In-Vivo Contact Patterns of the Glenohumeral Joint during Scapular Plane Abduction with External Arm Rotation

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Introduction: One of the end goals of surgical intervention for the treatment of shoulder joint pathology is the belief that glenohumeral joint mechanics must be restored in order to obtain good clinical outcomes. Previous studies have used clinical imaging modalities, such as fluoroscopy, computed tomography (CT) and magnetic resonance imaging (MRI) to investigate in-vivo joint mechanics. Similarly cadavers have been studied where invasive contact measurement techniques were employed. There are however limitations to these techniques, clinical imaging modalities were not designed to accurately measure kinematics in three-dimensions and in-vitro studies do not accurately simulate in-vivo muscle forces. A recent technique used by Bey and colleagues combines three-dimensional kinematics imaging with CT to determine in-vivo glenohumeral contact patterns [1]. However, this technique neglects cartilage in it calculation of contact due to the difficult nature of imaging cartilage with CT. Therefore, the objectives of this study are to (1) describe a technique for measuring in-vivo glenohumeral joint contact patterns utilizing cartilage data from MRI, and (2) compare this technique to one that ignores cartilage data.
Methods: After institutional review board approval and informed consent, 9 healthy right hand dominant subjects (4 males, 5 females; age 26.3 ± 2.4) were enrolled in the study. All subjects underwent a clinical shoulder exam to document a normal range of motion and absence of scapular dyskinesis. Subjects who did not pass the clinical exam or had pain, injury or previous surgery were excluded from study. Each subject underwent a 3-Tesla T2 weighted MRI with 1.5mm slice spacing. Triangle mesh surface
models of the humerus, scapula, and humeral and glenoid cartilage were constructed from manually segmented axial images. Subjects were then posed with their right shoulder in the center of the viewing volume of a dual fluoroscopic imaging system [2]. Pulsed simultaneous fluoroscopic images of the right shoulder were acquired at 30Hz while subjects cyclically performed abduction adduction motion in the scapular plane from 0° to approximately 110° of humerothoracic angle. To position the shoulder for testing, subjects begin with their extended arm fully adducted at their right side in neutral rotation, followed by flexing the elbow to 90° and then externally rotating the forearm about the humeral shaft axis to the plane of the scapula. Subjects maintained this elbow flexed external rotation position during cyclic abduction adduction motion. Male subjects held a 4-pound dumbbell and female subjects a 2-pound dumbbell while performing this motion cycle in approximately four seconds. Three repetitions were performed in a continuous fashion with the middle cycle being used for analysis. Joint kinematics for the humerus and scapula were tracked using a semiautomatic registration algorithm that optimizes the six-degree of freedom bone model position based on minimizing the error between the projected bone model surface and the corresponding contours on the fluoroscopic images (Fig 1) [3]. Glenohumeral joint contact patterns were calculated from the registered bone positions for every 10% of the motion cycle. The 3D distance from each mesh vertex/face of the humerus bone to the scapula bone model and the humeral cartilage to the glenoid cartilage model was calculated using custom MATLAB code (Fig 2). The centroid of contact was determined by using a weighted average of the 3D distances that were within 150% of the minimum distance. The centroid location was expressed relative to a glenoid coordinate system. To account for differences in glenoid cartilage and underlying bone size between subjects, the centroid locations were normalized to the maximum cartilage/bone dimensions in anterior/posterior (A/P) and superior/inferior (S/I) directions. Results are expressed as a percentage of the maximum A/P and S/I cartilage/bone dimensions. To quantify differences between glenohumeral contact locations using cartilage data and ignoring cartilage data, five measures were calculated. These were the A/P and S/I locations of the contact centroid, the A/P and S/I range of travel and the total contact path length (Fig 3). A Mann-Whitney U test was performed for each of the five measures to determine the effect of utilizing or neglecting MRI cartilage data had on the measure. Statistical significance was set at P < 0.05.
Results: No differences were found between the locations of the contact centroid determined using cartilage data or neglecting cartilage data for both the A/P and S/I directions at each 10% of the motion cycle analyzed. No difference in the A/P range of travel \((P = 0.895)\) was found between techniques. However, a significant difference in the S/I range of travel \((P = 0.012)\) and total contact path length \((P = 0.038)\) was found between techniques. The average total contact path length neglecting cartilage was 118.5% and 89.8% when including cartilage data.
Figure 3: Average contact path for healthy right hand dominant subjects. The blue path neglects cartilage, whereas the red path includes cartilage data.

Discussion: This study describes a technique for measuring in-vivo glenohumeral joint contact patterns utilizing cartilage data from MRI, and compares this technique to one that ignores cartilage data. The MRI based technique can be used to quantify the restoration effects that surgical interventions have on glenohumeral joint contact mechanics (e.g., instability and rotator cuff tendon repair). Contact was found primarily anterior/inferior, whereas Bey et al. found contact superior/posterior on the glenoid face [1]. This is most likely explained by the internal/external rotation of the humerus about the humeral shaft axis. Glenohumeral contact centroid locations normalized to cartilage/bone dimensions were not statistically different whether using bone models alone or including available cartilage data. However, neglecting cartilage data significantly overestimated the S/I range of travel and overestimated the total contact path length by nearly 30%. Caution should be used when using bone models alone to determine in-vivo glenohumeral contact patterns as it is possible to overestimate the S/I range of travel and total contact path length.
Significance:

Acknowledgments:
