Tendons, Ligaments, and Capsule of the Rotator Cuff

Gross and Microscopic Anatomy*†

BY J. M. CLARK, M.D., PH.D.‡, AND D. T. HARRYMAN, II, M.D.‡, SEATTLE, WASHINGTON

Investigation performed at the Adult Reconstruction and Shoulder Services, University of Washington School of Medicine, Seattle

ABSTRACT: We investigated the structure of the myotendinous rotator cuff in thirty-two grossly intact cuffs from thirty fresh cadavera of subjects who had been seventeen to seventy-two years old at the time of death. We studied the gross anatomy of the capsule and ligaments of the cuff, as well as histological sections of the tendons of the subscapularis, supraspinatus, and infraspinatus muscles. The tendons were found to splay out and interdigitate to form a common, continuous insertion on the humerus. The biceps tendon was ensheathed by interwoven fibers derived from the subscapularis and supraspinatus tendons. The anterior margin and bursal surface of the supraspinatus tendon were enveloped by a thick sheet of fibrous tissue derived from the coracohumeral ligament. Fibers from the coracohumeral and glenohumeral ligaments were found concentrated in a plane between the capsule and the tendons of the cuff. Microscopically, in the region of the supraspinatus and infraspinatus tendons, the cuff was composed of five layers defined by the attachments and orientations of the fibrous elements in each of these layers.

CLINICAL RELEVANCE: In the rotator cuff, which is a composite of the capsule, the ligaments, and the tendons around the shoulder, the supraspinatus tendon is reinforced by fibers of the coracohumeral ligament and fibers from adjacent tendons. Therefore, lesions in the area of the supraspinatus tendon may involve one or more of these elements, and the evolution of a tear in this area may be determined by the location of the initial lesion.

Tears of the rotator cuff typically begin in the supraspinatus tendon[4]. The vulnerability of that tendon to tearing and the resultant degeneration of this area are believed to be related to the avascularity of the tendon, to age-related changes in the collagen, and to mechanical trauma[2,4,6,7,17,18,20-22,25,26]. It is commonly assumed that the configurations of the myotendinous cuff and the capsular and ligamentous components can withstand physiological loading and minimize concentrations of stress. The normal anatomical features that enable the rotator cuff to function effectively throughout life and the features that may be important in the development of localized lesions of the cuff have received relatively little attention. Most gross anatomical studies have dealt primarily with pathological changes observed in randomly selected specimens at autopsy[4,7,18].

Materials and Methods

Eighty shoulders from seventy-eight cadavera were obtained within twenty hours after death. Forty-eight of the eighty shoulders were excluded because of gross pathological changes in the myotendinous cuff, such as tears or thinning of the rotator cuff, that were not recognized until the cuff had been dissected.

In thirty-two shoulders from thirty cadavera, the myotendinous cuff was intact. In two cadavera of men, both shoulders were studied; the ages at the time of death had been twenty-one and sixty years. There were twelve cadavera of men and sixteen cadavera of women, and the age at the time of death ranged from seventeen to seventy-two years.

The entire scapula and proximal one-third of the humerus with the attached soft tissues was removed *en bloc* in order to keep the shoulder joint intact. The *en bloc* specimens were then evaluated by various methods.

Thirteen of the thirty-two specimens were fixed in buffered formalin with the shoulder joint in the adducted position, after the skin and the deltoid muscle had been removed. Following fixation for twenty-four hours, the specimens were decalcified in formic acid. The muscles of the myotendinous cuff were then divided just proximal to the musculotendinous junctions. The scapula was separated by detachment of the glenohumeral capsule from the glenoid, with the cuff and capsule left attached to the humerus.

To prepare blocks of tissue, the cuff and subjacent capsule were cut into strips and one-cubic-centimeter blocks of the humerus were removed from the site of attachment of the capsule and the various tendons to bone (Fig. 1-A). The strips were approximately one centimeter wide and five centimeters long and included what was thought to be the tendon of each cuff muscle, as well as its site of insertion on the humerus. The strips

*No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article. Funds were received in total or partial support of the research or clinical study presented in this article. The funding source was National Institutes of Health Basic Research Support Grant RR05432.

†Read in part at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Atlanta, Georgia, February 5, 1988.

‡Department of Orthopaedics, University of Washington, RK-10, Seattle, Washington 98195. Please address requests for reprints to Dr. J. Clark.

