Effect of lesions of the superior portion of the glenoid labrum on glenohumeral translation

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Effect of Lesions of the Superior Portion of the Glenoid Labrum on Glenohumeral Translation*

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ABSTRACT: Lesions of the superior portion of the glenoid labrum were created in seven cadaveric shoulders. The shoulders were mounted on a special apparatus attached to a servocontrolled hydraulic materials-testing device. Sequential fifty-newton anterior, posterior, superior, and inferior forces and a twenty-two-newton joint compressive load were applied to the shoulders. In addition, a fifty-five-newton force was applied to the tendon of the long head of the biceps brachii. The shoulders were tested in seven positions of glenohumeral elevation and rotation.

An isolated lesion of the anterosuperior portion of the labrum, which did not involve the supraglenoid insertion of the biceps brachii, had no significant effect on anteroposterior or superoinferior glenohumeral translation, either with or without application of the fifty-five-newton force to the biceps brachii tendon. In contrast, a complete lesion of the superior portion of the labrum that destabilized the insertion of the biceps resulted in significant increases in anteroposterior and superoinferior glenohumeral translations. At 45 degrees of glenohumeral elevation, the complete lesion led to a 6.0-millimeter increase in anterior translation when the arm was in neutral rotation and to a 6.3-millimeter increase when the arm was in internal rotation; inferior translation also increased, by 1.9 to 2.5 millimeters. The increases in translation persisted despite application of a fifty-five-newton force to the long head of the biceps.

The glenoid labrum contributes to the stability of the glenohumeral joint by increasing the concavity of the glenoid fossa[13,15,21,22]. While detachment of the anteroinferior portion of the labrum is recognized as an important part of anterior instability of the shoulder[3,16], the pathomechanics of lesions of the superior portion of the labrum have not been clearly described. Detachment of the superior portion of the labrum from the glenoid in association with increased motility of the tendon of the long head of the biceps brachii has been observed after injury to the shoulder, notably in athletes who engage in sports activities involving throwing[2,10,20]. On the basis of our clinical experience suggesting increases in glenohumeral translation in association with lesions of the superior portion of the labrum[1,6,18], we undertook a biomechanical investigation of cadavera in order to evaluate the effect of detachment of the superior portion of the labrum on translations of the glenohumeral joint.

Materials and Methods

Preparation of Specimens

Eleven fresh-frozen specimens of the shoulder were obtained from cadavera and were examined with use of anteroposterior radiographs. Two shoulders had radiographic evidence of osteoarthrotic changes and were excluded.

All tissues superficial to the rotator cuff muscles were removed. The rotator cuff muscles were amputated approximately eight centimeters medial to the joint, leaving the lateral portion of the rotator cuff intact and attached to the scapula. This technique ensured that the capsular attachments on the glenoid were not disrupted during dissection. The medial portion of the scapula was exposed subperiosteally, and the most medial portion of the exposed scapula was resected with a table saw. The distal portion of the humerus was sectioned in the middle portion of the shaft and was exposed subperiosteally. The tendon of the long head of the biceps brachii was preserved. Two specimens were excluded because a full-thickness tear of the supraspinatus tendon was noted after dissection. This left seven shoulders for the biomechanical testing. These seven specimens had been obtained from five men and two women whose ages had ranged from forty-seven to seventy-two years at the time of death.

The osseous ends of the dissected specimens were fixed in stainless-steel cylindrical holders with epoxy cement. The surface of the glenoid was oriented perpendicular to the long axis of the scapular cylinder. The distal

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portion of the humerus was placed in the center of the humeral cylinder; an air cylinder with a 5/16-inch (0.79-centimeter) bore and a one-inch (2.54-centimeter) stroke (Bimba Manufacturing, Monee, Illinois) was also placed in the humeral cylinder and was aligned with the longitudinal axis of the long head of the biceps brachii. The shoulders were re-examined with biplanar radiography to verify that the articular surface of the glenoid was aligned perpendicular to the long axis of the scapular cylinder.

Because of the intimate relationship between the tendon of the long head of the biceps brachii and the superior portion of the labrum[7], the effect of a lesion of the superior portion of the labrum during simulated contraction of the long head of the biceps was also studied. Two number-1 braided, Teflon (polytetrafluoroethylene) impregnated polyester traction sutures (Deknatel, Fall River, Massachusetts) were placed in the biceps tendon with a modification of the Bunnell method, under direct visualization, as the tendon entered the bicipital groove of the humerus. Care was taken not to disrupt the transverse humeral ligament. The Bunnell technique prevented slippage of the sutures within the tendon. The sutures were connected to the air-cylinder piston by passing them through a small metal coupler, which was fixed to a threaded rod on the end of the piston.

