Average Rotation Matrices for Converting Scapula-Based and Glenoid-Based Scapula Coordinate Systems to ISB Recommendations

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Summary

This study evaluates the use of average rotation matrices to standardise scapula local coordinate systems (LCS). Using a statistical shape model based on 80 scapulae, 1000 models were generated. Eleven LCS were defined, including scapula-based and glenoid-based LCS. The average rotation matrix was computed between 10 different LCS observed in the literature and the LCS recommended by the International Society of Biomechanics using a singular value decomposition. Results showed minimal angular differences between model and average rotation matrices. These findings highlight the potential of average rotation matrices for consistent comparison of scapula LCS in biomechanical studies and clinical applications.

Introduction

Accurate comparison of scapula movements in biomechanical studies relies on consistent LCS. However, the lack of a universally accepted scapula LCS has led to variability across studies. A recent review by our group identified 11 different scapula LCS across 20 datasets, highlighting discrepancies in axis orientations and construction methods [1]. These discrepancies were partly linked to the measurement techniques used: imaging-based methods often result in glenoid-based LCS, while marker-based methods tend to yield scapula-based LCS. For the past two decades, the ISB recommendations [2] have provided a reference for joint kinematics. Kolz et al. [3] proposed using average rotation matrices to re-express rotations from two commonly used scapula LCS into the ISB-defined system. This study aims to verify Kolz et al.'s approach with an independent dataset and extend it to include additional scapula LCS identified in our review [1].

Methods

This study used a statistical shape model created from a dataset based on the work of Zhang et al. [4] and composed of the 3D reconstructions of 80 scapulae from biplane X-ray images. The dataset includes 28 asymptomatic participants (15 ♀, average age 56 ± 7 years) and 52 symptomatic participants with a transfixing rupture of the supraspinatus (32 ♀, average age 56 ± 7 years). From this model, 1000 scapula surface models were generated and used to compute average rotation matrices. Each generated model shares the same topology, vertex count, and anatomical landmarks.

Eleven scapula LCS were defined in the 1000 generated scapula surface models, based on the anatomical landmarks of the model. All these LCS vary in axis orientations and construction. In particular, LCS-4 and 5 correspond to the acromioclavicular joint-centred LCS and glenoid-centred LCS used by Kolz et al. [3].

To compute the average rotation matrix, the 3x3 rotation components from each joint coordinate system were extracted. The arithmetic mean of these matrices was calculated, and a singular value decomposition (SVD) was applied to ensure orthogonality.

The minimal angle θ between each model's rotation matrix $\mathbf{R}_1$, or the average rotation matrix proposed by Kolz et al. [3], and each average rotation matrix $\mathbf{R}_2$ was computed using: $\theta = \arccos\left(\frac{\mathrm{tr}(\mathbf{R}_1^T\mathbf{R}_2)-1}{2}\right)$.

Results and Discussion

The minimal angle between the average rotation matrix and the model rotation matrix was ranged up to 5.1±2.1°. Smaller angles were observed for scapula-based LCS (up to 2.8±1.2°) compared to glenoid-based LCS (up to 5.1±2.1°). The minimal angle between the average rotation matrices proposed by Kolz et al. [3] and the present study was 3.9° for LCS-4 and 1.7° for LCS-5.

Conclusions

The average rotation matrices proposed in this study closely align with those reported by Kolz et al. [3]. The results suggest that the use of average rotation matrices can provide a consistent transformation for comparing different scapula LCS, enhancing the comparability of biomechanical studies and clinical applications.

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