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The Role of the Rotator Interval Capsule in Passive Motion and Stability of the Shoulder*

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ABSTRACT: The purpose of this study was to characterize the role of the capsule in the interval between the supraspinatus and subscapularis tendons with respect to glenohumeral motion, translation, and stability. We used a six-degrees-of-freedom position-sensor and a six-degrees-of-freedom force and torque-transducer to determine the glenohumeral rotations and translations that resulted from applied loads in eight cadaver shoulders. The range of motion of each specimen was measured with the capsule in the rotator interval in a normal state, after the capsule had been sectioned, and after it had been imbricated.

Operative alteration of this capsular interval was found to affect flexion, extension, external rotation, and adduction of the humerus with respect to the scapula. Modification of this portion of the capsule also affected obligate anterior translation of the humeral head on the glenoid during flexion. Limitation of motion and obligate translation were increased by operative imbrication and diminished by sectioning of the rotator interval capsule.

Passive stability of the glenohumeral joint was evaluated with the use of anterior, posterior, and inferior stress tests. Instability and occasional frank dislocation of the glenohumeral joint occurred inferiorly and posteriorly after section of the rotator interval capsule. Imbrication of this part of the capsule increased the resistance to inferior and posterior translation.

CLINICAL RELEVANCE: The results of the present study suggest that the capsule in the rotator interval plays an important role in glenohumeral motion and stability. Release of this part of the capsule may improve the range of motion of shoulders that have limited flexion and external rotation. Conversely, imbrication of the rotator interval capsule may help to control posterior and inferior instability.

Functions have been attributed to specialized thickened capsular "ligamentous" bands, which include the anterior glenohumeral ligaments, the inferior sling, and the coracohumeral ligament[7,23,28,29]. The anatomy and function of each individual ligament have been studied, but this apparently is the first quantitative study of glenohumeral kinematics that has focused directly on the role of the capsule in the interval between the supraspinatus and the subscapularis.

The rotator cuff is perforated anterosuperiorly by the coracoid process, which separates the anterior border of the supraspinatus tendon from the superior border of the subscapularis tendon, creating the triangular rotator interval, which is bridged by capsule. The base of the interval is the coracoid process, from which capsular tissue (the coracohumeral ligament) originates. The transverse humeral ligament at the biceps intertubercular sulcus forms the apex of the rotator interval (Fig. 1-A). The coracohumeral and superior glenohumeral ligaments are considered to be structural contents of the rotator interval capsule, but each have separate origins and insertions[5,21]. These two ligaments are considered to be the most constant structures of the fibrous joint capsule[6]. In this paper, we use the term rotator interval capsule to designate the capsule and the coracohumeral ligament that bridge the gap between the supraspinatus and the subscapularis.

The coracohumeral ligament was described by DePalma as a dense fibrous structure connecting the base of the coracoid process to the greater and lesser tuberosities near the bicipital groove[5]. Classic texts on anatomy[10,11] have described the coracohumeral ligament as originating on the lateral surface of the coracoid process or, rarely, as a continuation of the pectoralis minor tendon, inserting into the greater tuberosity and blending with the supraspinatus tendon and the articular capsule. The coracohumeral ligament has a broad, thin origin, one to two centimeters wide, near the base of the coracoid process, along its lateral border.

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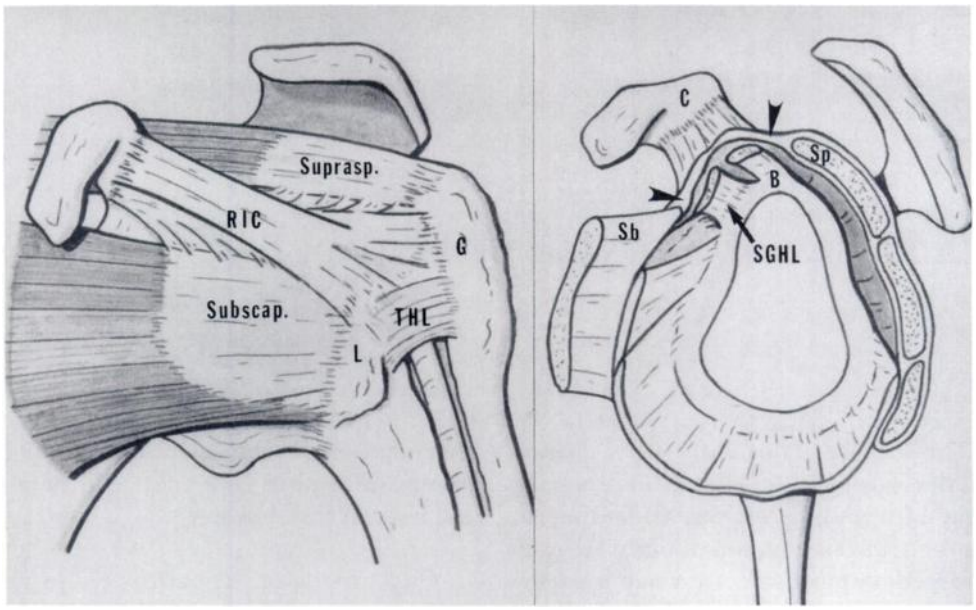

FIG. 1-A FIG. 1-B

Fig. 1-A: The boundaries of the rotator interval capsule (RIC) include the lateral part of the coracoid base, the anterior border of the supraspinatus (Suprasp.), and the superior border of the subscapularis (Subscap.). The apex of the interval is the transverse humeral ligament (THL). The fibers of the capsule and coracohumeral ligament blend together and insert into the borders of the supraspinatus and subscapularis, the transverse humeral ligament, and the greater (G) and lesser (L) tuberosities. This anatomical sketch is drawn from the specimen shown in Figure 1-C.

Fig. 1-B: Anatomical sketch of the specimen, with the humeral head removed, showing a profile of the rotator interval capsule (between the arrowheads) and its relationship to the superior glenohumeral ligament (SGHL, arrow), the origin of the long head of the biceps (B), the anterior border of the supraspinatus tendon (Sp), the superior border of the subscapularis tendon (Sb), and the base of the coracoid process (C).

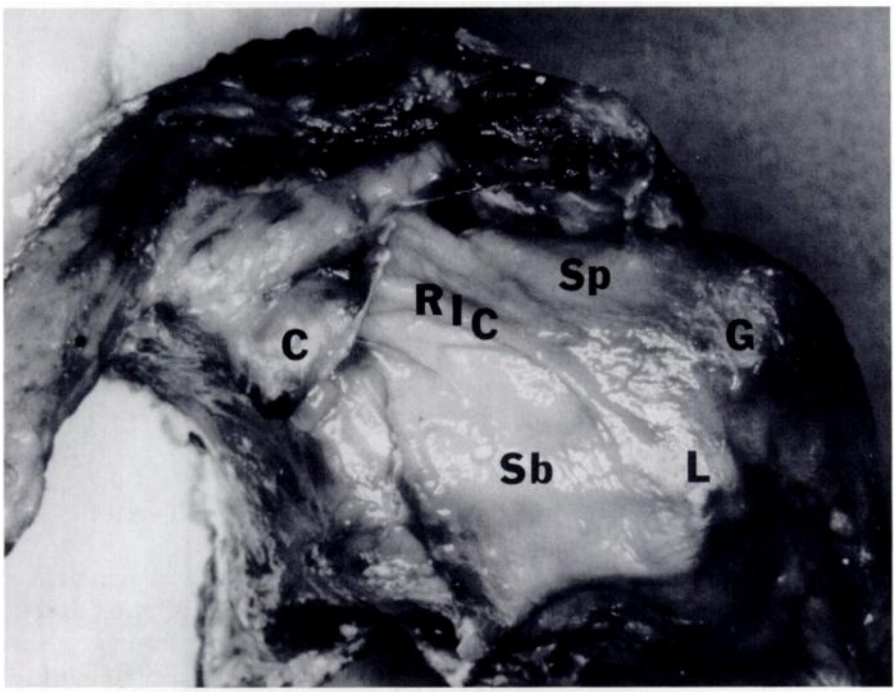

FIG. 1-C

The vertically mounted left shoulder. The specimen is distracted inferiorly to accentuate the folded, thick portion of the rotator interval capsule known as the coracohumeral ligament. Figure 1-A shows the schematic drawing of this specimen and defines the boundaries of the rotator interval capsule. RIC = rotator interval capsule, C = coracoid process, Sb = subscapularis tendon, Sp = supraspinatus tendon, L = lesser tuberosity, and G = greater tuberosity.

