Role of the long head of the biceps brachii in glenohumeral stability: A biomechanical study in cadavera

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Ten cadaveric shoulders were tested to evaluate the effect of simulated contraction of the long head of the biceps brachii on glenohumeral translation. The shoulders were mounted on a special apparatus attached to a servo-controlled hydraulic testing device. Sequential 50 N anterior, posterior, superior, and inferior forces and a 22 N joint compressive load were applied to the shoulders. An air cylinder applied a constant force to the tendon of the long head of the biceps brachii. The shoulders were tested in seven positions of glenohumeral elevation and rotation. Application of a force to the long head of the biceps brachii resulted in statistically significant decreases in humeral head translation. The influence of the long head of the biceps was more pronounced at middle and lower elevation angles. When the shoulder was placed in 45° of elevation and neutral rotation, application of a 55 N force to the biceps tendon reduced anterior translation by 10.4 mm (p = 0.001), inferior translation by 5.3 mm (p = 0.01), and superior translation by 1.2 mm (p = 0.004). (J SHOULDER ELBOW SURG 1996;5:255-62.)

The soft tissues surrounding the glenohumeral joint are major determinants of shoulder stability. The shoulder capsule, glenohumeral ligaments, glenoid labrum, rotator cuff muscles, and scapular rotator muscles are considered to be important components of a complex system that controls motion of the humeral head on the glenoid fossa. Contraction of the rotator cuff muscles is commonly believed to cause compression of the humeral head into the glenoid fossa, increasing the force needed to translate the humeral head.[10, 11] The biceps brachii muscle is generally considered to be a supinator of the forearm and a flexor of the elbow. However, the biceps crosses the glenohumeral joint and the elbow. As it passes to its insertion in the supraglenoid region, the tendon of the long head of the biceps occupies an intraarticular position in the shoulder. Some authors have hypothesized that the long head of the biceps may function to stabilize the glenohumeral joint.[1, 5-8, 13-15]

We performed a biomechanical study to determine the effect of simulated contraction of the long head of the biceps brachii on glenohumeral translation in multiple shoulder positions.

MATERIAL AND METHODS

Thirteen fresh-frozen cadaveric shoulder specimens were obtained for testing. All specimens were examined by radiography with an anteroposterior projection. None of the shoulders had evidence of arthritic change or superior migration of the humeral head resulting from rotator cuff disease. The specimens were prepared by removing skin, subcutaneous tissue, and muscles superficial to the rotator cuff muscles. The rotator cuff muscles were amputated in the middle portion of the scapula, leaving the lateral portion of the rotator cuff intact. The medial aspect of the scapula was exposed by subperiosteal dissection and was then resected. Osteotomy of the humeral shaft was

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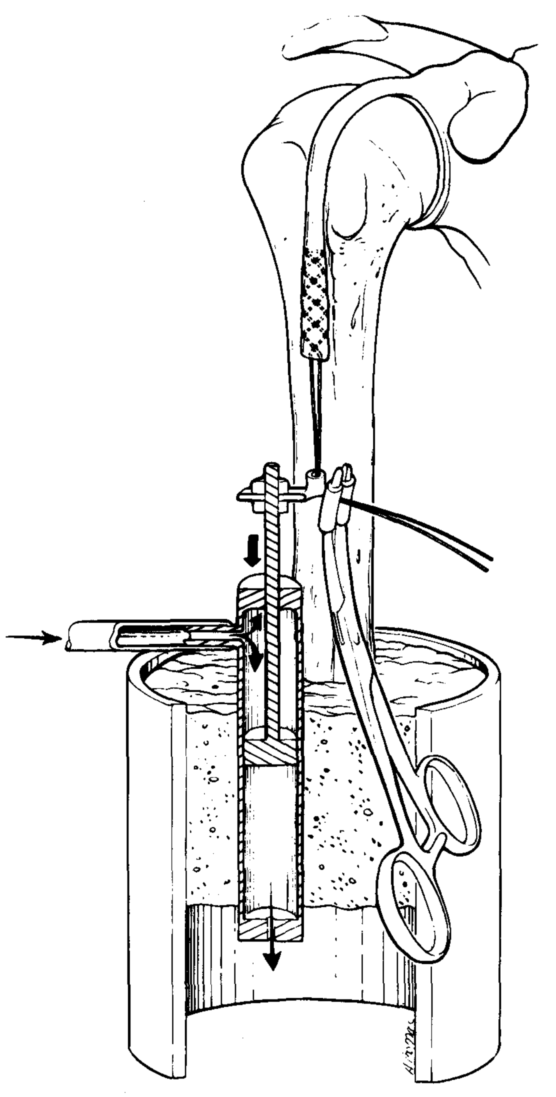

