Anatomy and dimensions of rotator cuff insertions

Jeffrey R. Dugas, MD, Deirdre A. Campbell, MEng, Russell F. Warren, MD, Bruce H. Robie, PhD, and Peter J. Millett, MD, *New York, NY*

The purpose of this study was to devise and implement an accurate and reproducible method of measuring the area and dimensions of the rotator cuff tendon insertions and their distance from the articular surface. Twenty fresh-frozen cadaveric upper-extremity specimens were divided into 2 groups of 10. In group 1 the specimens were dissected, leaving only the most distal rotator cuff tendons attached to the humerus. The periphery of the insertion onto the greater tuberosity was marked at 3-mm intervals. The specimens were then mounted onto a custom jig, and the insertion was mapped by a 3-space digitizer. In group 2 the specimens were prepared by removing all tissues except the rotator cuff muscles and tendons and the joint capsule. The interval between the muscles of the rotator cuff was identified and marked. The rotator cuff muscles and tendons were then removed, leaving only the most distal tendons attached to the tuberosities. The periphery of the individual cuff insertions was then marked as in group 1 and mapped in the same fashion. The articular margin also was marked at similar intervals and mapped with the same technique. The area of insertion of the 3 tendons on the greater tuberosity averaged 6.24 cm^2 (SD, 2.04 cm^2) in group 1. The mean minimum transverse dimension across the cuff insertion occurred in the mid portion of the supraspinatus, with a mean distance of 14.7 mm (SD, 3.22 mm). In group 2 the mean area of insertion of the supraspinatus was 1.55 cm^2 (range, 0.68-2.64 cm^2; SD, 0.66 cm^2) and the mean area of insertion for the infraspinatus was 1.76 cm^2 (range, 1.23-2.53 cm^2; SD, 0.40 cm^2). The distance from the articular margin to the most medial rotator cuff fibers was less than 1 mm along the anterior-most 2.1 cm of the cuff insertion onto the greater tuberosity. No correlation could be made between humeral head dimension and the dimensions of the rotator cuff insertions. The mean minimum medial-to-lateral distance across the rotator cuff insertion was sizeable, at 14.7 mm. This represents the minimum possible distance, as the mathematical calculation to determine the dimensions used a perpendicular measurement. The rotator cuff inserts very closely to the articular margin along the anterior 2.1 cm of the greater tuberosity. These anatomic measurements may be useful in evaluating and reattaching the rotator cuff to the humerus. (J Shoulder Elbow Surg 2002;11:498–503.)

From the Hospital for Special Surgery, New York, NY.
Reprint requests: Jeffrey R. Dugas, MD, American Sports Medicine Institute, 1313 13th St South, Birmingham, AL 35205.

1058-2746/2002/$35.00 + 0 **32/1/126208**
doi:10.1067/mse.2002.126208

Rotator cuff pathology is a common finding. Cadaveric studies have demonstrated that the incidence of full-thickness rotator cuff defects in patients aged under 60 years is less than 6%, whereas in those aged over 60 years, the incidence can reach nearly 30%.[7] Partial-thickness tears are twice as common as full-thickness defects.[3-5,9] An important study by Yamanaka and Matsumoto[10] demonstrated that untreated atraumatic partial-thickness tears have a tendency to progress to full-thickness defects. Techniques have been described for repairing the cuff tendons to the humerus by means of open, mini-open, and arthroscopic methods. Regardless of technique, the goal of rotator cuff repair is to restore continuity of the cuff tissue to the humerus in order to allow healing of the tendon to bone and subsequent return of strength and function.

Brewer[1] demonstrated a diminution in fibrocartilage content at the rotator cuff insertion with increasing age. Kumagai et al[6] similarly showed an increase in type III collagen at the insertion with increasing age. Altered biomechanics have been noted in patients with degenerative lesions of the rotator cuff.[8] Several studies have documented the overlapping of fibers from adjacent tendons on the superior surface of the insertion onto the humerus.[2] Despite the vast quantity of information available on the anatomy, biologic content, and function of the rotator cuff, we know of no data or previous report that documents the anatomy of the rotator cuff insertion with regard to area, dimensions, and distance from the articular surface. The purpose of this study was to design and implement an accurate and reproducible method for measuring the area and dimensions of the rotator cuff attachments to the humerus. A further purpose was to determine whether the radius of curvature or dimen-