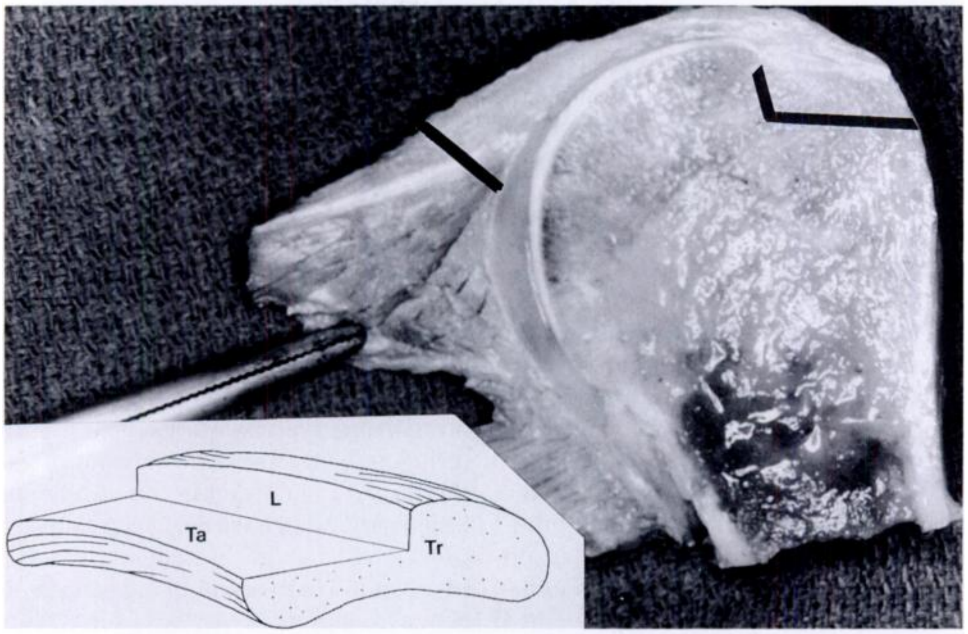

FIG. 1-A

Figs. 1-A through 1-D: The dissections used in the study.

Fig. 1-A: Frontal section through a fixed and decalcified specimen of an adducted shoulder during preparation for microscopic examination. The segment of the rotator cuff that is to be trimmed and embedded in paraffin is the portion between the black lines. The inset shows the three planes in which sections of the cuff were cut: longitudinal (L), transverse (Tr), and tangential (Ta). The specimen shown was cut longitudinally.

were trimmed, embedded in paraffin, and sectioned at a thickness of eleven micrometers in one of three planes: a longitudinal plane in the direction of the tendon fibers and perpendicular to the articular surface of the humeral head, a transverse plane perpendicular to the direction of the fibers, and a horizontal plane tangential to the articular surface of the humeral head (Fig. 1-A). From this group of thirteen myotendinous cuffs, one preparation from each of the four individual tendons was sectioned tangentially.

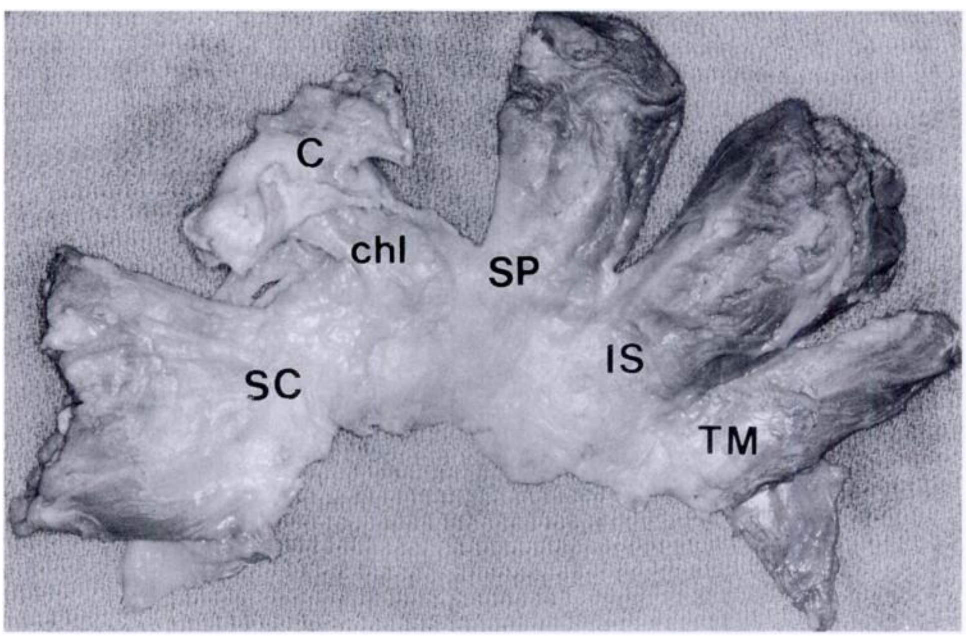

FIG. 1-B

Complete myotendinous cuff and capsule spread out after they were removed from the humeral head and scapula and were incised through the axillary pouch. The anterior (left), superior (top), and posterior (right) aspects of the cuff, as seen from above, are shown before fixation. The humeral attachments are below, and the divided muscle bellies are above. The structures shown are the subscapularis (SC), the osteotomized coracoid process (C) with the attached coracohumeral ligament (chl), the supraspinatus (SP), the infraspinatus (IS), and the teres minor (TM). Note the fleshy portions of the teres minor and subscapularis that have been detached from the humerus.

