

Multiquadrant Digital Analysis of Shoulder Capsular Thickness

William J. Ciccone II, M.D., Timothy J. Hunt, M.D., Richard Lieber, Ph.D.,
Robert Pedowitz, M.D., Ph.D., James Esch, M.D., and James P. Tasto, M.D.

Purpose: Nonablative thermal capsular shrinkage has been developed in an attempt to address the plastic capsule deformation thought to cause increased rates of recurrent instability following arthroscopic stabilization procedures. Although the temperature required to optimize collagen shrinkage is known, a safe depth of thermal penetration, in various locations about the shoulder capsule, has not been defined. The purpose of this study was to measure shoulder capsule thickness by quadrant and circumferentially from the glenoid to the humerus so that thermal energy in shoulder procedures can be more precisely applied to limit possible injury to pericapsular structures. **Type of Study:** This is an anatomic study using a cadaveric shoulder specimens. **Materials and Methods:** Soft tissue was dissected from 8 fresh cadaveric shoulders to isolate intact glenohumeral joint capsules. The humeral insertion was released and the capsule was cut into 6 longitudinal quadrants around the glenoid. The capsule specimens were then flash frozen and stored at -80°C . Quadrant tissue was cut into longitudinal sections 14 to 16 μm wide and stained with hematoxylin and eosin. The specimens were then digitized under a dissecting microscope and measured using computer imaging software at approximately 4-mm intervals. Two-way analysis of variance (ANOVA) was performed on the measurements of the intact capsule specimens 2.5 cm off the glenoid. Humeral insertion data were recorded separately. **Results:** A total of 248 separate measurements were made throughout the capsule in 8 specimens. Capsular thickness increased from an average of 2.42 mm anteriorly to 2.80 mm in the inferior capsular pouch and again thinned to 2.22 mm posteriorly. Global shoulder capsule thickness ranged from 1.32 to 4.47 mm. When analyzed by position, from glenoid to humerus, a general thinning was noted with a mean thickness of 3.03 mm at the glenoid to 2.17 mm at the humeral insertion. Two-way ANOVA showed a significant thickness variation along the specimen ($P < .05$), a nearly significant thickness variation with regard to quadrant ($P < .03$), and no significant interaction ($P > .07$) when applied to specimen measurements approximately 2.5 cm off the glenoid. **Conclusions:** The thickness of the shoulder capsule ranges from 1.32 to 4.47 mm, with a significant thinning laterally from the glenoid to the humerus. Further, capsule thickness ranges from 2.76 to 3.18 mm in the regions in closest proximity to the axillary nerve. These data may help determine the proper amount of thermal penetration necessary when performing shrinkage procedures and provide safety guidelines to limit the depth of thermal penetration to avoid possible injury to pericapsular structures. **Key Words:** Shoulder instability—Capsule shrinkage.

Operative intervention for recurrent glenohumeral instability has traditionally depended on open pro-

cedures for labral repair and capsular shift. Advances in arthroscopic technology allows for these stabilization procedures to be performed with a minimally invasive approach. Initially, the early reports of acceptable results with arthroscopic stabilization techniques led to an increase in their popularity.^{1,2} However, long-term follow-up of these procedures has shown rates of recurrent instability that greatly exceed those reported for open procedures.³⁻⁵ Plastic deformation of the anterior capsular structures, not well addressed arthroscopically in these series, has been speculated to be the cause of these failures.^{6,7} Nonablative thermal capsuloplasty (capsular shrinkage) proce-

From the San Diego Sports Medicine and Orthopaedic Center, and the Department of Orthopaedics, the University of California San Diego; and Tri-City Orthopaedics, Oceanside (J.E.), California, U.S.A.

Supported by an unrestricted research grant from the Alvarado Knee Research Institute, San Diego, California, and Arthrocare Corporation, Sunnyvale, California.

Address correspondence and reprint requests to James P. Tasto, M.D., San Diego Sports Medicine and Orthopaedic Center, 6719 Alvarado Rd, #200, San Diego, CA 92120, U.S.A.

