

7-2015

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## eCommons Citation

Kinney, Allison and Fregly, Benjamin J., "Development of a Muscle Model Parameter Calibration Method via Passive Muscle Force Minimization" (2015). *Mechanical and Aerospace Engineering Faculty Publications*. Paper 25.

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## *Computer Simulation*

SS-0026

### DEVELOPMENT OF A MUSCLE MODEL PARAMETER CALIBRATION METHOD VIA PASSIVE MUSCLE FORCE MINIMIZATION

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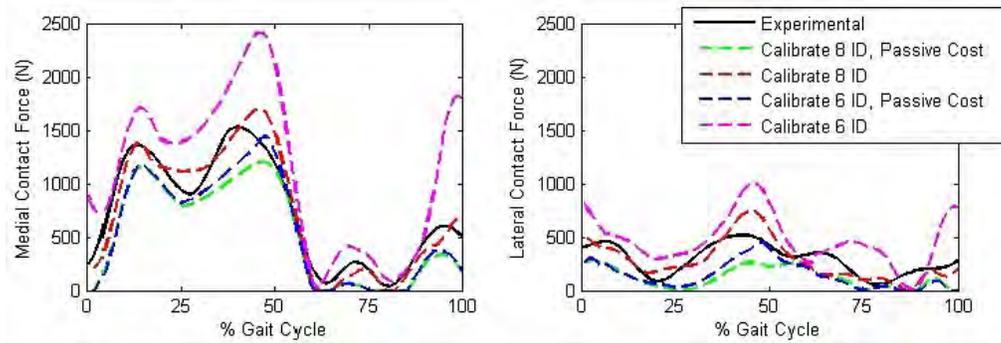
**Introduction and Objectives:** Computational predictions of subject-specific muscle and knee joint contact forces during walking may improve individual rehabilitation treatment design. Such predictions depend directly on specified model parameter values. However, model parameters are difficult to measure non-invasively. Methods for muscle model parameter calibration have been developed previously [1]. However, it is currently unknown how the musculoskeletal system chooses muscle model parameter values. Previous studies have hypothesized that muscles avoid injury during walking by generating little passive force and operating in the ascending region of the force-length curve [2]. This hypothesis suggests that muscle model parameter values may be selected by the body to minimize passive force. The purpose of this study was to develop a method for calibrating muscle model parameter values and muscle moment arms during walking via minimization of passive force.

**Methods:** Experimental data were collected from a subject with a force-measuring knee implant [3-4]. A subject-specific model was created in OpenSim [5]. Muscle geometry and muscle model parameter values were transferred from a generic OpenSim model [6]. Inverse kinematics and inverse dynamics analyses were performed for one gait cycle of walking. All muscles were modeled with a rigid tendon muscle model. A reserve actuator was included at each joint. A two-level optimization-based calibration method was developed. The outer level optimization calibrated muscle model parameter values and muscle moment arms with the goal of obtaining a solution with all muscle activations between 0 and 1. Muscle model parameter values were calibrated by optimizing scale factors for tendon slack length and optimal fiber length relative to the generic OpenSim model. Muscle moment arms were calibrated by optimizing offsets that allowed deviations in the moment arms. The inner level optimization optimized the muscle and reserve actuator activations while minimizing the activation and matching the experimental inverse dynamics loads. Four calibrations were performed with the two-level optimization-based approach. During two optimizations, calibration was performed by tracking 8 inverse dynamics loads (3 hip, 3 knee, and 2 ankle) using the in vivo knee contact force data. During the remaining optimizations, calibration was performed by tracking 6 inverse dynamics loads (3 hip, 1 knee, 2 ankle). Two optimizations were performed where passive muscle force was minimized by the outer level optimization. Medial and lateral contact forces were predicted for each optimization and compared with the experimental knee contact forces.

**Results:** Optimizations that minimized passive muscle force increased all tendon slack length and optimal fiber length values (average: 1.2, range: 1.0 – 1.4) and predicted smaller medial and lateral contact forces relative to the experimental measurements (Figure 1). Optimizations that did not minimize passive muscle force changed tendon slack length and optimal fiber length values minimally (average: 1.0, range: 0.8 – 1.2) and predicted medial and lateral contact forces larger than the experimental knee contact forces (Figure 1). Muscle moment arm offsets for all optimizations were generally

small (average: 0.2 cm) but varied across muscles (range: 0 – 2.6 cm). Calibration with 6 inverse dynamics loads and no passive force minimization predicted the least accurate medial and lateral forces (Table 1).

Figure:



Caption: Medial and lateral contact force predictions

**Conclusion:** Calibration of muscle model parameter values and muscle moment arms was influenced by passive muscle force minimization. Minimization of passive muscle force caused muscles to operate only in the ascending region of the force-length curve and eliminated passive force in all muscles. Optimizations that did not minimize passive force allowed large passive force generation in some muscles. Calibration without in vivo knee contact force data and passive force minimization represents the common approach used by researchers when contact force data are not available. The high contact force predictions from this approach suggest that excessive passive muscle force may contribute to the general tendency to overpredict knee contact forces.

Table:

	Medial Contact Force		Lateral Contact Force	
	RMS E	R <sup>2</sup>	RMS E	R <sup>2</sup>
Calibrate 8 ID, Passive Cost	242	0.76	191	-0.84
Calibrate 8 ID	133	0.93	104	0.45
Calibrate 6 ID, Passive Cost	219	0.81	167	-0.41
Calibrate 6 ID	500	-0.02	253	-2.2

Caption: RMSE and R<sup>2</sup> values for medial and lateral contact force predictions

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**Disclosure of Interest:** None Declared