gastrocnemius, reduced muscle belly [4] and fascicle length [5,6], increased in-vivo sarcomere length [7], a lack of sarcomeres in series [7] or increased intramuscular connective tissue [8] may mechanically reduce its extensibility.

Many interventions aim to increase joint excursion and stretching is very popular but its effectiveness is debated [9]. In healthy subjects, plantarflexor stretching can increase passive dorsiflexion [10–12], arguable by a mechanical muscle response or by solely modifying stretch tolerance [13]. In non-ambulant children with SCP, stretching seems

Abbreviations: SCP, Spastic Cerebral Palsy; BDTT, Backward-downhill treadmill training; MTU, Muscle–tendon unit

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capable of increasing passive dorsiflexion and decreasing joint stiffness, but plausibly without promoting muscle growth [14]. Beyond that, no effects on strength or gait have been reported. Theoretically, more joint flexibility may also improve walking. Yet, in neurally intact subjects, more passive dorsiflexion after stretching was not reflected during gait [16] and intense stretching immediately even induces transient weakness [17]. The functional impact of stretching in SCP-patients remains doubtful.

When focusing on the weakness of SCP-patients, resistance training is typically recommended and increases in strength and muscle size have been partly shown [19]. Supposedly, stronger plantarflexors might also produce more propulsive joint power [20] but strength exercises did not necessarily improve gait in the past [21]. Therefore, joining strength and walking exercises could be promising and the muscles' contractile modes could be pivotal: For healthy subjects, in particular eccentric plantarflexor training increases passive dorsiflexion, decreases resistive torques [22], promotes strength and increases muscle fascicle length [23].

Recently, backward-downhill treadmill training [BDTT] was shown to provide such eccentric fascicle loadings on the gastrocnemius of SCP-patients [24]. Although no longitudinal results on strength, joint stiffness or muscle morphometrics have been reported so far, promisingly, flat-backward walking was shown to increase forward-walking speed in SCP-patients [25]. Eccentric exercise by BDTT could thus be a novel, functional alternative to plantarflexor stretching in ambulatory SCP children.

We therefore compared both interventions, hypothesizing that BDTT will increase Gastrocnemius muscle and fascicle length, promote strength and ankle joint extensibility and decrease passive joint stiffness. Stretching will increase passive dorsiflexion and decrease passive stiffness while showing no signs of muscle growth. In terms of gait, BDTT will enable subjects to walk faster, due to increased strength and increased ankle joint push-off power. We expected that gains in passive dorsiflexion with stretching will not translate to gait.

2. Methods

2.1. Participants

10 participants with SCP (age: 12 [SD 4, range: 5–19] years) were included (4/6 in GMFCS Level I/II). Two were uni- and 8 bilaterally involved. None of them received any Botulinum Toxin within 24 months. Two subjects had surgeries to the femur more than 24 months apart, but none had any surgery to the lower leg. No orthotics were worn during the study to solely assess the interventions' effect.

2.2. Design

A two-treatment, two-period crossover-design was used, thus all 10 subjects received both treatments but were initially randomized so that one group started with stretching, the other one with BDTT (Fig. 1). Two 9 week treatment periods (3 sessions per week) were preceded by a passive run-in and wash-out of 5 weeks. Each period started and ended with an assessment of 3D gait, muscle-joint biomechanics and functional ambulatory mobility. The protocol was ethically approved by the German Physiotherapy Association (2014-08) and informed consent was obtained.

2.3. Static calf stretching

The program consisted of 7 exercises (Fig. 1, details in supplements) referring to Morrel and Lau [43]. Despite the bilateral maneuvers (Fig. 1), exercises were alternately executed with 5 repetitions per leg and end-range positions were held for 20 s. [26]. In unilaterally affected children only the hemiparetic side was treated.

2.4. Backward-downhill treadmill training [BDTT]

An Atlantis treadmill (Heinz Kettler, Ense-Parsit, Germany) and a ceiling-mounted safety harness (h/p/cosmos, Nussdorf-Traunstein, Germany) was used. During the first session, the belt was declined at −10.8% and comfortable backward velocity was determined (0.47 [SD 0.11] m/s). To do so, the belt was set to 50% of comfortable forward walking velocity and if necessary reduced. From week 2–6 onwards, beltspeed was weekly increased by ∼10%. During week 4–6, the decline slope was weekly raised by −1.6%. During the last 2 weeks, the participants had to carry weight belts of 5% and 10% bodyweight to increase the load on the calf. The beltspeed during the final week was 0.64 (SD 0.25) m/s at a decline of −15.6%. 23 min of walking was set as a goal for each session, which could be split into 2–4 bouts (max. 11.5 min), interspersed by seated rest. Subjects should take large steps, maintain an erected posture and limit hand-rail support.

2.5. Assessments

All tests were performed after 1 day of rest. 8 MX Vicon Cameras were used to capture overground barefoot walking at comfortable and at 'as fast as possible' speed. Markers were placed according to the Plug-In gait Model and sampled at 200 Hz. Force data was captured at 1000 Hz via two AMTI force plates. Three to five clean strikes on the force plates could be obtained. All affected legs were investigated. To quantify ambulatory mobility a Timed Up-and-Go test [28] the Gross-Motor-Function-Measure-66 D & E [29] were used.

Due to time constrains, muscle and joint properties were investigated only in the more affected leg (based on passive dorsiflexion) Fig. 2 displays the set-up. Leg markers were place similar to [6] and a hand-held force sensor (Mobie, Sakaimed) was equipped with 3 markers and aligned with the metatarsal heads. A continuous force signal and the surface EMG of the medial Gastrocnemius, Soleus and Tibialis anterior was captured with a Noraxon DTS System. Analog signals were captured at 1000 Hz, marker data at 200 Hz. To analyze gastrocnemius morphometrics, a 7.5 MHz, 8 cm width, linear ultrasound probe (Sonoline Adara, Siemens) was attached with a carbon cast and a cluster of four markers [6]. The probe was once attached over the medial Gastrocnemius muscle-tendon junction (MTJ) and once over the mid-belly [6] and testing was performed twice. Ultrasound videos were captured at 25 Hz. The examiner manually moved the ankle slowly and continuously from plantar flexion to maximal dorsiflexion and back and each stretch lasted a 3 s. count [30]. The ankle was preconditioned with 3 stretches and then 10 oscillations were captured. For plantarflexor strength tests, 5 MVCs were carried out. The ankle was positioned close as possible to neutral and a 'make test' was used, in which the child maximally pushed for 3 sec. (1 min rest). In addition, modified Ashworth Scores for the plantarflexors were determined during physical examination.

2.6. Data analysis

For gait analysis, walking velocity (m/s), step length (cm) and cadence (steps/min) were calculated. For kinematics, mean knee- and dorsiflexion during single stance (°), peak knee- and dorsiflexion (°) and mean vertical toe clearance (cm) during swing phase (= distance of the toe marker to the ground - toe marker height in single stance) were chosen. For kinetics, peak ankle plantarflexion moment (Nm/kg) and power (W/kg) was extracted. During gait the Gastrocnemius muscle-tendon unit (MTU) length was calculated according to Orendurff et al. [31] to extract the peak Gastrocnemius MTU stretch velocity during swing [18].

Concerning muscle-joint biomechanics, marker and force data were bi-directionally low-pass filtered with a 3rd order Butterworth filter at 8 Hz and 5 Hz, respectively. The EMG was rectified and filtered bi-directionally with a 4th order 30 Hz high- and 10 Hz low-pass