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The Anatomy and Histology of the Rotator Interval Capsule of the Shoulder

Brian J. Cole, MD, MBA; Scott A. Rodeo, MD**; Stephen J. O'Brien, MD**; David Altchek, MD**; Doohi Lee, MD**; Edward F. DiCarlo, MD**; and Hollis Potter, MD***

Forty-seven rotator interval regions from fetuses and 10 fresh-frozen rotator interval regions from adult cadavers were evaluated by gross dissection and light microscopy. Specimens from adults also were evaluated with ultrasound and magnetic resonance imaging. An analysis of 37 fetal specimens (> 14 weeks gestation) revealed two rotator interval types: Type I (9 of 37) was defined by a contiguous bridge of capsule consisting of poorly organized collagen fibers. A Type II rotator interval (28 of 37) had a complete defect covered by only a thin layer of synovium. Similar to the Type II rotator interval in the fetus, a rotator interval defect was present in six of eight specimens from adults. Histologically, the capsular tissue within the rotator interval consisted of poorly organized collagen fibers in specimens from the fetus and adult. Maximal opening of the rotator interval was seen by ultrasound with internal rotation and downward traction of the hyperextended arm in the coronal, oblique, and sagittal planes. Magnetic resonance imaging of the rotator interval region permitted anatomic evaluation. The complete absence of tissue in 28 of 37 fetuses suggests that the rotator interval defect is congenital. The authors recommend that surgeons carefully evaluate the integrity of the tissue within the rotator interval. When rotator interval closure is desired such as in patients with a persistent sulcus sign after arthroscopic stabilization, suturing the edges of more substantial tissue immediately adjacent to the boundaries of the rotator interval region would seem prudent.

Evidence suggests that the rotator interval region plays an integral role in the pathogenesis and treatment of some patients with shoulder instability.[3–5,9,15] However, there have been few investigations of the functional anatomy and histology of the rotator interval region.[2,8] A better understanding of the anatomy in this region will clarify the significance that the rotator interval region has for patients with shoulder instability. Improved evaluation of this region before surgery ultimately could direct a more specific strategy during surgical stabilization.

The rotator interval region is a source of confusion among shoulder specialists. The rotator interval subtends a medially-based triangular space bordered superiorly by the anterior margin of the supraspinatus tendon, inferiorly by the superior border of the subscapularis tendon, medially by the base of the coracoid, and laterally by the long head of the biceps tendon and sulcus. The floor of the rotator in-

From *Rush University, Division of Sports Medicine, Section of Shoulder Surgery, Rush-Presbyterian-St-Luke's Medical Center, Chicago, IL; and **The Hospital for Special Surgery, New York, NY.

Reprint requests to Brian J. Cole, MD, MBA, Rush-Presbyterian St-Luke's Medical Center, Suite 1063, 1725 East Harrison Street, Chicago, IL 60612.

terval region is variably bridged by capsule, the coracohumeral ligament, the superior glenohumeral ligament, and occasionally, the middle glenohumeral ligament.

When the capsule spanning the rotator interval is completely absent, it is described as a rotator interval defect.[7] There is renewed interest in this entity because this opening has been associated with recurrent anteroinferior and multidirectional instability. In general, studies suggest that a complete rotator interval capsular defect should be closed as part of a stabilization procedure, especially when inferior translation predominates.[6,7,12–14,16]

Harryman et al[6] characterized the relative biomechanical contribution of the capsule within the rotator interval to shoulder stability using shoulders from cadavers. A transverse incision in the rotator interval region including the capsule, coracohumeral ligament, and superior glenohumeral ligament allowed for statistically significant increases in humeral head translations in all planes tested. Imbrication of the rotator interval decreased inferior translation in adduction and posterior translation in flexion to less than the intact state. No attempt was made to isolate the role of individual anterorsuperior capsuloligamentous structures.