Moseley, whose description amplified DePalma's, stated that the coracohumeral ligament contributes to the superficial capsular roof of the interval between the supraspinatus and the subscapularis. The coracohumeral ligament divides into two major bands, one of which inserts into the tendinous anterior edge of the supra-

spinatus and the greater tuberosity and the other of which inserts into the superior border of the subscapularis, the transverse humeral ligament, and the lesser tuberosity (Figs. 1-A, 1-B, and 1-C). The fibers of these insertions are interlaced intimately and are indistinguishable from and common with those of the capsule[4]. Adjacent to their humeral attachments, the capsule, coracohumeral ligament, superior glenohumeral ligament, and rotator cuff tendons all blend together[3].

Neer et al. found the coracohumeral ligament to be a consistent, well defined structure in fifty-nine of sixty-three dissections of cadavera and absent or vestigial in four specimens. Gross dissection revealed that the origin at the base of the coracoid process extended along the lateral border for an average of eighteen millimeters. Neer et al. noted that the coracohumeral ligament inserted into the rotator interval, the supraspinatus tendon, or the subscapularis tendon.

Clark et al. studied the fibrous anatomy of the rotator cuff histologically and found that the collagenous extensions of the coracohumeral ligament envelop the cuff tendons and blend into superficial and deep layers of the supraspinatus and subscapularis as well as into the articular capsule. This relationship reinforces the capsule at the interval and the borders of these cuff tendons.

The diminutive but consistent superior glenohumeral ligament originates from the labrum adjacent to the supraglenoid tubercle and crosses the floor of the rotator interval deep to the coracohumeral ligament (Fig. 1-B)[21]. The superior glenohumeral ligament inserts into the fovea capitis of the proximal part of the humerus, which is located at the superior aspect of the lesser tuberosity.

Similar functions have been ascribed to the superior glenohumeral and coracohumeral ligaments, which reportedly provide passive resistance to inferior and posterior translation of the humeral head[2,22,23,27,28]. Recently, Nobuhara and Ikeda described operative methods that had been designed to alter the motion and stability of the glenohumeral joint by release or plication of the rotator interval.

We investigated the function of the rotator interval capsule in scapulohumeral preparations from cadavera because the capsule is a scapulohumeral structure. Data were collected from preparations in which the rotator interval capsule was anatomically normal, preparations in which it had been operatively sectioned, and preparations in which it had been imbricated. We were able to define the effects of modifications of the interval capsule on rotation, translation, and stability of the glenohumeral joint.

Methods

Our methodology was similar to that used in the study of other joints of cadavera, such as the knee. Various forces and torques were applied to the glenohumeral joint, and the resulting motion of the joint was measured. Operative alterations were performed, and changes in the motions were studied when identical forces and torques were again applied. The technical details of the application and instrumentation of the cadaveric specimens in the device that was used in the present study were similar to those of our previously reported methods[12].

Preparation of the Specimens

Eight fresh-frozen shoulders, from the cadavera of people who had been fifty-six, sixty-five, sixty-seven (both shoulders), seventy-two, seventy-four, and seventy-eight years old (both shoulders) at the time of death, were prepared with scapulothoracic, sternoclavicular, and carpal disarticulation after they were thawed on the day of use. The skin, subcutaneous tissue, muscle, and tendons that crossed the glenohumeral joint were excised, leaving the ligamentous and capsular tissue intact (Fig. 1-C). A specimen was selected only if it had a full range of glenohumeral motion, passive motion was smooth without intermittent catching or roughness, and the shoulder was stable on gross examination. Also, the joint surfaces and the rotator cuff had to be normal on inspection at the time of the dissection at the conclusion of the experiment.

Instrumentation

The vertebral border of each scapula was potted with plaster-of-Paris in a plastic dish that was five centimeters deep. This container was fixed rigidly to a vertically mounted six-degrees-of-freedom load-cell (Astek, model FS160A-600; Barry Wright, Watertown, Massachusetts) so that the scapular body and the face of the glenoid were vertical[12]. In contrast to simple load-cells, which measure force as a scalar quantity (that is, a certain number of newtons), the Astek load-cell supplies vector-applied force and vector-applied torque. The forces and torques were determined by projection of the raw data vectors that had been supplied by the sensor onto anatomical axes that were determined as will be described. Minor variations in the position of the scapula during fixation were not consequential for this reason.

The transmitter coil of a six-degrees-of-freedom spatial digitizer (Polhemus; Navigation Sciences, Colchester, Vermont) was secured to the scapula and positioned approximately fifteen centimeters lateral to the humerus. The receiving coil of this sensor was attached to the humeral shaft, as close to the humeral head as possible without interference with a full range of motion. The load-cell permitted accurate resolution of the applied forces and torques, while the six-degrees-of-freedom spatial sensor detected the translation and rotation of the humerus with respect to the scapula[12]. Data from the load-cell and the spatial sensor were recorded with the use of a Macintosh-II computer.

There is a time-lag in the spatial sensor, which we measured to be about 0.1 second for the angular outputs. We made all of our measurements quasi-statically to

prevent this from becoming a source of error[12].

We found the spatial sensor to be accurate to within one millimeter, and the angular accuracy was within 0.5 degree. This is consistent with the results of An et al. However, we did not rely on the absolute accuracy of the sensor. Instead, we used control measurements to correct systematic errors, as described in the section on Protocols for the Motion Testing[12].

Definition of the Anatomical Axes

All glenohumeral motions were defined with respect to the scapula. Thus, flexion and extension were forward and backward rotations of the humerus about a horizontal axis perpendicular to the face of the glenoid. Abduction and adduction were outward and inward rotations about a horizontal axis parallel to the face of the glenoid. External and internal rotation were outward and inward rotations about a vertical axis parallel to the humeral shaft. These scapula-referenced motions are not the same as motions that are referenced to the plane of the body, as is common in clinical evaluations of the shoulder.

Raw sensor data were transformed into results referenced to scapular axes with the use of defined manipulations of the shoulder. For specification of the scapular axes, the shoulder was placed in the neutral position and its position was recorded. Then the shoulder was flexed approximately 30 degrees, and the new position was recorded. The flexion axis was defined as the axis of the rotation between the two measured points. The anterior axis was determined in a similar manner, but with abduction of the arm, and the inferior axis was defined with external rotation of the arm. The humeral head was held centered in the socket during these motions. These measured axes were found to be orthogonal (mutually perpendicular) to within 5 degrees or less in each shoulder. The axes were rectified with the use of a singular value-decomposition technique for enforcement of orthogonality[25]. A similar technique was used to specify the defined scapular axes for the force measurements. The force axes that were determined in this way were orthogonal to within 5 degrees and rectified as described.

