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Effect of humeral head rotation on bony glenohumeral stability

Tomoya Matsuhashi [a], Alexander W. Hooke [a], Kristin D. Zhao [a], John W. Sperling [b], Scott P. Steinmann [b], Kai-Nan An [a,]*

[a] Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, Rochester, MN, USA
[b] Department of Orthopedic Surgery, Mayo Clinic, Rochester, MN, USA

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ABSTRACT

Background: The humeral head and glenoid cavity are not perfectly spherical, nor do they have matching radii of curvature. We hypothesized that glenohumeral stability is dependent on axial humeral rotation.
Methods: Seven cadaveric shoulders were investigated. For each test, the humeral head was translated relative to the glenoid in 2 directions (starting from neutral), anterior and anteroinferior. Contact forces and lateral humeral displacement were recorded. Joint stability was quantified using the stability ratio and energy to dislocation. The humerus was set in 60° of abduction for all tests. Testing was performed in neutral rotation and 60° of external rotation.
Findings: The force displacement curves differed between rotations. In both displacement directions, the peak translational force occurred with less displacement in neutral rotation than in external rotation. The stability ratio and energy to dislocation in the anteroinferior direction were greater than in the anterior direction for both rotation positions. While there were no significant differences in the stability ratio or energy to dislocation between rotation conditions at complete dislocation, the energy required to move the humeral head 10% of the glenoid width was significantly greater with the arm in neutral rotation.
Interpretation: The energy to dislocation, a new parameter of dislocation risk, and the stability ratio, indicate that the glenohumeral joint is more stable in the anteroinferior direction than the anterior direction. During initial displacement, axial rotation of the humeral head contributes to glenohumeral geometrical stability. However, humeral head rotation does not have a significant effect when looking at complete dislocation.

1. Introduction

The shoulder is one of the most mobile and least constrained joints in the body. During shoulder motion, both static and dynamic factors are responsible for glenohumeral stability (Itoi et al., 1996; Lee et al., 2000). Dynamic factors are active stabilizers and are composed of the rotator cuff, deltoid, biceps, and other periscapular muscles. Static factors are passive stabilizers and are composed of the glenoid labrum, joint capsule, glenohumeral ligaments, and glenoid geometry. Looking more closely at glenoid geometry, several groups report that glenoid concavity contributes to joint stability (Halder et al., 2001; Lazarus et al., 1996).

Although several studies have focused on glenohumeral instability, there are only two primary parameters commonly used to quantify stability, the stability ratio and peak dislocation force (Halder et al., 2001; Itoi et al., 2000; Sekiya et al., 2009, 2012; Yamamoto et al., 2010). These parameters are somewhat limited in that they look at only single instances in time, the point of peak dislocation force, and do not account for what is happening during the dislocation process as a whole. In the field of tissue failure testing, energy is a commonly utilized metric (Jeon et al., 2009; Turk et al., 2010). In these studies, the energy to failure is defined as the amount of work required to rupture a tissue. In this study, we propose the computation of the energy to dislocation, defined as the amount of work needed to dislocate the humeral head as an additional metric to quantify glenohumeral stability that accounts for the entire dislocation process.

The humeral head is an asymmetrical spherical structure (Fig. 1). Given these geometric considerations, we hypothesized that glenohumeral stability is also dependent on humeral head rotation. More specifically, this asymmetry will lead to changes in the glenohumeral joint congruency even as the curvature of the glenoid remains constant. We hypothesize that glenohumeral stability changes in the external rotated position. To test the hypothesis, we evaluated glenohumeral stability using both the stability ratio and the energy to dislocation.

2. Methods

Seven fresh-frozen shoulder specimens were used for this study (mean age, 76.0 years; range 58 to 87 years; 5 F/2 M). The shoulders were stored at −20 °C and thawed to room temperature overnight before testing. The exclusion criteria included shoulders with rotator cuff tears, fractures, contracture, osteoarthritis, or other disease of the

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* Corresponding author at: Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, 200 First Street S.W., Rochester, MN 55905, USA.
E-mail address: an@mayo.edu (K.-N. An).

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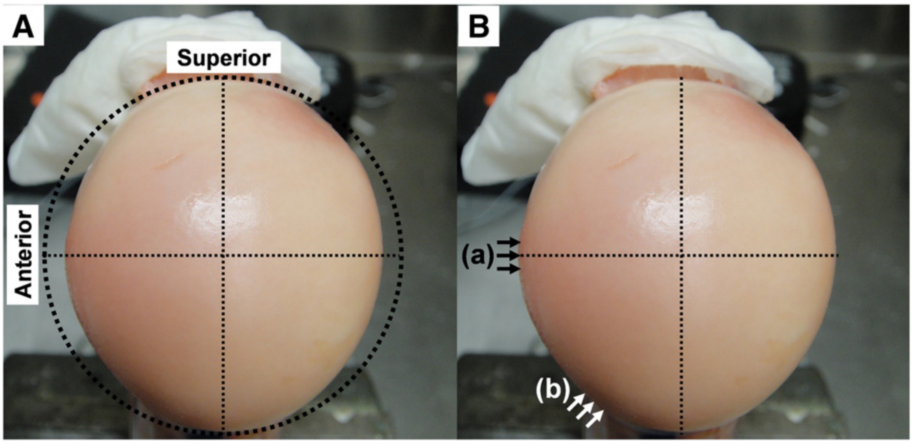