During testing, the tissues were constantly moist-

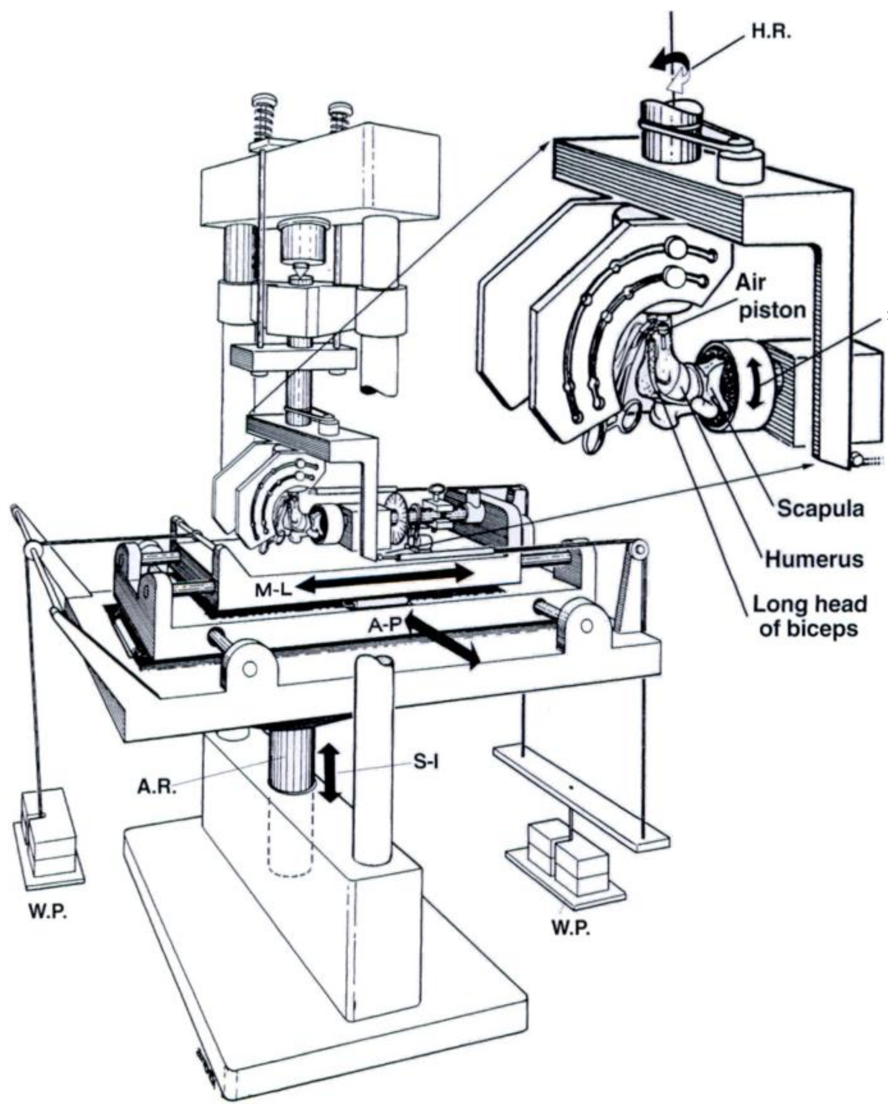

FIG. 1

Drawing of the shoulder-testing apparatus. Free mediolateral (M-L) and anteroposterior (A-P) translations were permitted along two parallel platforms when a fifty-newton superoinferior (S-I) force was applied to the shoulder. The testing apparatus was mounted on the actuator ram (A.R.) of a servocontrolled hydraulic materials-testing system. Maximum internal-external rotation of the humerus (H.R.) was determined by application of a five-newton-meter moment with use of a torque wrench. A twenty-two-newton joint compressive load was applied by the suspension of weights from two weight platforms (W.P.). Humeral flexion-extension and scapular rotation (S.R.) were held constant during each test. An air cylinder permitted application of a fifty-five-newton force to the tendon of the long head of the biceps brachii. (Modified, with permission, from: Warner, J. J.; Deng, X. H.; Warren, R. F.; and Torzilli, P. A.: Static capsuloligamentous restraints to superior-inferior translation of the glenohumeral joint. Am. J. Sports Med., 20: 676-677, 1992.)

ened by loosely wrapped gauze that had been saturated with a glycerol-based solution. The solution was applied to the gauze periodically during the testing procedure.

Testing Apparatus and Protocol

The specimens were tested with use of a special shoulder apparatus that was mounted on a servocontrolled hydraulic materials-testing system (MTS, Minneapolis, Minnesota)[5,23,25,26] (Fig. 1). The scapular cylinder was mounted on a horizontal shaft, with the plane of the glenoid oriented parallel to the actuator ram of the materials-testing system. The humeral cylinder was placed in a third metal cylinder, which was fixed between two parallel plates and attached to a 2.2-kilonewton load-cell (Lebow, Troy, Michigan). The apparatus permitted application of sequential anterior, posterior, superior, and inferior forces to the shoulder. These forces were applied perpendicular to the plane of the scapula.

Weights were suspended from the portions of the apparatus that supported the humeral and scapular cylinders in order to apply a small (twenty-two-newton) joint compressive load to stabilize the shoulder. This load was isolated from the testing apparatus and oriented perpendicular to the face of the glenoid to avoid the application of bending moments to the load-cell.

The testing apparatus allowed free translations of the humeral head with respect to the surface of the glenoid. Mediolateral, anteroposterior, and superoinferior translations were measured with linear variable differential transducers (Shaevitz Engineering, Pennsauken, New Jersey)[9,14,24]. The three rotations of the humerus (horizontal flexion-extension, elevation, and internal-external rotation) were constrained. Horizontal flexion was held constant with the humerus in the plane of the scapula. Elevation was defined as abduction in the plane of the scapula. Applied forces and resultant translations were continuously recorded with a data-acquisition computer system.