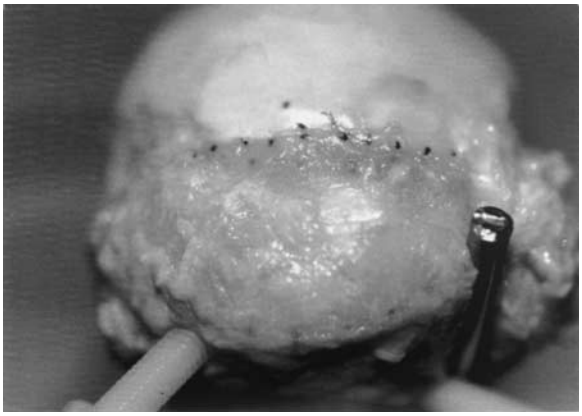

Figure 1 Photograph of specimen with soft tissues removed. The periphery of the rotator cuff has been marked at 3-mm intervals, as has the articular margin.

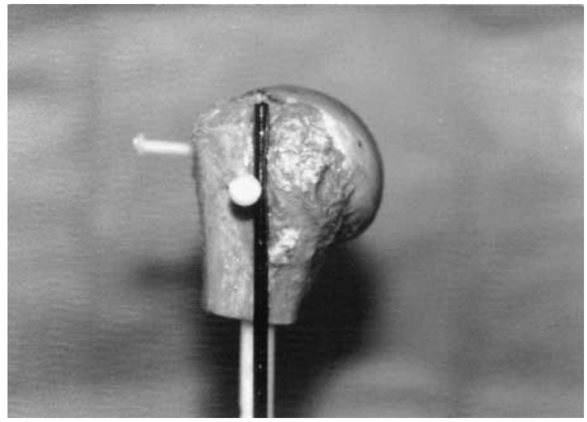

Figure 2 Photograph of specimen in custom jig. Specimens were fixed to the polyethylene post with 2 polyethylene screws at 90° to each other in order to prevent rotation and migration.

sions of the humeral head were in any way related to the dimensions of the rotator cuff insertion.

MATERIALS AND METHODS

Twenty fresh-frozen human cadaveric upper-extremity specimens were obtained (10 matched pairs). They were divided into 2 groups of 10, with 5 matched pairs in each group. Each specimen included the entire scapula and all of the periscapular muscles. The mean age of the specimens was 63 years (range, 48-88 years). None had any evidence of previous shoulder surgery or visible gross shoulder abnormality. No rim rents or craters were present in any of the specimens included in this study. They were kept frozen at −4°C until dissection and testing. Each specimen was thawed to room temperature before dissection.

Group 1

For group 1 specimens, the humeral head was disarticulated from the glenoid by incising the capsule circumferentially at dissection. All of the soft tissues about the proximal humerus were removed except the rotator cuff tendons and joint capsule. The bicipital groove was opened, and the biceps tendon remnant, if present, was removed. The humerus was then cut transversely in the midshaft region, leaving only its proximal half. The rotator cuff tendons and joint capsule were cut close to their insertions on the humerus. The periphery of the rotator cuff insertion onto the greater tuberosity was then marked at 3-mm intervals with a permanent ultra-fine– tipped marker (Figure 1). The articular margin was also marked at 3-mm intervals, beginning at the entrance to the bicipital groove and progressing posteriorly. The height and width of the articular surface were then measured with calipers. The articular surface was marked at 10-mm intervals along lines bisecting the height and width of the humeral head. The specimen was then fixed to a rigid intramedullary polyethylene rod by placing 2 polyethylene screws through the specimen and rod with use of a plastic jig. The bicortical screws were positioned at 90° to each other in order to prevent both rotation and superior/inferior translation (Figure 2). The polyethylene rod was placed into a solid, clear plastic base. A large Steinmann pin was used to lock the specimen into the base by placing one end along the course of the bicipital groove and the other end into a precut hole in the base. In order to accommodate specimens of various sizes, the holes in the base for the Steinmann pin were cut in a spiral fashion at 30° intervals, progressively moving away from the center post hole.