Figure 1 Application of force to tendon of long head of biceps brachii. Air cylinder was potted adjacent to humeral shaft. Air cylinder was connected to tendon with sutures and couplers that were attached to piston of air cylinder. Activation of air cylinder applied constant force to tendon.

done approximately 15 cm distal to the greater tuberosity, and the remaining humerus was exposed subperiosteally. The tendon of the long head of the biceps brachii was preserved. Three specimens were excluded because of full-thickness tears of the supraspinatus tendon, leaving 10 shoulders for biomechanical testing.

The scapular and humeral portions of the dissected specimen were each fixed into stainless steel cylindric holders with epoxy cement. The glenoid surface was oriented perpendicular to the long axis of the scapular cylinder, while the distal portion of the remaining shaft of the humerus was axially aligned with the center of the humeral cylinder. A 5/16-inch bore air cylinder with a stroke of 1 inch (Bimba Manufacturing Co., Monee, Ill.) was aligned with the longitudinal axis of the long head of the biceps brachii and was potted adjacent to the shaft of the humerus. Supplemental fixation of the humerus was achieved with stainless steel transfixation pins through holes in the humeral cylinder. The shoulders were reexamined with biplanar radiography to verify that the glenoid was properly aligned. Two heavy nonabsorbable traction sutures were placed into the biceps tendon with a modified Bunnell technique. The sutures were connected to the air cylinder piston by passing them through a small metal coupler that was fixed to the threaded end of the piston rod (Figure 1). The specimens were tested on a special shoulder test apparatus mounted on a servo-controlled hydraulic materials test system (Materials Testing Systems, Minneapolis, Minn.)[18, 19] (Figure 2). The scapular cylinder was mounted on a horizontal shaft with the specimen oriented to allow full elevation in the plane of the scapula. The humeral cylinder was placed within a third stainless steel cylinder and was fixed between two parallel plates that were attached to a 2.2 kN load cell (Lebow, Inc., Troy, Mich.). Weights were suspended from the portion of the apparatus that supported the humeral and scapular cylinders to apply a joint compressive load to stabilize the shoulder. This load was isolated from the test apparatus and was oriented parallel to the plane of the scapula to avoid bending moments in the load cell. The test apparatus allowed free translations of the humeral head with respect to the glenoid surface. Medial-lateral, anterior-posterior, and superior-inferior translations were measured with linear variable differential transformers (Shaevitz, N. J.). The three rotations of the humerus were constrained: flexion-extension, elevation, and internal-external rotation. Sequential 50 N anterior, posterior, superior, and inferior forces were applied to the shoulder. These forces were directed parallel to the sagittal plane of the glenoid. Applied forces and resultant translations were continuously recorded with a data acquisition computer system.

Three glenohumeral starting positions, termed the reference neutral positions, were defined for anteroposterior and superoinferior humeral trans-