The remaining specimens were divided equally into those that were cut longitudinally and those that were cut transversely. The tangential and longitudinal sections extended from the musculotendinous junction to the bone of the humerus. The longitudinal sections were cut both from the center and from the two edges of each of the cuff tendons that were studied. Multiple transverse sections for histological study were cut, at three-millimeter intervals, from the tendinous region of each cuff. The tissue in the interval between the subscapularis and supraspinatus tendons also was trimmed, embedded, and sectioned transversely at five-millimeter intervals, with the biceps tendon kept in place.

The sections were stained with hematoxylin and eosin and Masson trichrome and were studied under a microscope (model BHT2; Olympus, Tokyo, Japan) that was equipped with polarizing filters. Particular attention was paid to the orientations of the collagen fibers, the vascular anatomy, and degenerative changes such as calcification, hyaline necrosis of collagen, and acellular areas.

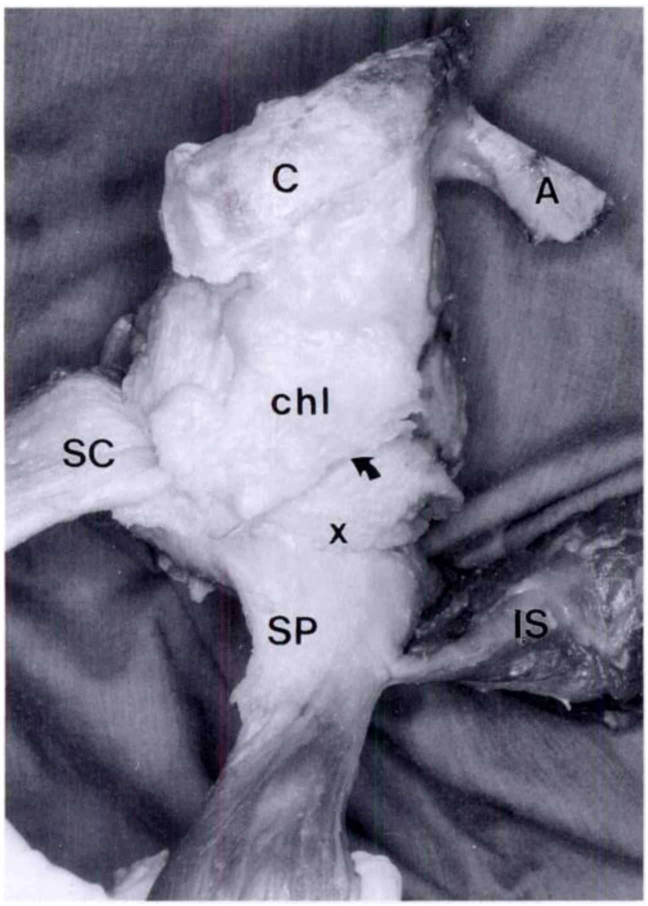

FIG. 1-C

Photograph of the superior aspect of a specimen from a left shoulder after the myotendinous cuff muscles (SC, SP, and IS) have been dissected off the shoulder capsule and reflected laterally, with their attachments to the humerus left intact. The acromion (A) and the coracoacromial ligament were removed with the specimen. Shown are the superior aspects of the capsule and of the coracohumeral ligament (chl), which, in the intact shoulder, extends from its humeral attachment to the lateral border of the coracoid process (C) in the interval between the subscapularis and supraspinatus tendons. The posterior portion of this ligament, which normally crosses over the supraspinatus tendon, has been incised along the line indicated by the curved arrow and then reflected posteriorly together with the supraspinatus tendon. A thinner layer of transversely oriented fibers (X) extends posteriorly from the ligament, passes deep to the supraspinatus and infraspinatus, and terminates approximately at the border between the infraspinatus and the teres minor (see Figs. 2-A, 2-B, and 6).

Another ten of the thirty-two fresh specimens were prepared for histological study with use of the dissection technique that was described by Brewer. The cuff, including the ligaments and the attached capsule, was removed by sharp dissection from its attachments to both the humerus and the scapula, and the resultant tube of tendon, ligament, and capsule was divided longitudinally through the region of the axillary pouch. The tube was then spread out flat, pinned to a slab of dental wax, and fixed by immersion in 2 per cent glutaraldehyde for twenty-four hours (Figs. 1-B and 2-A). After fixation, these flat preparations were cut into one-centimeter-wide longitudinal strips and were processed for microscopic examination in one of two ways. In seven of the ten specimens, paraffin sections, similar to those prepared from the first thirteen shoulders, were made in the three planes and various locations that have been described. For the other three shoulders, the entire strip was immersed in liquid nitrogen for sixty seconds and then was broken open longitudinally, along the muscle-tendon axis, with a steel chisel to direct the fracture. The surfaces of the fracture were then critical-point-dried, gold-coated, and studied with a scanning electron microscope (model JSM 35c; JEOL, Tokyo, Japan)[15].