*© 2000 by the Arthroscopy Association of North America
0749-8063/00/1605-2440\$3.00/0
doi:10.1053/jars.2000.7807*

dures have been developed to arthroscopically address this issue.

Although the temperature required to optimize collagen shrinkage is known,⁸ a paucity of data exist on the effects of the depth of thermal penetration on the capsular healing response. With current technology, there is no method available to measure accurately the amount of thermal energy being transferred to the capsular tissue, and thus the penetration produced by thermal probes is difficult to assess. Hecht et al.⁹ showed that the depth of thermal penetration using a radiofrequency probe could be up to 5 mm and was associated with necrosis of surrounding pericapsular tissue. Biomechanically, diminished capsular stiffness occurred after applying nonablative laser energy at a higher energy density.¹⁰ Further, the close proximity of the axillary nerve and other pericapsular structures may increase their risk of thermal injury with full capsular penetration.^{11,12}

Without an understanding of the global variations in glenohumeral capsular thickness, it is difficult to define the appropriate depth of thermal penetration required to optimize capsular healing potential in shrinkage procedures. The purpose of this study was to measure variations in shoulder capsular thickness by quadrant from glenoid to humerus.

MATERIALS AND METHODS

Eight fresh cadaveric shoulder joints were used in this study. The average age of the specimens was 77 years (range, 64 to 98 years). Using both sharp and blunt dissection, all specimens were stripped of soft tissue extra-articularly to isolate an intact capsule surrounding an intact glenohumeral joint. The capsule was then released from its humeral insertion and was cut into 6 quadrants at specific locations from the glenoid laterally (Fig 1). Using a clock face superimposed on the glenoid, the 6 longitudinal quadrants for a right [left] shoulder were approximately located with quadrant A at 3 o'clock [9 o'clock], B at 4 o'clock [8 o'clock], C at 6 o'clock [6 o'clock], D at 8 o'clock [4 o'clock], E at 9 o'clock [3 o'clock], and F at the edge of normal-appearing capsular tissue posterior and superior to the rotator interval, 11 o'clock [1 o'clock] to 12 o'clock [12 o'clock]. The rotator interval itself contained thin, friable, intermittently absent capsular tissue and was excluded from sectioning.

The capsular specimens were mounted on cork, flash frozen in liquid nitrogen-cooled isopentane (-159°C) and then stored at -80°C until sectioned

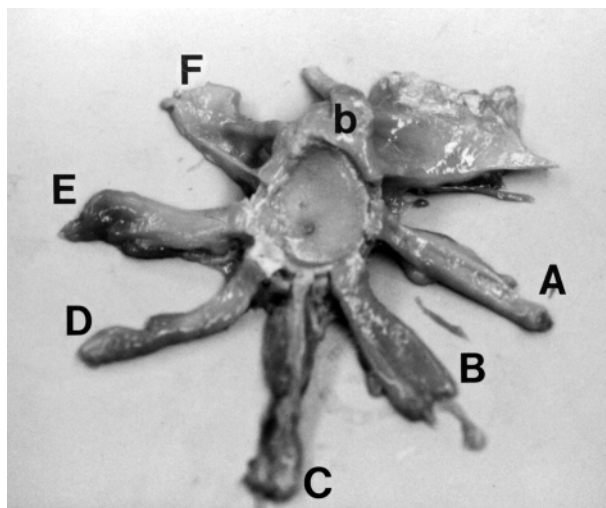


FIGURE 1. View of the glenoid of a right shoulder with attached capsular quadrants (A-F) following detachment from the humerus. b, biceps attachment to glenoid.

for microscopic examination. Each of the 6 capsular specimens from each shoulder were then cut into 5 longitudinal sections, 14 to 16 μm wide, using a microtome (Reichert-Jun, Nusloch, Germany), and stained with hematoxylin and eosin to establish general morphology. The best section was then chosen for digitization. The longitudinal length of the specimen sections was limited by the width of the microtome blade to approximately 2.5 cm laterally off the glenoid. In the longer specimens, separate sectioning and thickness measurements were also performed 3 to 5 mm from the humeral insertion. Therefore, a few shoulders required 2 sections to obtain capsule measurements all the way from glenoid to humerus.

