The Use of a Platform for Dynamic Simulation of Movement: Application to Balance Recovery

Misagh Mansouri, Ashley E. Clark and Jeffrey A. Reinbolt

University of Tennessee, Knoxville, TN, USA
email: misagh@utk.edu, web: http://rrg.utk.edu

INTRODUCTION

Numerical simulations play an important role in solving complex engineering problems and have the potential to revolutionize medical decision making and treatment strategies. Whereas experimental data from clinical studies aids in the evaluation and treatment of movement abnormalities as seen in children with cerebral palsy, it remains difficult to elucidate mechanisms responsible for these abnormal movements. Simulation offers a means of integrating experimental data, anatomical models, and dynamic principles to thoroughly understand human movement and perform "what if" studies for optimal treatment planning.

Stiff-knee gait is a prevalent movement disorder among children with cerebral palsy that could benefit from simulations. Rectus femoris transfer surgery, a common treatment for stiff-knee gait, reattaches the distal tendon of this two-joint muscle to a new site such as the sartorius insertion on the tibia. Biarticular muscles, such as the rectus femoris, play a unique role in motor control. As a biarticular muscle, rectus femoris may offer unrecognized benefits to maintain balance.

In this study, we used a simulation platform including an OpenSim and MATLAB interface [1] to perform forward dynamic simulations and applied the closed-loop control capability of this interface to investigate the influence of biarticular muscles on balance recovery. Our goal was to use the rapid model-based design and control of the interface by implementing the previously developed stretch-reflex controller [2] in MATLAB. We then employed the controller to maintain the whole-body center of mass (CoM) displacements in response to support-surface translations for simulations of preoperative, unilateral, and bilateral rectus femoris transferred models.

METHODS

Musculoskeletal Models and Platform Dynamics

A three-dimensional musculoskeletal model with 92 muscle-tendon actuators and 23 degrees of freedom was created in OpenSim (Fig. 1). The model was scaled to represent the size of the patient using previously collected gait analysis data [3, 4]. A pre-surgical simulation (Fig. 1a) was altered to represent surgical transfer of the rectus femoris to the sartorius for both a unilateral (Fig. 1b) and bilateral case [4]. The foot-ground interface was modeled using elastic foundation contact and the feet were based on cadaver foot geometry [5].

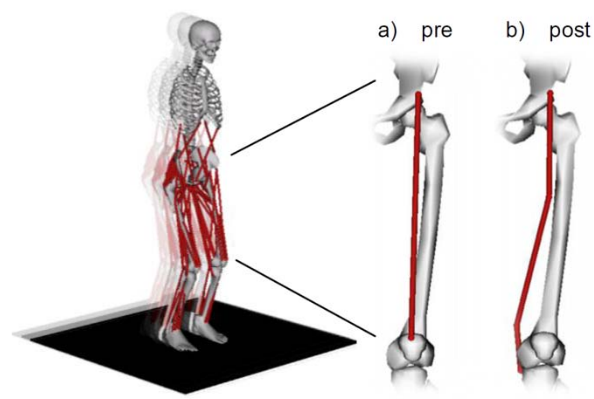

Figure 1: Musculoskeletal model of a patient with cerebral palsy on an anteriorly translating support surface, and biarticular attachments for the rectus femoris muscle (a) pre- and (b) post-surgical transfer to the sartorius.

Stretch-Reflex Controller

The mechanism used to maintain balance was based on a muscle stretch-reflex control model [6]. The closed-loop stretch–reflex controller was implemented in Simulink as an "Embedded MATLAB Function" (Fig. 2). Simulink used the interface to integrate state derivatives of the musculoskeletal model and generates new states based on the feedback controls. Each simulation included 0.25 seconds of quiet standing, 0.35 seconds of support-surface translation (6 cm in the anterior and posterior directions, with a peak velocity of 23 cm/s [2]). Controller gains for the stretch-reflex were found using MATLAB's Optimization Toolbox to keep the CoM position above the base of support. This controller is analogous (but not identical) to monosynaptic reflexes and afferent mechanisms (e.g., muscle spindles and Golgi tendon organs) responsible for lower-level motor control, and should not be affected following surgical transfer; thus, the same stretch-reflex controller was used for all model simulations.