The remaining nine shoulders were dissected while still fresh to study the gross relationships of the tendons, ligaments, capsule, and overlying tissue, including the subdeltoid bursa. Each muscle with its attached tendon was detached from the scapula and was meticulously separated from the periarticular structures — notably, the capsule — and then reflected laterally, leaving the insertion of the muscle on the humerus intact (Fig. 1-C). The relationships of the tendons, capsule, and overlying tissue were recorded and photographed at each step of the sharp dissection. The separated tendons and capsule of the cuff were pinned out flat and prepared for light microscopy in the manner already described (Fig. 1-D).

Results

Gross Examination

The tendons of the rotator cuff were seen to fuse into one structure at or near their insertions into the tuberosities of the humerus (Figs. 1-B and 2-A). This fusion was apparent when the two surfaces of the intact cuff were exposed by removal of the overlying bursa and the underlying capsule (Figs. 1-C and 1-D). The supraspinatus and infraspinatus tendons join about fifteen millimeters proximal to their insertions on the humerus and cannot be separated by additional blunt dissection (Figs. 1-D, 3-A, 3-B, and 3-C). Although there is an interval between the muscular portions of the teres minor and

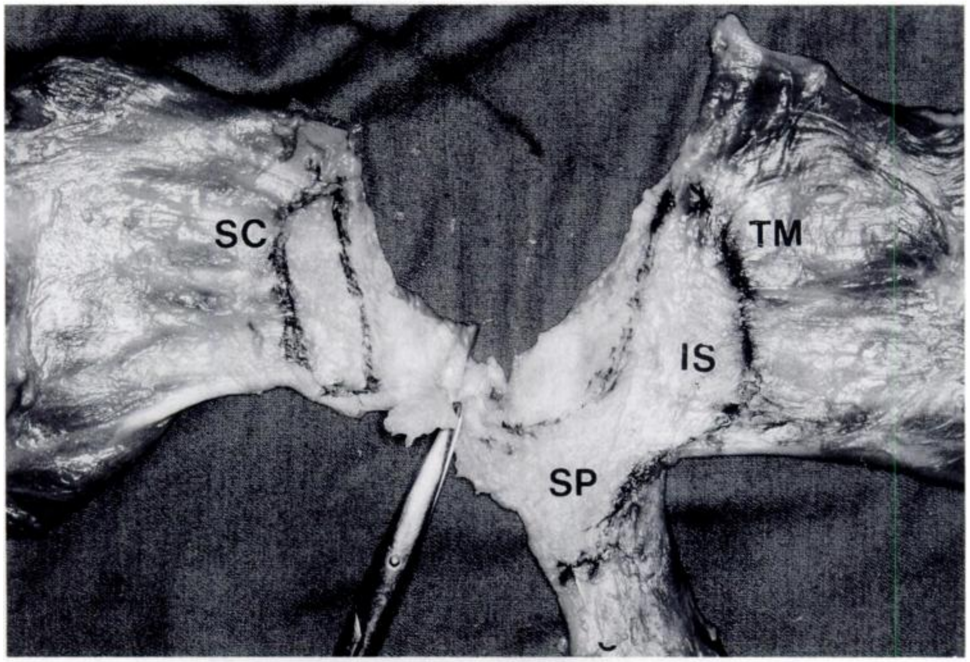

FIG. 1-D

Photograph of the under (capsular) surface of the cuff after it has been dissected off the shoulder capsule and detached from its insertion on the humerus. The tendons of the subscapularis (SC), supraspinatus (SP), infraspinatus (IS), and teres minor (TM) are fused to form a continuous tendinous ring that normally encircles the humeral head. The scissors indicate the location of the biceps tendon where it would normally pass over the blended insertions of the subscapularis and supraspinatus tendons in the bicipital groove. The areas enclosed within the lines of black ink indicate where the tendons had been firmly adherent to the capsule and were separated by sharp dissection. The portions of the tendons central to the outlined areas had been dissected off the humerus and hence were the insertions of the cuff tendons on the tuberosities.

infraspinatus, these muscles merge inseparably just proximal to the musculotendinous junction (Figs. 1-D and 3-A). The teres minor and the subscapularis have muscular insertions on the surgical neck of the humerus, which extends approximately two centimeters inferior to their tendinous attachment onto the tuberosities.

The subscapularis and supraspinatus tendons fuse to form a sheath that surrounds the biceps tendon at the proximal end of the bicipital groove (Figs. 1-D, 2-A, 2-B, 3-A, 3-B, and 3-C). A tendinous slip extends anterolaterally from the supraspinatus tendon to form the roof of the sheath, and the superior part of the subscapularis tendon passes under the biceps tendon to join with fibers from the supraspinatus tendon to form the floor of the sheath. The deep portion of the sheath runs adjacent to the bone and forms a fibrocartilaginous lining for the bicipital groove, which extends approximately seven millimeters.