It still is unclear exactly which structures limit inferior translation of the adducted shoulder. Basmajian et al[1] indicated from electromyographic and anatomic dissections that the superior capsule and the coracohumeral ligament resisted downward displacement with the arm adducted, independent of load. The supraspinatus (and to a lesser extent the posterior fibers of the deltoid) augmented the resistance to downward displacement of the adducted arm when loads were applied. Warner et al[18] identified similar contributions of the anterosuperior capsule in cadaver studies in which the static restraints were evaluated to superoinferior stability.

Unfortunately, few studies have specifically examined the specific anatomy and histology of the rotator interval capsular region either during development or in the adult.[2,8] Although there are reports of microscopic studies of the shoulder capsule, the capsule within the rotator interval has not been examined carefully.[10] Comparisons between fetal and adult anatomy may help determine whether a defect of the capsule within the rotator interval is congenital or acquired. In addition, the ability to image this region accurately by ultrasound or magnetic resonance imaging (MRI) might facilitate surgical decision making for patients who present with symptomatic shoulder instability.

The purpose of the current study is to describe the anatomic and histologic composition of the fetal and adult rotator interval capsule by gross dissection and light microscopy. ultrasound, and MRI were done to assess their ability to define this portion of the shoulder capsule.

MATERIALS AND METHODS

The current study was divided into two sections: (1) analysis of shoulders from fetuses by gross dissection with subsequent sectioning and preparation of the rotator interval capsular region for plain and polarized light microscopy; and (2) analysis of shoulders from adult cadavers by arthroscopy, ultrasound, and MRI before and after arthroscopic placement of an identification suture within the rotator interval. Histologic evaluation was done as in the fetal specimens.

Fetal Specimen Preparation

After approval from the Institutional Review Board, 47 shoulders from fetuses in 37 separate specimens were obtained from the International Institute for Advancement of Medicine. The specimens were obtained from cases of fetal demise (n = 4) or elective pregnancy terminations (n = 33). The gestational ages of these fetuses ranged from 9 to 40 weeks. Ten fetal specimens were less than 14 weeks gestation and 37 fetal specimens were greater than 14 weeks gestation.

After dissection done under a dissecting microscope, the tissue was fixed in 10% neutral buffered formalin, decalcified in 5% nitric acid, and embedded in paraffin. Five micron-thick sections were made in the coronal and sagittal planes, stained with hematoxylin and eosin, and examined with light and polarized light microscopy.

Adult Specimen Evaluation

Ten fresh-frozen intact shoulders from adult cadavers (including the entire scapula, clavicle, and arm) were thawed completely and evaluated by arthroscopy with gravity inflow, ultrasound, and MRI. The mean age of the donors at the time of death was 63 years (range, 58–71 years). Left and right shoulders were available for three of the cadavers. A specimen was selected only if it had full range of glenohumeral motion without instability, no glenohumeral arthritis, nor significant soft tissue disease. The vertebral border of each specimen then was mounted in a vice and subsequently was examined by routine shoulder arthroscopy to document the status of the capsule, ligaments, labrum, and rotator cuff. Two specimens were excluded because of significant soft tissue disease. In eight specimens, a suture was placed arthroscopically from inside-out through the lateral aspect of the rotator interval just medial to the biceps tendon to ensure accurate identification of the rotator interval region by ultrasound, MRI, and histologic evaluation. Completely thawed specimens underwent static and dynamic ultrasound imaging followed by MRI before histologic sectioning.

Before refreezing, skin and subcutaneous fat were removed to expose the underlying bony and musculotendinous anatomy taking care to preserve the original orientation of the rotator cuff musculature, capsule, and bursal tissue. Specimens were refrozen and sagittal sections were made through joint and capsule at 5-mm intervals beginning medially at the level of the coracoid and progressing laterally to the insertion of the rotator cuff into the greater and lesser tuberosities. Sections were fixed in 10% neutral buffered formalin and decalcified in 5% nitric acid if bone was present. Selected sections then were prepared and evaluated as described for the fetal specimens.

