

Stability in the shoulder: labrum and concavity compression contribution assessed through musculoskeletal modelling

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INTRODUCTION: Simulating the stability of the glenohumeral joint in musculoskeletal models represents a challenge. Currently, the approach is purely geometrical: enforcing a boundary for the joint reaction force's line of action and assuming a fixed centre of rotation for the shoulder. While this has some theoretical validity, cadaveric studies highlighted the importance of humeral translations (which are unaccounted for in computational simulations) and of the soft tissue to the stability of the joint (1); humeral head translations of up to 4 mm have been measured during physiological motion (2). The present study aims to quantify the contribution of the labrum and concavity-compression to the glenohumeral joint stability, using a validated musculoskeletal model.

METHODS: The musculoskeletal model used in this study is the UK National Shoulder Model (UKNSM). This inverse dynamics model includes six bone components and 21 muscles divided in a total of 87 muscle segments (3, 4). The muscle force redundancy is accounted for by the following optimizations: minimization of the sum of squared muscle stresses, the maximum muscle force is limited by its physiological cross-sectional area, and the projection of the glenohumeral force is geometrically limited to a standard sized ellipse to model the glenoid rim.

To quantify the stability of the joint, a stability ratio defined by Fukuda et al (5) was used. The mathematical formula for the stability ratio (SR) was extracted from a finite element analysis study by Klemm et al (6). The formula enables the SR to be quantified for any direction of humeral head translation on the glenoid and accounts for the mechanical properties of the labrum as well as concavity-compression. Using the UKNSM's output of compression force and the SR formula, a shear force can be calculated, and the contribution of the labrum can be quantified. In this work, the kinematic and kinetic data from seven healthy participants was used, performing planar tasks: abduction and forward flexion, at different speeds (slow, fast and maximal).

Data were tested for normality and then t-tests and 2-way ANOVA tests using statistical parametric mapping were applied.

RESULTS SECTION: Including the contribution of concavity compression and the effect of the labrum increased the stability ratio by 4 to 11% for abduction, for all speeds of motion, and 7 to 11% for forward flexion, for all speeds of motion (Figure 1). The addition of labrum and concavity compression to the stability ratio was statistically significant when the motion was performed fast and at maximum speed. For the slow motion, differences were statistically significant only for abduction angles above 100°, and for forward flexion above 20°.

DISCUSSION: The contribution of the labrum and concavity-compression to glenohumeral stability is at a clinically significant level of up to 11% and therefore should be accounted for in musculoskeletal models. This could lead to changes in the calculation of glenohumeral joint reaction force and muscle forces and may therefore result in more fidelic musculoskeletal modelling outputs. Future work will apply this methodology to include activities of daily life and extreme motions, in which we would expect an increase in labrum contribution, particularly at extremes of motion and loading. The limitation of this work is the extrapolation of the mathematical formula for stability ratio to motion angles above those tested in the cadaveric studies on which the computational work of Klemm et al (6) is based.

SIGNIFICANCE/CLINICAL RELEVANCE: Musculoskeletal models are widely used to assess the muscle activation and forces in a clinical context. Increasing the robustness of the model allows for a better understanding of the biomechanics behind the motions of daily life. This also offers a convenient environment to test clinical questions and hypotheses before commencing clinical trials and testing in vivo.

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IMAGES AND TABLES:

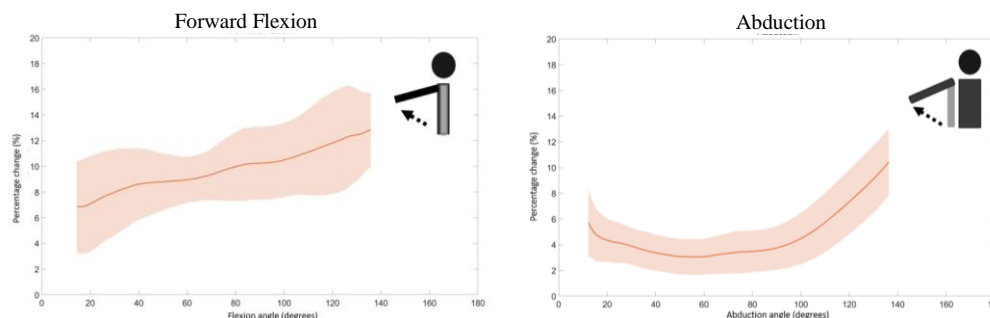


Fig 1. Change of the stability ratio after inclusion of concavity-compression and the labrum (mean \pm standard deviation, n=7)