Development of Subject-Specific Musculoskeletal Models to Predict Quadriceps Strength

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Introduction: Clinicians and researchers use musculoskeletal models to better understand strength loss or gain mechanisms. The accuracy of the models is critical to advancing the knowledge of these mechanisms. Knee flexor moments from a previous model[1] accurately resembled experimental data, however knee extensor predictions appeared unrealistic due to higher moment arms and optimal fiber lengths peaking early in the range of motion. *In vivo* knee joint kinematics,[2] improved quadriceps attachments,[3] and more realistic muscle paths may rectify this issue.

Methods: Original kinematics and axes[1] were replaced with those based on *in-vivo* motion,[2] quadriceps muscle attachments were modified,[3] and via points were added to reflect more realistic muscle paths for this modified generic model. Model moment arms were qualitatively compared to literature experimental data.[4] Scaled subject-specific models were created from anthropometric measurements and ultrasound data (four male, four female, 21.7±1.04 yrs, 1.7±0.095 m, and 70.2±9.61 kg). Passive fascicle lengths were compared to model predicted passive fiber lengths and isometric knee extensor moments were compared to model predicted values. The East Carolina University Institutional Review Board approved this study.

Results and Discussion: Quadriceps moment arms of the current generic model were qualitatively better matched to experimental data[4] than those from the previous model[1] (Figure 1). Passive fiber lengths from the current generic model and scaled models matched well with ultrasound based measurements of fascicle lengths. These results indicated the geometry of the knee extensors were reasonably accurate.

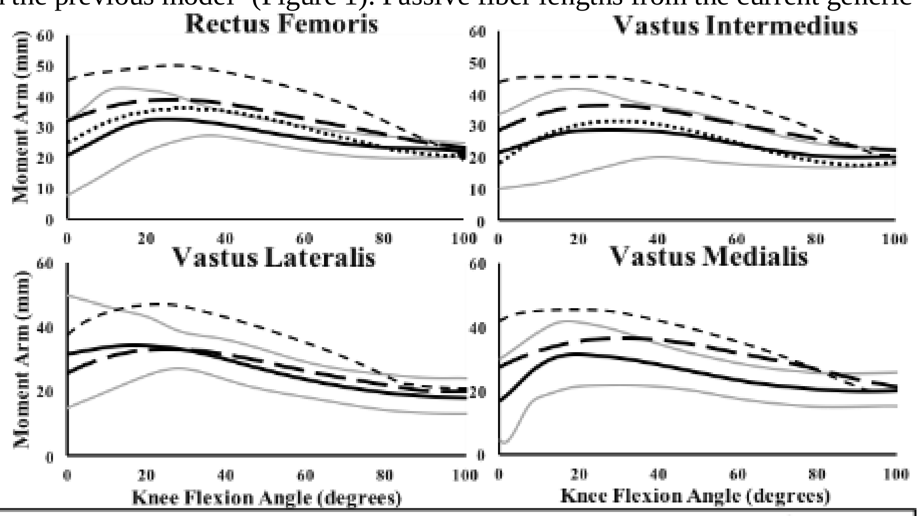

Figure 1- Quadriceps muscles moment arms from models by Arnold et al[1] (— — -), Blemker et al[6] (••••••), and the current model (—— ——) compared to mean (━━━━) and SD (———) of experimental data from Buford et al.[4]

Total isometric knee extensor moment peaked later in the current generic model than in previous model,[1] leading to realistic passive force production. However, mean total isometric knee extensor moments from the scaled models still peaked earlier in the range of motion compared to experimental measurements. This was possibly due to muscle force-producing properties. The vasti originally were measured in a slack position,[5] potentially leading to inaccuracies in normalized fiber lengths and excursions (0.74 – 1.29FL, 0.55). Setting operating ranges towards the ascending/plateau regions (0.62 – 1.08FL, 0.46) of the force-length curve altered the moment curve shape, but failed to enhance comparisons to experimental data.

Conclusions: Modifications to the original lower extremity model[1] resulted in quadriceps moment arm and fiber length predictions that more closely aligned with experimental data,[4] however isometric knee extensor moments remained only moderately accurate. Further investigation should focus on force producing properties and fiber behavior not captured by the lumped-parameter model.

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References:

[1]Arnold EM., *Ann Biomed Eng*, 2009, 38(2), 269-279.
[2] Li G, *Journ Biomed Eng*, 2007, 129(6), 937.
[3] Becker I, *Clin Anat*, 2010, 23, 575-585.
[4] Buford W, *IEEE Trans Rehab Eng*, 1997, 5(4), 367-379.
[5] Ward SR, *Clin Orthop Relat Res*, 2009, 467, 1074-1082.
[6] Blemker SS., *Journ Biomech*, 2006, 39(8), 1383-1391.