Ultrasound Evaluation

High frequency sonography was done on completely thawed specimens in multiple planes before and after suture placement by an experienced ultrasonographer (DL) using 7.5 MHz linear array and 5.0 MHz curved array transducers (Acoustic Imaging, Model 5200-S, Phoenix, AZ). The examination was done with the shoulder mounted and manipulated into various positions: neutral, adduction, abduction, and hyperextension with and without internal and external rotations. The rotator interval region first was examined and measured by ultrasound before arthroscopy without the presence of a suture marker. To ensure correct identification of the rotator interval, the shoulder was reexamined by real-time ultrasound with a probe placed within the rotator interval from outside-in with its placement verified by arthroscopy. Additionally, the status of the rotator interval was evaluated with respect to shoulder position after placement of the suture marker from inside-out.

Magnetic Resonance Imaging

Magnetic resonance imaging was done on the completely thawed specimens with a 1.5 T magnet with a dedicated shoulder coil (anterior loop coil, General Electric, Milwaukee, WI). Images were obtained in the oblique sagittal and oblique coronal planes using a 4 mm slice thickness with no interslice gap. The field of view was 16 × 16 cm, and the matrix was 256 × 192/256, at 2 to 4 excitations. Images included multiplanar gradient recalled echo (45°/TR/TE 450/20), and fast spin-echo (TR/TE 3500–5000/23–100 (Ef)). Images were repeated after suture placement in the oblique coronal plane using the gradient echo sequence and the oblique sagittal plane using the fast spin-echo technique.

RESULTS

Fetal Specimen Evaluation

The superior glenohumeral ligament and middle glenohumeral ligament were less distinct than the inferior glenohumeral ligament. The superior glenohumeral ligament and middle glenohumeral ligament often were seen only as capsular thickenings. The capsule within this interval assumed one of two forms, both of which were identifiable only in fetuses older than 14 gestation weeks (N = 37). This interval capsule was seen consistently at the 1 o'clock position in a right shoulder, or 11 o'clock position in a left shoulder. A Type I rotator interval was identified in nine of 37 of these specimens and was defined as a rotator interval region with a contiguous capsular layer in the region of the superior glenohumeral ligament and middle glenohumeral ligament (Fig 1). Under light and polarized light microscopy, a 19-week fetal specimen had a poorly organized array of collagen fibers (Fig 2).

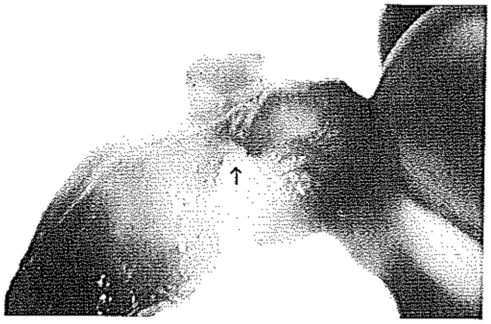

Fig 1. Photograph of a fetal specimen showing a Type I rotator interval capsule with a contiguous capsular layer. The arrow marks the center of the rotator interval region.

A Type II rotator interval was seen in 28 of 37 specimens defined by a capsular defect in the region of the superior glenohumeral ligament and middle glenohumeral ligament (Fig 3). Frequently, the capsular tissue that was present originated from the middle glenohumeral ligament and passed superficial to the defect. Lifting this layer typically revealed a rotator interval capsular defect located between the superior glenohumeral ligament and the middle glenohumeral ligament.

