UNCERTAINTY, VALIDATION & SENSITIVITY ANALYSES OF THE OPENSIM MUSCLE MODEL FOR PRE- AND POST-FLIGHT STRENGTH PREDICTIONS

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INTRODUCTION: The Digital Astronaut Project (DAP) is developing computational models to inform exercise countermeasure development and to predict in-space performance capabilities. Integrated biomechanical and exercise device models are being developed to determine biomechanical loading [1-2]. The DAP muscle adaptation model, a computational model of spaceflight induced muscle atrophy, is being developed in conjunction with the integrated models [3]. OpenSim's built-in muscle model is the starting point for the DAP muscle adaptation model. Uncertainty, validation and sensitivity analyses used to determine OpenSim's capabilities and limitations in modeling the effects of spaceflight on muscle performance are described and discussed.

METHODS: Isometric and isokinetic plantar-flexion exercise simulations were constructed based upon plantar-flexion strength measurement exercises performed on a torque velocity dynamometer [4]. The simulations were performed using the OpenSim Full Body Model [5]. Muscle excitation patterns were calculated with computed muscle control analyses, using kinematics files to describe ankle joint angles and applied force files to describe the prescribed torques at the talus. Lower leg musculotendon forces were calculated with forward dynamics analyses, using the muscle excitation patterns as input. The musculotendon forces were multiplied to their corresponding moment arms and the muscle moments were summed to obtain simulated ankle torques. For the uncertainty analyses, the simulated ankle moments were compared to the prescribed ankle torques and the percent error was calculated. The validation analyses compared simulated ankle torque with pre- and post-flight experimental ankle torque measurements [4]. Default OpenSim muscle model parameters were used in the preflight cases. For the post-flight cases, three parameters, maximum isometric force, maximum shortening velocity and the force-velocity shape factor, were adjusted based on spaceflight data [4;6-7]. Sensitivity analyses were performed to determine the model parameters which caused the most variation in model output when perturbed from their default values.

RESULTS: The percent error between the simulated and prescribed isometric ankle torques ranged from 1.3 to 3.3%, depending on ankle angle and prescribed torque. For an isokinetic velocity of 45°/s, the mean(standard deviation) percent error between the simulated and prescribed ankle torque was 4.2(5.1)% ; for 90°/s it was 4.8(4.0)%. These errors reflect the OpenSim calculation error and provide a bound on the necessary difference between two conditions before a case can be made that the difference is due to the phenomenon being modeled. The percent error between the measured and simulated preflight isometric and isokinetic torques were similar to the range observed in the uncertainty analyses. However, the percent error between the measured and simulated isometric post-flight ankle torque ranged between 3.9 and 8.7%. The mean percent error between the measured and simulated post-flight ankle torque was 11.2% for an isokinetic velocity of 30°/s. The mean error increased with velocity, to an unacceptably high value of 71% at 300°/s. The soleus and gastrocnemius tendon slack lengths were the most sensitive OpenSim muscle parameters in the isometric sensitivity analysis. They accounted for 25 and 21% of the variation in response, respectively. The maximum shortening velocity of several of the lower leg muscles were sensitive parameters within the isokinetic sensitivity analyses.

CONCLUSIONS AND FUTURE WORK: The percent error between the simulated and measured torque for the post-flight isometric and isokinetic validation cases was higher than the OpenSim calculation error. In order to reduce the error, more work is needed in determining the necessary adjustments of the OpenSim muscle parameters for correctly modeling spaceflight induced changes. Focus will be placed on the tendon slack length and the maximum shortening velocity parameters, since these were identified as sensitive parameters in the sensitivity analyses.

REFERENCES: [1] Thompson et al., Poster #1085, *IWS 2013*, Galveston, TX, [2] Newby et al., Poster #1167, *IWS 2013*, Galveston, TX, [3] Lewandowski et al., Poster #1122, *IWS 2013*, Galveston, TX, [4] Trappe et al. (2009) *J Appl Physiol*, 106(4) 1159-68. [5] Hamner et al. (2010) *J Biomech* 43(14) 2709-16. [6] Fitts et al. (2010) *J Physiol*, 588(18) 3567-92. [7] Gopalakrishnan et al. (2010) *Aviat Space Environ Med* 81(2) 91-102.