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DEVELOPMENT OF AN OPENSIM SHOULDER MODEL FOR MANUAL WHEELCHAIR USERS WITH TETRAPLEGIA

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INTRODUCTION

Extended manual wheelchair use has been associated with repetitive strain injuries in the shoulder and has been identified as a contributing factor to upper limb pain experienced by manual wheelchair users with spinal cord injury (SCI) [1]. Due to the nature of their SCI, individuals with *tetraplegia* (formerly *quadriplegia*) may be at an even greater risk for developing shoulder injuries because they often have only partial innervation of their shoulder, scapular, and thoracohumeral muscles [2].

Attempts to understand shoulder injury during wheelchair propulsion have included investigations of electromoyography (EMG) and kinematics. Mulroy et al. [3] utilized fine wire EMG to identify the shoulder muscles at greatest risk for fatigue, by examining muscle activation and recruitment patterns, during wheelchair propulsion. Newsam et al. [4] investigated three-dimensional upper extremity motion generated by manual wheelchair users with tetraplegia and paraplegia. Expanding upon their work, Dubowsky et al. [5] developed the first computer graphics-based model for wheelchair propulsion. This unique model was an active visual representation of the movement, as opposed to passive plots of shoulder kinematics and muscle activity, from which movement patterns had to be interpreted. Unfortunately, it included surface EMG as inputs and was developed for manual wheelchair users with paraplegia.

Our aim was to build upon these previous studies to develop an OpenSim [6] shoulder model for wheelchair propulsion in individuals with tetraplegia. OpenSim is open-source software that incorporates kinematic, kinetic, and EMG data as inputs to generate a dynamic simulation. The novelty of our model is that it is the first model to include fine wire EMG and an upper limb joint coordinate system in accordance with the International Society of Biomechanics standards [7]. Our model could potentially impact the clinical diagnosis, cause and treatment of shoulder injury for manual wheelchair users with tetraplegia.

METHODS

When developing a model in OpenSim, one can choose between two general options: 1) use an existing model as is or 2) create/edit a model (Figure 1). Since none of the models in the OpenSim neuromuscular biomechanics library were made specifically for SCI or wheelchair propulsion, we decided to edit existing library models. We decided to combine components of the Head and Neck Model [8] with the Stanford VA Upper Extremity (Stanford) Model [9] to create an initial model with the kinematic features we desired (Figure 2).

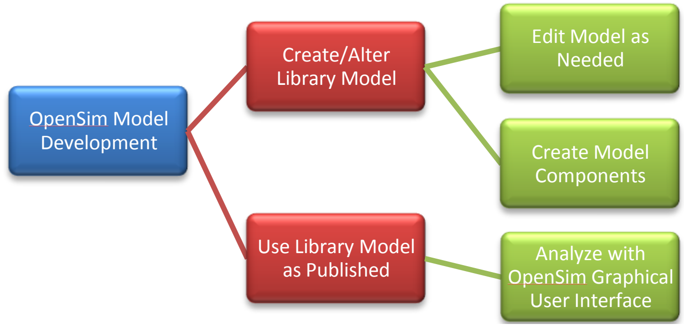

Figure 1. General options for OpenSim model development.

To create a dynamic version of our model, we began with the OpenSim Arm26 example model, a planar model consisting of a head, upper limb, and trunk actuated by the biceps, triceps, and brachialis muscles. Instead of selecting the default components of interest to develop the model, as we did with our first model, we added complexity to this simple model to create our OpenSim shoulder model for wheelchair propulsion. We added degrees of freedom and segments with mass and moments of inertia to the model as well as additional muscles.

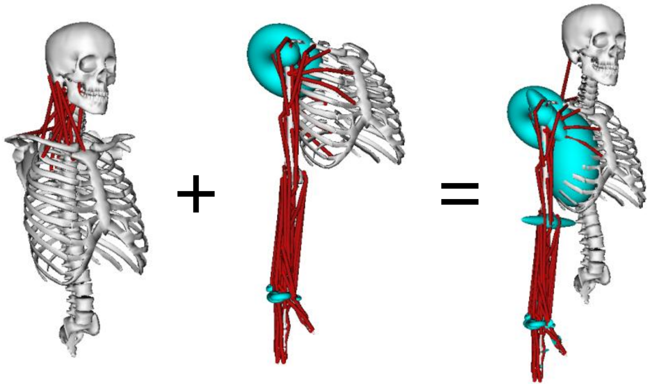

Figure 2. Model components of combined Head and Neck Model [8] and Stanford VA Upper Extremity Model [9].

RESULTS AND DISCUSSION

During the course of developing a shoulder model for wheelchair propulsion in individuals with tetraplegia, we have developed two models: one kinematic-only model and one dynamic model. Our dynamic model consists of a head, upper limb, and trunk with muscles crossing the shoulder and elbow consistent with the Stanford Model [9] (Figure 3). To simulate wheelchair propulsion, the shoulder joint kinematics remained consistent with the Stanford Model and also included degrees of freedom at the elbow and wrist. The remaining upper limb muscles that cross the neck and wrist are currently being added to the model. Fine wire EMG data were recorded for thirteen upper limb muscles, which will be included: pectoralis major, subscapularis, serratus anterior, upper trapezius, middle trapezius, anterior deltoid, middle deltoid, posterior deltoid, supraspinatus, infraspinatus, rhomboid major, biceps, and triceps.

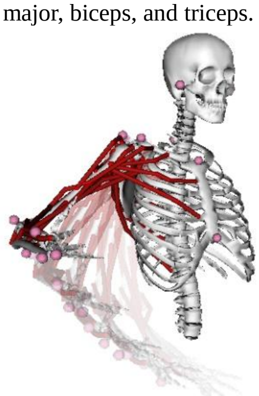

Figure 3. Current dynamic shoulder model with 7 degrees of freedom and 26 muscle-tendon actuators (*wrapping surfaces not shown*).

In order to develop an optimal shoulder model for wheelchair propulsion in SCI, accuracy, reliability, and repeatability must be considered. As we strive to develop an optimal model, we realize that our model is a work in progress. Our proposed model has gone through two iterations. The main difference between the first and second model is that the first model is kinematic-only and the second model is suitable for dynamic simulations. A kinematic model only allows a user to track movement without regard for the forces/moments producing the movement. To understand the relationship between shoulder injury and wheelchair propulsion, we need to determine the muscle forces that contribute to the movement. A dynamic model not only produces a movement but includes the forces and moments responsible for that movement. Our shoulder model was developed to track and analyze complex movements and pathology of wheelchair propulsion in SCI. The approach used to develop our model enhances the clinical utility of the model so that it may potentially impact shoulder injury biomechanics in manual wheelchair users with tetraplegia.

CONCLUSIONS

We have developed a shoulder model for manual wheelchair users with tetraplegia in order to understand the relationship between wheelchair propulsion and shoulder injury in this unique population. There are challenges faced when developing models, especially models that include the complex architecture of the shoulder. Further customizing the model to the pathology of tetraplegia creates an additional challenge. To address those challenges, our current modeling approach is to add complexity to a simpler model. From this approach, we have a model that includes the superficial and deep muscles of the shoulder, and additional degrees of freedom in the upper limb joints.

ACKNOWLEDGMENTS

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