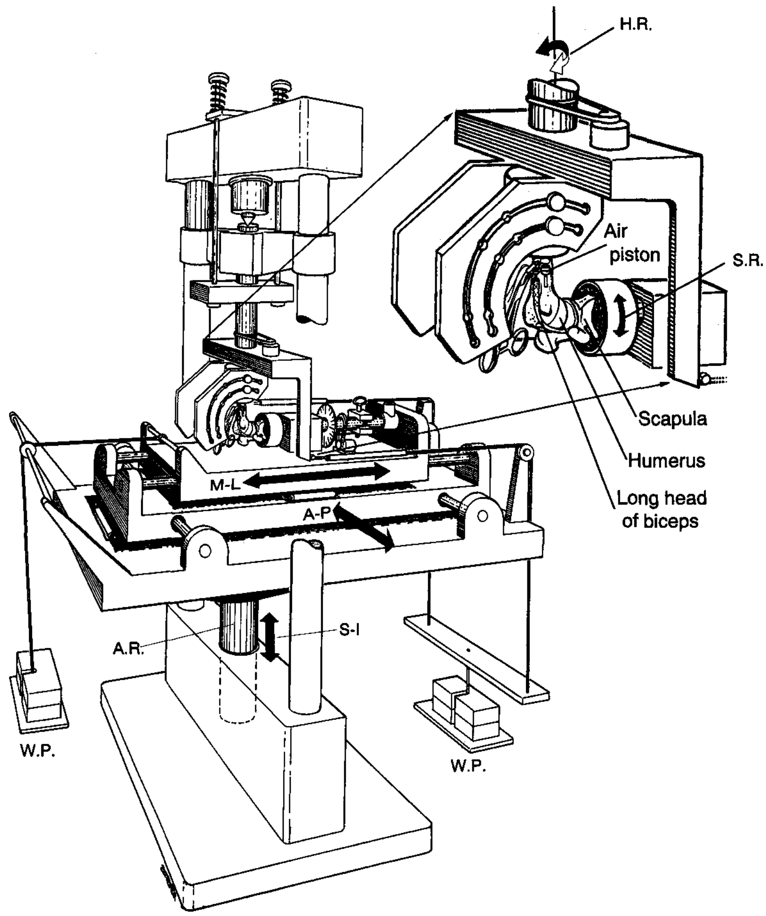

Figure 2 Shoulder test apparatus. Free medial-lateral *(M-L)* and anteroposterior *(A-P)* translations were permitted along two parallel platforms when 50 N superoinferior *(S-I)* force was applied to shoulder. Testing apparatus was mounted on actuator arm *(A.R.)* of servo-controlled materials testing system. Maximal internal-external rotation of humerus *(H.R.)* was determined by application of 5 N-meter moment with torque wrench *(T.W.)*. Joint compression load was applied by suspension of weights from two weight platforms *(W.P.)*. Humeral flexion-extension and scapular rotation *(S.R.)* were held constant during each test.

lations and for internal-external rotation of the humerus. The reference neutral positions for the glenohumeral translations were determined by locating the "deepest" or most medial position of the humeral head in the glenoid fossa. This goal was accomplished by finding the maximum medial humeral head translation (position) during anteroposterior and superoinferior translation with 50 N anterior, posterior, superior, and inferior forces and a 22 N joint compressive load. A 22 N joint compressive load was chosen for most of our testing conditions, because we have noted that joint loads in excess of this value tend to stabilize the joint regardless of capsular disease.[3] A position of neutral internal-external rotation of the humerus was established by positioning the humeral head in the referenced neutral translation position and applying five N-meter internal-external rotational moments to the inner humeral cylinder, which was allowed to rotate within the outer humeral cylinder. The resulting internal and external rotations of the humerus were recorded. Reference neutral internal-external rotation was defined as the midpoint between maximum internal and external rotations. Neutral positions for translations and rotation were defined for each position of elevation. All subsequent motions of the humeral head on the glenoid fossa were measured relative to