The tendons of the cuff are reinforced near their insertions on the tuberosities of the humerus by fibrous structures that are located both superficial and deep to the tendons. The superficial aspects of the infraspinatus and supraspinatus tendons are covered by a thick sheet of fibrous tissue that lies directly beneath the deep layer of the subdeltoid bursa but is not part of the bursa itself. When this sheet is sharply dissected from the tendons of the cuff, it is seen to be a fan-like posterolateral extension of a broad, thick, fibrous band extending from the lateral edge of the coracoid process over the supraspinatus and infraspinatus tendons to the humerus (Fig. 4-A). This band also sends slips along the surface of the capsule into the interval between the subscapularis and supraspinatus tendons that attach to both tuberosities deep to the insertions of the cuff tendons (Figs. 1-C, 4-A, and 4-C). These slips that run from the coracoid process into the interval between the subscapularis and supraspinatus tendons correspond to the structure referred to as the coracohumeral ligament[6,10,13].

Additional components of the coracohumeral ligament are revealed when the tendons of the rotator cuff are dissected from the underlying capsule of the shoulder and reflected laterally (Fig. 1-C) or when the cuff and capsule are resected together and their deep surfaces are examined (Figs. 2-A and 2-B). When viewed from these perspectives, the tendons are seen to be tightly adherent to the joint capsule near their insertions on the humerus, as previously described[3]. The capsule beneath the supraspinatus and infraspinatus tendons is thickened by a strip of fibrous tissue, one centimeter wide, that runs posteriorly in a direction perpendicular to the fibers of the tendons. The strip extends to the posterior edge of the infraspinatus tendon and appears to be a deep extension of the coracohumeral ligament, which runs in an interval between the capsule and the tendons of the cuff.

The coracohumeral ligament and capsule also form part of the roof of the sheath of the biceps tendon in the interval between the infraspinatus and subscapularis tendons (Figs. 4-A, 4-C, and 5-C). Along the lateral margin

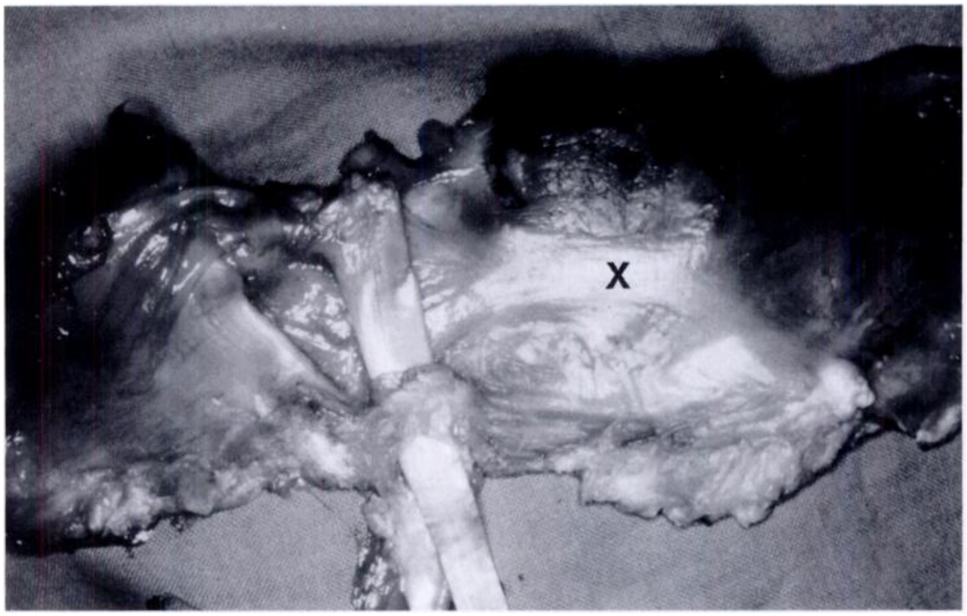

FIG. 2-A

Figs. 2-A and 2-B: The deep (capsular) aspect of the rotator cuff, showing the capsule overlying the cuff.

Fig. 2-A: Photograph of the deep (articular) aspect of the cuff-capsule complex of a specimen composed of the shoulder capsule and attached rotator cuff after the cuff-capsule complex was dissected off the humerus (top) and the scapula (bottom). The cuff muscles have also been divided near their musculotendinous junctions (see drawing [Fig. 2-B] for explanation). A band of fibers (X) extends posteriorly as a branch of the coracohumeral ligament into the plane between the capsule and tendons where it ends or blends with the capsule approximately at the superior edge of the teres minor.

of that interval, the capsule blends with the extension of the supraspinatus tendon where it crosses the biceps tendon and its groove. The superior and middle glenohumeral ligaments and the coracohumeral ligament are firmly attached to the outer, non-articular surface of the joint capsule. The humeral insertion of the superior glenohumeral ligament merges with the anterior edge of the coracohumeral ligament beneath the superior edge of the subscapularis tendon. Once all of the capsule and ligament have been meticulously resected, the musculotendinous units, which are now clearly visible, are all that remain of the cuff.