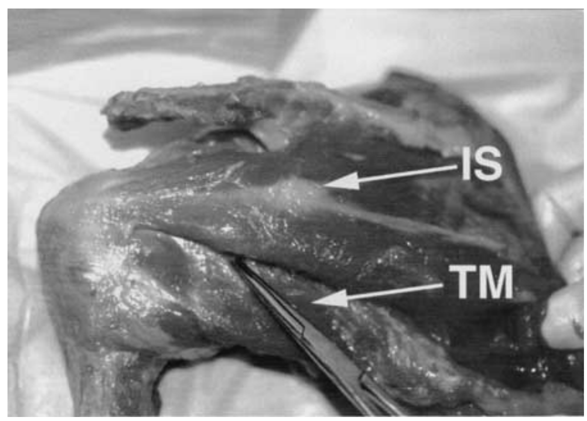

Figure 3 The interval between the muscle bellies was dissected bluntly after all other soft tissues had been removed. *IS,* Infraspinatus; *TM,* teres minor.

Group 2

Group 2 specimens were prepared for dissection in the same manner as those in group 1. Once thawed, the skin and subcutaneous tissues were removed. The deltoid was removed from its proximal origin, exposing the acromion, scapular spine, and spinati. The interval between the supraspinatus and infraspinatus muscle bellies and the interval between the infraspinatus and teres minor muscle bellies were developed bluntly (Figure 3). The humerus was then internally rotated, placing tension on the infraspinatus and teres minor. A sharp No. 11 blade was used to incise the confluence of the rotator cuff tendons in line with the interval

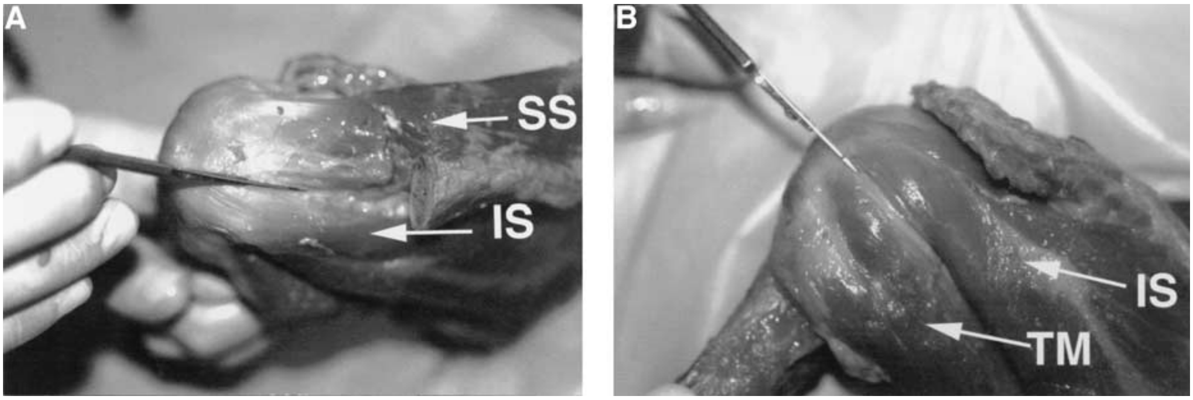

Figure 4 After the intervals between the muscle bellies had been established, a sharp blade was used to incise the confluence of tendons in line with the muscular interval while the muscles were placed under stretch. **A,** Interval between the supraspinatus *(SS)* and infraspinatus *(IS)*. **B,** Interval between the infraspinatus *(IS)* and teres minor *(TM)*.

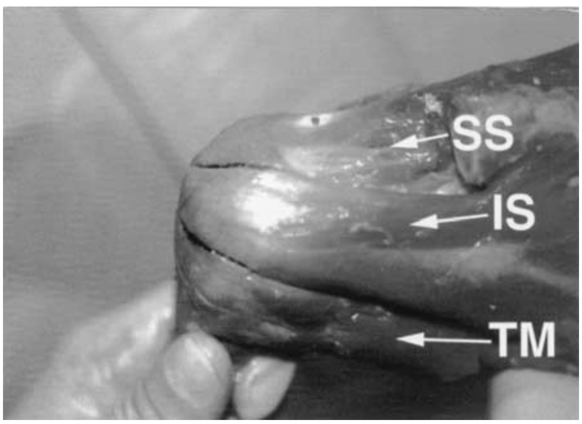

Figure 5 The intervals between the tendons were marked sharply with methylene blue. *IS,* Infraspinatus; *TM,* teres minor; *SS,* supraspinatus.

