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Assessing Mechanism of Gait Improvement in Cerebral Palsy Patients Undergoing Hamstring Lengthening Surgery Using Musculoskeletal Modeling

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***Abstract*— Cerebral Palsy (CP) is a permanent movement disorder seen in early childhood causing crouch gait. Such crouch gait is often ascribed to excessive knee flexion due to shortness or slowness of knee flexors (i.e., hamstrings). While hamstring lengthening surgery is a well-established intervention for CP patients with impaired knee flexion, a subset of patients exhibits an improved knee movement post-operatively despite pre-operatively having normal muscle length and velocity. In this study, we examined the post-operative gait improvements of patients with such normal hamstrings and calculated changes of muscle length and velocity using musculoskeletal modeling. Our results indicate that the improvement is not related to surgery induced changes in muscle length or velocity. This remarkable finding can be explained based on our previous studies in CP patients, which showed that epimuscular myofascial force transmission can change hamstring muscles' mechanics to become more representative of the pathological condition in the knee: the intervention may have relaxed the pre-operatively overly tight epimuscular connective structures and led to an isometric position shift of hamstrings to distal positions.**

Keywords*— *Cerebral palsy, Spasticity, Muscle shortness, Muscle lengthening velocity, Hamstring lengthening surgery, Musculoskeletal modelling, OpenSim, Epimuscular myofascial force transmission.

I. Introduction

Cerebral Palsy (CP) is a permanent movement disorder seen in early childhood causing difficulty in walking [1]. Excessive knee flexion causing crouch gait is a common impairment and often corrected by lengthening hamstrings through remedial surgery. Crouch gait, presumed to originate from contracture (i.e., shortness) and/or spasticity (i.e., slowness in lengthening) of affected muscles, is attenuated by surgically increasing muscle length or its velocity. However, a third group of patients exists who have neither short, nor slow hamstrings pre-operatively. In literature, numerous cases report such CP patients, unaffected by short or slow (hence normal) hamstrings pre-operatively that can undergo hamstring lengthening surgery and still benefitted from this intervention (e.g., 2). However, objective assessments are lacking, and the mechanism of this improvement is unclear. In order to fill this gap, we aim at investigating the post-operative gait improvement of CP patients with normal hamstrings. Accordingly, this study was designed to assess changes in the muscle tendon unit (MTU) length and lengthening velocity of the hamstrings of such patients using musculoskeletal modeling.

II. Methods

8 limbs of 4 CP patients (mean age: 13.75, SD: 1.707) that underwent hamstring lengthening surgery were analyzed. Pre- and post-surgical knee and hip joint angles and angular velocities were compared to age-matched typically developing (TD) children (14 limbs of 7 participants) to assess gait improvement. Pre- and post-operative gait deviation index (GDI) was computed as a metric to evaluate changes in total gait. Changes in MTU length and lengthening velocity of hamstrings were computed using OpenSim [3] gait_2392 model.

III. Results

After surgery the average knee angle decreased significantly ($p<0.05$) in the initial contact, terminal stance, and terminal swing phases (by 0-3%, 28-43%, 95-100%, respectively), while the mean knee angular velocity did decrease significantly ($p<0.05$) in the mid-swing phase (82%). However, no significant changes were observed in hip angles or GDI. In addition, no significant changes in hamstring MTU and lengthening velocities were found (Figures 1-4.).

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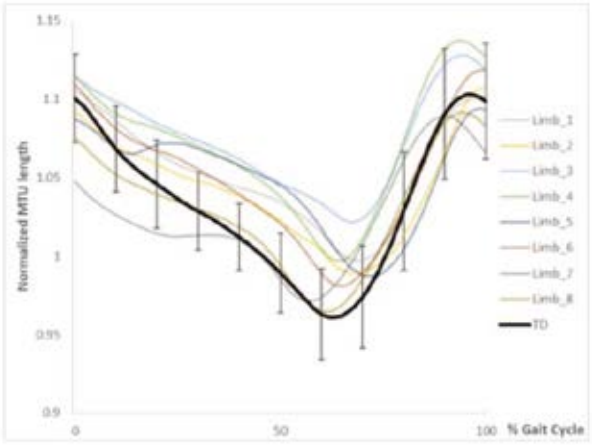


Figure 1. Pre-operative semimembranosus MTU lengths of CP patients compared to that of typically developing (TD) group for a gait cycle. All peak MTU lengths are in the range of 2 standard deviation of peak mean MTU length of TD, indicating semimembranosus muscles of all patients are not short (i.e., normal).