A dissecting microscope was used to capture a video image of each longitudinal specimen for digitization. Capsular thickness was then measured at approximately 4-mm intervals along the quadrant length using computer imaging software. The thickness of specimens was compared as a function of location around the glenoid (quadrant) and their position (glenoid to humerus) using 2-way analysis of variance (ANOVA); the significance level was $P = .05$.

RESULTS

Gross capsular length ranged from 25 to 45 mm from glenoid to humerus (Fig 2). A total of 248 separate measurements were made throughout the capsular length in 8 specimens. Occasional capsular deficiency precluded accurate thickness measurements



FIGURE 2. Digitized longitudinal section of capsular tissue showing thinning from glenoid (G) laterally toward the humerus (H).

on all specimens at all locations. Six shoulders required separate sectioning, because of their long length, to obtain humeral insertion thickness data.

Capsule thickness ranged from 2.22 ± 0.98 mm to 2.97 ± 1.5 mm by quadrant (Table 1). The thickest quadrant was C (6 o'clock) with a mean thickness of 2.97 ± 1.5 mm. The thinnest quadrant was E (9 o'clock) with a mean thickness of 2.22 ± 0.98 mm. A trend in capsular thickening was noted from quadrant A (3 o'clock) with a mean thickness of 2.42 ± 1.05 mm to quadrant C (6 o'clock) with a thickness of 2.97 ± 1.5 mm, and then thinning again to quadrant E (9 o'clock). The capsule at quadrant F was slightly thicker at 2.55 ± 1.05 mm.

When capsular specimens were analyzed by position, from glenoid to humerus, a general thinning was noted with a mean thickness of 3.03 ± 1.22 mm at the glenoid to 2.17 ± 1.30 mm at the humeral insertion (Table 2). This trend was consistent in all sections except for B (4 o'clock) where the thickness increased from 2.72 ± 1.14 mm to 3.15 ± 1.21 mm laterally (Table 3). Two-way ANOVA revealed a significant thickness variation along the specimen ($P < .05$), a nearly significant thickness variation with regard to quadrant ($P < .03$), and no significant interaction ($P > .7$). This analysis was performed only on capsular measurements to approximately 2.5 cm lateral to the glenoid. When the humeral insertion data were included, a significant thickness variation along each specimen was confirmed ($P < .02$).

TABLE 1. Shoulder Capsule Thickness Variation by Quadrant

Quadrant	Count	Mean (mm)	SD
A	35	2.424	1.048
B	46	2.863	1.204
C	41	2.965	1.487
D	43	2.577	0.996
E	39	2.216	0.979
F	44	2.548	1.046

TABLE 2. Shoulder Capsule Thickness by Position From Glenoid to Humerus

Position	Count	Mean (mm)	SD
Glenoid			
1	45	3.026	1.219
2	45	2.832	1.252
3	45	2.511	1.087
4	43	2.486	1.017
5	37	2.498	0.961
Humerus	33	2.168	1.259

DISCUSSION

Various anatomic aspects of the shoulder capsule have been addressed in the literature. O'Brien et al.¹³ reported that the inferior glenohumeral ligament is a complex structure consisting of an anterior band, a posterior band, and a diffuse thickening between the bands termed the axillary pouch. However, they made no reference to specific thickness measurements made in this region. While no attempt was made in the present study to section-specific capsular structures, the thickest capsule was encountered in quadrants B through D (4 o'clock to 8 o'clock), which correlates with the location of the axillary pouch. Capsular thickness then dropped to its thinnest value along quadrant E (9 o'clock) posteriorly. Other studies evaluated capsular thickness.¹³⁻¹⁵ In research performed by Bigliani et al.,¹⁴ biomechanical properties of the inferior glenohumeral ligament were studied. In this study, the inferior glenohumeral ligament was divided into 3 anatomic regions: the superior band, the anterior portion of the axillary pouch, and the posterior portion of the pouch. Specimen thickness was then measured using an electro-optical micrometer at 7 locations along the ligament; however, no measurements from glenoid to humerus showing thickness trends were recorded. In another study, Itoi et al.¹⁵ evaluated capsular thickness from midcapsule laterally