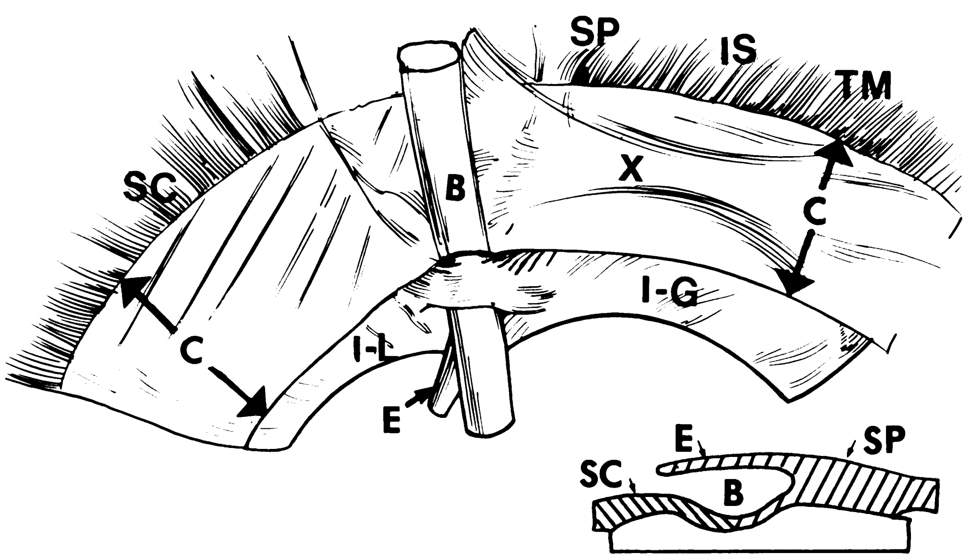

FIG. 2-B

Drawing of the deep surface of the rotator cuff-capsule complex after it has been detached from the humerus, as shown in Figure 2-A. The diagram in the inset is a cross section of the bicipital groove and related structures. Note the relationships of the capsule (C), subscapularis (SC), supraspinatus (SP), infraspinatus (IS), and teres minor (TM) tendons, as well as the confluence of the supraspinatus and subscapularis tendons proximal to their insertions on the lesser (I-L) and greater (I-G) tuberosities. In the inset, the complex sheath surrounding the biceps tendon (B) is shown diagrammatically in cross section. The deep portion of this sheath is formed by the subscapularis tendon, and a slip (E) from the supraspinatus tendon forms a roof over the biceps tendon. Also shown is the pericapsular band (X) seen in Figures 1-C and 2-A.

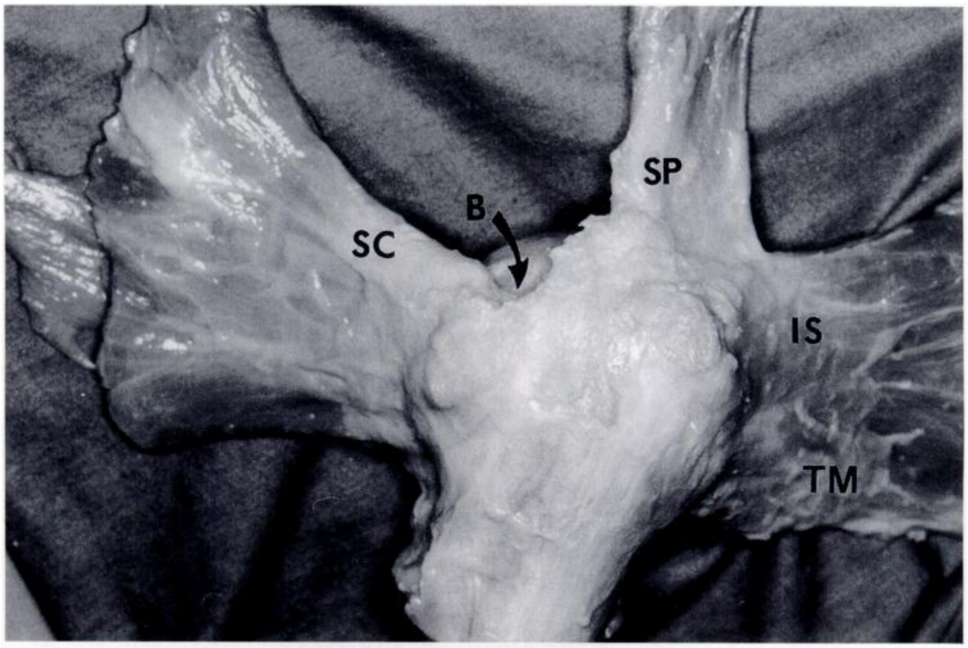

FIG. 3-A

Figs. 3-A, 3-B, and 3-C: Photograph and diagrams of a dissection of the cuff tendons, showing how the tendons converge as they insert on the humerus.