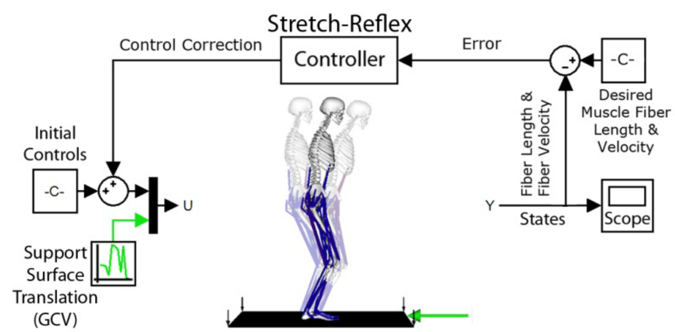

Figure 2: Closed-loop Simulink model of balance recovery using a muscle stretch-reflex controller. The controller uses the muscle's fiber length and velocity to generate a control correction to maintain the CoM position above the base of support.

RESULTS AND DISCUSSION

The closed-loop stretch-reflex controller was developed in Simulink using MATLAB's rapid design and control capabilities to demonstrate the application of a platform for dynamic simulation to investigate the influence of biarticular muscles on balance recovery. The platform not only made the procedure of implementing the previously written C++ code [3] easier but also provided access to all MATLAB toolboxes and numerical solvers.

The CoM had various displacements in the anterior-posterior directions relative to support-surface translations for preoperative, unilateral, and bilateral tendon transfers (Fig. 3). For the anterior translation, all three cases recovered balance; however, the preoperative model recovered faster than the post-surgical ones. For the posterior translation, the post-surgical models maintained balance while the pre-surgical one did not.

Patient-specific simulation is a powerful tool to investigate the role of rectus femoris tendon transfer in control tasks. Our results suggest that rectus femoris tendon transfer will change the balance recovery, illustrating the biomechanical uniqueness that biarticular muscles have in motor control. Future study is necessary to include higher-level motor control and investigate other treatments (e.g., hamstrings lengthening) for other movement abnormalities (e.g., crouch gait).

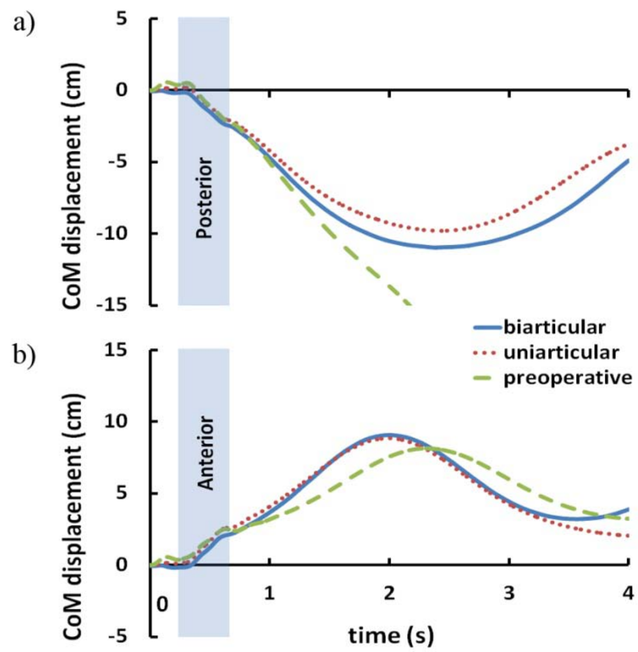

Figure 3: Center of mass (CoM) displacements relative to the support-surface translating (a) posterior and (b) anterior for simulations of preoperative, unilateral, and bilateral tendon transfer. The shaded regions highlight the duration of support-surface translations.

REFERENCES

1. Mansouri M, et al. *Proc. of ASB10*, Providence, RI, 2010.
2. Clark AE, et al. *Proc. of BMES11*, Hartford,CT, 2011.
3. Goldberg SR, et al. *J Biomech* **39**, 689-698, 2006.
4. Fox MD, et al. *J Biomech* **42**, 614-619, 2009.
5. Erdemir A, et al. *J Biomech. Eng.* **131(9),** 094502, 2009.
6. Feng CJ, et al. *IEEE Proc.* **20-5**:2317-20. 1998.