The so-called neutral position of the shoulder was defined by recording of the output of the spatial sensor while the humeral head was manually pressed into the glenoid socket in 0 degree of flexion, rotation, and abduction. Similarly, the so-called neutral load of the shoulder was determined by recording of the output of the force sensor while the weight of the humerus was supported.

Location of a Reference Point within the Humeral Head

Translations were computed by tracking of the motion of a reference point approximating the center of the humeral head. Control measurements ensure that net glenohumeral translations are independent of the choice of the reference point of the humeral head, as is discussed later. Location of the reference point near the center of the humeral head is desirable because it minimizes error in the control measurements.

The humeral reference point was located with the humeral head pressed into the glenoid socket, and its position and orientation were recorded in ten positions as the shoulder was flexed, extended, abducted, and internally and externally rotated through angles of less than 45 degrees — positions in which the capsule remained lax. The reference point of the humeral head was defined as the point that moved least during these maneuvers, as determined with a least-mean-squares fitting algorithm. Residual motion of the reference point of the humeral head averaged 0.7 millimeter root-mean-square. A similar technique was used to locate the reference point of the humeral head relative to the force transducer[12].

Translations were defined as motions of the reference point of the humeral head along the defined scapular axes, relative to the determined neutral position. All torques were calculated with the use of moment arms originating at the reference point of the humeral head.

Three rotations, three translations, three forces, and three torques were displayed on the computer screen during passive movement of the glenohumeral joint. This real-time presentation of data made it possible to reproduce desired motions and to apply a specified torque or force to the joint. Motions were performed manually in a fashion similar to the manipulations that are used in clinical examination of the joint. The humeral head was pressed securely into the glenoid concavity while each motion was performed.

Measurement of Force and Torque

We chose a maximum net torque magnitude of 1500 newton-millimeters for each specified plane of motion, because this level of torque did not cause failure of tissue or sutures in previous experiments[12,22,23] and was sufficient to cause reproducible translation, as evidenced on analysis of multiple repetitions for each shoulder and each motion. For example, the mean standard deviation for multiple repetitions (two and three trials) among all shoulders for flexion angles and anterior translation at 1500 newton-millimeters of flexion torque in intact shoulders was 1.1 degrees and 0.6 millimeter, respectively.

Strongly coupled moments were characteristic of many of the motions that were studied. The nature of the shoulder is such that a pure rotational motion about a given axis is obtained by application of a torque that is not necessarily aligned with the rotation axis. For example, for the production of rotation about the lateral axis (that is, flexion) at a net torque magnitude of 1500 newton-millimeters, the applied moments (mean and standard deviation) were 1132 ± 234 newton-millimeters of flexion moment and 887 ± 353 newton-millimeters of adduction moment, with a negligible 13.04 ± 159 newton-millimeters of external rotation moment. Thus, a com-

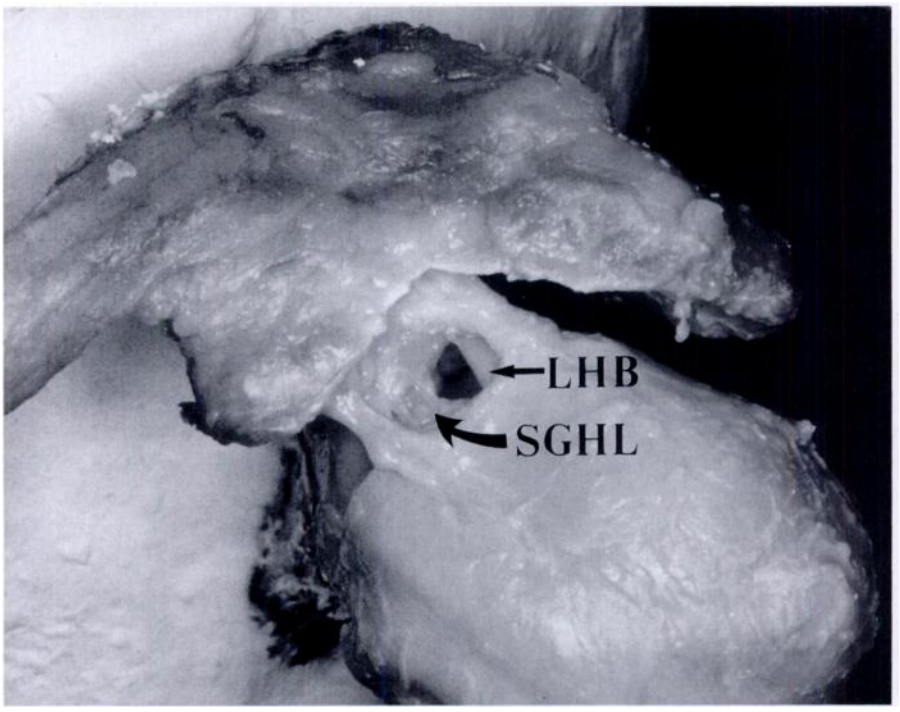

FIG. 2-A

The mounted and distracted specimen after transverse operative section of the rotator interval capsule and coracohumeral ligament approximately 1.5 centimeters lateral to the base of the coracoid process. The superior glenohumeral ligament (SGHL) is separate from the rotator interval capsule in this location (see Figure 1-B). The specimen is distracted inferiorly so that the capsular defect can be visualized. The long head of the biceps tendon (LHB) is seen deep to the section in the capsular interval. The superior glenohumeral ligament is intact, originating from the glenoid labrum anterior to the origin of the biceps tendon.

bined flexion-adduction torsional load was necessary to produce the motion of pure flexion.

The magnitude of associated anterior-posterior, superior-inferior, and medial-lateral forces was reviewed for all tested motions. For example, when flexion was produced by a 1500-newton-millimeter net torque load, the applied forces that accompanied flexion motion in the intact state were (mean and one standard deviation): posterior, 0.44 ± 3.3 newtons; medial, 12.02 ± 4.4 newtons; and superior, 5.6 ± 0.93 newtons. This indicates that, while the flexion motion was performed, the manually applied forces consisted of a superior force supporting the weight of the arm, a substantial medially directed force holding the humeral head in the glenoid fossa, and essentially no anterior or posterior force component. A similar range and magnitude of forces were measured accompanying each motion.

We analyzed the coupled torques and forces that were associated with each motion and with each preparation of the rotator interval capsule (intact, cut, and short), and we found that the torque and force components were consistent for each motion and each preparation. The applied forces that were associated with stability testing were resolved into their three force-vector components. The greatest component of force that was applied during each stability test was always in the primary direction of loading. For example, the components of force that were associated with anterior drawer in the neutral position at a magnitude of force of thirty newtons were as follows: anterior, 22.9 ± 2.1 newtons; superior, 5.0 ± 3.3 newtons; and medial, 17.9 ± 3.5 newtons. The examiner always applied a medial force to center the humeral head into the glenoid fossa during stability testing. This method is consistent with that used for clinical

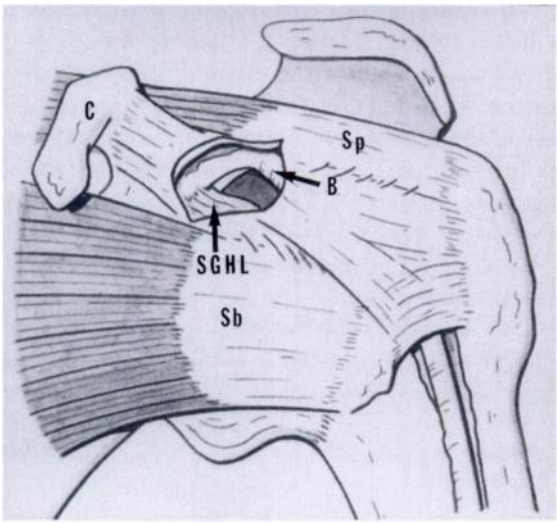

FIG. 2-B

Drawing of the sectioned rotator-interval capsule, showing transection of all fibers that have a ligamentous appearance (referred to as the coracohumeral ligament). Note that the superior glenohumeral ligament (SGHL) originates in this specimen anterior to the biceps tendon from the glenoid labrum. B = origin of the long head of the biceps, C = base of the coracoid process, Sb = subscapularis tendon, and Sp = supraspinatus tendon.

drawer tests of the shoulder, as described by Hawkins and Bokor.