Fig. 3-A: Photograph of the lateral aspect of the proximal end of the humerus and of the outer aspects of the attached muscles of the cuff, which have been separated from each other and dissected off the capsule, with their insertions on the humerus left intact. In the intact shoulder, the cuff forms a solid sleeve of fibrous tissue that surrounds the proximal end of the humerus. The supraspinatus (SP) and infraspinatus (IS) tendons blend together about 1.5 centimeters proximal to their insertions on the humerus, and the tendon of the teres minor (TM) is inseparable from that of the infraspinatus. Fibers of the supraspinatus tendon intermingle with those of the subscapularis tendon (SC) to form a tunnel for the biceps tendon (B) as diagrammed in Figure 3-B.

Histological Examination

Sections were made in the tangential, longitudinal, and transverse planes from the one-centimeter strips that had been cut from the regions of the subscapularis, supraspinatus, and infraspinatus tendons. These sections were studied to (1) determine the orientation and extent

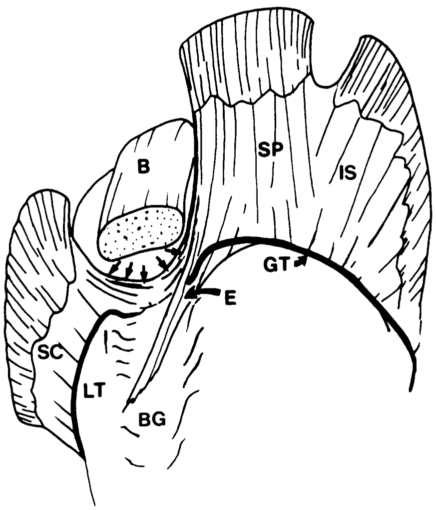

FIG. 3-B

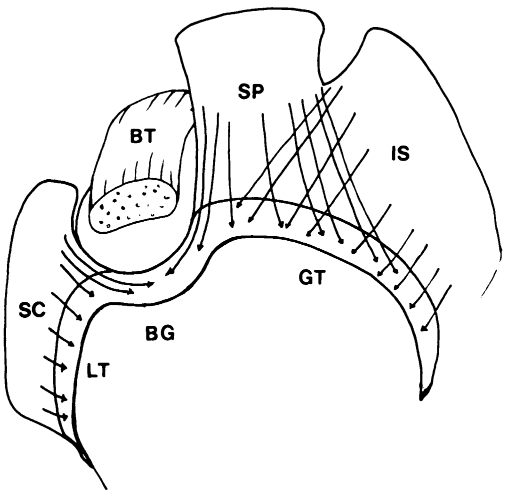

FIG. 3-C

Fig. 3-B: Diagram of the specimen shown in Figure 3-A, illustrating the relationships of the subscapularis (SC), biceps (B), supraspinatus (SP), and infraspinatus (IS) tendons and of the bicipital groove (BG) at the level of the insertion of the cuff on the greater (GT) and lesser (LT) tuberosities. The portion of the biceps tendon that is normally in the bicipital groove has been removed to expose the bed of the tendon. This bed (small arrows) is formed by the blending of fibers from the adjacent cuff tendons. Note the lateral extension (E) of the supraspinatus tendon. This extension normally forms the roof over the groove (see text and Figure 2-B).

Fig. 3-C: Diagrammatic representation of Figures 3-A and 3-B showing the normal interweaving of the fibers (arrows) from the subscapularis (SC), supraspinatus (SP), and infraspinatus (IS) tendons in the region of the rotator cuff. The fibers from the subscapularis and supraspinatus tendons form the floor of the sheath of the biceps tendon (BT) within the bicipital groove (BG).

of the various fiber groups within the cuff-capsule complex, (2) assess the blood supply of different parts of the cuff, and (3) identify early evidence of degeneration, if any, in the various parts of the cuff-capsule complex. The sections from specimens that had been pinned flat were the most satisfactory, because the direction and location of the sections could be controlled more reliably; also, because these specimens were not decalcified, the histological detail was better. In cuffs that had not been exposed to formic acid, the collagen fascicles within the tendons were more compactly grouped, had a more uniform crimp pattern (periodic weave pattern in normal tendon collagen), and stained more intensely. Alternatively, in the thirteen *en bloc* preparations, study of the interface between bone and cuff was possible. Regardless of the method of preparation, the density of the tendons made it difficult to obtain transverse sections.

Supraspinatus and Infraspinatus

The sections through the supraspinatus and infraspinatus tendons and the subjacent ligaments and capsule showed that the cuff-capsule complex is composed of five layers at this site (Figs. 5-A, 5-B, and 6).

Layer 1: The most superficial layer is thin (one millimeter thick) and is composed of fibers of the coracohumeral ligament, obliquely oriented with respect to the axis of each muscle (Figs. 5-A and 5-B). These fibers extend to the greater tuberosity of the humerus in the interval between the subscapularis tendon and the supraspinatus tendons, where they blend with the periosteum. Large arterioles are commonly present throughout this layer.

