DEVELOPMENT OF A COMPUTATIONAL SHOULDER MODEL USING ISB MARKER SET AND FINE-WIRE EMG FOR SIMULATING WHEELCHAIR PROPULSION

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INTRODUCTION

Individuals with spinal cord injury (SCI) who use manual wheelchairs are at risk for developing shoulder injuries. Computational biomechanical models have been utilized to investigate shoulder biomechanics during propulsion to elucidate potential causes of shoulder pain and injury. However, none of the current models are specific to individuals with tetraplegia, who may be at an even greater risk due to partial innervation of the shoulder muscle complexes. The goal of this project is to develop a computational model of the shoulder to simulate wheelchair propulsion in individuals with tetraplegia. The model is being developed with OpenSim, open-source software that allows for the integration of kinematic, kinetic, and fine wire electromyographic (EMG) data to drive a neuromuscular biomechanical model. The marker set for the model is based on the International Society of Biomechanics (ISB) recommendations for the upper limb. This paper discusses the development of our model, as it has undergone two iterations, thus far.

METHODS

OpenSim is open-source software that allows users to develop neuromuscular models by modifying existing library models [1]. The first version of our model was developed by modifying and combining: i) Upper Extremity Model by Holzbaur and colleagues [2] and ii) Head and Neck Model by Vasavada and colleagues [3]. Although our model consists of a head, trunk, and upper limb, a major limitation is that it did not accurately reflect wheelchair propulsion in individuals with SCI. Also, the combination model was developed from models that are purely descriptive, based on kinematics and cannot be utilized for forward simulations.

An updated and second version of our model is currently being developed using the Arm26 Model - a planar arm model. Although limitations to this model include: i) no degrees of freedom (DOF) at the shoulder and wrist; ii) no upper limb muscles; iii) simplified movement of the shoulder joint, OpenSim allows for modifications to the models so that these limitations can adequately be addressed. The open-source feature of OpenSim allows for the addition of DOF to the upper limb joints as well as the upper limb musculature, via model source code modifications. A custom shoulder joint may be added so that the shoulder moves along the ribcage. By basing our model on a simple, planar model and including the features relevant to the research questions, we expect to develop a model that has the potential to be more accurate for simulating the movement of the shoulder during wheelchair propulsion.

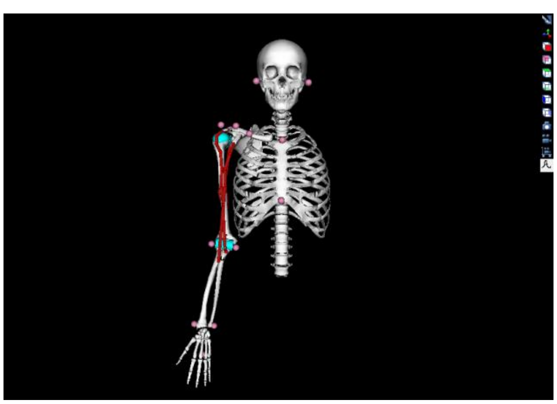
In order to obtain accurate results, it is not only critical to have an adequate model, but an appropriate marker set is necessary as well. The ISB has established a set of standards for defining joint coordinate systems for the shoulder, elbow, wrist and hand [4]. One of the earliest biomechanical models was developed by Mulroy and colleagues [5]; and a limitation of their model was that they used their own joint coordinate system to compute wheelchair propulsion biomechanics. This made it challenging for other researchers to compare their results to the method used by Mulroy and colleagues. The ISB standards were proposed to provide all researchers with an accepted joint coordinate system to facilitate comparison of results across studies. The marker set used for our model reflects the anatomical ISB system. Since our model is for tetraplegia, we made a modification to the marker placement. We placed a marker on T3 instead of T8 on the thoracic segment of the spine.

A more contemporary biomechanical model of wheelchair propulsion was the computational model developed by Dubowsky and colleagues [6]. The power of their computational model was the ability to see the propulsion patterns generated by the subjects. However, the model was developed with surface EMG. The limitations to incorporating surface EMG in their model was that their muscle activity results were less accurate and they were unable to obtain muscle activity data from the deeper muscles of the shoulder complex. As an alternative, we will incorporate fine-wire EMG in our model. By utilizing OpenSim to incorporate kinematic, kinetic, and fine-wire EMG data, we expect to obtain a model that generates wheelchair propulsion in real-time.

RESULTS AND DISCUSSION

Having a proper marker set up is not only crucial for biomechanical computations, but for scaling the computational model to each subject in the study. Data from 21 individuals with tetraplegia collected during trials of manual wheelchair propulsion will serve as inputs to the model. One marker placement file will be created for the model in OpenSim (Fig. 1) and a model will be scaled for each individual participant.

A



B

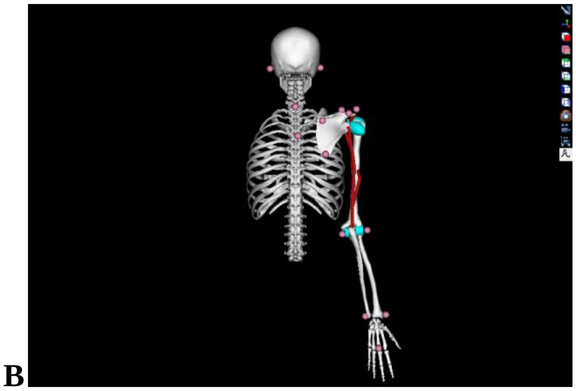


Figure 1: Front view (A) and back view (B) of model with markers based on marker placement protocol.

CONCLUSIONS

Our research is extremely novel to shoulder biomechanics and wheelchair propulsion. Accuracy, reliability, and repeatability are critical for us to understand the relationship between manual wheelchair propulsion and upper limb pain/injury. Therefore, our model has undergone two iterations as we strive to develop an optimal model. The proposed model may undergo even more iterations until an optimal model is achieved. Once developed, we anticipate that our model could have a strong clinical impact in the diagnosis, cause and treatment of shoulder injury for individuals with tetraplegia who are manual wheelchair users.

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