TABLE 3. Mean Shoulder Capsular Thickness Variation by Quadrant and Position From Glenoid to Humerus in Millimeters

Quadrant	Position						
	Glenoid	1	2	3	4	5	Humerus
A	3.35	2.64	2.05	1.91	2.47	2.15	2.15
B	2.72	2.80	2.76	3.12	3.15	2.64	2.64
C	3.43	3.60	3.18	2.87	2.18	1.78	1.78
D	3.64	2.91	2.47	2.23	2.25	1.45	1.45
E	2.39	2.27	2.19	2.04	2.27	2.10	2.10
F	2.63	2.66	2.27	2.55	2.54	2.69	2.69

to the humeral insertion. To ascertain the biomechanical properties of the lateral shoulder capsule, capsular thickness was measured in 4 quadrants; superior (12 o'clock), anterior (3 o'clock), inferior (6 o'clock), and posterior (9 o'clock). They encountered a significant difference in the capsular thickness in 4 different sites. They also found that the thickness of the anterior and superior capsule was greater than that of the posterior capsule. Our data concur with their findings; we found the posterior capsule the thinnest at 9 o'clock (quadrant E) and the thickest at 6 o'clock (quadrant C).

In our study, we were unable to obtain full longitudinal sections in 6 shoulders because of the length restriction of our microtome blade. Our statistical analysis was based only on the intact longitudinal specimens that were measured to approximately 22.5 mm off the glenoid. We then sectioned those longer capsular sections within 3 to 5 mm of their humeral insertions and digitized them to establish the trend of capsular thinning laterally. The capsule thinned significantly from a mean of 3.03 mm at the glenoid to a mean of 2.17 mm at the humerus ($P < .02$). Zanotti et al.,¹² while studying the anatomic structures at risk during arthroscopic capsular release, found the axillary nerve to be closest to the shoulder capsule, approximately 17 mm lateral to the glenoid, as it coursed inferior to the subscapularis. Because our thickness measurements were obtained at approximately 4-mm intervals, position 4 is the closest measurement we have to this location. The average capsule thickness in the area of the axillary nerve ranged from 2.05 mm (quadrant A) to 3.18 mm (quadrant C) (Table 3). These results provide guidelines for a safe depth of penetration when using thermal probes in this area.

This analysis has some shortcomings. Thermal procedures for shoulder capsulorrhaphy have been described in a younger patient population; our specimens averaged 77 years of age. Other significant studies evaluating aspects of shoulder capsule thickness also used older specimens.^{14,15} While there have been reports on variations in the mechanical properties of the shoulder capsule associated with aging,¹⁶ we are unaware of any published work on possible variations of capsule thickness associated with aging. This may be a topic worth continued research. Further, our specimens required flash freezing techniques in order to be sectioned for digitization, which may have affected the natural thickness. Our measurements differed from those of previous studies from 0.2 to 1.2 mm in different locations around the capsule.^{14,15} Although these differences may be attributed to our

freezing of the capsule, they may also be the result of our more accurate computerized measurements.

Shoulder capsular procedures have been described throughout the literature for the treatment of instability. More recently, nonablative thermal capsular shrinkage has been described for the arthroscopic treatment of instability.¹⁷ Our study shows that the thickness of the shoulder capsule globally ranges from 2.22 ± 0.98 mm to 2.97 ± 1.5 mm, with quadrant C being the thickest on average and quadrant E the thinnest (Table 1). These data may help determine the proper amount of thermal penetration when performing capsular shrinkage procedures. Computer digitization technology was used to measure capsule thickness to establish a platform for further study on the effects of thermal penetration on capsular healing. This study also provides safety guidelines for limits of depth of penetration when using thermal probes about the shoulder capsule.