The apparatus permitted the shoulder to be placed in three positions of glenohumeral elevation (0, 45, and 90 degrees) in the scapular plane. A reference neutral rotation for internal-external rotation of the humerus was defined in each position of elevation by applying five-newton-meter internal-external rotational moments to the inner humeral cylinder, which was allowed to rotate within the outer humeral cylinder. Resultant internal and external rotations were measured, and the reference neutral rotation was defined as the mid-point between total internal and external rotations.

Two starting positions, called the reference neutral translation positions, were determined for anteroposterior and superoinferior translations of the humeral head by locating the most medial position of the head where it fit most deeply into the glenoid fossa. This was accomplished by determining the maximum medial translation (position) of the humeral head with use of fifty-newton anteroposterior and superoinferior forces and a twenty-two-newton joint compressive load[5]. These neutral positions were determined for each position of elevation of the shoulder. All subsequent motions of the humeral head on the glenoid fossa were measured relative to these positions. Measurement of these translations was permitted through the use of the linear variable differential transducers, which were connected to the testing device[9,14,24]. The data were transmitted to the computerized data-acquisition system, where they were recorded.

Activation of the air cylinder resulted in application of a constant fifty-five-newton force (the so-called biceps force, designed to simulate contraction of the biceps muscle) to the tendon of the long head of the biceps. The magnitude of the force was based on a report in which the maximum moment generated by the long head of the biceps was predicted[4]. This force was calibrated with use of a load-cell. The load on the biceps was removed in certain test situations by disconnecting the air cylinder from both the air-compression source and the traction sutures in the biceps tendon.

Each shoulder was tested in three positions of internal-external rotation (neutral, 30 degrees of internal rotation, and 30 degrees of external rotation) at 90 and 45 degrees of elevation. At 0 degrees of elevation, the shoulder was tested in the neutral internal-external rotation position only. Thus, each shoulder was tested in seven different positions.

Before testing, each shoulder was vented with an 18-gauge needle to eliminate the effect of negative intra-articular pressure. The mounted shoulder was examined with an arthroscope to visualize the superior portion of the labrum and the intra-articular aspect of the tendon of the long head of the biceps. A standard posterior arthroscopic portal was created three centimeters inferior and two centimeters medial to the posterolateral corner of the acromion. A second portal was created through the inferior portion of the capsule. A number-15 scalpel was used to open the portals, which were oriented transversely to avoid transection of the capsular ligaments. The same portals were used

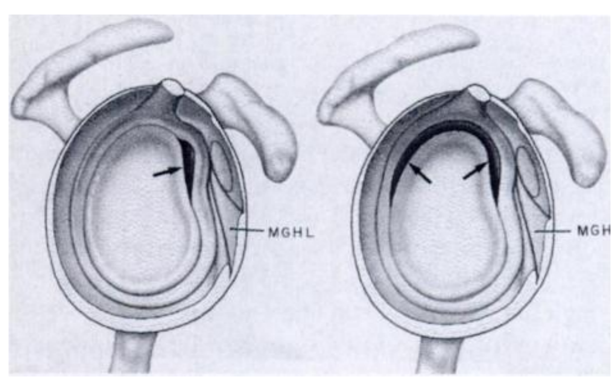

FIG. 2

En face views of the glenoid fossa with the arrows pointing to the simulated anterosuperior lesion (left) and the complete lesion (right) of the superior portion of the labrum. MGHL = middle glenohumeral ligament.

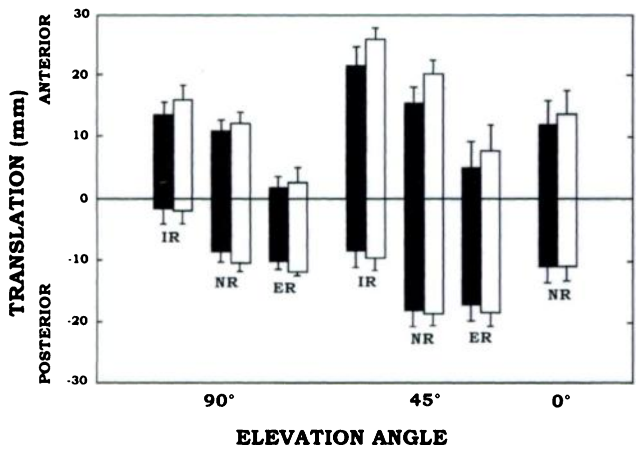

FIG. 3-A

Figs. 3-A through 3-D: Bar graphs showing the effect of the anterosuperior lesion of the superior portion of the labrum on glenohumeral translation without and with a force applied to the long head of the biceps brachii. A twenty-two-newton joint compressive load and fifty-newton anterior, posterior, superior, and inferior forces were applied to the shoulders. The black bars represent mean translations with the shoulder in the vented condition before creation of the lesion, and the white bars represent mean translations after creation of the lesion. The I-bars represent the standard error of the mean. No significant increases in translation resulted from the lesion. IR = internal rotation, NR = neutral rotation, and ER = external rotation.