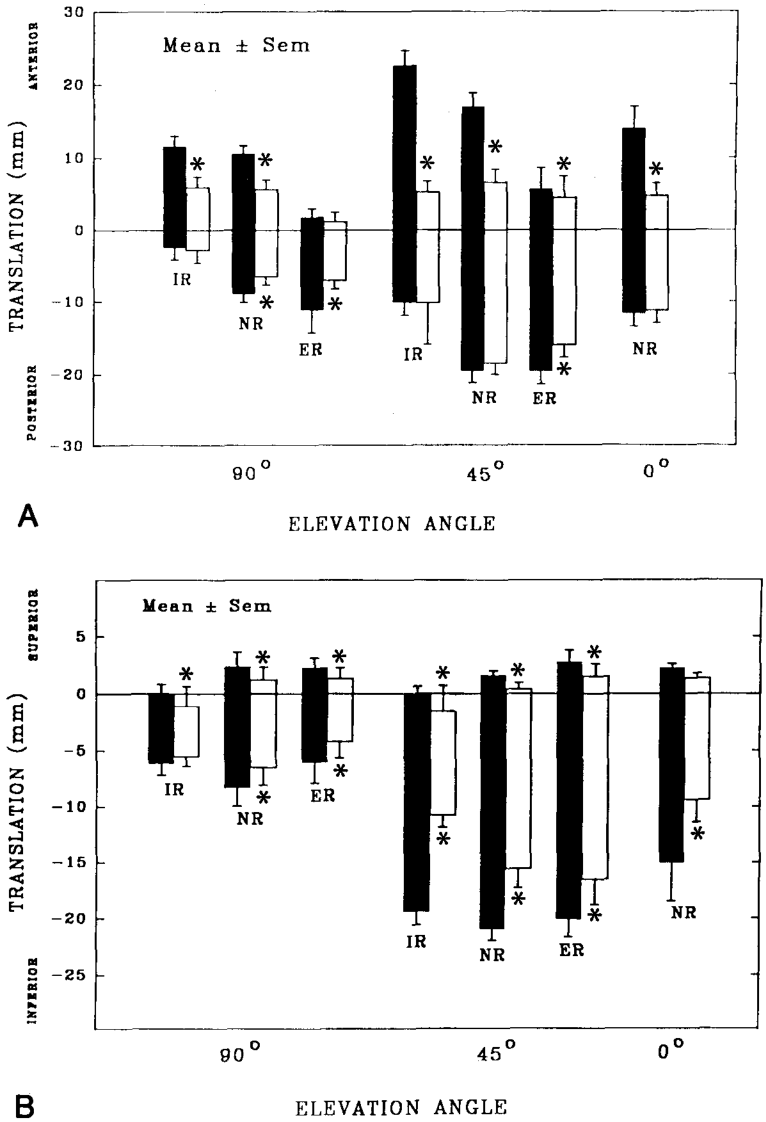

Figure 3 Effect of 55 N force applied to long head of biceps brachii on glenohumeral translation. Twenty-two N joint compressive load and 50 N anterior, posterior, superior, and inferior displacement forces were applied. *Dark bars* represent mean translations in vented condition before application of biceps force. *White bars* represent mean translations after application of biceps force. Statistically significant decreases in translation resulted form application of biceps force and are indicated by asterisks (*). *IR,* Internal rotation; *NR,* neutral rotation; *ER,* external rotation. **A,** Anteroposterior translation. **B,** Superoinferior translation.

these reference neutral positions. Activation of the air cylinder applied a constant traction force to the tendon of the long head of the biceps brachii ("the biceps force"). This force was varied by adjusting the air pressure to the air cylinder. In most of our tests a 55 N force was applied to the biceps. This force magnitude was based on a report that predicted the maximum moment generated by the long head.[2] The force was independently calibrated with a load cell.

Before testing was begun, the capsule of each shoulder was vented with an 18-gauge needle, which eliminated the stabilizing effect of negative intraarticular pressure.[18] All motions are reported for the vented shoulder. The shoulder was tested in three positions of glenohumeral elevation in the

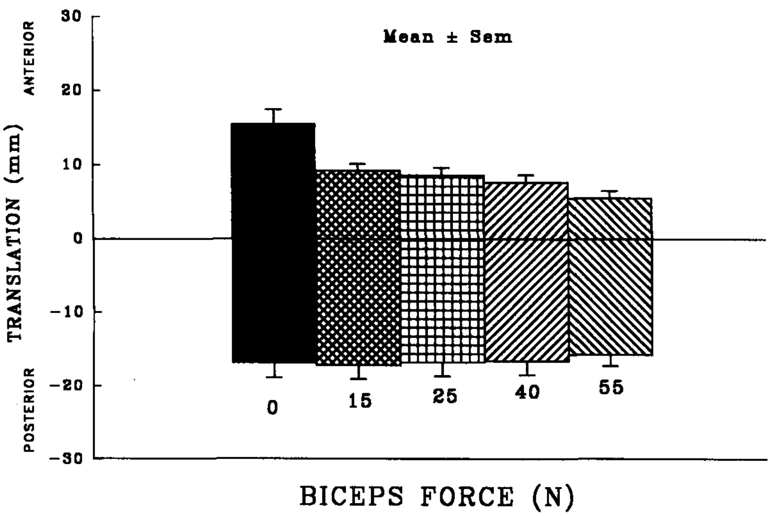

Figure 4 Effect of varying force on long head of biceps. Shoulders were tested in position of 45° of elevation and neutral rotation. Twenty-two N joint compressive load and 50 N anterior and posterior displacement forces were applied. Each *bar* represents mean anteroposterior translation with application of indicated force on long head of biceps.