Figure 6 The periphery of the rotator cuff insertions was marked with a fine-tipped marker at 3-mm intervals after removal of the soft tissues.

between the 2 muscle bellies (Figure 4). With the tendons still under tension, the blade was dipped in methylene blue and the incision in the tendon was marked (Figure 5). The interval between the supraspinatus and infraspinatus was identified and marked in a similar fashion.

The muscles and tendons of the teres minor, infraspinatus, supraspinatus, and subscapularis were then incised near their insertions onto the humerus. The joint capsule was also incised near the humeral insertion, and the humerus was disarticulated from the scapula. The humerus was cut transversely as in group 1, the bicipital groove was opened, and the biceps remnant was removed. The periphery of each individual tendon insertion onto the humerus was then marked at 3-mm intervals with an ultra-fine– tipped permanent marker (Figure 6). The specimens were fixed to the base by the same procedure and technique used in group 1.

Data acquisition and calculations

Through use of a 3-space digitizing device (Polhemus Inc, Colchester, Vt) with the reference point fixed to the base of the jig holding the specimen, the points that were marked on each specimen were mapped in 3 dimensions. Two trials each by 2 individuals were recorded for each specimen, for a total of 4 sets of data for each specimen.

Custom-written software that uses a least-squares regression algorithm found a best-fit plane for the 3-dimensional data of each insertion. The 3-dimensional data were reduced to 2 dimensions by projection of the points into this plane. The area and centroid of the insertions were calculated from these reduced data. The maximum and minimum dimensions that passed through the centroid of the area were also calculated.

RESULTS

General

No significant interobserver variability could be demonstrated ($P > .52$ for each specimen) (Figure 7). No correlation could be made between the dimensions of the humeral head and the dimensions of the rotator cuff insertion (Pearson correlation analysis).

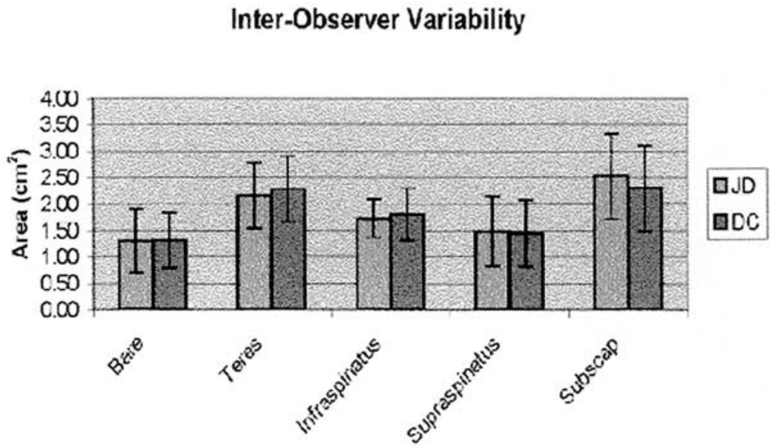

Figure 7 No significant interobserver or intraobserver variability could be demonstrated. *Subscap,* Subscapularis.

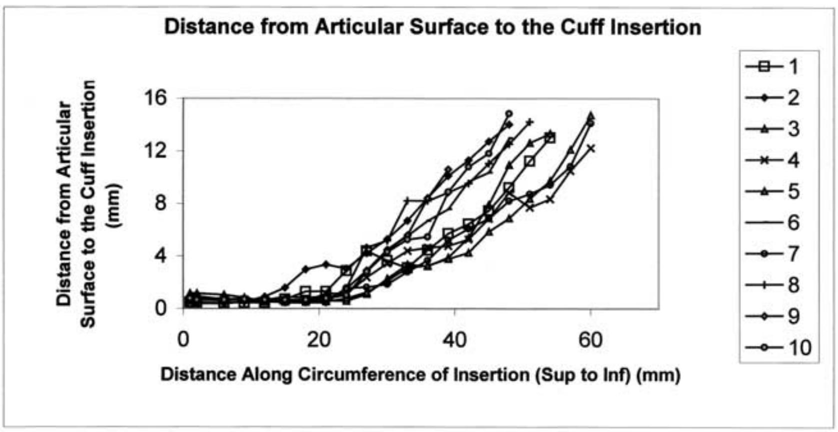

Figure 8 Plots of the distance from the articular margin to the most medial cuff fibers. Note that the distance is minimal along the anterior-most 2 cm and subsequently increases to a maximum more posteriorly. *Sup,* Superior; *Inf,* inferior.