Glenohumeral stability was defined, for the purpose of this study, as the measured translation of the humeral head from a centered congruent position of the joint in response to the application of forces in an attempt to cause displacement (analogous to the degree of clinical subluxation or dislocation of the humeral head on the face of the glenoid).

Preparations of the Capsule

Each of the nine motions and eleven stability tests, which will be described, was performed with the rotator interval capsule intact and vented to air with an 18-gauge needle (Figs. 1-A and 1-C), after full-thickness operative sectioning of the capsule superficial to the glenoid rim (approximately 1.5 centimeters lateral to the coracoid process) (Figs. 2-A and 2-B), and after operative overlap imbrication of the cut edges of the capsule by one centimeter with the use of a modified Kessler technique[15] and reinforcement with mattress sutures (Fig. 3). The intact preparation was vented before measurement so that it would be comparable with the subsequent preparations, for which venting was inevitable. Transverse section of the rotator interval capsule ensured complete release of the capsule, including the coracohumeral ligamentous component.

Data for control (capsule-free) motion were provided by the repetition of each motion with the humeral head held centered in the glenoid concavity after complete resection of all of the glenohumeral capsule and ligaments (in-socket control preparations).

All of the translations that are reported in this paper are net translations — that is, the translation relative to that of the appropriate capsule-free control preparation at the same rotational position. For example, the measured translation in the capsule-free control preparation at 45 degrees of flexion subtracted from the translation that had been measured at 45 degrees of flexion with the capsule intact yielded the net translation of the humeral head at 45 degrees. This technique enabled us to measure translation without presumption of sphericity for the humeral head. In this respect, our techniques have an advantage comapred with radiographic studies, in which the judging of the relative positions of non-spherical articulating surfaces complicates measurements of glenohumeral translation. Another advantage is that systematic errors in sensor readings, such as those that could be induced by metallic objects near the magnetic sensors, are largely canceled when the control measurements are subtracted[12]. These corrections were small compared with the total observed translations in our experiments.

Protocols for the Motion Testing

The ranges of glenohumeral motion that were tested were referenced to the orthogonal scapular axes, as previously defined. All of the reported motions are measured scapulohumeral angles. We define the so-called neutral position as 0 degree of flexion-extension, abduction-adduction, and internal-external rotation.

The motions that were studied were: (1) flexion (perpendicular to the plane of the scapula) without rotation, (2) flexion with the arm in 40 degrees of internal rotation, (3) extension (perpendicular to the plane of the scapula) without rotation, (4) adduction (in the plane of the scapula) without rotation, (5) abduction (in the plane of the scapula) without rotation, (6) internal rotation of the arm from the neutral position, (7) external rotation of the arm

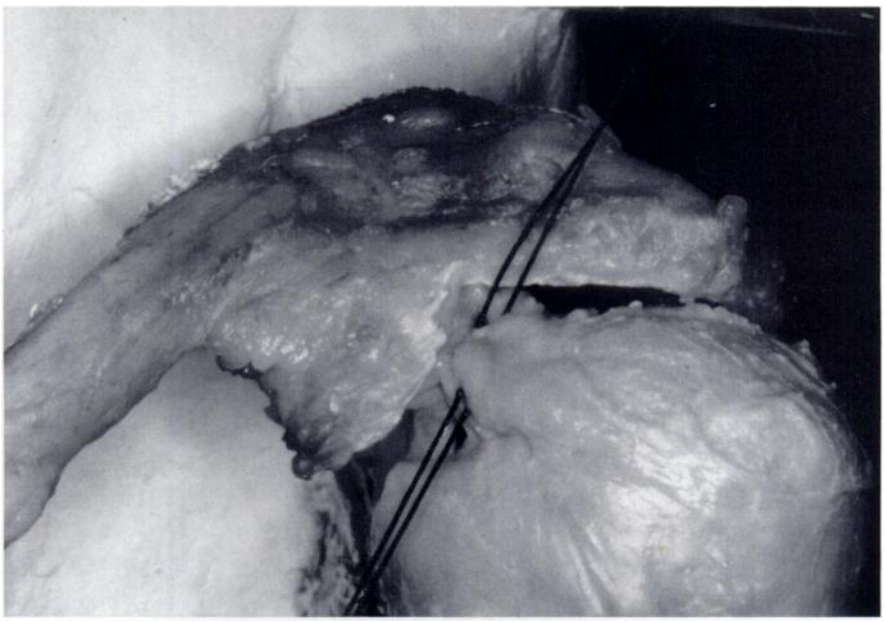

FIG. 3

The mounted specimen after repair of the sectioned rotator-interval capsule with a modified Kessler suture technique. The total length of the interval capsule was shortened by approximately one centimeter. The sutures have not been cut, so that the repair could be seen better.

TABLE I

NET OBLIGATE TRANSLATION AT A SELECTED TORQUE IN EIGHT SHOULDERS*

Type of Motion	Direction of Translation	Intact Capsule† (mm)	Cut Capsule† (mm)	Short Capsule† (mm)
Abduction	Superior	0.7 ± 2.2	0.8 ± 2.1	0.6 ± 2.3
Adduction	Inferior	1.0 ± 0.3	1.8 ± 1.8	0.5 ± 0.6
Flexion	Anterior	12.3 ± 4.0	8.9 ± 4.3	18.0 ± 3.6
Flexion	Superior	1.4 ± 2.9	0.3 ± 2.7	4.9 ± 4.4
Extension	Posterior	5.2 ± 2.3	5.4 ± 2.7	5.0 ± 2.0
External rotation	Posterior	0.2 ± 2.0	−1.7 ± 1.7	0.7 ± 1.3
Internal rotation	Anterior	2.2 ± 2.0	2.0 ± 1.8	2.3 ± 2.0
External rotation at 60 degrees of flexion	Anterior	15.4 ± 6.0	8.5 ± 8.8	19.1 ± 2.8
Internal rotation at 60 degrees of flexion	Anterior	5.2 ± 2.2	4.6 ± 1.9	9.5 ± 7.9
Flexion at 40 degrees of internal rotation	Anterior	5.3 ± 1.7	4.7 ± 2.2	7.7 ± 3.9

* The net translation is defined as the measured translation for a given motion induced by an applied torque of 1500 newton-millimeters, corrected for the apparent translation of the same shoulder in the same position after the capsule had been excised.

†Mean and standard deviation.

from the neutral position, (8) internal rotation beginning with the humerus flexed 60 degrees, and (9) external rotation beginning with the humerus flexed 60 degrees. Each specimen was preconditioned before motion testing with the application of 1500 newton-millimeters of torque in the direction of rotation. Similarly, a translational force of thirty newtons was applied in the appropriate direction to precondition the shoulder before stability stress tests.

Glenohumeral translations occurred in association with these motions, even though the investigator exerted a medially directed force that tended to center the humeral head in the glenoid socket. We call these translations obligate; they occur in positions where the capsule becomes tight, and they can be eliminated only by capsular incision[12].