Adult Specimen Evaluation

Arthroscopic Evaluation

Two shoulders had full-thickness tears of the supraspinatus tendons with significant retrac-

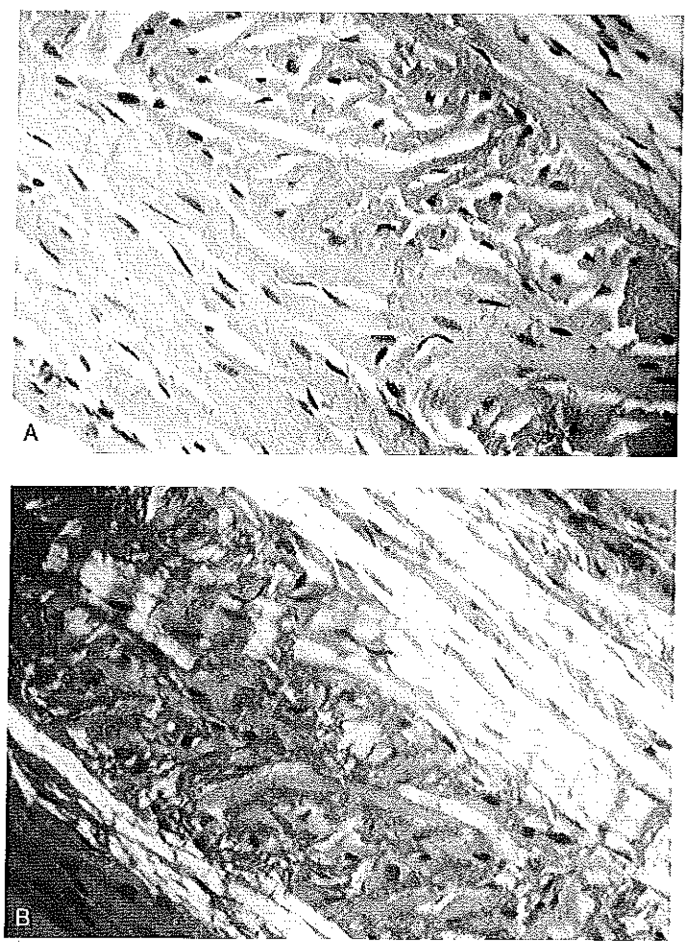

Fig 2A–B. Photomicrograph of the capsule taken from a 19-week fetus with a Type I rotator interval. (A) Light microscopy showed poorly organized collagen fibers. (B) Polarized light microscopy of the same specimen showed poorly organized collagen fibers. (Stain, hematoxylin and eosin; magnification, ×200.)

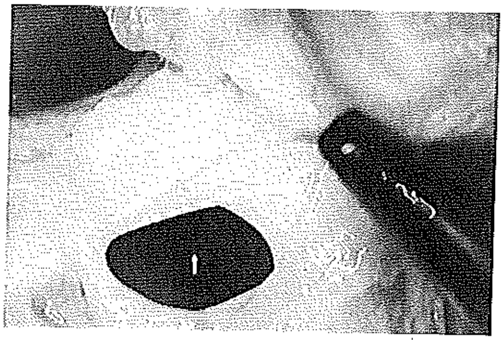

Fig 3. Photograph of a fetal specimen showing a Type II rotator interval capsule with complete rotator interval defect. The arrow marks the center of the rotator interval defect.

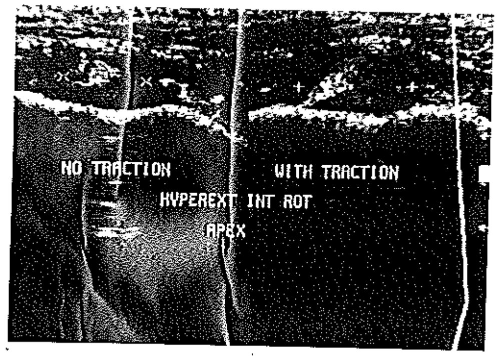

Fig 4. Ultrasound of a specimen from an adult obtained in the sagittal plane. The X marks the borders of the rotator interval. The change in distance between these areas can be seen. (A) Ultrasound obtained in internal rotation (int rot) and extension without traction. (B) Ultrasound obtained with internal rotation and extension with traction. hyperext = hyperextension.

tion making them unacceptable for complete evaluation. The other eight shoulders had no more than partial-thickness tears of the supraspinatus tendons and were thought to be acceptable for suture placement within the rotator interval for ultrasound and MRI evaluation. No appreciable differences were seen between the integrity of the inferior, anterior, and superior capsular regions.

