Quantifying Dynamic Muscle Lengths and Moment Arms of Musculoskeletal Joints Using FEBio Studio: A Demonstration in the Glenohumeral Joint

Breydon J Hardy[1], Steve A. Maas[1], Brittany Percin[1,2], K. Bo Foreman[1], Peyton L. King[1], Heath B. Henninger[1]
[1]University of Utah, Salt Lake City, UT, [2]University of California San Diego, San Diego, CA
breydon.hardy@utah.edu

Disclosures: Breydon J Hardy (N), Steve A. Maas (N), Brittany Percin (N), K. Bo Foreman (N), Peyton L. King (N), Heath B. Henninger (5 – Stryker, Smith+Nephew)

INTRODUCTION: Muscle moment arms are the perpendicular distance from a muscle's line of action to a joint axis of rotation and help quantify a muscle's ability to generate torque and assess its role in creating motion. They are especially useful in quantifying changes after reverse total shoulder arthroplasty (rTSA), where transposing the glenohumeral ball and socket changes muscle lengths, lines of action, and moment arms. Existing computational approaches have often relied on generic anatomy, static postures, or simplified wrapping models, limiting their ability to capture patient-specific changes, particularly after surgical interventions. Most previous computational studies have reported only the net moment arm magnitude, which indicates a muscle's overall ability to generate any rotation but does not reveal how that ability translates to physiologic planes of motion. Decomposing moment arms into anatomic coordinate system components allows quantification of a muscle's relative contributions to specific motions (e.g., elevation, axial rotation), offering greater functional insight, especially in joints like the shoulder with extreme range of motion. This study integrates a fully dynamic, 3D method for computing muscle lengths and moment arms into the open-source FEBio Studio platform, enabling evaluation of subject-specific anatomy and kinematics.

METHODS: A verification/validation model with known geometry (sphere radius 30 mm) and prescribed rotations was used to ensure the accuracy of the method. A clinical use case compared the pre- and post-rTSA subscapularis lengths and moment arms in one 62-year-old male patient during scapular plane abduction (IRB #71782). Patient-specific three-dimensional anatomy and kinematic data gathered from computed tomography scans and biplane fluoroscopy were imported into FEBio Studio. Muscle origins and insertions were defined, and muscle lines of action were calculated either directly or with deformable, compliant muscle sheets that guided the muscle lines to wrap around bony contours (Figure 1). The sheets were modeled with sliding elastic contact interfaces to prevent bone penetration. An iterative smoothing algorithm adjusted line nodes to minimize path length while avoiding bony penetration. Pre-tensioning was applied to the muscle sheets to prevent buckling during dynamic motion. Departure points and unit force direction vectors were exported for each frame of motion, and dynamic moment arms were computed in MATLAB by projecting onto anatomic coordinate system axes. Moment arms were decomposed into elevation/depression, plane of elevation, and axial rotation components relative to the scapular coordinate system. Muscle length was calculated directly in FEBio Studio.

RESULTS SECTION: In the validation model, unconstrained lines had small muscle length errors (<4%) but produced large deviations in decomposed moment arms (45–227%) compared to constrained lines. Muscle sheets reduced errors to <7.2% and produced expected physiologic moment arm profiles. In the rTSA case, subscapularis muscle lengths at rest increased up to 25% post-operatively (Figure 2). Moment arms shifted in magnitude and direction: anterior plane of elevation components decreased markedly, the superior line performed effectively the same elevation function, whereas the bisector and inferior line created progressively increasing depression moment arms (Figure 3), and internal rotation moment arms were reduced at rest but increased near peak motion. These patterns reflected altered departure point locations and changes in line-of-action orientation due to placement of the rTSA implant.

DISCUSSION: Quantifying muscle lengths and moment arms is critical for understanding a muscle's efficacy and role in joint function. Our method provides an open-source framework to assess these factors using 3D morphology and kinematics. The verification/validation model confirmed the accuracy of the method by reproducing known solutions, while the rTSA case illustrated its clinical utility for quantifying how surgical changes to bone geometry affect muscle function. The rTSA was shown to substantially alter subscapularis length and moment arm components, with potential implications for post-operative function, stability, and rehabilitation planning. While sheets may still buckle with complex anatomy, strategic use of constrained and unconstrained lines can balance accuracy and stability of the computational solutions. The demonstration cases provide a template for others to build upon in the study of health, pathology, and surgical interventions and their roles in musculoskeletal function.

SIGNIFICANCE/CLINICAL RELEVANCE: Our open-source implementation enables researchers and clinicians to quantify dynamic muscle lengths and moment arms from subject-specific morphology and kinematics. Such analysis can inform implant design, surgical planning, and rehabilitation strategies in shoulder arthroplasty and other orthopedic interventions.

ACKNOWLEDGEMENTS: This study was supported by the National Institutes of Health (R01 and R56 AR067196), the National Institute of General Medical Sciences (R01 GM083925), a Shared Instrumentation Grant (S10 OD021644), and the University of Utah Department of Orthopaedics. The research content herein is solely the responsibility of the authors and does not necessarily represent the official views or contributions of the sponsors.

IMAGES AND TABLES:

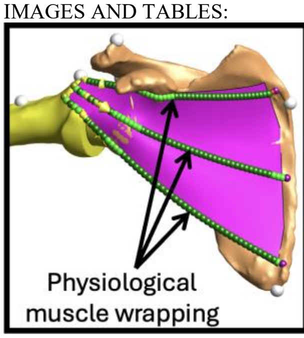

__Figure 1__ Reverse total shoulder arthroplasty patient model after a pre-tensioned muscle sheet was used to guide subscapularis muscle line paths. Point probes are shown in white.

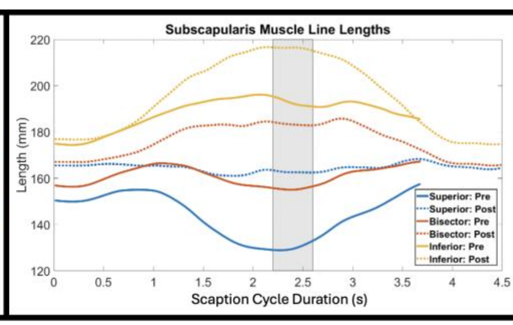

__Figure 2__ Superior, bisecting, and inferior subscapularis muscle line lengths in the pre-op and post-op rTSA patient, plotted over the time it took to complete one scaption cycle in seconds. The peak of both the pre- and post-operative scaption cycle occurs in the shaded gray box (2.3 seconds and 2.52 seconds, respectively).

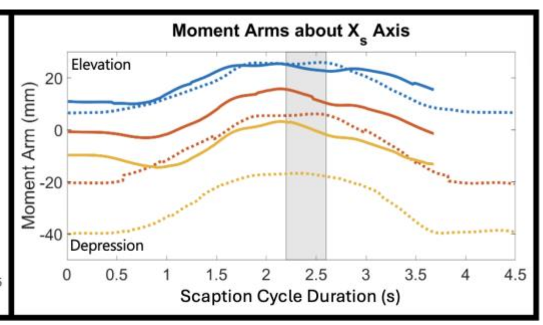

__Figure 3__ Decomposed subscapularis muscle moment arms about the scapular X-axis in the pre-op and post-op rTSA patient, plotted over the time it took to complete one scaption cycle in seconds. Values above 0 represent the potential of the muscle line to create elevation and values below 0 represent the potential to create depression.