We measured the translation at an applied torque of 1500 newton-millimeters, as well as the angle at which this torque was achieved, for each intact shoulder (Fig. 4). The net obligate translations that resulted from the application of a 1500-newton-millimeter torque were determined by subtraction of the apparent translation that was observed when the arm was placed in the same position after the capsule had been excised completely (the in-socket control preparation). The effect of sectioning of the rotator interval capsule was determined with a comparison, in each shoulder, of the obligate translation that was associated with the application of a 1500-newton-millimeter torque to the preparation in which the rotator interval capsule was intact with that occurring in the same position when the rotator interval capsule had been sectioned. The translation at this angle was measured after the rotator interval capsule had been cut. (In this position, the torque was less, due to the section of the rotator interval capsule [Fig. 5]). In addition, the obligate translation at a flexion torque of 1500 newton-millimeters was measured after imbrication of the rotator interval capsule, as was the angle at which this torque was achieved, and the torque was compared in each shoulder with that occurring in the same position when the rotator interval capsule was intact.

The mean paired differences in translation were determined for the intact, sectioned, and imbricated rotator-interval capsule. Identical calculations were performed for all directions of motion (Table I). One consequence of this method is that the mean translations of the short (imbricated) rotator-interval capsule minus the mean translations of the intact rotator-interval capsule (Table I) are not necessarily equal to the mean short-intact rotator-interval capsule translations. The same pertains to the cut-intact rotator-interval capsule translations.

Stability Tests

The stability tests were based on clinical methods of examination for so-called allowed translations. In contrast to obligate translations, allowed translations are displacements of the humeral head that can occur in positions of the joint in which the capsuloligamentous constraints are lax. Stability tests were performed with the application of various magnitudes of load in a pilot experiment preceding this study. We concluded that thirty newtons was sufficient to stress the joint, yet not great enough to cause failure of tissue or sutures on multiple repetitions (that is, there was no significant change in translation).

Eleven stability tests were performed for each capsular preparation (intact, cut, and short) for every specimen.

Sulcus test: This is performed by application of a downward pull on the arm with thirty newtons of inferiorly directed force.

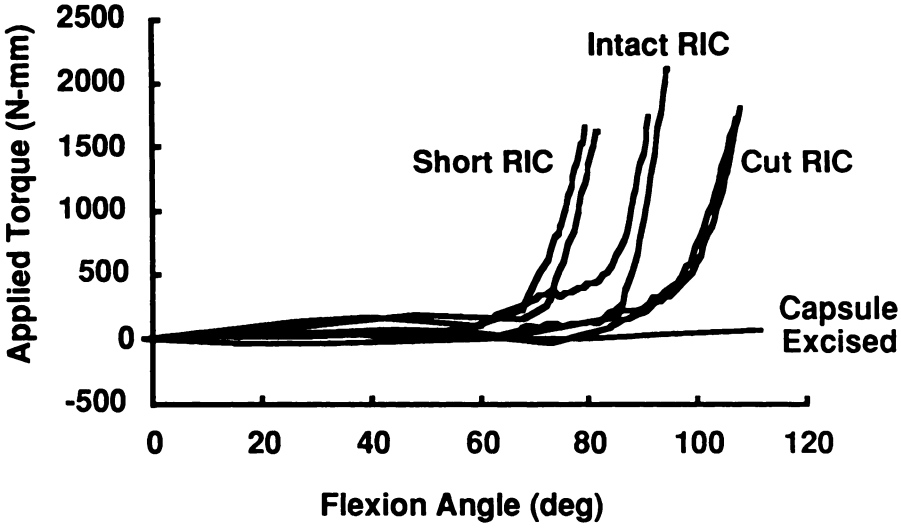

FIG. 4

Graph showing multiple repetitions of flexion motion, to a limit of 1500 newton-millimeters, for one representative specimen (the same specimen as in Figures 5 and 6). Note the high degree of reproducibility for manual manipulations in a given specimen. This graph shows glenohumeral torque as a function of the angle of flexion. RIC = rotator interval capsule.

Anterior and posterior drawer tests in the neutral position: These tests, which are similar to the load and shift tests[17], are performed by the examiner centering the humeral head in the glenoid fossa, then pushing anteriorly with a thirty-newton force, recentering, and then pushing posteriorly with a thirty-newton force.

Anterior and posterior drawer tests in 60 degrees of abduction: These tests, which are similar to the push-pull tests[13], are performed by the examiner centering the humeral head in the glenoid fossa, then pushing anteriorly with a thirty-newton force, recentering, and then pushing posteriorly with a similar force.

Anterior and posterior drawer tests in 60 degrees of abduction and 60 degrees of external rotation: The anterior component of these tests is similar to the fulcrum test, with the arm placed in the position that is used for the apprehension test, commonly employed to detect anterior stability[17]. These tests are performed by the examiner centering the humeral head in the glenoid fossa, then pushing anteriorly with a thirty-newton force, recentering, and then pushing posteriorly with a similar force.

Anterior and posterior drawer tests in 60 degrees of flexion without rotation: These are performed by application of an anterior force of thirty newtons to the humeral head, followed by application of a posterior force of thirty newtons.

Anterior and posterior drawer tests in 60 degrees of forward flexion with 90 degrees of internal rotation: These tests are performed by the examiner centering the humeral head in the glenoid fossa, then pushing anteriorly with a thirty-newton force, recentering, and then pushing posteriorly with a similar force. The posterior component of this test is similar to the jerk test[17].

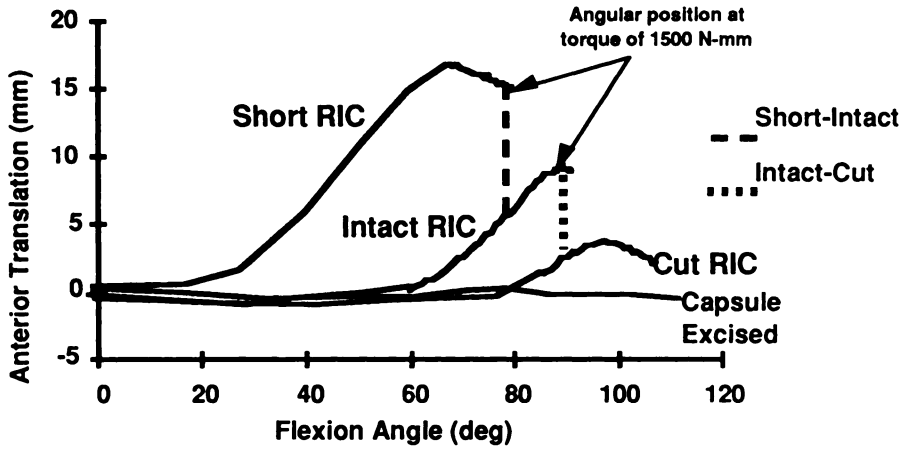

FIG. 5

The obligate anterior translation that accompanies flexion motion perpendicular to the plane of the scapula is diminished by cutting and augmented by shortening of the rotator interval capsule (RIC). The graph shows how the results of sectioning and of shortening of the interval capsule were determined for each motion in each specimen.