Ultrasound Evaluation

Ultrasound correctly identified and delineated the rotator interval in coronal and axial planes validated by suture placement and direct probing of the rotator interval during real time sonography. The area of the rotator interval region was determined by quantitative measurements from static images of the margins defined by the coracoid medially, anterior border of the supraspinatus superiorly, subscapularis inferiorly, and the bicipital sulcus laterally. Measurements ranged from 1 to 3 cm in width. Maximal opening of the rotator interval was seen in all cases with internal rotation of the hyperextended arm with downward traction measured in the coronal and sagittal planes (Fig 4).

Magnetic Resonance Imaging

The authors were able to define the anatomic limits of the rotator interval and confirm correct suture placement within the rotator interval with MRI. Using this information, the authors developed a sequence to image human shoulders in the intact state. This pulse sequence included axial and oblique coronal high-resolution fast spin-echo sequences obtained throughout the anterior and superior margins of the shoulder capsule. Images were obtained with a 512 × 256 matrix at two excitations with 4 mm slice thickness without interslice gap. Pulse parameters included TR/TE 3500–5000/17–34(Ef) (Fig 5).

Gross Dissection

Accurate placement of the suture within the rotator interval was verified in all specimens during gross sectioning. The anterior capsule was seen clearly on sagittal sectioning within the confines of the supraspinatus superiorly and the subscapularis inferiorly. A complete rotator interval defect was seen in six of eight specimens. The capsule within the rotator interval, when present, was observed to be significantly thinner and more attenuated than the inferior and posterior capsular regions by gross observation (Fig 6).

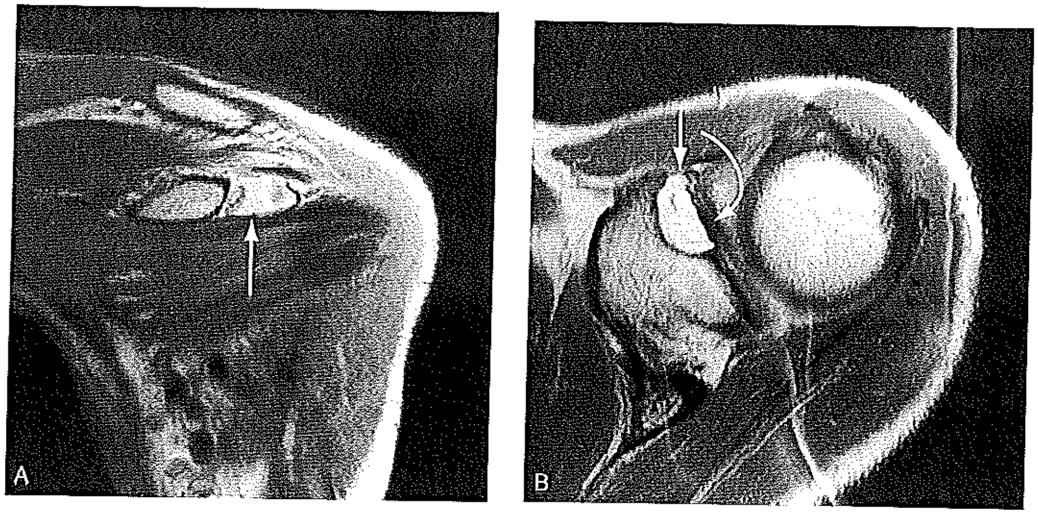

Fig 5A–B. Magnetic resonance image of the anterosuperior capsule obtained in the oblique coronal and axial planes. (A). Oblique coronal long TR/Short TE (TRFTE ms 4000/21 [Ef]) magnetic resonance image shows fluid collection containing paticulate synovial debris (arrow) localized superior to the subscapularis tendon, and inferior to the supraspinatus tendon, reflecting a surgically confirmed ganglion decompressing into the rotator interval. (B). Axial fast spin-echo (TRFTE ms 4500/30 [Ef]) image shows fluid collection in the rotator interval (curved arrow). The anterior coracohumeral ligament and the superior glenohumeral ligament (straight arrow) can be seen.