Group 1

In group 1 the mean minimum distance across the rotator cuff insertion onto the greater tuberosity from medial to lateral was 14.7 mm (SD, 3.2 mm). This minimum perpendicular distance routinely occurred in the mid portion of the supraspinatus insertion. The mean distance across the rotator cuff insertions onto the greater tuberosity from anterior to posterior was 37.8 mm (SD, 7.70 mm). The mean total area of insertion of the 3 tendons inserting onto the greater tuberosity was 6.24 cm^2 (SD, 2.04 cm^2). The mean distance from the articular surface to the most medial fibers of the rotator cuff insertion was 1 mm, beginning at the posterior entrance to the bicipital groove and progressing posteriorly a distance of 2.1 cm (Figure 8). Beyond the 2.1-cm point, the distance from the articular surface to the medial fibers of the rotator cuff gradually increased to a mean maximum of 13.9 mm at the inferior aspect of the teres minor insertion.

Group 2

Data from representative trials for each tendon insertion are depicted in Figure 9. In group 2 the mean area of insertion of the subscapularis onto the lesser tuberosity was 2.41 cm^2 (SD, 0.81 cm^2; range 0.98-3.61 cm^2). The mean dimension of the subscapularis insertion in the superior-to-inferior direction was 2.43 cm (SD, 0.43 cm; range, 1.81-2.78 cm). The mean dimension of the subscapularis insertion in the medial-to-lateral direction was 1.79 cm (SD, 0.73 cm; range, 0.93-1.81 cm). The mean area of the supraspinatus insertion onto the greater tuberosity was 1.55 cm^2 (SD, 0.66 cm^2; range, 0.68-2.64