TABLE II

THE EFFECT OF ALTERATIONS OF THE ROTATOR INTERVAL CAPSULE ON THE RANGE OF GLENOHUMERAL MOTION IN EIGHT SHOULDERS

	Angular Range of Motion*† *(Degrees)*			Relative Change in Range of Motion Resulting from Cutting or Shortening of Capsule‡ *(Degrees)*			
Type of Motion	Intact Capsule	Cut Capsule	Short Capsule	Cut-Intact*	t Value	Short-Intact*	t Value
Abduction	76.0 ± 6.3	74.2 ± 6.6	76.5 ± 5.9	−1.8 ± 3.1	1.87	0.6 ± 2.8	0.61
Adduction	24.9 ± 4.6	27.0 ± 6.3	16.5 ± 4.6	2.1 ± 2.7	1.69	−8.4 ± 3.5	6.81§
Flexion	75.8 ± 12.7	82.0 ± 17.1	68.1 ± 11.9	6.2 ± 8.8	2.40	−7.7 ± 5.1	3.02§
Extension	63.6 ± 9.3	70.9 ± 12.4	46.0 ± 13.1	7.3 ± 6.4	1.34	−17.7 ± 15.2	3.26§
External rotation	69.5 ± 9.8	75.1 ± 6.5	31.8 ± 21.0	5.6 ± 5.1	0.82	−37.7 ± 20.8	5.47§
Internal rotation	59.0 ± 11.3	58.5 ± 10.0	57.3 ± 11.2	−0.4 ± 1.8	0.61	−1.7 ± 1.7	2.37
External rotation at 60 degrees of flexion	27.2 ± 9.3	38.0 ± 17.4	9.4 ± 12.7	10.8 ± 8.8	3.54§	−17.8 ± 6.3	5.84§
Internal rotation at 60 degrees of flexion	43.1 ± 12.4	45.5 ± 12.2	37.8 ± 19.3	2.4 ± 5.8	0.62	−5.3 ± 13.3	1.38
Flexion at 40 degrees of Internal rotation	65.3 ± 16.2	68.3 ± 17.4	60.2 ± 15.2	3.0 ± 6.5	1.0	−5.1 ± 6.5	1.78

*Mean and standard deviation.
†Achieved by the application of 1500 newton-millimeters of torque.
‡A positive value indicates an increase and a negative value, a decrease in the angular magnitude measured for all specimens.
§ $P < 0.05$, from paired analysis-of-variance t values corrected for multiple comparisons.

Statistical Analysis

The mean paired differences of each specimen for range of motion, obligate translation accompanying each motion, and allowed translation on stability testing for the intact, sectioned, and imbricated rotator-interval capsule were determined. Using these data, we performed a one-way analysis of variance with the multiple comparison correction factor (Bonferroni) and we derived the t results (Tables II, III, and IV)[14].

Results

Typical motion and stability data for a single shoulder are shown in Figures 4 through 7. All motion and stability tests were repeated at least twice for each capsular preparation (intact, cut, and short) in each shoulder.

A graph was prepared for each range-of-motion test of each shoulder, as shown in Figures 4 and 5. We determined the angle value at 1500 newton-millimeters of torque for each motion (Fig. 4) for each capsular prepa-

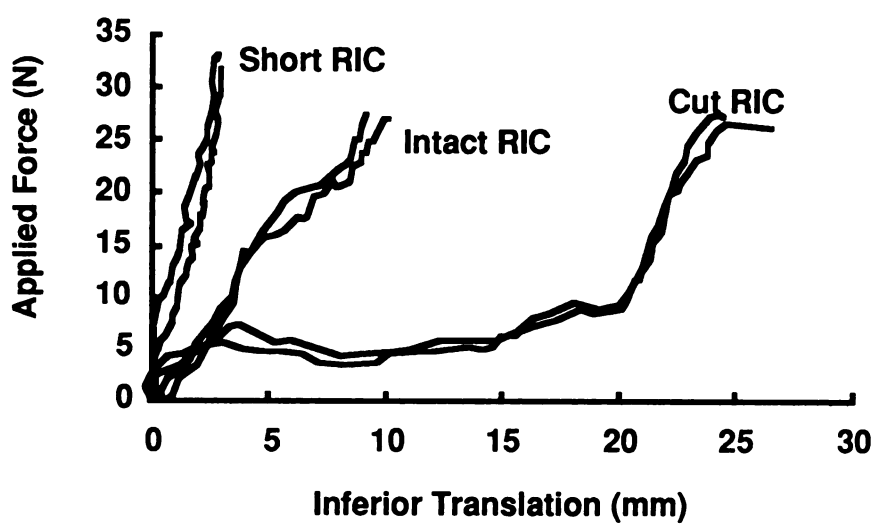

FIG. 6

The sulcus test. A representative graph for a single shoulder (the same specimen as in Figures 4 and 5) shows inferior glenohumeral translation as a function of an applied inferior force. RIC = rotator interval capsule.

TABLE III

THE EFFECT OF CUTTING AND OF IMBRICATION OF THE ROTATOR INTERVAL CAPSULE ON OBLIGATE TRANSLATION AT A SELECTED POSITION

Type of Motion	Direction of Translation	Translation for Cut Capsule Minus That for Intact Capsule*† (mm)	T Value	Net Change	Translation for Short Capsule Minus That for Intact Capsule*‡ (mm)	T Value	Net Change
Abduction	Superior	−0.1 ± 0.5	0.48	No change	0.0 ± 0.6	0.19	No change
Adduction	Inferior	0.8 ± 1.5	1.72	No change	−0.6 ± 0.7	1.23	No change
Flexion	Anterior	−4.2 ± 3.2	3.33§	Decrease	4.9 ± 3.0	3.82§	Increase
Flexion	Superior	−1.1 ± 1.5	1.27	No change	3.5 ± 3.1	3.87§	Increase
Extension	Posterior	0.1 ± 1.7	0.19	No change	−0.2 ± 1.6	0.23	No change
External rotation	Posterior	1.9 ± 1.7	2.04	No change	−0.5 ± 2.6	0.53	No change
Internal rotation	Anterior	−0.2 ± 0.0	0.91	No change	0.1 ± 0.0	0.25	No change
External rotation at 60 degrees of flexion	Anterior	−7.0 ± 7.3	2.45	No change	3.7 ± 6.9	1.29	No change
Internal rotation at 60 degrees of flexion	Anterior	−0.6 ± 1.2	0.25	No change	4.3 ± 7.6	1.83	No change
Flexion at 40 degrees of internal rotation	Anterior	−0.6 ± 1.0	0.62	No change	2.4 ± 3.1	2.30	No change

* Mean and standard deviation.

† The selected position (glenohumeral angle) for both measurements was that resulting from the application of 1500 newton-millimeters of torque, in the indicated direction, in which the rotator interval capsule was intact (see Fig. 5).

‡ The selected position (glenohumeral angle) for both measurements was that resulting from the application of 1500 newton-millimeters of torque, in the indicated direction, in which the rotator interval capsule was shortened (see Fig. 5).

§ $P < 0.05$, from paired analysis-of-variance corrected for multiple comparisons.

ration (intact, cut, and short). We also determined the obligate translation of the humeral head for each preparation at each angle (Fig. 5). Figure 5 demonstrates how the effects of imbrication and of sectioning of the rotator interval capsule were characterized. We prepared a graph for each stability test in every shoulder, as shown in Figures 6 and 7. From each graph, we determined the allowed translation of the humeral head for the intact, cut, and short capsules at an applied force of thirty newtons. The two measurements of each preparation were averaged.