Fig. 1. Photograph of set humeral head. A) Humeral head is an asymmetrical spheroid structure. B) Arrows indicate the area that humeral head contacts against the glenoid wall. a is in neutral rotation. b is in 60° of external rotation.

shoulder detectable by direct inspection or radiographs. Each specimen was disarticulated and dissected at the middle part of the humerus distal to the deltoid attachment. The skin, subcutaneous tissue, and all soft tissues, except for the labrum, were removed. The humeral shaft was potted in an acrylic tube and fixed using bone cement (Fig. 2). The scapula was osteotomized about 5 cm medial to the glenoid surface. The glenoid was mounted with polymethylmethacrylate bone cement to a custom made testing machine (Avalon Technologies, Rochester, Minnesota). Using a bubble level, the glenoid surface was set parallel to the floor. The specimen was kept moist with a spray of saline solution applied every ten to fifteen minutes during the test, which was performed at room temperature (24 °C).

The cemented glenoid was fixed onto the testing apparatus (Fig. 3) consisting of a six-degree-of freedom load-cell (JR3, Woodland, California). The load-cell was mounted on a motorized x–y stage (DCI Design Components, Franklin, Massachusetts). The capacity and resolution of the load cell were 1000 N and 1.3 N, respectively. This custom testing apparatus has been validated in previous studies (Itoi et al., 2000; Tammachote et al., 2007). In this study, the x and y axes were defined in the horizontal plane, and the z direction was defined as the vertical direction. The x–y table allowed for motor-driven, computer controlled translations of the glenoid surface. A vertical slide provided unconstrained movement in the z direction. The vertical displacement of the humeral head was measured with a linear-position transducer (TR-50; Novotechnik, Stuttgart Germany). The repeatability of this linear position sensor was 0.002 mm and independent linearity was 0.15%. A 50-N compressive force was constantly applied across the glenohumeral joint with a low-friction pneumatic cylinder while the translational force and humeral displacement were recorded.

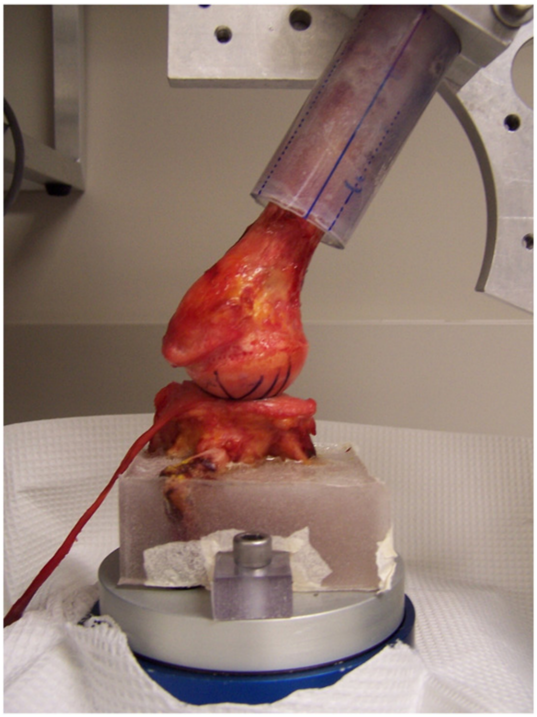

Fig. 2. Photograph of the glenohumeral joint on the six-degrees-of-freedom load-cell machine.

The glenoid was translated at a rate of 2.0 mm/s underneath the humeral head. The starting position of the humeral head was defined as when it was in contact with and centered on the glenoid, with a lack of forces in the x–y plane. The glenoid was translated in 2 directions, anterior and anteroinferior, until dislocation (Fig. 4). The peak translational force needed to move the humeral head and the displacement distance to dislocation of the center of the humeral head were recorded. The analysis was based on a normalized displacement, which was divided by the size of the glenoid width. Dislocation was defined as the point when the direction of the translational force changed on the force displacement curve (Fig. 5).

Two trials were performed in each condition, and the mean value was used for data analysis. In addition, the stability ratio, defined as the peak translational force divided by the applied compressive force, was calculated to quantify joint stability (Fukuda et al., 1988). Because this stability ratio solely reflects the bony contour of the glenoid socket, it is commonly used to assess the stability provided by the bony structures (Halder et al., 2001; Montgomery and Jobe, 1994; Novotny et al., 1998; Palmer and Widen, 1948). We also calculated the energy to dislocation, defined as the amount of work needed to dislocate the humeral head, by calculating the area under the force–displacement curve from the starting position until the position at dislocation (Fig. 5). To account for anatomical differences between specimens, the humeral head size and the glenoid depth were measured. The humeral head sizes were measured using a precision caliper (0.1 mm accuracy). The major diameter of humeral head was defined as the superior–inferior direction, the minor diameter was defined as the anterior–posterior direction. The glenoid depth was defined as a maximum vertical displacement of the humeral head until dislocation.

The humerus was mounted in 60° of abduction relative to the scapula (90° of abduction relative to the trunk), as tested in previous studies (Sekiya et al., 2009; Yamamoto et al., 2010). Anterior shoulder instability is commonly associated with the position of 90° of