Fig. 3-A: Anteroposterior translation without the force applied to the biceps brachii.

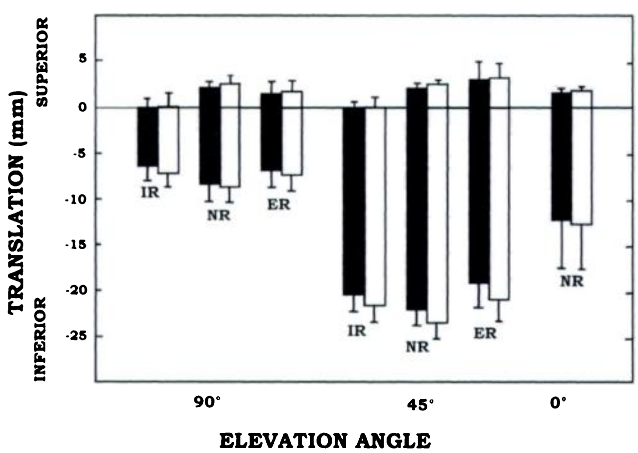

FIG. 3-B

Superoinferior translation without the force applied to the biceps brachii.

repeatedly in each shoulder; no additional portals were created. The arthroscope was introduced through the posterior portal. The joint was examined without irrigation. The labrum and the glenohumeral ligaments were identified. An arthroscopic probe was introduced through the inferior portal and was used to palpate the superior portion of the labrum and the glenohumeral ligaments. No shoulder demonstrated abnormal motility of the superior portion of the labrum. Lack of capsular distention made characterization of the quality of the capsular ligaments difficult, but the superior and middle glenohumeral ligaments were identified in each specimen near their glenoid insertions in association with the superior portion of the labrum[7,8,25].

Sequential fifty-newton anterior, posterior, superior, and inferior forces were then applied to the shoulder in each of the seven positions already described. The translations that occurred secondary to these loads were recorded for the vented shoulder. The shoulder was tested in each position both with and without application of a fifty-five-newton force to the biceps tendon.

Creation of the Lesion of the Superior Portion of the Labrum

An arthroscopic knife-rasp was introduced through the inferior portal and was used to strip the anterosuperior portion of the labrum from the margin of the glenoid with a subperiosteal technique. The region of the labrum immediately beneath the biceps tendon was left intact, while the portion anterior to the biceps was stripped to a point corresponding to the inferior extent of the glenoid insertion of the middle glenohumeral ligament (Fig. 2, left). Thus, the glenoid attachments of

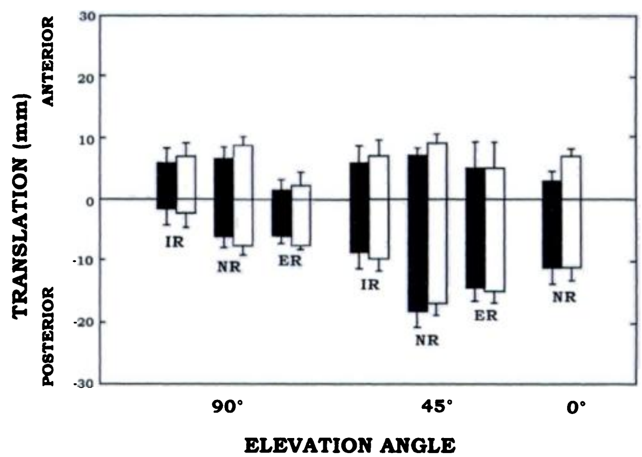

FIG. 3-C

Anteroposterior translation with the force applied to the biceps brachii.

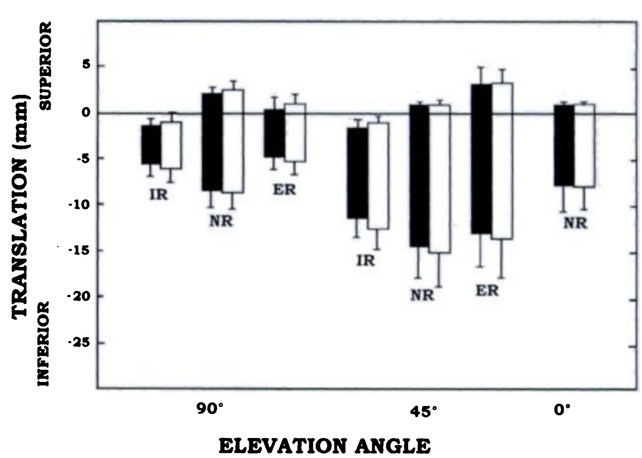

FIG. 3-D

Superoinferior translation with the force applied to the biceps brachii.