The test results for seven of the eight specimens were

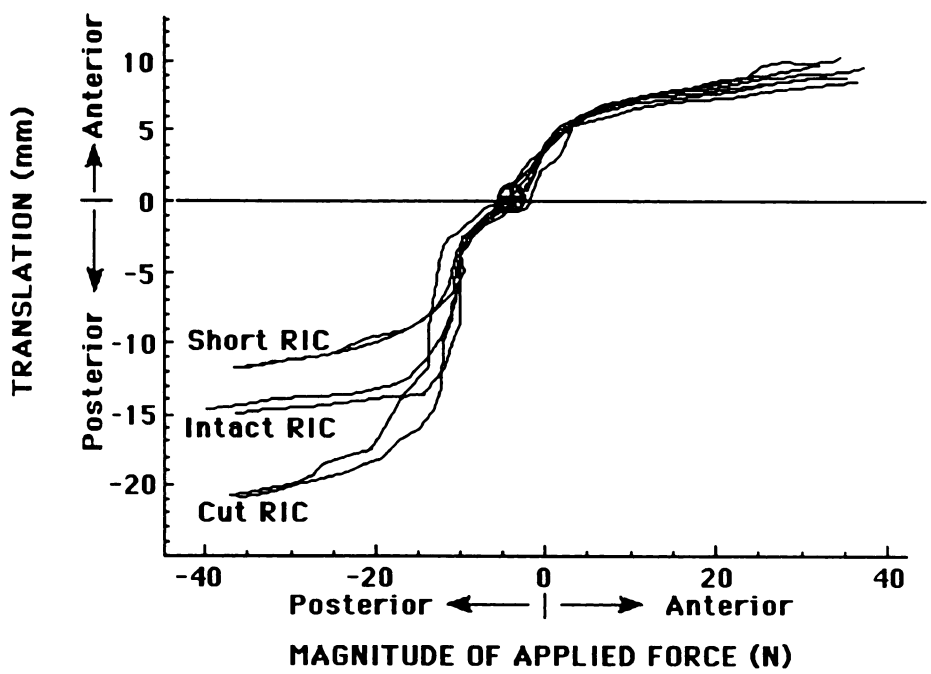

FIG. 7

The fulcrum test. A representative graph for a single shoulder (the same specimen as in Figures 4, 5, and 6), showing anterior and posterior translation as a function of anterior and posterior forces applied to the humeral head with the eextremity in 60 degrees of glenohumeral abduction and 60 degrees of external rotation. No difference in anterior laxity was demonstrated among the intact, cut, or short rotator-interval capsules (RIC), as opposed to the significant differences that were noted for posterior laxity.

TABLE IV

THE EFFECT OF THE INTEGRITY OF THE ROTATOR INTERVAL CAPSULE ON GLENOHUMERAL STABILITY

Stability Tests	Allowed Translation *† (mm)			Paired Differences in Allowed Net Translation			
	Intact Capsule	Cut Capsule	Short Capsule	Cut-Intact*‡ (mm)	T Value	Short-Intact*‡ (mm)	T Value
Inferior sulcus	I: 10.1 ± 5.8	I: 18.2 ± 11.1	I: 2.3 ± 1.1	8.2 ± 7.9	2.60¶	−7.7 ± 5.8	2.64¶
Anterior drawer at neutral	A: 19.8 ± 3.4	A: 22.8 ± 5.2	A: 15.0 ± 9.3	3.0 ± 3.3	0.97	−4.7 ± 9.8	1.52
Posterior drawer at neutral	P: 17.4 ± 3.7	P: 19.3 ± 3.6	P: 9.1 ± 4.2	1.9 ± 2.3	1.16	−8.3 ± 5.8	4.98¶
Anterior drawer at 60 degrees of abduction	A: 13.8 ± 7.9	A: 15.6 ± 8.6	A: 12.3 ± 8.1	1.8 ± 2.3	1.06	−1.5 ± 5.1	0.89
Posterior drawer at 60 degrees of abduction	P: 9.6 ± 4.4	P: 10.1 ± 4.8	P: 10.0 ± 4.3	0.5 ± 1.1	1.17	0.3 ± 1.1	0.78
Anterior drawer at 60 degrees of flexion	A: 20.1 ± 3.1	A: 21.0 ± 3.1	A: 21.7 ± 3.0	0.9 ± 0.2	3.44¶	1.7 ± 0.8	6.45¶
Posterior drawer at 60 degrees of flexion	P: −5.1 ± 4.5	P: −1.7 ± 6.0†	P: −12.5 ± 5.2†	3.4 ± 3.6	2.27	−7.3 ± 4.4	4.88¶
Anterior drawer at 60 degrees of flexion and 90 degrees of internal rotation	A: 14.2 ± 5.5	A: 13.7 ± 5.8	A: 14.8 ± 5.2	−0.5 ± 3.5	0.55	0.6 ± 2.5	0.58
Posterior drawer at 60 degrees of flexion and 90 degrees of internal rotation	P: −3.0 ± 4.1§	P: −2.1 ± 3.5§	P: −5.7 ± 3.3§	0.9 ± 1.0	0.78	−2.8 ± 3.9	2.48
Anterior drawer at 60 degrees of abduction and 60 degrees of external rotation	A: 7.5 ± 4.6	A: 7.8 ± 4.2	A: 7.5 ± 3.4	0.3 ± 1.3	0.45	0.0 ± 1.7	0.02
Posterior drawer at 60 degrees of abduction and 60 degrees of external rotation	P: 14.7 ± 4.4	P: 20.8 ± 7.7	P: 7.4 ± 4.5	6.1 ± 5.1	2.65¶	−7.3 ± 4.9	3.16¶

* Mean and standard deviation.
† At a force of thirty newtons. A = anterior, P = posterior, I = inferior, and S = superior translation.
‡ A positive value indicates an increase and a negative value, a decrease in allowed net translation.
§ Glenohumeral flexion of 60 degrees causes obligatory anterior translation; this test indicates allowed posterior translation in the position noted .
¶ $P < 0.05$, from paired analysis-of-variance t values corrected for multiple comparisons.

consistent with the data in Figures 4 through 7. The motions of these shoulders were strongly dependent on the interval capsule. The one atypical shoulder in our series had a coracohumeral ligament originating from the coracoacromial ligament, but the rotator interval capsule remained intact to the base of the coracoid process. Section of the rotator interval capsule had a marginal effect in this shoulder. It is not known whether this condition was congenital, but there was no evidence of a previous operation or of traumatic injury. In general, the relatively large standard deviations for the translations in the series reflect the substantial biological variability that we observed in our specimens.

Tables I through IV summarize the means and standard deviations for each permutation of motion and capsular preparation. Range-of-motion data are listed in Table II. The values for obligate translations accompanying passive motion are shown in Table I. The effects of sectioning and imbrication of the rotator interval capsule on obligate translation are shown in Table III. The allowed translations that occurred on stability stress-testing are recorded in Table IV, as are the results of section and of imbrication of the rotator interval capsule.

Tests of Glenohumeral Motion

The effects of sectioning of the rotator interval capsule on the range of various motions at 1500 newton-millimeters of applied torque are summarized in Table II. On the average, sectioning of the interval capsule increased the range of flexion by a mean of 6 degrees (Fig. 4), extension by 7 degrees, external rotation in the neutral position by 6 degrees, and external rotation at 60 degrees of flexion by 11 degrees. However, only the range of external rotation at 60 degrees of flexion for the sectioned rotator-interval capsule was significantly different from that for the intact capsule ($p < 0.05$), as demonstrated by the use of multiple comparison analysis of variance. On the average, shortening of the rotator interval capsule reduced the range of flexion, compared with that of the intact capsule, by 8 degrees (Fig. 4), extension by 18 degrees, external rotation in the neutral position by 38 degrees, external rotation at 60 degrees of flexion by 18 degrees, and adduction by 8 degrees. All of these reductions in the magnitude of motion were significant for the

imbricated rotator-interval capsule ($p < 0.05$). The ranges of internal rotation and abduction from the neutral position were not affected appreciably by alterations in the rotator interval.

