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Influence of different degrees of bilateral emulated contractures at the triceps surae on gait kinematics: The difference between gastrocnemius and soleus

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ABSTRACT

Introduction: Ankle plantarflexion contracture results from a permanent shortening of the muscle-tendon complex. It often leads to gait alterations. The objective of this study was to compare the kinematic adaptations of different degrees of contractures and between isolated bilateral gastrocnemius and soleus emulated contractures using an exoskeleton.

Methods: Eight combinations of contractures were emulated bilaterally on 10 asymptomatic participants using an exoskeleton that was able to emulate different degrees of contracture of gastrocnemius (biarticular muscle) and soleus (monoarticular muscle), corresponding at 0°, 10°, 20°, and 30° ankle plantarflexion contracture (knee-flexed and knee-extended). Range of motion was limited by ropes attached for soleus on heel and below the knee and for gastrocnemius on heel and above the knee. A gait analysis session was performed to evaluate the effect of these different emulated contractures on the Gait Profile Score, walking speed and gait kinematics.

Results: Gastrocnemius and soleus contractures influence gait kinematics, with an increase of the Gait Profile Score. Significant differences were found in the kinematics of the ankles, knees and hips. Contractures of soleus cause a more important decrease in the range of motion at the ankle than the same degree of gastrocnemius contractures. Gastrocnemius contractures cause greater knee flexion (during the stance phase) and hip flexion (during all the gait cycle) than the same level of soleus contractures.

Conclusion: These results can support the interpretation of the Clinical Gait Analysis data by providing a better understanding of the effect of isolate contracture of soleus and gastrocnemius on gait kinematics.

1. Introduction

Contracture is defined as the inability of a joint to move through its full range of motion and an excessive resistance during passive mobilization of this joint. The expression "soft tissue contracture" is often used to define contracture because the structures involved are mainly muscles, tendons, aponeurosis, and, but also ligaments and capsules, for which the extensibility may have been limited and the stiffness increased [1]. Contracture is involved in many neurological conditions (e.g., cerebral palsy, multiple sclerosis, spinal cord injury, stroke) and can impair walking [2–4]. Among contractures, ankle plantarflexion contracture (APC) is one of the most common causes of gait deviations in many conditions (cerebral palsy [5], neuropathy [6] and muscular dystrophy [7]) and can lead to other complications (e.g., metatarsalgia, neuropathic ulceration, plantar fasciitis and Charcot midfoot breakdown) [8]. Gait with APC is characterized by an absence of a first rocker (which enables a heel-toe pattern at initial contact [9]) and a limitation of dorsiflexion during swing [10], causing an inadequate foot clearance [11]. APC is caused by a contracture of the triceps surae that is composed of two muscles: gastrocnemius (a biarticular muscle which passes through on the ankle and knee joints) and soleus (a monoarticular muscle which passes through only on the ankle joint) [12,13].

To rectify gait deviations, it is necessary to understand gait deviations; and to distinguish between primary deviations (directly resulting from the pathology) and secondary deviations (compensatory mechanisms) [14]. Clinicians need to understand the influence of contracture of individual muscle to evaluate its biomechanical impact in terms of primary deviations and secondary deviations (compensations).

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Different approaches have been used to elucidate the effect of APC on gait and are described in a systematic review [15]. These approaches include a comparison of APC in patients and matched healthy subjects (pathological contracture versus healthy controls) [16,17], comparison of patient's gait before and after treating APC (pre- and post-kinematics after surgical muscle lengthening) [18,19], and emulation of contracture(s) with an exoskeleton or an orthosis (simulated contracture versus healthy controls) [10,13,20–22].

The systematic review by Attias et al. [15] showed that it is difficult to isolate a contracture because it is always associated with other impairments, such as spasticity or muscle weakness [11,23]. A mixed of several impairments makes it difficult to establish a clear relationship between the impairments and the gait deviations. The isolation of a specific impairment (contracture) would permit to better establish this relationship. Two previous studies have compared the effects of gastrocnemius and soleus contractures on gait [13,24] by emulating these contractures unilaterally with an exoskeleton. They found that on the ipsilateral side, soleus contracture mainly influenced the ankle angle increasing ankle plantarflexion during gait, whereas gastrocnemius contractures influenced the ankle and knee angles (increase of ankle plantarflexion but less than soleus associated with increase knee flexion during gait). However, no studies have investigated the effect of gastrocnemius and soleus contractures bilaterally whereas equinus is commonly a bilateral gait impairment [25]. In cerebral palsy patient, equinus is the 4th gait impairment for diplegic patient [26].

Hence, with the support of an exoskeleton to emulate contractures, the aim of this study was 1) to compare the kinematic adaptations of varying degrees of emulated contracture for the isolated bilateral gastrocnemius (biarticular muscle) and soleus (monoarticular muscle) 2) to compare the kinematic adaptations between isolated bilateral gastrocnemius (biarticular muscle) and soleus (monoarticular muscle) at the same degree of emulated contracture.