Histology

Evaluation of the capsular region bridging the rotator interval between the inferior border of the subscapularis tendon and the anterior margin of the supraspinatus was done by plain and polarized light microscopy. Beginning at the level just superior to the anterior band of the inferior glenohumeral ligament complex, a synovial lining supporting a thin layer of loose, primarily circularly (coursing around

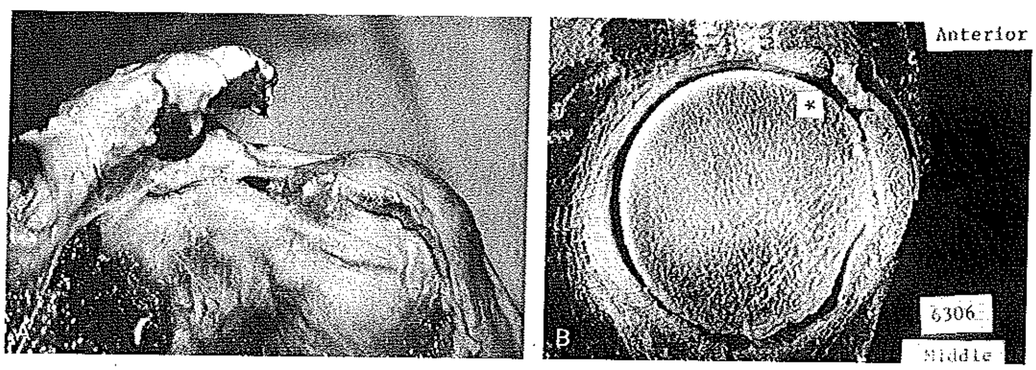

Fig 6A–B. Photograph of a specimen from an adult showing the rotator interval capsular region. (A) Gross specimen showing the rotator interval opening between the supraspinatus and subscapularis muscle tendons. (B) Sagittally sectioned specimen showing the rotator interval capsule as an attenuated region of the capsule. * = rotator interval region.

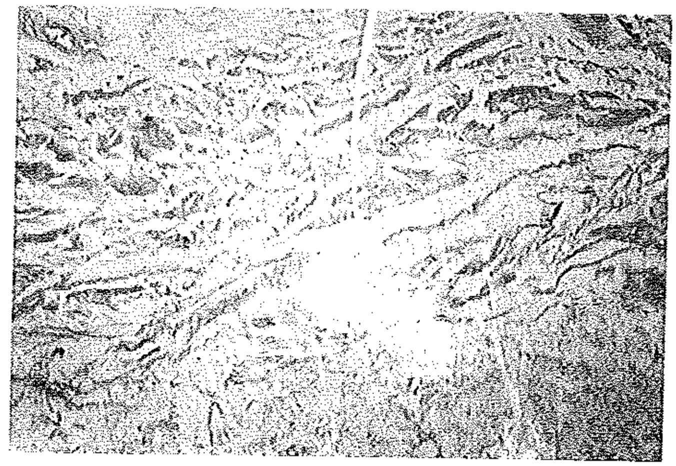

Fig 7. Photomicrograph of a specimen from an adult taken from within the rotator interval region. The lack of organization of the collagen bundles is shown (Stain, hematoxylin and eosin; magnification, ×200)

the joint) oriented collagen fibers with sparse sagittally-oriented (coursing from glenoid to humerus) collagen fibers was typically identified (Fig 7). Cell populations were morphologically most similar to fibroblasts.