Obligate translation of the humeral head occurred as an integral part of some of the glenohumeral motions at 1500 newton-millimeters of applied torque (Table I). The values for obligate translation (Table I) were corrected for any apparent translation of the humeral head after the complete capsule and ligaments were excised, to yield the net translation that was produced by tension in the interval capsule. These translations occurred even though the investigator exerted a medially directed force to center the head in the glenoid fossa. For example, flexion was accompanied by a mean of 12.3 millimeters of anterior and 1.4 millimeters of superior translation (Fig. 5). Cutting of the rotator interval capsule significantly reduced the anterior translation with flexion (by 4.2 millimeters) (Table III). Shortening of the rotator interval capsule significantly increased the anterior and superior translation on flexion by 4.9 and 3.5 millimeters, respectively. Internal and external rotation, abduction, and adduction motions did not change glenohumeral translation substantially.

Tests of Glenohumeral Stability

The status of the interval capsule substantially affected the allowed translation of the humeral head during certain stability tests that were carried out with the use of a displacing force of thirty newtons. The 60-degree flexed position that was necessary for the performance of some of the stability tests caused the humeral head to undergo obligate anterior translation. This anterior translation was diminished remarkably by internal rotation and increased by external rotation, with flexion held fixed at 60 degrees (Tables I and IV).

Sectioning of the rotator interval capsule increased the allowed anterior translation for the anterior drawer at 0 and 60 degrees of abduction and at 60 degrees of flexion and also allowed inferior translation on the sulcus test (Fig. 6). However, the differences were not significant for the anterior drawer in 0 degree and in 60 degrees of abduction. There was a significant increase in the allowed posterior translation in a position of 60 degrees of abduction and 60 degrees of external rotation (6.1 millimeters). When a posterior directed force was applied to the humeral head with the arm in this position, posterior-inferior dislocation of the glenohumeral joint resulted in four of the eight specimens (Fig. 7).

A striking reduction in the allowed posterior translation on drawer testing was apparent when the operatively imbricated capsule was tested in the positions of neutral drawer (8.3 millimeters), 60 degrees of flexion and neutral rotation (7.3 millimeters), and 60 degrees of abduction and 60 degrees of external rotation (7.3 millimeters). Shortening of the rotator interval capsule reduced the allowed inferior translation for the inferior sulcus by 7.7 millimeters (Fig. 6). All of the mentioned changes in stability were significant ($p < 0.05$).

Discussion

Great progress has been made recently in the definition of the relationship of specific ligaments to glenohumeral motion and stability. However, little is known about the effects of operative modification of the interval capsule on glenohumeral motion or stability. We could not find a study that defined quantitatively the effect of operative section or imbrication of the rotator interval.

Gagey et al. identified the coracohumeral ligament as a checkrein that limits the excursion of maximum forward elevation and external rotation of the glenohumeral joint. Neer et al. observed, in a recent study in cadavera, that release of the coracohumeral ligament increased external rotation both with the arm at the side (average external rotation, 32 degrees) and with it in 90 degrees of forward elevation (average external rotation, 15 degrees). Several authors[5,16,19,24,26] have recommended release of the coracohumeral ligament, to increase glenohumeral motion, when a frozen shoulder is treated with open release.

Basmajian and Bazant stated, in 1959, that the superior part of the capsule and the related ligaments acted together as a "locking mechanism", resisting downward displacement in the adducted unloaded arm. Debate remains over which ligamentous structure is most important in the prevention of inferior subluxation of the humeral head when the arm is adducted. Ovesen and Nielsen[22] stated that the coracohumeral ligament is most important in this role. However, Cooper et al. concluded not only that the coracohumeral ligament had no suspensory role but also that it was unusual to find a true coracohumeral ligament. They attributed the gross finding of this ligament to folding of the interval capsule. Schwartz et al.[27,28] noted that posterior dislocation of the glenohumeral joint did not occur during selective cutting of the posterior part of the capsule until the anterosuperior structures had been released. Therefore, we surmise that the rotator interval capsule, together with its associated ligaments, is a primary restraint to inferior and posterior translation of the adducted shoulder.

Recently, Nobuhara and Ikeda characterized a "rotator interval lesion." Disease involving the rotator interval of the shoulder was documented clinically as stiffness (Type I) or instability (Type II). Posterior-inferior instability of the glenohumeral joint in some of their patients disappeared when the rotator interval capsule became taut during external rotation. So-called repair of the rotator interval by closing and reinforcement of the rotator interval capsule substantially decreased the symptoms of instability in most of their patients.

The results of our study indicate that the interval capsule plays a major role in the range of certain motions, in the obligate translation, and in the allowed translation of the glenohumeral joint. The magnitude of these

effects varied among shoulders, but the direction of the effect was consistent. Sectioning of the interval capsule increased the ranges of flexion, extension, adduction, and external rotation, and imbrication decreased these ranges of motion. Positions of abduction and internal rotation relaxed the interval capsule, so sectioning or shortening did not alter these ranges of motion. These results confirm and augment the conclusions of Gagey et al., Neer et al., and others[5,16,24,26].

Obligate translations occurred typically near the limits of the motion arcs and were consistent in direction for the given motion among specimens. There was no significant translation of the humeral head in association with arcs of motion in which the capsuloligamentous tissue was lax (as evidenced by the lack of significant torque). Obligate anterior and superior translation on flexion was increased by shortening of the interval capsule and was reduced, but not eliminated, by section of the capsule. This translation was eliminated only by complete excision of the capsule and glenohumeral ligaments.

A major component of the resistance to posterior and inferior glenohumeral translatory displacement was provided by the intact rotator-interval capsule. Section increased and imbrication decreased the allowed translation on the sulcus and posterior drawer tests. Dislocation of the glenohumeral joint usually occurred, both inferiorly and posteriorly, when the interval capsule had been sectioned. These results support previous conclusions regarding posterior and inferior stability of the glenohumeral joint, but we did not attempt to isolate the role of specific rotator-interval capsular ligaments[2,4,22,27,28].

The type of study that we performed has limitations. The scapula was fixed and not allowed to move as it does during normal motion of the shoulder. Also, the influence of muscle action was not present. The magnitude of the recorded translations was greater than that of *in vivo* motion, due to venting of the capsule and resection of the skin and muscle[8,9,23].

The primary justification for this type of study is that it permits the selective isolation of specific variables, such as the integrity of the rotator interval capsule, allowing a controlled analysis of the effect of the interval on the system.

Our results, taken together, suggest that the function of the rotator interval capsule is to check the range of flexion, extension, adduction, and external rotation; to check inferior translation of the glenohumeral joint in the adducted shoulder; and to provide stability of the joint against posterior dislocation in the position of flexion or of abduction-external rotation.

These data have relevance for the shoulder surgeon. Stretching or release of the interval capsule may be a necessary adjunct to treatment when the range of flexion and external rotation is limited, as in patients who have adhesive capsulitis or degenerative joint disease. A tight interval capsule may not only limit the range of motion, but it may also produce unwanted obligate anterosuperior translation at the extremes of flexion. This may aggravate impingement of the rotator cuff against the coracoacromial arch, particularly if the interval capsule has been shortened in the process of advancement of the cuff to the humeral tuberosity. Thus, release of the interval capsule can be expected to relieve tension on the repair and minimize the anterosuperior translation, which could otherwise jeopardize the repair. Obligate translation may be a particular problem in shoulder arthroplasty, in which the addition of space-consuming components may place the interval capsule under even greater tension on flexion and lead to subluxation of the joint and contact of the rim on the glenoid component. Finally, shoulders that are unstable inferiorly in adduction or unstable posteriorly in flexion may benefit from operative reconstruction of the interval capsule.

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