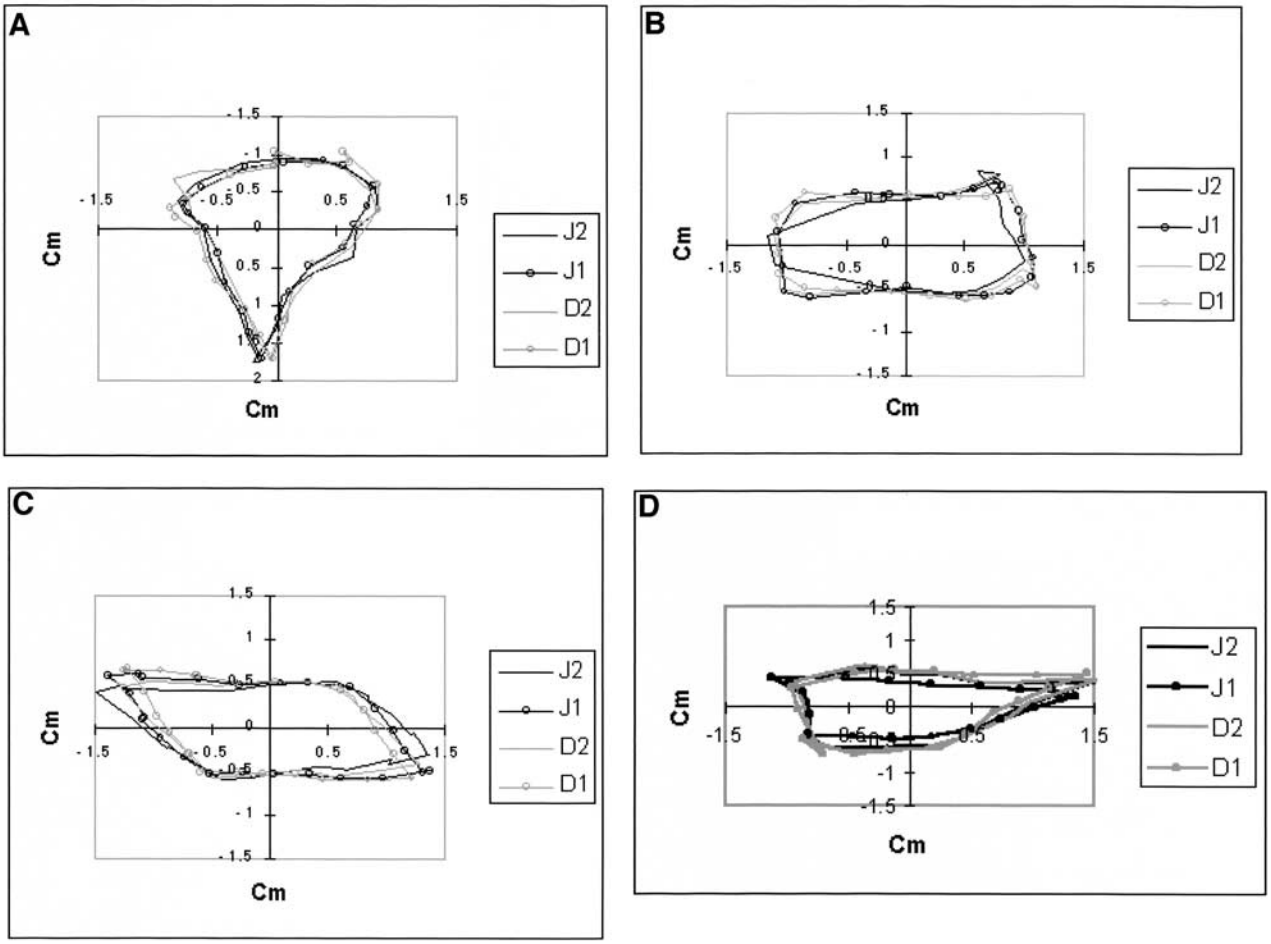

Figure 9 Sample plots of 4 trials mapping points around the subscapularis **(A)**, supraspinatus **(B)**, infraspinatus **(C)**, and teres minor **(D)** insertions. Note the shape of the subscapularis insertion. The upper tendinous portion of the subscapularis inserts over a wider area than the lower, mostly muscular portion of the insertion.

cm^2). The mean dimensions of the supraspinatus insertion were 1.27 cm in the medial-to-lateral direction (SD, 0.63 cm; range, 0.69-1.46 cm) and 1.63 cm in the anterior-to-posterior direction (SD, 0.55 cm; range, 1.01-2.08 cm). The mean area of the infraspinatus insertion onto the greater tuberosity was 1.76 cm^2 (SD, 0.40 cm^2; range, 1.23-2.53 cm^2). The mean dimensions of the infraspinatus insertion were 1.34 cm in the medial-to-lateral direction (SD, 0.20 cm; range, 1.01-1.42 cm) and 1.64 cm in the anterior-to-posterior direction (SD, 0.31 cm; range, 1.19-2.11 cm). The mean area of the teres minor insertion onto the greater tuberosity was 2.22 cm^2 (SD, 0.62 cm^2; range, 1.56-3.39 cm^2). The mean dimensions of the teres minor insertion were 1.14 cm in the medial-to-lateral direction (SD, 0.32 cm; range, 0.70-1.69 cm) and 2.07 cm in the anterior-to-posterior direction (SD, 0.54 cm; range, 1.76-2.65 cm). The mean total area of insertion of the rotator cuff tendons onto the greater tuberosity in group 2 was 5.53 cm^2.

DISCUSSION

The goal of this project was to provide quantitative data describing the area and dimensions of the rotator cuff insertion onto the humerus. We know of no published or anecdotal reports of such information. This study in no way attempted to describe the thickness of the rotator cuff itself, only its insertion onto the humerus. Several limitations are inherent in the methods used in this study. No information with regard to the handedness, height, weight, medical history, work history, or social history was available for any of the specimens. This information may have been useful in correlating our findings with other nonanatomic objective information. Micromotion was certainly possible within the system used to hold the specimens to the jig. Such motion is possible as a result of decreased rigidity of the polyethylene screws and post, as well as any microscopic or macroscopic differences between the size of the drill bit and the size of the screws. It was necessary to use polyethylene for the screws and post because of interference with the digitizing device (Polhemus, Inc) that occurs with the use of any metallic substances within several feet of the base. Motion of the post with the specimen fixed in place was not a problem with regard to data collection and analysis, because the position of the data points relative to one another would be unaffected. Although the entire plot may be shifted in space, the area and dimension information would not be altered.

The study methodology was validated by digitizing an area with known dimensions and comparing the computer program's output with those dimensions. The resulting errors for width and area calculations were all less than 1%.

