A THREE-DIMENSIONAL MODEL OF THE SUPRASPINATUS MUSCLE

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INTRODUCTION

The rotator cuff is an important group of muscles that dynamically stabilizes the glenohumeral joint. Each of these muscles has a complex and specialized structure. For example, the supraspinatus muscle wraps around several structures, has a broad attachment site, and has varied fiber orientation within the muscle. How do these features of the muscle's structure influence its function?

Previous models typically represented this muscle as a collection of line segments (van der Helm, 1994). This approach employs methods such as geometric primitives to represent wrapping around underlying structures and assumes all fibers within the muscle function uniformly. The purpose of this project is to create a three-dimensional finite element model of the supraspinatus muscle that represents its complex fiber geometry and the mechanics of its interaction with surrounding structures, allowing for exploration of the relationship between fiber geometry and fiber behavior.

METHODS

A 3D finite element model (Fig. 1C) of the supraspinatus muscle and tendon was developed from magnetic resonance images. The muscle and tendon were modeled using a hyperelastic, transversely isotropic constitutive relationship between stress and strain. The representation for the 3D fiber orientations (Fig. 1B) within the muscle was created by morphing a fiber template to the finite element mesh (Blemker and Delp, 2005).

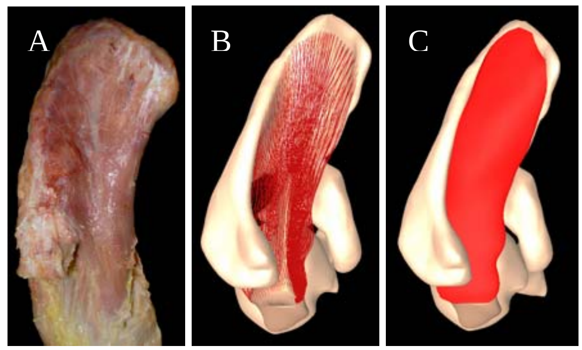

Figure 1: Superior view of cadaver supraspinatus muscle (A), fiber representation of the model (B), and finite element model with fibers and mesh(C)

Finite element simulations were run in NIKE3D (Puso et al., 2001), an implicit finite element solver. The bones were assumed to be triangulated rigid bodies and a penalty formulation was used for resolving bone-muscle and bone-tendon contact. Input boundary conditions were specified bone displacements and muscle activation. Regression equations (de Groot and Brand, 2001) were used to prescribe the motions of the scapula and clavicle as functions of humerus orientation.

The model was tested by comparisons of its fiber moment arms with experimental data (Langenderfer et al., 2006) and with moment arms computed using a model of the upper extremity that represents supraspinatus as a set of line segments (Holzbaur et al., 2005).

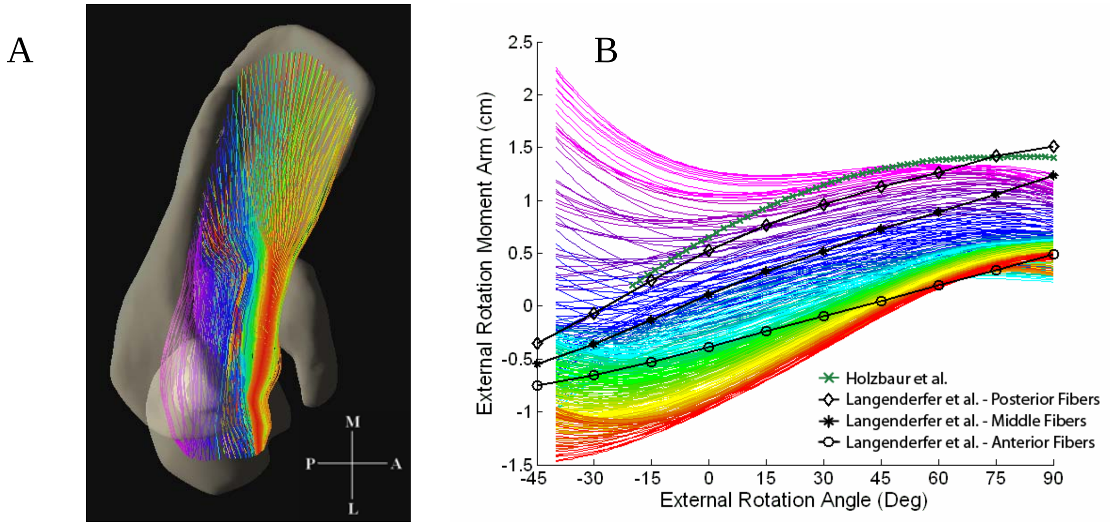

Figure 2: Fiber trajectories within the supraspinatus muscle (A) and external rotation moment arms as a function of external rotation angle (B). External rotation moment arm curves were determined with the joint at 10 degrees of glenohumeral elevation and compared to experimental data (Langenderfer et al., 2006) and a model of shoulder muscles (Holzbaur et al., 2005). Consistent coloring of fibers shown in (A) and fiber moment arm curves shown in (B) illustrates how fiber moment arms vary spatially throughout the muscle.

RESULTS AND DISCUSSION

External rotation moment arms were found to vary primarily with the anterior-posterior location of the fibers. The anterior and middle fibers (red, yellow and green fibers in Fig. 2) are internal rotators at internally rotated positions but switch to weak external rotators at external rotation angles greater than 50 degrees. The posterior fibers (purple fibers) are external rotators at all values of rotation angle. The 3D model predicted a broad range of moment arms across the individual fibers especially at internally rotated positions.

Fiber geometry influences the external moment produced in different regions of the supraspinatus muscle. Calculated moment arms and lengths indicate that the fibers experience different excursions and do not behave uniformly. Modeling that includes this level of detail will give improved understanding of rotator cuff mechanics by more accurately calculating muscle behavior and allowing for a more detailed understanding of structure and function.

REFERENCES

Blemker, S.S., Delp, S.L. (2005). *Annals of Biomed. Eng.*, **33**, 661-673(5).

de Groot, J.H., Brand, R. (2001). *Clin. Biomech.*, **16**, 735-743(9).

Holzbaur et al. (2005). *Annals of Biomed. Eng.*, **33**, 829-840(6).

Langenderfer et al. (2006). *J. Ortho. Res.*, **24**, 1737-1744(8).

Puso et al. (2002). *Lawrence Livermore Natl. Labs Tech. Report*, UCRLMA-105268.

van der Helm, F.C.T. (1994). *J.Biomech.*. **27**, 551-569(5).

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