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Towards a Musculoskeletal Shoulder Model Depicting Glenohumeral Translations Considering Bony, Ligamentous and Muscular Stability Constraints

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INTRODUCTION

Glenohumeral (GH) stability is a delicate interplay between bony congruence, muscle contraction and ligamentous or capsular stability. The bony congruence confines the translational kinematics. While muscles provide stability to the humeral head in midrange motion, ligamentous and further connective tissue structures constrain the joint at endrange motion [1]. An imbalance can cause pathologies such as shoulder instability, osteoarthritis or rotator cuff tears, however, the underlying effect is not yet well understood.

The few shoulder models implementing GH translation define GH joint stiffness based on a reverse engineering approach of measured humeral head translations [2]. A musculoskeletal shoulder model applying biomechanical properties of bony, muscular and ligamentous structures would enable further investigation of pathological mechanisms.

We aimed to develop an advanced musculoskeletal shoulder model, considering bony contact forces, muscle active and passive stability and ligament mechanical properties, to calculate GH translations using force-dependent kinematics (FDK) [3].

METHODS

Motion capture data of 15 participants performing three 0° to 30° abduction-adduction cycles (VICON, UK) with 0 to 3kg handheld weight were incorporated into a musculoskeletal model of the right shoulder (Anybody 7.3, repository AMMR v.2.3.1) for subject scaling and to drive subject-specific motion [4]. Segmented glenoid, labrum and humeral head contact surfaces were developed from MRI images. GH and coracohumeral ligament stiffness, slack length and insertion sites were defined generically. The Hill muscle model was calibrated to subject size. Based on the acting joint forces and constraints, GH translations were calculated in each time step using FDK[3]. Resulting GH translations were compared between abduction-adduction cycles with different handheld weights and to existing measured inferior-superior translations from dynamic fluoroscopy imaging of the same subjects.

RESULTS

At 0kg handheld weight, seven shoulder models presented an anterosuperior GH escape and three an initial inferior drop. The remaining six models converged, and mean inferior-superior translations decreased from 3.5 to 1.8mm for 0 to 3kg handheld weight, however, did not match the 1.6mm and 0.8mm measured in patients with 0 and 2kg handheld weight, respectively (Figure 1).

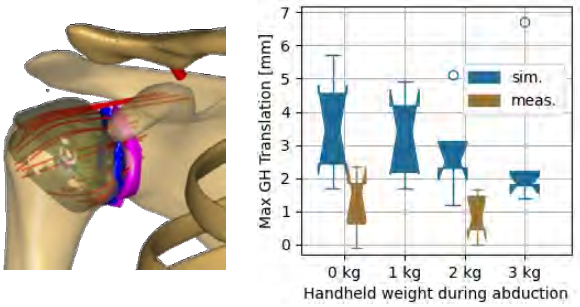

Figure 1 *(A) FDK Shoulder model and (b) Comparison of measured (meas.) and simulated (sim.)* inferior-superior GH translations

DISCUSSION AND CONCLUSIONS

This work presents a novel pipeline for more physiological shoulder modelling. GH translations calculated with this model are significantly higher than measured values especially at lighter handheld weights, indicating that muscular stabilisation is currently underrepresented. Enforced muscle recruitment with greater handheld weights led to the required stabilisation effect of the GH joint. Future work will focus on emphasizing the muscular recruitment for joint stability to subsequently further apply this model to assess pathological shoulders.

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