Evaluation of the Translation Distance of the Glenohumeral Joint and the Function of the Rotator Cuff on Its Translation: A Cadaveric Study

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Purpose: To evaluate the distance and position of humeral head translation during glenohumeral motion and to investigate the function of the rotator cuff in glenohumeral translation. **Methods:** Using 9 cadavers, glenohumeral translation during passive pendulum motion was tracked by an optical motion capture system. Tension was applied to 5 compartments of the rotator cuff muscles, and 7 different conditions of rotator cuff dysfunction were sequentially simulated. Three-dimensional glenohumeral structure was reconstructed from the computed tomography images of the specimens, and the distance and position of glenohumeral translation were compared among the conditions. **Results:** The average radius of glenohumeral translation was 10.6 ± 4.3 mm when static loading was applied to all rotator cuff muscles. The radius increased significantly in the models without traction force on the supraspinatus and total subscapularis tendons ($P = .030$). The position of the translation center did not change in the mediolateral direction ($P = .587$) and in the anteroposterior direction ($P = .138$), but it moved significantly superiorly in the models without supraspinatus and infraspinatus loading ($P = .011$) and in those without supraspinatus, infraspinatus, and teres minor loading ($P < .001$). **Conclusions:** The distance and position of humeral head translation during glenohumeral motion changed with rotator cuff deficiency. The present study indicated that the subscapularis plays an important role in maintaining the central position of the humeral head, and that the infraspinatus acts as a major depressor of the humeral head during shoulder motion. **Clinical Relevance:** The results of this study suggest that extension of a tear into the subscapularis should be avoided to maintain the centering function of the glenohumeral joint in cases with rotator cuff tear.

Joint articulating motion is commonly described by the terms *sliding, spinning,* and *rolling*.[1] Sliding motion is equal to joint translation, spinning is joint rotation, and rolling includes both translation and rotation. During glenohumeral motion, the humeral head translates with respect to the glenoid, along with glenohumeral rotation. Glenohumeral translation could possibly contribute to the large range of motion of the shoulder joint, and several past studies have evaluated this translation. Past in vivo and in vitro studies evaluated glenohumeral translation during a particular direction of shoulder motion,[2-9] with external loading to the humeral head,[10,11] with muscle loading,[10] or with tendon detachment.[12] However, the distance and position of glenohumeral translation have not been sufficiently evaluated.

The rotator cuff muscles compress the humeral head into the glenoid and serve as the primary dynamic stabilizing mechanism during the functional range of motion.[11,13,14] In the transverse plane, the stabilizing mechanism of the rotator cuff depends on the integrity of a force couple, formed by the anatomic arrangement of the anterior and posterior rotator cuff tendons.[11,15] In the coronal plane, the rotator cuff tendon works as a depressor of the humeral head and resists the superior pull of the deltoid muscle during glenohumeral

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elevation.[10,12] Thus, the rotator cuff enables concentric rotation of the humeral head on the glenoid, and the glenohumeral joint is reported to lose its stability with a massive rotator cuff tear.[15] Although many rotator cuff tears are asymptomatic,[16] some cases with rotator cuff tears have severe impairment of shoulder function.[17] However, past cadaveric studies assessed translation under static conditions,[10,12] and the influence of rotator cuff dysfunction on glenohumeral translation during shoulder motion remained unclear.

The purpose of this study was to evaluate the distance and position of humeral head translation during glenohumeral motion and to investigate the function of the rotator cuff in glenohumeral translation. We hypothesized that the pattern of glenohumeral translation changes with rotator cuff deficiency.

