Personalization of Novel Shoulder Model Leads to Improved Experimental Marker Matching Over Glenoid or Acromion Centered Scapular Rotation

Claire V. Hammond[1], Heath B. Henninger[2], Benjamin J. Fregly[1], Jonathan A. Gustafson[3],
[1]Rice University, Houston, TX. [2]University of Utah, Salt Lake City, UT. [3]Rush University Medical Center, Chicago, IL.
cvhammond@rice.edu

DISCLOSURES: None

INTRODUCTION: One in two adults will suffer a debilitating shoulder injury, chronic or acute, in their lifetime. The existing treatments for shoulder injuries result in highly variable post-treatment shoulder function. Efforts to develop personalized neuromusculoskeletal models offer the ability to investigate "what if" scenarios while accounting for functional, morphological, and neural control differences between individuals. A major debate in the biomechanics community is the relative importance of defining the joint origin for the scapulothoracic joint. The ISB standards[1] describe the acromioclavicular joint as the center of rotation of the scapula. Some research groups have used the glenoid center—only obtained through imaging or regression methods—as the joint center for the scapula. The objective of this work was to employ a novel Joint Model Personalization (JMP) tool, part of the Neuromusculoskeletal Modeling (NMSM) Pipeline, combined with a new shoulder model to investigate the effects of scapular joint tracking with different joint center definitions.

METHODS: Experimental Data for this work consisted of patient-specific, high-resolution MR-images and biplane fluoroscopy kinematic data of the shoulder from an open-source repository[2]. Briefly, subject-specific 3D reconstructions of the scapula and humerus were created from MR-images and anatomical landmarks were generated for the scapula (glenoid center, GC; inferior angle, IA; trigonum spinae, TS; posterolateral acromion, PLA; acromioclavicular joint, AC) and the humerus (humeral head center, HHC; elbow lateral epicondyle, LE, and medial epicondyle, ME) using published methods[3]. Model-based markerless tracking was used with the biplane fluoroscopic system to generate accurate kinematics of the scapulothoracic joint and glenohumeral joint following standard Euler decomposition techniques to generate joint angles[1]. Activities assessed included a combination of weighted and unweighted overhead tasks during shoulder flexion, scaption, abduction, and internal/external humeral rotation (n=8 tasks).

Computational Model. A shoulder model was developed, composed of standard joint types (e.g., hinge / ball-and-socket), for easy personalization by established methods of model personalization—a major limitation of existing models. First, a subject-specific model using model geometry described above was developed within the OpenSim modeling platform (v4.4). The scapulothoracic joint was modeled with 5 degrees of freedom (DoF), 2 rotations about a spherical coordinate system, 1 translation about an intermediate body, and 2 last rotations about a scapula-based rotation center. The clavicle was modeled as a rotational joint with 2 DoF and attached at the AC marker of the patient. The glenohumeral joint was modeled as a 3 DoF ball-and-socket joint.

Three shoulder models were personalized using JMP. This tool personalizes joint parameters (positions/orientations), scales bodies and moves markers based on user-provided settings to minimize the normalized mean squared distance between experimental and model markers on the bodies of interest. Scapula rotation center definitions varied between models as follows: fixed at the GC, fixed at the AC, free to move through personalization. All eight overhead tasks were used to personalize the shoulder models. After personalization, the normalized mean squared distance between experimental and model markers were calculated for each of the three rotation joint center cases (GC, AC, and personalized).

RESULTS: On average across all tasks assessed (Figure 1), using the personalized rotational joint center of the scapula found by JMP led to greater accuracy (avg error = 1.1mm) compared to the personalized shoulder model with a scapula rotation center fixed at the AC joint (28% worse; avg error = 1.5mm) and the personalized shoulder model with a scapula rotation center fixed at the GC joint (15% worse; avg error = 1.3mm).

DISCUSSION: The purpose of this study was to determine the effect of different scapula joint center definitions on experimental marker matching based on a novel shoulder model. A secondary goal was to illustrate the use of JMP to personalize a shoulder model that closely matches experimental marker data. The results of this study indicate that a personalized free scapula joint center definition better describes the motion of the scapula through a variety of movements. Both the GC model and the AC model matched experimental marker data worse, although the GC joint center definition matched better than the AC joint definition. More research is needed to determine the relevance of the differences in average marker distance errors identified in this study and their potential clinical implications.

SIGNIFICANCE/CLINICAL RELEVANCE: Personalization of a shoulder model through JMP facilitated the discovery of insights into the ability to describe experimental scapular motion through fixed AC and fixed GC joint centers as compared to a freely moving joint center. These findings may help improve the descriptions of scapular motion and provide insights for a consensus description and model of the scapula and shoulder complex.

REFERENCES: [1] Wu et al., J Biomech, 2005. [2] Kolz et al., J Biomech, 2021. [3] Kolz et al., Gait Posture, 2020.
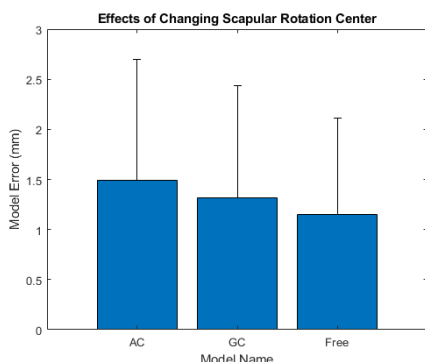
IMAGES AND TABLES:

Figure 1: shows the average marker error across all motions for each personalized model.

Table 1: shows the average marker error by marker for each personalized model.

Average Marker Error by Marker and Model (mm)

Markers	GC	IA	TS	PLA	AC	HHC	LE	ME
AC center	0.6	2.7	1.7	1.5	1.7	1.7	0.8	0.8
GC center	0.8	2.8	1.5	1.1	1.5	1.1	0.7	0.7
Free center	0.6	2.2	1.4	0.9	1.3	1.1	0.6	0.6