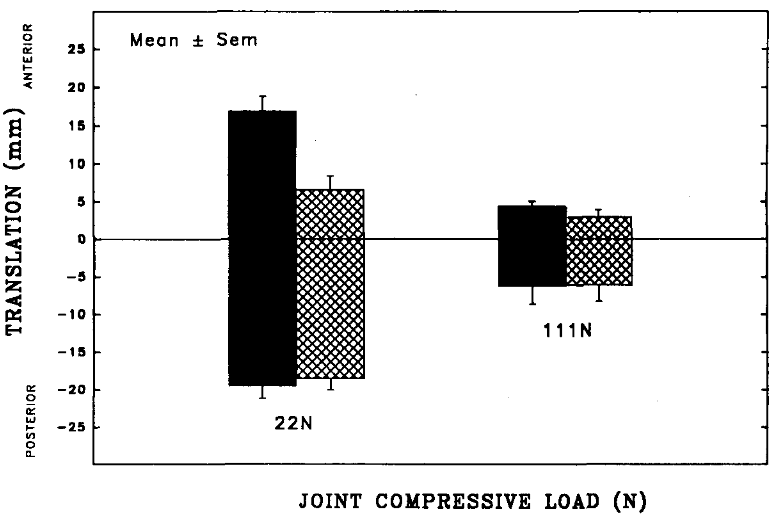

Figure 5 Effect of varying joint compressive load. Shoulders were tested in position of 45° of elevation and neutral rotation. Fifty N anterior and posterior displacement forces were applied. *Paired bars* on left represent mean anteroposterior translations in presence of 22 N joint compressive load. *Paired bars* on right represent mean anteroposterior translations in presence of 111 N joint compressive load. *Dark bars* represent mean anteroposterior translations in vented condition before application of biceps force. *Cross-hatched bars* represent mean anteroposterior translations after application of biceps force.

plane of the scapula (0°, 45°, and 90°) and three positions of internal-external rotation of the humerus (30° external, 30° internal, and neutral). Each shoulder was tested in all three positions of internal-external rotation at 90° and 45° of elevation. At 0° of elevation the shoulder was tested in neutral internal-external rotation only. Thus each shoulder was tested in seven different positions. In