Methods

Preparation of Cadaveric Specimens

This study was approved by our institutional review board. A total of 22 consecutive cadaveric shoulders were inspected before the experiments, and the specimens with a full-thickness rotator cuff tear and glenohumeral osteoarthritis, which were confirmed by direct inspection and computed tomography (CT), respectively, were excluded. Nine fresh-frozen upper extremities including the scapula, clavicle, humerus, forearm, and hand (6 males and 3 females, 2 right sides and 7 left sides, mean age 86.6 ± 9.9 years; range 68-101 years) were used in this study. The muscles that originate from the thorax (trapezius, latissimus dorsi, pectoralis major, pectoralis minor, serratus anterior, rhomboid, levator scapulae) were resected at their insertions, but all of the muscles originating from the scapula (rotator cuff muscles, teres major, deltoid, biceps brachii, coracobrachialis, and triceps brachii) were maintained. The cadaveric upper extremity was thawed at room temperature immediately before testing, and the skin and subcutaneous fat of the specimens were removed. Three optical markers with a 9-mm diameter were fixed directly to the middle of the scapular spine and the distal two-thirds of the humeral shaft between the triceps brachii and brachial muscles with threaded stainless steel pins and a custom-built triangular fixation apparatus, respectively (Fig 1A). To avoid self-collisions during shoulder motion and to eliminate the influence of reaction forces on the glenohumeral joint produced by the distal joints, the humeroulnar, radioulnar, and radiocarpal joints were temporarily fixed using 3 stainless steel Kirschner wires, 1.6 mm in diameter. The cadaveric upper extremities were then scanned by CT with 0.625-mm-thick slices (GE Healthcare Discovery CT750 HD, Amersham, UK) to assess the 3-dimensional positions and orientation of the glenohumeral joint and to measure the positional relationships between the optical markers and the bones.

A custom-built metallic plate with 2 pairs of bars was used to fix the cadaveric extremities, and the scapular body was placed between the bars and attached with screws to the plate and bars. Metal pulleys were directly attached to the root of the scapular spine and the inferior angle of the scapular body (Fig 1A). Then, the plate was fixed to the ground with the custom-built fixation apparatus, and the scapula was inclined 45° inferiorly to avoid contact between the scapula and upper extremity. Nylon cords (Super strong PE 12lb; Toray, Tokyo, Japan) were connected to 5 compartments of the rotator cuff (supraspinatus [SSP],

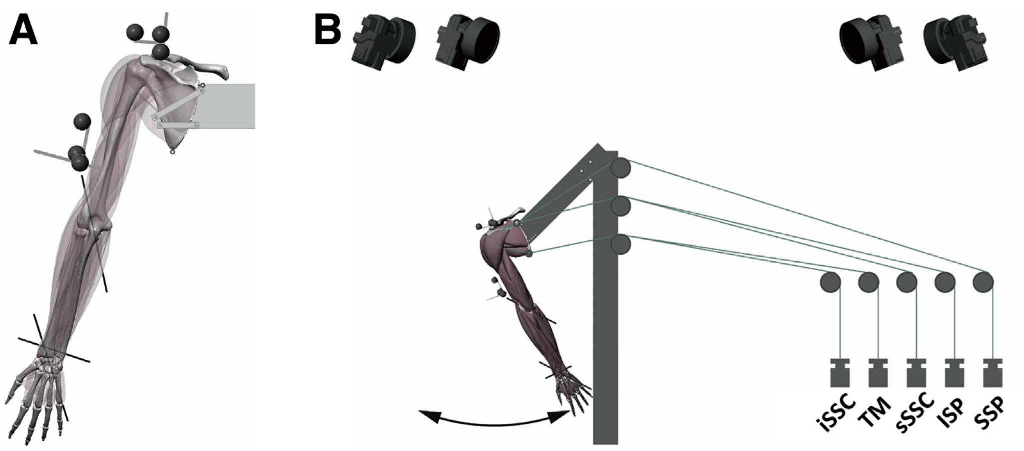

Fig 1. (A) The cadaveric extremities are fixed by a metallic plate and bars. Metal pulleys are attached to the root of the scapular spine and the inferior angle of the scapular body, and 3 optical markers are fixed directly to the scapular spine and the humeral shaft with the threaded stainless steel pins. The humeroulnar, radioulnar, and radiocarpal joints are temporarily fixed using stainless steel Kirschner wires. (B) The motions of the markers during passive pendulum motion of the glenohumeral joint with/without rotator cuff loading are recorded by an optical motion capture system.