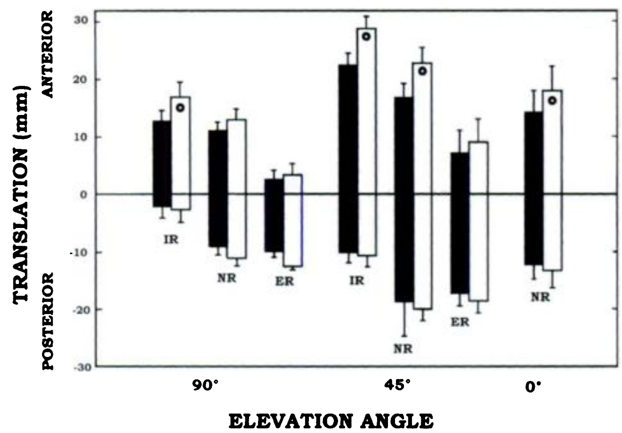

FIG. 4-A

Figs. 4-A through 4-D: Bar graphs showing the effect of the complete lesion of the superior portion of the labrum on glenohumeral translation without and with a force applied to the long head of the biceps brachii. A twenty-two-newton joint compressive load and fifty-newton anterior, posterior, superior, and inferior forces were applied to the shoulder. The black bars represent mean translations with the shoulder in the vented condition before creation of the lesion, and the white bars represent mean translations after creation of the lesion. The I-bars represent the standard error of the mean. Significant increases in translation that resulted from the lesion are indicated by black circles within the white bars. IR = internal rotation, NR = neutral rotation, and ER = external rotation.

Fig. 4-A: Anteroposterior translation without the force applied to the biceps brachii.

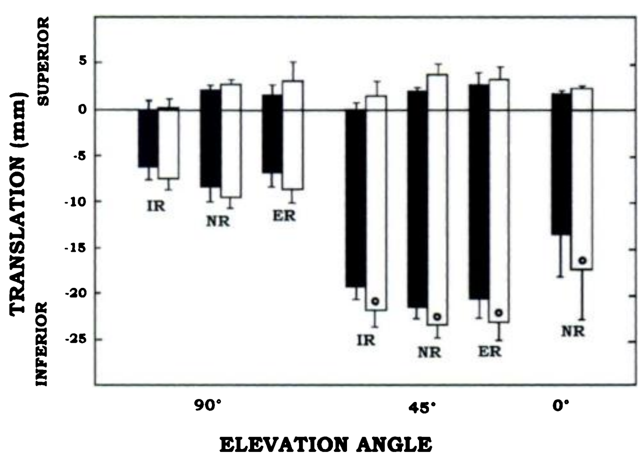

FIG. 4-B

Superoinferior translation without the force applied to the biceps brachii.

the superior and middle glenohumeral ligaments were disrupted by creation of the lesion[8]. The shoulders were tested again in each of the seven positions, both with and without application of a force to the biceps, and the resultant translations were recorded for the simulated anterosuperior lesions.

After this second series of tests, the shoulders were again visualized arthroscopically. The knife-rasp was used to extend the labral lesion posteriorly to a point that was in approximately the same transverse plane as the most inferior point of the anterosuperior lesion. This enlarged lesion included the portion of the labrum that was intimately connected to the biceps tendon as well as the portion that was intimately associated with the glenoid attachments of the posterosuperior aspect of the capsule (Fig. 2, right). Creation of this more extensive lesion consistently led to a functional lengthening of the proximal portion of the biceps tendon, which exceeded the available stroke of the air cylinder. Therefore, it was necessary to relocate the sutures to a more proximal portion of the biceps tendon in order for the air cylinder to maintain a constant force on the tendon. The shoulders were then retested in each of the seven positions, both with and without application of a force to the biceps, and the resultant translations were recorded for the simulated complete lesions.

After the biomechanical testing had been completed, each shoulder was dissected to ensure that a satisfactory lesion had been created and that the traction sutures had remained in place without slippage within the biceps tendon.

Anterior, posterior, superior, and inferior translations that resulted from application of fifty-newton anterior, posterior, superior, and inferior displacement

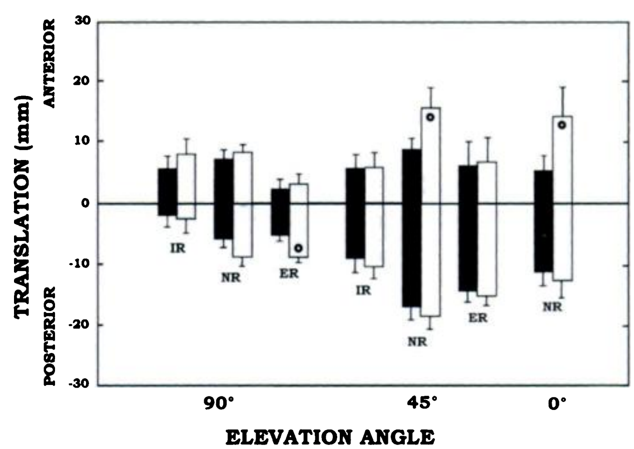

FIG. 4-C

Anteroposterior translation with the force applied to the biceps brachii.

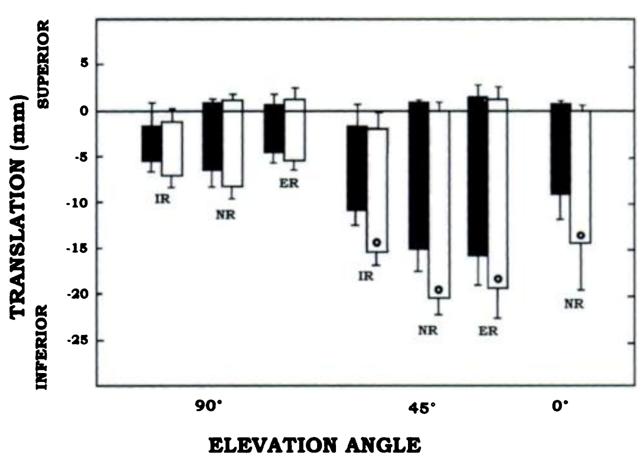

FIG. 4-D

Superoinferior translation with the force applied to the biceps brachii.

forces were recorded for each test. Mean translations, standard deviations, and standard errors of the mean were then calculated for each test condition.