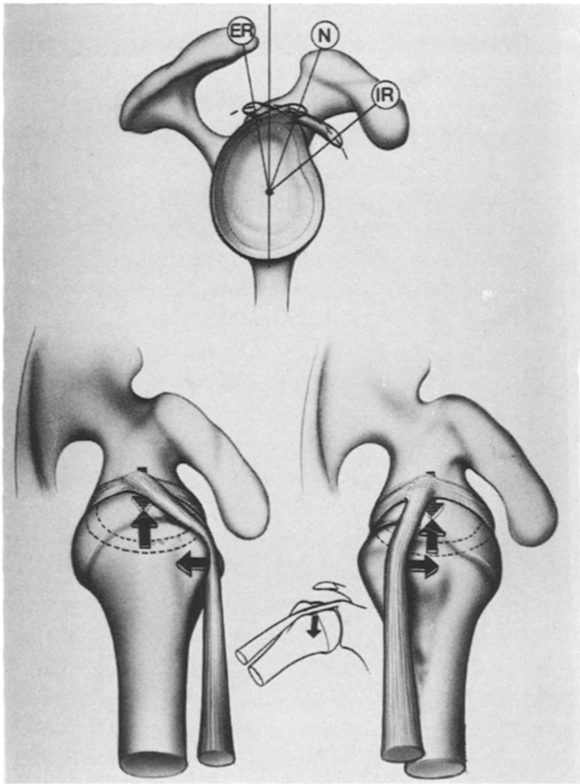

Figure 6 Diagrammatic representation of forces created with simulated contraction of long head of biceps brachii. *Top,* Rotation of humerus changes orientation of biceps tendon with respect to joint. In neutral rotation *(N)* tendon generally occupies slightly anterior position. With internal rotation *(IR)* tendon lies anterior to joint. In contrast, tendon occupies slightly posterior position with external rotation *(ER). Bottom left,* With internal rotation of humerus, biceps appears to generate joint compressive forces *(paired arrows)* and posteriorly directed force *(single arrow),* which restrain glenohumeral translation. *Bottom right,* With external rotation of humerus, anteriorly directed force *(single arrow)* appears to accompany joint compressive forces *(paired arrows).*

each of the seven positions the shoulder was tested with a 22 N joint compressive load with and without the application of a 55 N force on the tendon of the long head of the biceps. The effect of varying the force on the long head of the biceps brachii was examined in six of the shoulders. In these six shoulders additional tests were performed with lesser forces (15, 25, and 40 N) on the biceps tendon with a 22 N joint compressive load. These additional tests were performed only in the position of 45° of elevation and neutral rotation. In the same shoulder position the effect of increasing the joint compressive load was analyzed in four shoulders. These four shoulders were tested with a 111 N joint compressive load with and without a 55 N biceps force.

The anterior, posterior, superior, and inferior translations that resulted from the application of 50 N anterior, posterior, superior, and inferior displacement forces were recorded for each test. Mean translations, SD, and SEM were then determined for each shoulder position under each testing condition. Repeated measures analysis of variance (ANOVA) with two independent factors (elevation angle and specific test condition) were performed for tests conducted at 45° and 90° of elevation.[3,4] Because only one position of rotation existed for 0° of elevation, repeated measures ANOVA with one independent variable (specific test condition) was performed for tests conducted in this position. The ANOVA was then followed by post hoc paired *t* tests for humeral head positions and translations of interest.[20] α was set at 0.05.

RESULTS

Effect of the biceps force on humeral head translation. ANOVA showed that the application of the biceps force had a significant effect on humeral head translation ($p < 0.0001$). The interaction of the biceps force and the specific test condition was also significant at 45° and 90° of elevation ($p < 0.0001$) and at 0° of elevation ($p = 0.0006$). Specific statistically significant changes in humeral head translation as determined by post hoc *t* tests are described in the following text (Figure 3). When a 50 N anterior force was applied at 90° of elevation, application of a 55 N biceps force (Figure 3, *A*) caused anterior translation to be significantly reduced in neutral rotation by 4.9 mm ($p = 0.008$) and in internal rotation by 5.7 mm ($p = 0.006$). When a 50 N posterior force was applied, posterior translation was reduced in neutral rotation by 2.4 mm ($p = 0.008$) and in external rotation by 4.2 mm ($p = 0.0002$). Small decreases in superior translation were noted in each position of rotation when a 50 N superior force was applied. Superior translation (Figure 3, *B*) was reduced by 1.6 mm in neutral rotation ($p = 0.001$), by 1.2 mm in internal rotation ($p = 0.009$), and by 1 mm in external rotation ($p = 0.006$). Inferior translation was slightly reduced in neutral rotation by 1.8 mm ($p = 0.02$) and in external rotation by 1.9 mm ($p = 0.002$) when a 50 N inferior force was applied.

At 45° of elevation forced anterior, inferior, and superior translations were reduced by a 55 N biceps force in all positions of rotation. The magnitudes of the changes in anterior and inferior translation were large when the humerus was in neutral or internal rotation. In neutral rotation anterior translation decreased by 10.4 mm ($p = 0.001$), inferior translation was decreased by 5.3 mm ($p = 0.01$), and superior translation was reduced by 1.2 mm ($p = 0.004$). With internal translation anterior translation decreased by 17.4 mm ($p < 0.0001$), inferior translation was reduced by 8.7 mm ($p < 0.0001$), and superior translation decreased by 0.7 mm ($p = 0.0004$). With external rotation anterior translation was reduced by 1.2 mm ($p = 0.04$), inferior translation decreased by 3.6 mm ($p = 0.03$), and superior translation was reduced by 1.2 mm ($p = 0.001$). Posterior translation was also reduced by 3.6 mm with external rotation of the humerus ($p = 0.02$).