Acknowledgment: The authors thank Sang-Jin Cheon, M.D., Chol Kim, M.D., and Amir Jamali, M.D., for their initial help with the shoulder dissections.

REFERENCES

1. Morgan CD, Bodenstab AB. Arthroscopic Bankart suture repair: Technique and early results. *Arthroscopy* 1987;3:111-122.
2. Green MR, Christensen KP. Arthroscopic versus open Bankart procedures: A comparison of early morbidity and complications. *Arthroscopy* 1993;9:371-374.
3. Walch G, Boileau P, Levigne C, Mandrino A, Neyret P, Donell S. Arthroscopic stabilization for recurrent anterior shoulder dislocation: Results of 59 cases. *Arthroscopy* 1995;11:173-179.
4. Green MR, Christensen KP. Arthroscopic Bankart procedure: Two to five year follow up with clinical correlation to severity of glenoid labral lesion. *Am J Sports Med* 1995;23:276-281.
5. Grana WA, Buckley PD, Carian Y. Arthroscopic Bankart suture repair. *Am J Sports Med* 1993;21:348-353.
6. Speer KP, Deng X, Borrero S, Torzilli PA, Altchek DA, Warren RF. Biomechanical evaluation a simulated Bankart lesion. *J Bone Joint Surg Am* 1994;76:1819-1826.
7. Pagnani MJ, Warren RF, Altchek DW, Wickiewicz TL, Anderson AF. Arthroscopic shoulder stabilization using transglenoid sutures. A four year minimum follow up. *Am J Sports Med* 1996;24:459-467.
8. Vangsness CT, Mitchell W, Nimmi M, Erlich M, Saadat V, Schmotzer H. Collagen shortening. An experimental approach with heat. *Clin Orthop Rel Res* 1997;337:267-271.
9. Hecht P, Hayashi K, Cooley AJ, Lu Y, Fanton GS, Thabit G, Markel MD. The thermal effect of monopolar radiofrequency energy on the properties of joint capsule. An in vivo histologic study using a sheep model. *Am J Sports Med* 1998;26:808-814.
10. Hayashi K, Markel MD, Thabit G, Bogdanske JJ, Thielke RJ. The effect of nonablative laser energy on joint capsular properties. An in vitro mechanical study using a rabbit model. *Am J Sports Med* 1995;23:482-487.
11. Bryan WJ, Schauder K, Tullos HS. The axillary nerve and its relationship to common sports medicine procedures. *Am J Sports Med* 1986;14:113-116.

12. Zanotti RM, Kuhn JE. Arthroscopic capsular release for the stiff shoulder. Description of technique and anatomic considerations. *Am J Sports Med* 1997;25:294-298.
13. O'Brien SJ, Neves MC, Arnoczky SP, et al. The anatomy and histology of the inferior glenohumeral ligament complex of the shoulder. *Am J Sports Med* 1990;18:449-456.
14. Bigliani LU, Pollock RG, Soslowksi LJ, Flatow EL, Pawluk RJ, Mow VC. Tensile properties of the inferior glenohumeral ligament. *J Orthop Res* 1992;10:187-197.
15. Itoi E, Grabowski JT, Morrey BF, An KN. Capsular properties of the shoulder. *Tohoku J Exp Med* 1993;171:203-210.
16. Reeves B. Experiments on the tensile strength of the anterior capsular structures of the shoulder in man. *J Bone and Joint Surg Br* 1968;50:858-865.
17. Tibone JE, McMahon PJ, Shrader TA, Sandusky MD, Thay QL. Glenohumeral joint translation after arthroscopic, nonablative, thermal capsuloplasty with a laser. *Am J Sports Med* 1998;26:495-498.