For the tests conducted at 45 and 90 degrees of glenohumeral elevation, repeated-measures analyses of variance with two independent factors (the angle of elevation and the specific test condition) were performed. Separate analyses were performed for data regarding anteroposterior translations and for data regarding superoinferior translations. Since only one position of rotation was tested at 0 degrees of elevation, repeated-measures analysis of variance with one independent variable (the specific test condition) was performed for tests conducted in this position. The analyses of variance were followed by special-effects analysis for the positions and translations of the humeral head that were of interest. Special-effects analysis is similar to a separate one-way analysis of variance at each level of grouping factor except that the same repeated-measures error term is used as was used in the full analysis. The value for alpha was set at 0.05.

Results

Effect of the Anterosuperior Lesion

With the numbers available, the anterosuperior labral lesion had no significant effect on anteroposterior or superoinferior translation compared with the translation when the shoulder was in the vented condition. There was no effect with or without application of a fifty-five-newton force to the long head of the biceps (Figs. 3-A through 3-D).

Effect of the Complete Lesion

Analysis of variance revealed that the complete lesion had a significant effect on anteroposterior ($p = 0.04$) and superoinferior ($p < 0.0001$) translations of the humeral head at 45 and 90 degrees of elevation, as well as at 0 degrees of elevation ($p = 0.04$ and $p = 0.006$ for anteroposterior and superoinferior translations, respectively). The interaction of the complete lesion and the specific test condition was significant at 45 and 90 degrees of elevation ($p < 0.0001$), but, with the numbers available, it was not significant at 0 degrees of elevation ($p = 0.07$).

Creation of the complete lesion resulted in increases in glenohumeral translations, as determined with special-effects analysis (Figs. 4-A and 4-B). Without application of a force to the biceps, there was a significant increase in anterior translation of 4.0 millimeters with the arm in 90 degrees of elevation and internal rotation ($p = 0.004$). At 45 degrees of elevation, there was a significant increase in anterior translation of 6.0 millimeters with the arm in neutral rotation and of 6.3 millimeters with the arm in internal rotation ($p < 0.0001$ for both). Inferior translation increased significantly with the arm in all positions of internal-external rotation (1.9 millimeters with the arm in neutral rotation [$p = 0.05$], 2.5 millimeters with the arm in internal rotation [$p = 0.01$], and 2.5 millimeters with the arm in external rotation [$p = 0.01$]). The complete lesion also resulted in significant increases of 3.7 millimeters for anterior translation ($p = 0.04$) and of 3.8 millimeters for inferior translation ($p = 0.001$) with the arm in 0 degrees of elevation and neutral rotation.

Effect of the Force Applied to the Biceps in the Presence of the Complete Lesion

The force applied to the biceps reduced over-all translation in the presence of the complete lesion (Figs. 4-C and 4-D). However, translations remained increased compared with those measured with the shoulder in the vented condition.

Specific increases in translations of the humeral head were determined with a special-effects analysis. At 90 degrees of elevation and external rotation, a significant increase in posterior translation of 3.6 millimeters was noted ($p = 0.009$). At 45 degrees of elevation, there was a significant increase in anterior translation of 6.8 millimeters with the arm in neutral rotation ($p < 0.0001$). Inferior translation increased significantly with the arm in all positions of internal-external rotation (5.3 millimeters with the arm in neutral rotation [$p < 0.0001$], 4.5 millimeters with the arm in internal rotation [$p < 0.0001$], and 3.5 millimeters with the arm in external rotation [$p = 0.0004$]). At 0 degrees, there were significant increases of 9.0 millimeters for anterior translation ($p = 0.004$) and 5.4 millimeters for inferior translation ($p = 0.003$).

Discussion

The data from this study of cadavera show that lesions of the superior portion of the glenoid labrum that involve the supraglenoid insertion of the biceps increase glenohumeral translation in a number of directions in the lower and middle ranges of elevation. The labrum deepens the glenoid socket and may also serve as a chock, acting as a wedge in preventing glenohumeral translation[13]. Lippitt et al. recently reported that resection of the labrum reduced resistance to translation in shoulders that were subjected to a compressive load. When the humeral head articulates with the periphery of the glenoid, it may articulate with the labrum as well[21]. The presence of the labrum increases the articular surface of the glenoid[22], and separation of the labrum from the glenoid rim decreases the concavity of the socket.