With the shoulder at 0° of elevation and neutral rotation, the application of a biceps force significantly reduced anterior translation by 9.2 mm ($p = 0.02$) and decreased inferior translation by 5.7 mm ($p = 0.01$) compared with the vented condition.

Effect of varying biceps force and joint compressive load. In a position of 45° of elevation and neutral rotation, the effects of varying the magnitudes of the biceps force and the joint compressive load were examined (Figure 4). When the shoulders were subjected to a 22 N joint compressive load and to 50 N anterior and posterior forces, the application of a 15 N biceps force significantly decreased anterior translation by 6.3 mm ($p = 0.02$) compared with the translation resulting when no force was placed on the biceps. Anterior translation continued to decrease as the biceps force was sequentially increased to a maximum of 55 N. With a 55 N biceps force anterior translation was further reduced by 3.7 mm compared with when a 15 N biceps force was applied. Posterior translation was not significantly affected with any magnitude of biceps force in this shoulder position.

When a 111 N joint compressive force was applied to the shoulder, both anterior and posterior translations were significantly decreased compared with when a 22 N joint compressive load was used (Figure 5). Application of a 55 N biceps force in addition to the 111 N joint compressive load further reduced anterior translation by 1.5 mm. In part because of the small number of shoulders tested under these conditions, this change was not significant. Posterior translation was not affected by the addition of a biceps force.

DISCUSSION

The results of this cadaveric study suggest that the long head of the biceps brachii contributes to shoulder stability. Application of a force to the biceps tendon reduced both anteroposterior and superoinferior translations. Recent cadaveric studies examined the effect of the long head of the biceps on anterior stability while the glenohumeral joint was maintained in abduction and external humeral rotation. The results of these studies support a role for the biceps in stabilizing the shoulder. Itoi et al.[7, 8] found that loading the long and short heads of the biceps significantly reduced anterior displacement of the humeral head and that their role in stabilizing the shoulder increased after a Bankart lesion was created. Rodosky et al.[15] found that application of a force to the long head of the biceps reduced stress on the inferior glenohumeral ligament and increased resistance to torsional forces.

In this study the effect of the long head of the biceps on anterior, posterior, superior, and inferior translation of the humeral head was assessed in multiple shoulder positions. The stabilizing mechanisms of the shoulder joint are generally classified into static and dynamic categories. The effects of bony architecture, negative intraarticular pressure, the glenoid labrum, the capsule, and the glenohumeral ligaments are usually considered to be static restraints to glenohumeral translation. The rotator cuff muscles are considered to be the primary dynamic contributors to shoulder stability. Contraction of the rotator cuff is believed to compress the humeral head into the glenoid fossa, requiring an increased force to cause humeral head translation.[10, 12] In addition, some authors have hypothesized that selective contraction of the rotator cuff musculature may allow subtle adjustments in response to changes in capsuloligamentous tension.[16] If the rotator cuff is damaged or inactive during a particular activity or if the capsular ligaments are insufficient, the importance of the biceps may increase. Loss of biceps function may result in increased glenohumeral translation, which could lead to or aggravate clinical symptoms.

The effect of simulated contraction of the long head of the biceps on anteroposterior translation was dependent on the position of the shoulder. The biceps tended to stabilize the joint anteriorly when the arm was internally rotated and served as a posterior stabilizer when the humerus was externally rotated (Figure 6). The effect of the biceps was more pronounced with the arm at the lower and middle elevation angles. These variations in the effect of the biceps tendon may be related to its anatomic position in relation to the joint and to the generation of joint compressive forces. Another possible factor in the stabilizing effect of the long head of the biceps relates to the intimate relationship between the superior portion of the glenoid labrum and the supraglenoid insertion of the biceps tendon. The superior and middle glenohumeral ligaments, which are believed to be important in controlling anteroposterior and inferior translation at lower elevation levels,[17, 18] are attached to the superior portion of the labrum as well. Because the superior portion of the labrum is quite mobile in the normal situation, it is conceivable that tension in the biceps would be transmitted through the labrum and into the superior and middle glenohumeral ligaments. Tension in these capsular ligaments would contribute to joint stability, particularly at lower levels of elevation.