The reduction of the 3-dimensional data into 2-dimensional space causes an overall underestimation of area and dimensions. However, the relatively small size of the insertion as compared with the radius of the humeral head results in these errors being small and within the interobserver variability. Through use of the average (although one observer was left-handed and one was right-handed), no intraobserver or interobserver variability could be detected ($P > .52$ for each specimen). Different specimens were used for each group. No correlation or comparison would be valid from one group to another. The area of insertion of the 3 tendons onto the greater tuberosity in group 1 averaged 6.24 cm^2, whereas the sum of the mean areas for the 3 tendinous insertions onto the greater tuberosity in group 2 was 5.53 cm^2. Comparison of these values may lead to invalid conclusions because the specimens were different. In addition, the method of determining the intertendinous interval by visual inspection and sharp dissection contains obvious observer-related bias. At the time of these determinations, an attempt was made to place the interval under tension to straighten the line of pull of the musculature, making identification of the interval easier at the level of the musculotendinous junction. A straight incision was then made in the tendon in line with the interval. It is possible that this imprecise method has led to error in measurement and subsequent data collection, but we know of no more precise method for determination of the intervals in question.

The importance of exact re-creation of the normal anatomic area and dimensions of insertion at the time of rotator cuff repair is unknown. Inherently, it would make sense that re-creating the normal condition would lead to an increased likelihood of normal healing and, subsequently, normal function. However, no data are available nor has this study attempted to indicate that such a conclusion is valid. With regard to the distance from the articular surface to the rotator cuff fibers, it is possible that this information will be useful in the diagnosis of partial undersurface tears of the cuff, as well as in the evaluation of rotator cuff repair. As noted above, the necessity of anatomic re-creation of the insertional anatomy is uncertain. However, a knowledge of the normal condition may help direct the reconstruction techniques and methods at the time of surgery.

The area of insertion of the rotator cuff onto the greater tuberosity is sizeable, at an average greater than 6 cm^2. Similarly, the mean distance across the insertion is significant, at 14.7 mm. The distance from the articular surface to the rotator cuff is minimal along the anterior aspect of the insertions onto the greater tuberosity. The size and dimensions of the individual tendinous insertions have been delineated through use of a reproducible technique. The size of the supraspinatus in both area and dimensions was smaller than that of the infraspinatus (mean area of supraspinatus, 1.55 cm^2, vs mean area of infraspinatus, 1.76 cm^2). This was initially surprising; however, given the relative size of the 2 muscle bellies, it should not be. The infraspinatus fossa and muscle belly are larger than the corresponding anatomy of the supraspinatus. No attempt was made to determine whether there was any intermingling of fibers from adjacent muscle-tendon units at the insertion; however, we could not identify such fibers.

This information may be useful as surgeons attempt to re-create the normal anatomy of the shoulder in an effort to better restore function to the rotator cuff.

REFERENCES

1. Brewer BJ. Aging of the rotator cuff. Am J Sports Med 1979;7:102-10.
2. Clark JM, Harryman DT. Tendons, ligaments and capsule of the rotator cuff. J Bone Joint Surg Am 1992;74:713-25.
3. Fukuda H. Rotator cuff tears [in Japanese]. Geka Chiryo (Osaka) 1980;43:28.
4. Fukuda H, Mikasa M, Ogawa K, et al. The partial thickness tear of the rotator cuff. Orthop Trans 1983;7:137.
5. Fukuda H, Mikasa M, Yamanaka K. Incomplete thickness rotator cuff tears diagnosed by subacromial bursography. Clin Orthop 1987;223:51-8.
6. Kumagai J, Sarkar K, Uhthoff HK. The collagen types in the attachment zone of rotator cuff tendons in the elderly. An immunohistochemical study. J Rheumatol 1994;21:2096-100.
7. Lehman C, Cuomo F, Kummer FJ, Zuckerman JD. The incidence of full thickness rotator cuff tears in a large cadaveric population. Bull Hosp Jt Dis 1995;54:30-1.
8. Matsen FA, Arntz CT, Lippitt SB. Rotator cuff. In: Rockwood CA, Matsen FA, editors. The shoulder. 2nd ed. Philadelphia: Saunders; 1998. p. 755-839.
9. Yamanaka K, Fukuda H, Hamada K, Mikasa M. Incomplete thickness tears of the rotator cuff [in Japanese]. Saigai Geka (Tokyo) 1983;26:713.
10. Yamanaka K, Matsumoto T. The joint side tear of the rotator cuff: a follow-up study by arthrography. Clin Orthop 1994;304:68-73.