2. Method

2.1. Participants

Ten healthy participants (6 females, 4 males) aged 27.9 years ± 3.2, with a height of 1.71 m ± 0.09 and weight of 64.0 kg ± 10.3 and no known neurologic or orthopedic problems, participated in this study. Ethical approval and the participant's informed consent were obtained prior to data collection.

2.2. Gait evaluation

The participants were equipped with 34 reflective markers aligned to anatomical and technical landmarks on the head, trunk and pelvis and bilaterally on the arms, thighs, shanks and feet according to the full-body Plug-in-Gait model [27]. All participants were requested to walk along a 10-m walkway at a spontaneous, self-selected speed and were equipped with the MIkE exoskeleton (Fig. 1a), which the characteristics and reliability were reported in a previous study [22]. The main components of the exoskeleton are listed below in order to allow the understanding of this article. The exoskeleton was built to bilaterally embrace the pelvis, thighs, and shanks with plastic cuffs, with modified shoes that include attachment points. Contractures were induced by ropes attached to rings (see Fig. 1b). The characteristics of the ropes were chosen to avoid a sudden stop and to mimic a progressive increase of stiffness at the limit of the ROM as reported for muscle contractures. Because muscle insertion points are usually deep and multiple, only the main muscle lines of action were used to define the ropes attached to the rings [22]. In addition, the exoskeleton was built to induce unilateral and bilateral contractures in relation to the following main muscles or muscle groups affected by contractures in the lower body and identified in the literature: hamstring, iliopsoas, hip adductor, rectus femoris, gastrocnemius, soleus, tibialis posterior and peroneus [22]. A cut was made in the plastic cuffs to enable reflective markers to be placed directly on the skin as required for Clinical Gait Analysis (CGA). CGA is a clinical examination enabling to get quantitative information on the patient's gait including generally video, spatio-temporal, kinematic, kinetic and EMG data [28]. This exoskeleton was used in the current study to emulate gastrocnemius and soleus contractures bilaterally. Each participant also walked without the exoskeleton for a control condition (CC). Kinematic recordings were performed with a twelve-camera motion analysis system (Oqus 7+, Qualisys, Göteborg, Sweden). A minimum of five gait cycles was averaged to produce a single angular displacement of the pelvis segments, hip, knee, and ankle joints.

To emulate contractures, we selected four degrees of contracture, 0°, 10°, 20°, and 30° of plantarflexion on both muscles (soleus and gastrocnemius), based on the study by Drefus et al. [29] that simulated ankle equinus but with an ankle foot orthosis not allowing the differentiation of soleus and gastrocnemius. The 0° level is considered to be a mild contracture and the 30° level is considered to be a severe contracture according to our experience. To set the contractures, the examiner adjusted the rope length of the exoskeleton in the position used for standard physical examination [30] and controlled it with a goniometer (Fig. 1b). For soleus (monoarticular muscle), the knee was flexed at 90° (with the aim to set the contracture following the clinical examination procedure [30]), and the plantarflexion of the ankle was adjusted according to the desired degree of contracture. The adjustment of the soleus contracture with the exoskeleton did not affect the knee because the attachment points for soleus emulation were on heel and below the knee respecting muscle insertions (Fig. 1b). For gastrocnemius (biarticular muscles), the knee was extended at 0° and the same procedure was used. The knee was considered for the adjustment of the gastrocnemius contracture because the attachment points for gastrocnemius emulation were on heel and above the knee respecting muscle insertions (Fig. 1b).

2.3. Data analysis and statistics

As non parametric tests are used, median and 1st and 3rd quartile are reported: median (1st quartile; 3rd quartile).

First, to evaluate whether there were significant differences in the different degrees of contracture for each muscle (gastrocnemius and soleus from 0° to 30° plantarflexion), a Kruskal–Wallis test and post hoc with Bonferroni correction were performed on the Gait Profile Score (GPS) [31] and walking speed (right and left sides together). CC and different degrees of emulated contracture (0°, 10°, 20° and 30° plantarflexion contractures) were compared with Wilcoxon tests considering Bonferroni correction.

Second, to evaluate the kinematic differences between gastrocnemius and soleus contractures, a Wilcoxon test with Bonferroni correction was performed between the same degrees of contracture in walking speed, GPS and fourteen kinematic parameters per side in the sagittal plane: range of motion (ROM) and mean position for pelvis angle; ROM and minimum flexion for hip angle; flexion at initial contact (IC), minimum in stance and ROM during the gait cycle for knee angles; dorsiflexion at initial contact (IC), maximum in stance and ROM during the gait cycle for ankle angles; and mean foot progression angle. MATLAB R2012b (MathWorks, Natick, Massachusetts, USA), the open-source Biomechanical ToolKit package for MATLAB [32] and SPSS Version 23 (IBM, Armonk, NY, USA) were used for data analysis, statistics and figure creation.

3. Results

The comparisons between CC and different degrees of emulated contracture are shown in Table 1 for walking speed, GPS and kinematic parameters. Fig. 2 depicts differences between each degree of contracture and CC for respectively gastrocnemius and soleus concerning