The biceps has been characterized as a "depressor" of the humeral head that creates a fulcrum to allow elevation of the arm.[9, 13, 14] This term implies that contraction of the biceps causes an inferior translation of the humeral head. We found that simulated biceps contraction reduced both superior and inferior translations. These findings suggest the biceps centers the humeral head on the glenoid, stabilizing the fulcrum, which allows arm elevation. Hypertrophy of the biceps tendon commonly occurs after the rotator cuff tears.[11, 13, 14, 16] Such hypertrophy could represent an attempt to constrain the humeral head through the secondary restraint of the biceps tendon.

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REFERENCES

1. Andrews JR, Carson WG, McLeod WD. Glenoid labrum tears related to the long head of the biceps. Am J Sports Med 1985;13:337-41.
2. Bassett RW, Browne AO, Morrey BF, An KN. Glenohumeral muscle force and moment mechanics in a position of shoulder instability. J Biomech 1990;23:405-15.
3. Bowen MK, Deng X, Warner JJP, Torzilli PA, Warren RF. The effect of joint compression on stability of the glenohumeral joint. Trans Orthop Res Soc 1992;17:289.
4. Cox GEP, Hunter WG, Hunter JS. Statistics for experimenters. New York: John Wiley and Sons, 1992.
5. Glousman R, Jobe F, Tibone J, Moynes D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. J Bone Joint Surg Am 1988;70A:220-6.
6. Itoi E, Motzkin NE, Morrey BF, An K-N. The stabilizing function of the long head of the biceps with the arm in the hanging position. Orthop Trans 1992-1993;16:775.
7. Itoi E, Kuechle DK, Newman SR, Morrey BF, An K-N. Stabilising function of the biceps in stable and unstable shoulders. J Bone Joint Surg Br 1993;75B:546-50.
8. Itoi E, Newman SR, Kuechle DK, Morrey BF, An K-N. Dynamic anterior stabilisers of the shoulder with the arm in abduction. J Bone Joint Surg Br 1994;76B:834-6.
9. Kumar VP, Satku K, Balasubramaniam P. The role of the long head of the biceps brachii in the stabilization of the head of the humerus. Clin Orthop 1989;244:172-5.
10. Lippitt SB, Vanderhooft E, Harris SL, Sidles JA, Harryman II DT, Matsen III FA. Glenohumeral stability from concavity-compression: a quantitative analysis. J SHOULDER ELBOW SURG 1993;2:27-35.
11. Matsen III FA, Arntz CT. Rotator cuff failure. In: Rockwood C, Matsen F, editors. The shoulder. Philadelphia: WB Saunders, 1990:647-65.
12. Matsen III FA, Harryman DT, Sidles JA. Mechanics of glenohumeral instability. Clin Sports Med 1991;10:783-8.
13. Neer II CS. Anterior acromioplasty for the chronic impingement syndrome in the shoulder: a preliminary report. J Bone Joint Surg Am 1972;54A:41-50.
14. Neer II CS. Impingement lesions. Clin Orthop 1983;173: 70-7.
15. Rodosky MW, Harner CH, Fu FH. The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. Am J Sports Med 1994;22:121-30.
16. Terry GC, Hammon D, France P, Norwood LA. The stabilizing function of passive shoulder restraints. Am J Sports Med 1991;19:26-34.
17. Ting A, Jobe F, Barto P, Ling B, Moynes D. An EMG analysis of the lateral biceps in shoulders with rotator cuff tears. Orthop Trans 1987;11:237.
18. Warner JJP, Deng X, Warren RF, Torzilli PA. Static capsuloligamentous constraints to superior-inferior translation of the glenohumeral joint. Am J Sports Med 1992;20:675-85.
19. Warner JJP, Deng X, Warren RF, Torzilli PA, O'Brien SJ. Superoinferior translation in the intact and vented glenohumeral joint. J SHOULDER ELBOW SURG 1993;2:99-105.
20. Yusuf S, Wittes J, Probstfield J, Tyroler HA. Analysis and interpretation of treatment effects in subgroups of patients in randomized clinical trials. JAMA 1991;266:93-8.