The superior portion of the labrum serves as a site of attachment for the superior and middle insertions of the glenohumeral ligament and for the posterosuperior aspect of the capsule[7,8]. Therefore, detachment of the labrum affects these superior capsular structures (Fig. 5). Detachment of the glenoid insertions of the superior and middle glenohumeral ligaments, which have been shown to be important contributors to glenohumeral stability in the lower and middle ranges of elevation[17,25,26],

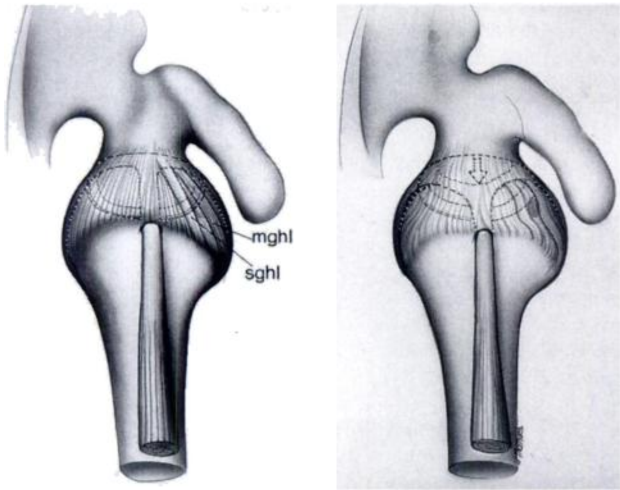

FIG. 5

Drawing depicting the effect of a complete lesion of the superior portion of the labrum on the capsular structures. (The normal shoulder is shown on the left.) With a lesion involving the supraglenoid insertion of the biceps (right), laxity of the superior capsular structures may contribute to the increases in translation that were noted. mghl = middle glenohumeral ligament and sghl = superior glenohumeral ligament.

would help to explain the increases in translation that were noted.

Several authors have thought that the long head of the biceps brachii has a role in stabilization of the shoulder[2,11,12]. In the current model, application of a force to the long head of the biceps brachii tended to stabilize the shoulder, although it was less effective in the presence of a complete lesion of the superior portion of the labrum. The long head of the biceps appears to stabilize the shoulder by generating joint compressive forces and by acting as a physical restraint to translation. In addition, the biceps tendon is indirectly connected to the superior portion of the capsule by means of the labrum[7], and tension on the biceps may increase capsular restraint by tightening the superior capsular structures. Despite application of a force to the biceps in the presence of the complete lesion of the superior portion of the labrum, translations remained increased compared with those measured with the shoulder in the vented condition.

Snyder et al. noted that lesions of the superior portion of the labrum were often associated with glenohumeral instability. Rodosky et al. found that experimental simulation of a lesion of the superior portion of the labrum that destabilized the insertion of the biceps increased strain in the anterior portion of the capsule. Recently, Burkhart and Fox reported on a patient in whom a lesion of the superior portion of the labrum that had destabilized the insertion of the biceps was associated with anterior instability. These authors hypothesized that the lesion contributed to glenohumeral laxity in this patient.

In our experience[1,18], lesions of the superior portion of the labrum that destabilize the insertion of the biceps are not usually associated with overt instability (dislocation or subluxation); however, the patient may have a subtle increase in translation of the shoulder on physical examination and may occasionally even note a sense of looseness or slippage of the shoulder. The increases in translation in the current study were relatively small, but they may be related to the symptoms associated with an isolated lesion of the superior portion of the labrum.

We noted that creation of a complete lesion of the superior portion of the labrum consistently led to a functional lengthening of the proximal portion of the biceps tendon. This lengthening increased the excursion of the tendon to a magnitude that exceeded the stroke of the air cylinder. The end of the piston therefore was in contact with the cylinder so that no force could be transmitted to the biceps tendon. We compensated for this phenomenon by placing the traction sutures more proximally in the tendon so that the air cylinder could apply a force to the tendon. *In vivo,* the biceps muscle may not be capable of compensating for this increase in excursion, and the force generated by the long head of the biceps may be reduced. Contraction of the biceps in the presence of a superior labral lesion may also be inhibited by pain. Our model, therefore, may not account for additional reductions in the stabilizing contribution of the long head of the biceps, which would result in greater increases in translation.

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References

1. **Altchek, D. W.; Warren, R. F.; Wickiewicz, T. L.;** and **Ortiz, G.:** Arthroscopic labral debridement. A three-year follow-up study. *Am. J. Sports Med.*, 20: 702-706, 1992.
2. **Andrews, J. R.; Carson, W. G., Jr.;** and **McLeod, W. D.:** Glenoid labrum tears related to the long head of the biceps. *Am. J. Sports Med.*, 13: 337-341, 1985.
3. **Bankart, A. S. B.:** Recurrent or habitual dislocation of the shoulder-joint. *British Med. J.*, 2: 1132-1133, 1923.
4. **Bassett, R. W.; Browne, A. O.; Morrey, B. F.;** and **An, K. N.:** Glenohumeral muscle force and moment mechanics in a position of shoulder instability. *J. Biomech.*, 23: 405-415, 1990.
5. **Bowen, M. K.; Deng, X. H.; Warner, J. P.; Warren, R. F.;** and **Torzilli, P. A.:** The effect of joint compression on stability of the glenohumeral joint. *Trans. Orthop. Res. Soc.*, 17: 289, 1992.
6. **Burkhart, S. S.,** and **Fox, D. L.:** Case report: arthroscopic repair of a type IV SLAP lesion — the red-on-white lesion as a component of anterior instability. *Arthroscopy*, 9: 488-492, 1993.
7. **Cooper, D. E.; Arnoczky, S. P.; O'Brien, S. J.; Warren, R. F.; DiCarlo, E.;** and **Allen, A. A.:** Anatomy, histology, and vascularity of the glenoid labrum. An anatomical study. *J. Bone and Joint Surg.*, 74-A: 46-52, Jan. 1992.