DISCUSSION

O'Brien et al[10] helped clarify the anatomy of the shoulder capsule up to the level of the anterior band of the inferior glenohumeral ligament complex. Their study provides evidence that this portion of the capsule is anatomically and histologically deficient compared with other parts of the shoulder capsule. Unlike the organized three layer architecture of the inferior glenohumeral ligament complex, the rotator interval capsule has a relatively disorganized system of collagen fibers and often subtends a congenital hole or defect located between the subscapularis and supraspinatus tendons. This evidence suggests that the rotator interval capsular defect located between the subscapularis and supraspinatus is congenital and not acquired.

Warner and Marks[17] presented a case report of recurrent anteroinferior and multidirectional instability with a complete absence of the capsuloligamentous structures above the anterior band of the inferior glenohumeral ligament complex. Because insufficient capsule was available to close the defect, the superior portion of the subscapularis tendon was used to close the capsular deficiency. The authors concluded that because this particular patient, when evaluated under anesthesia, had similar laxity of the asymptomatic shoulder, this defect might have been a congenital phenomenon. The findings of a complete absence of rotator interval capsule in more than ½ of the fetuses older than 14 weeks gestation provides support for this congenital etiology.

Arthrography has been useful in confirming a rotator interval defect by showing contrast medium within the subscapularis fossa that may be confused with a subscapularis bursa.[11] This finding, however, may be less specific for a rotator interval lesion. The authors were interested in a preliminary evaluation of noninvasive means such as MRI and ultrasound to assess the rotator interval region. Arthroscopic suture placement through the rotator interval with independent verification by gross dissection showed that the authors were, in fact, evaluating the rotator interval region by ultrasound and MRI. A prospective study comparing the correlation between ultrasound and MRI findings and surgical findings should improve the appreciation of these imaging techniques.

Operative intervention aimed at closing the rotator interval capsular defect is supported by clinical and biomechanical studies.[3–6] The authors think that excessive inferior translation during examination under anesthesia with the arm in adduction and internal rotation that is not dampened with external rotation may suggest the presence of a rotator interval lesion. Failure to sufficiently address the rotator interval capsule may result in treatment failure as shown in previous reports. For example, Rowe et al[13] reported that six of 32 reoperations for failed anterior stabilization procedures were associated with a separation between the subscapularis and supraspintus tendons extending laterally to the lesser tuberosity. In an earlier series, these authors identified large rotator interval defects in 20 of 37 patients (54%) undergoing open procedures for transient subluxation of the shoulder. Closure of these rotator interval defects was a component of their stabilization procedures.[12]

Field et al[3] retrospectively identified 15 patients who underwent isolated closure of a rotator interval defect during open shoulder stabilization. Four patients presented with pain in abduction and external rotation and 11 patients had symptoms related to instability. Unlike other series, repetitive activities commonly were associated with this disorder. A positive sulcus sign was present in all patients when they were examined under anesthesia. Intraoperataive measurements of the defect averaged 2.75 × 2.3 cm. The coracohumeral ligament, rotator interval capsule, and superior glenohumeral ligament were absent or poorly defined. Arthroscopy failed to identify the rotator interval defect. The average followup of 3.3 years showed no recurrence of instability and statistically significant improvements in pain, motion, strength, stability and function using the American Shoulder and Elbow Surgeon's shoulder evaluation form and rating scale of Rowe.

Recently, several authors have presented relatively simple techniques for rotator interval closure that can be implemented arthroscopically.[3,5,15] If the shoulder has inferoposterior translation after arthroscopic repair for shoulder instability, rotator interval closure is made possible with commercially available suture passing devices. Care is taken to position the arm in external rotation and adduction during suture placement and tensioning to avoid obligate loss of external rotation.

The current findings suggest that the rotator interval capsule may be congenitally deficient. Although the use of ultrasound and MRI might prove useful in the future, the rotator interval region is evaluated best during open or arthroscopic shoulder stabilization at the time closure is deemed necessary as an adjunct to the stabilization process. The authors recommend that surgeons carefully evaluate the integrity of the tissue within the rotator interval. When rotator interval closure is desired, suturing the edges of more substantial tissue immediately adjacent to the boundaries of this region would seem prudent.

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