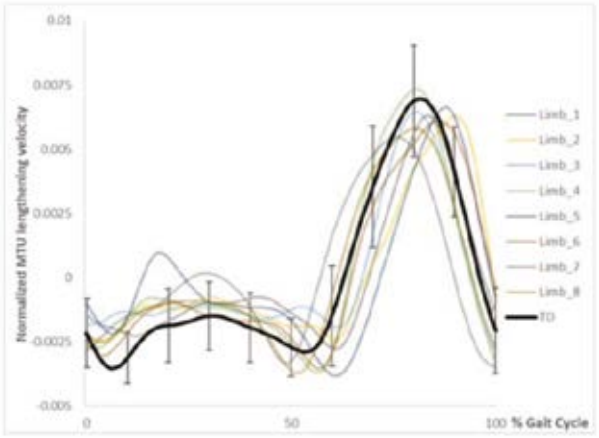
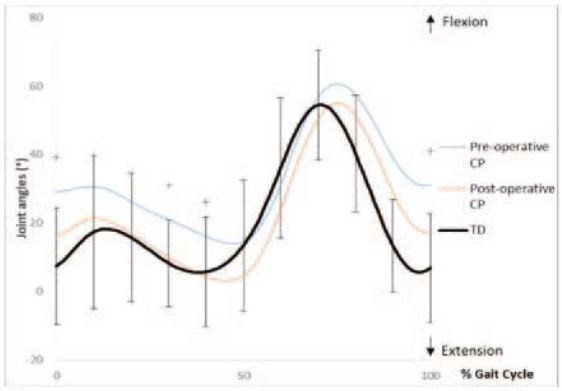


Figure 2. Pre-operative semimembranosus MTU lengthening velocity of CP patients compared to that of typically developing (TD) group. All peak lengthening velocities are within 2 standard deviations of the peak mean velocity of TD. Consequently, the semimembranosus muscles of the patients were classified as "not slow".

(a)



(b)

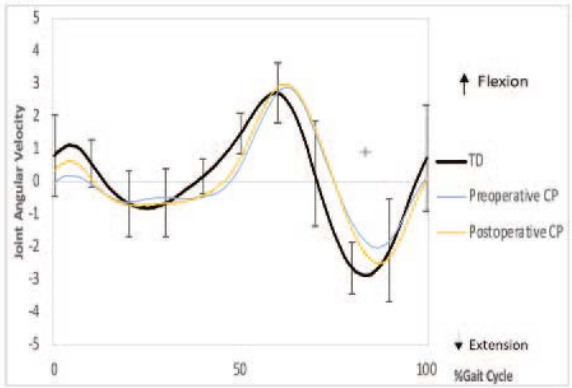


Figure 3. Pre- and post-operative a) joint angles and b) joint angular velocities of CP patients compared to that of TD group. In the sagittal plane, the average knee angle decreases significantly in the initial contact, terminal stance, and terminal swing phases (0-3%, 28-43%, 95-100%, respectively) ($p<0.05$), while the mean knee angular velocity shows a significant decrease in the mid-swing phase (82%) ($p<0.05$).

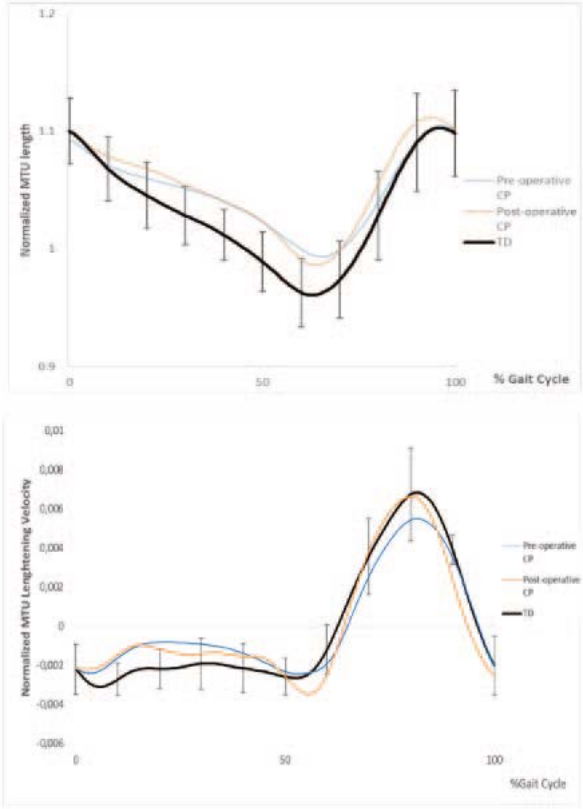


Figure 4. Calculated normalized mean MTU lengths (above panel) and lengthening velocities (below panel) of CP patients compared to that of TD group.

IV. Discussion

The findings show that the post-operative improvement in the knee angle was achieved without any changes in muscle length, and lengthening velocity of hamstrings. Moreover, pre-operative excessive knee flexion decreased without any negative effects on hip movement or gait overall. Previous intraoperative studies showed that epimuscular myofascial force transmission (EMFT) (4) has sizable effects in CP, leading to an elevated knee flexion force in hamstring muscles (5) and contributing to limited joint movement (6). Based on those, the present findings showing improved knee joint movement after remedial surgery and without altered muscle lengths are ascribable to an isometric position shift of hamstrings to distal positions. This can be explained by the surgical relaxation of pre-operatively overly tight epimuscular structures (7). Recognizing that gait improvement after surgery can vary among patients due to differences in epimuscular tightness and neuromuscular function is important. Further, kinetic musculoskeletal analysis can enhance our understanding of these differences and the role of epimuscular myofascial force transmission (EMFT), enabling the development of more tailored rehabilitation strategies for optimal recovery.

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