8. **DePalma, A. F.; Callery, G.;** and **Bennett, G. A.:** Variational anatomy and degenerative lesions of the shoulder joint. In *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 6, pp. 255-281. Ann Arbor, J. W. Edwards, 1949.
9. **Fukubayashi, T.; Torzilli, P. A.; Sherman, M. F.;** and **Warren, R. F.:** An in vitro biomechanical evaluation of anterior-posterior motion of the knee. Tibial displacement, rotation, and torque. *J. Bone and Joint Surg.*, 64-A: 258-264, Feb. 1982.
10. **Garth, W. P., Jr.; Allman, F. L., Jr.;** and **Armstrong, W. S.:** Occult anterior subluxations of the shoulder in noncontact sports. *Am. J. Sports Med.*, 15: 579-585, 1987.
11. **Gilcreest, E. L.:** The common syndrome of rupture, dislocation and elongation of the long head of the biceps brachii. An analysis of one hundred cases. *Surg., Gynec. and Obstet.*, 58: 322-340, 1934.
12. **Glousman, R.; Jobe, F.; Tibone, J.; Moynes, D.; Antonelli, D.;** and **Perry, J.:** Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. *J. Bone and Joint Surg.*, 70-A: 220-226, Feb. 1988.
13. **Howell, S. M.,** and **Galinat, B. J.:** The glenoid-labral socket. A constrained articular surface. *Clin. Orthop.*, 243: 122-125, 1989.
14. **Levy, I. M.; Torzilli, P. A.;** and **Warren, R. F.:** The effect of medial meniscectomy on anterior-posterior motion of the knee. *J. Bone and Joint Surg.*, 64-A: 883-888, July 1982.
15. **Lippitt, S. B.; Vanderhooft, E.; Harris, S. L.; Sidles, J. A.; Harryman, D. T., II;** and **Matsen, F. A., III:** Glenohumeral stability from concavity-compression: a quantitative analysis. *J. Shoulder and Elbow Surg.*, 2: 27-35, 1993.
16. **Morgan, C. D.,** and **Bodenstab, A. B.:** Arthroscopic Bankart suture repair: technique and early results. *Arthroscopy*, 3: 111-122, 1987.
17. **O'Connell, P. W.; Nuber, G. W.; Mileski, R. A.;** and **Lautenschlager, E.:** The contribution of the glenohumeral ligaments to anterior stability of the shoulder joint. *Am. J. Sports Med.*, 18: 579-584, 1990.
18. **Pagnani, M. J.; Speer, K. P.; Altchek, D. W.; Warren, R. F.;** and **Dines, D. M.:** Arthroscopic fixation of superior labral lesions using a biodegradable implant: a preliminary report. *Arthroscopy*, 11: 194-198, 1995.
19. **Rodosky, M. W.; Harner, C. D.;** and **Fu, F. H.:** The role of the long head of the biceps muscle and superior glenoid labrum in anterior stability of the shoulder. *Am. J. Sports Med.*, 22: 121-130, 1994.
20. **Snyder, S. J.; Karzel, R. P.; Del Pizzo, W.; Ferkel, R. D.;** and **Friedman, M. J.:** SLAP lesions of the shoulder. *Arthroscopy*, 6: 274-279, 1990.
21. **Soslowsky, L. J.; Flatow, E. L.; Bigliani, L. U.;** and **Mow, V. C.:** Articular geometry of the glenohumeral joint. *Clin. Orthop.*, 285: 181-190, 1992.
22. **Soslowsky, L. J.; Flatow, E. L.; Bigliani, L. U.; Pawluk, R. J.; Ateshian, G. A.;** and **Mow, V. C.:** Quantitation of in situ contact areas at the glenohumeral joint: a biomechanical study. *J. Orthop. Res.*, 10: 524-535, 1992.
23. **Speer, K. P.; Deng, X.; Borrero, S.; Torzilli, P. A.; Altchek, D. A.;** and **Warren, R. F.:** A biomechanical evaluation of a simulated Bankart lesion. *J. Bone and Joint Surg.*, 76-A: 1819-1826, Dec. 1994.
24. **Sullivan, D.; Levy, I. M.; Sheskier, S.; Torzilli, P. A.;** and **Warren, R. F.:** Medial restraints to anterior-posterior motion of the knee. *J. Bone and Joint Surg.*, 66-A: 930-936, July 1984.
25. **Warner, J. J.; Deng, X. H.; Warren, R. F.;** and **Torzilli, P. A.:** Static capsuloligamentous restraints to superior-inferior translation of the glenohumeral joint. *Am. J. Sports Med.*, 20: 675-685, 1992.
26. **Warner, J. J. P.; Deng, X.; Warren, R. F.; Torzilli, P. A.;** and **O'Brien, S. J.:** Superoinferior translation in the intact and vented glenohumeral joint. *J. Shoulder and Elbow Surg.*, 2: 99-105, 1993.