STRAINS IN THE BICEPS BRACHII DURING DYNAMIC ELBOW FLEXION SHOW CONCENTRIC, ECCENTRIC AND ISOMETRIC BEHAVIOR SIMULTANEOUSLY

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INTRODUCTION

Skeletal muscles are complex, dynamic structures whose primary function is the application of force to their bony origins and insertions. There are various models of muscle function which generally assume a uniform behavior from origin to insertion during force generation. It is understood that skeletal muscles deform non-homogeneously but how is not clear. Changes in these internal mechanics could be important to understanding normal function and dysfunction with fatigue, pathology or aging (Pappas *et al.*, 2002). We have developed methods to quantify internal muscle mechanics using cine phase-contrast magnetic resonance imaging (CPC-MRI) and post-processing algorithms (Zhou and Novotny, 2006) and have described Lagrangian finite strains during cyclic motion in the supraspinatus and biceps brachii. The purpose of this paper is to define the overall uniformity of deformation within the normal biceps brachii during elbow flexion by observing frequency distributions of the finite Lagrangian and principal strain magnitudes. Areas within the muscle may be acting concentrically, eccentrically and isometrically simultaneously during overall contraction. The assumption of muscle incompressibility can also be assessed.

METHODS

MRI images were collected for 8 normal subjects (one female, seven males; age 24-34). Scans were performed with a clinical scanner (GE 1.5 Tesla, Milwaukee, WI). MRI images through the mid-plane of the biceps brachii (34×34 cm^2 FOV, 256×128, TR=24ms, flip angle=30°, V_{ENC} = 10cm/s) were collected during cyclic flexion-extension of the elbow at 24 equally spaced time frames. The arm moved from full extension to ~120° flexion. A resistive force was applied through an elastic band to a maximum of ~5% MVIC. We derived finite strain fields from the CPC-MRI data. The first frame at full extension and minimal resistive force was the zero strain reference. Longitudinal strain (SY), transverse strain (SX), shear strain (SXY), maximum principal strain (PS1), minimum principal strain (PS2) and maximum in-plane shear strain (PSXY) were calculated for 0.2×0.2 pixel triangular meshes at each frame for the distal half of the muscle. The percent areas of each muscle at various incremental ranges of strain magnitude were calculated and frequency distributions across the 24 time frames created and averaged across subjects.

RESULTS AND DISCUSSION

Mean frequency distributions of percent area at various strain increments are seen in Figures 1-4 for PS2 and PS1, averaged across subjects, at 150° and 120° flexion during muscle shortening. Due to space limitations, other strains will not be discussed. Contraction velocity was highest at 150° and near zero at 120° as the forearm slowed to change direction. Resistance force was intermediate at 150° and highest at 120°. In Fig. 1, PS2 values were generally negative showing shortening, with a peak around -15%, and a negative maximum near -40%. Surprisingly, portions showed positive PS2, or pure elongation, up to 25%. In Fig. 2, the distribution shifted to higher values of negative strain with a peak near -30%. There were lower standard deviations and less percent area with positive strains. For PS1 in Fig. 3, the distribution showed a peak near 20%, which was expected if the material was behaving incompressibly. A long tail to the distribution, though, extended upward from the peak to values of 250%. In Fig. 4, the peak area decreased in magnitude and shifted to more positive values, and the percent area at 50 to 100% strain increased. Standard deviations decreased also. Thus, as the overall muscle contracted, areas within the muscle underwent very complicated deformations, some being stretched eccentrically, some straining very little and some exhibiting Poisson's values much different than 0.5.

SUMMARY/CONCLUSIONS

These results indicate the possibility of compartmentalized muscle function within the biceps brachii, even during this simple motion and relatively low loads and velocities. Non-uniformity could be a function of non-uniform activation, material properties or fiber type and contractibility. Future work should focus on how these distributions change with fatigue, pathology or ageing, and aim to describe mechanisms. Other muscles' behaviors will be investigated. Results will aid in building models of internal muscle mechanics.

REFERENCES

Pappas, G.P. et al. (2002) *J Appl Physiol*, 92, 2381-2389.

Zhou H, Novotny JE (2006) *J Magn Reson Imaging*, Jan; 25(1):175-84.

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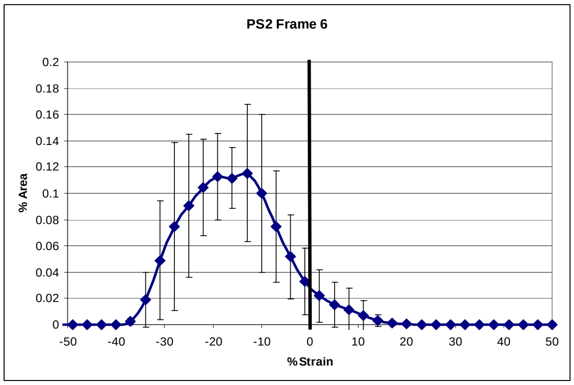

Figure 1. Mean percent area at various PS2 values over 3% strain ranges for 150°elbow flexion (with SD).

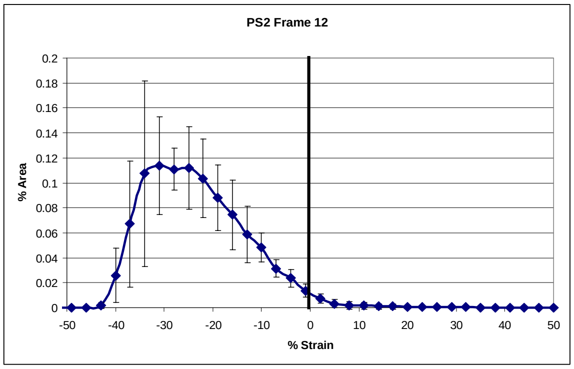

Figure 2. Mean percent area at various PS2 values over 3% strain ranges for 120°elbow flexion (with SD).

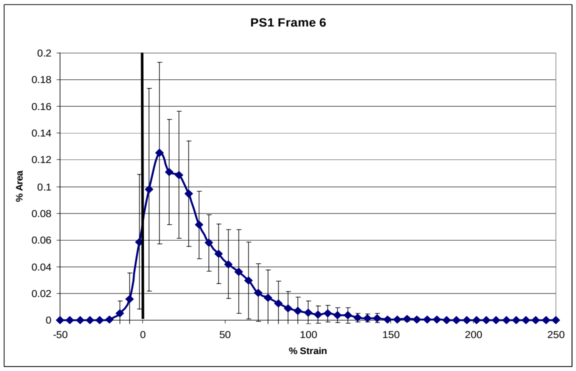

Figure 3. Mean percent area at various PS1 values over 6% strain ranges for 150°elbow flexion (with SD).

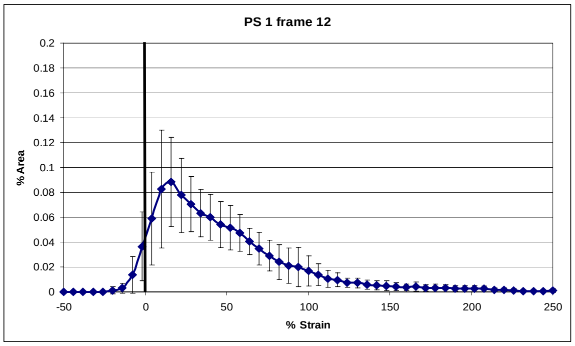

Figure 4. Mean percent area at various PS1 values over 6% strain ranges for 120°elbow flexion (with SD).