Layer 2: The second layer, three to five millimeters thick, is composed of closely packed, parallel tendon fibers grouped in large bundles. These bundles, one to two millimeters in diameter, extend directly from the supraspinatus or infraspinatus muscle belly to the humerus. Fibers from this layer also form the previously described extension of the supraspinatus tendon that is part of the roof over the biceps tendon within its groove. Arterioles from the first layer cross into this second layer between the fascicles.

Layer 3: The third layer, which is three millimeters thick, has a tendinous structure in which the fascicles are smaller than those in Layer 2 but lack a uniform orientation. In the longitudinal sections made for scanning electron microscopy (Fig. 5-C) and in the sections that were made parallel and perpendicular to the line of force of the supraspinatus and then studied by polarized light microscopy, the tendon fascicles in this layer crossed one another at an angle of 45 degrees. The individual fascicles are smaller than those in Layer 2 and are not as tightly packed. Blood vessels are also present in this layer, but they are smaller than those in Layers 1 and 2. Larger arteries that pass through the first and second layers turn and run in the interval between the second and third layers.

Layer 4: The fourth layer is composed of loose con-

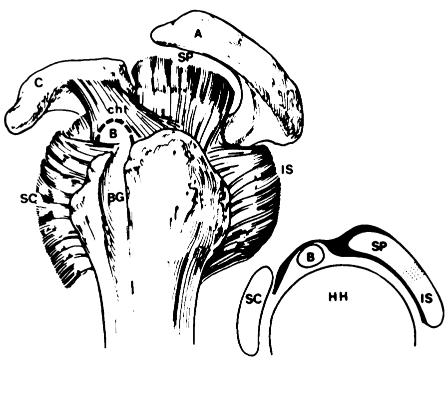

FIG. 4-A

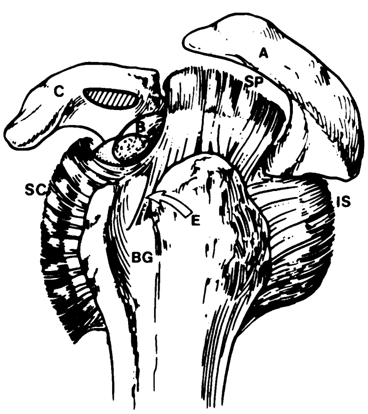

FIG. 4-B

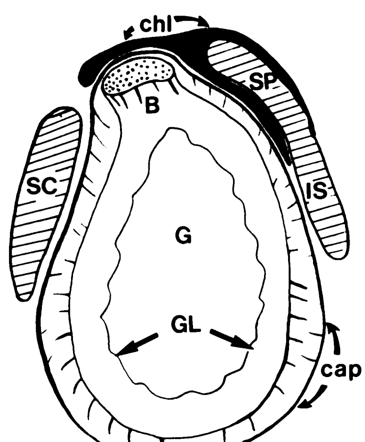

FIG. 4-C

Figs. 4-A, 4-B, and 4-C: Drawings showing the relationships of the coracohumeral ligament (chl).

Fig. 4-A: Lateral aspect of the shoulder. The coracohumeral ligament (chl) extends laterally from the coracoid process (C) and covers the biceps tendon (B) in the interval between the subscapularis (SC) and supraspinatus (SP) tendons. The attachments of the coracohumeral ligament and of the capsule to the humerus lie deep to these tendons. A sheet of the coracohumeral ligament fans out posteriorly over the supraspinatus tendon, extending as far as the infraspinatus (IS), and merges laterally with the periosteum of the greater tuberosity. Note the positions of the acromion (A) and bicipital groove (BG). The inset shows a diagram of a transverse section through the coracohumeral ligament, the cuff tendons, and the humeral head (HH). The ligament is depicted in black; the capsule is not shown.

Fig. 4-B: The lateral aspect of the shoulder with the coracohumeral ligament removed. (The site of attachment of the ligament on the coracoid [C] is the hatched area.) The supraspinatus (SP) and subscapularis (SC) tendons meet and interdigitate in the floor of the bicipital groove (BG). An extension (E) of the supraspinatus tendon runs over the biceps tendon (B) and bicipital groove but is deep to the coracohumeral ligament. A = acromion.

Fig. 4-C: Diagram of a cross section through the shoulder joint, parallel to the surface of the glenoid. Note the relationships of the subscapularis (SC) and biceps (B) tendons, the glenoid (G), the glenoid labrum (GL), and the supraspinatus (SP) and infraspinatus (IS) tendons. Also shown in cross section is the coracohumeral ligament (chl). The coracohumeral ligament is superficial to the shoulder capsule (cap) and overlies the biceps tendon (B), and its superficial and deep branches envelop the anterior part of the supraspinatus tendon.

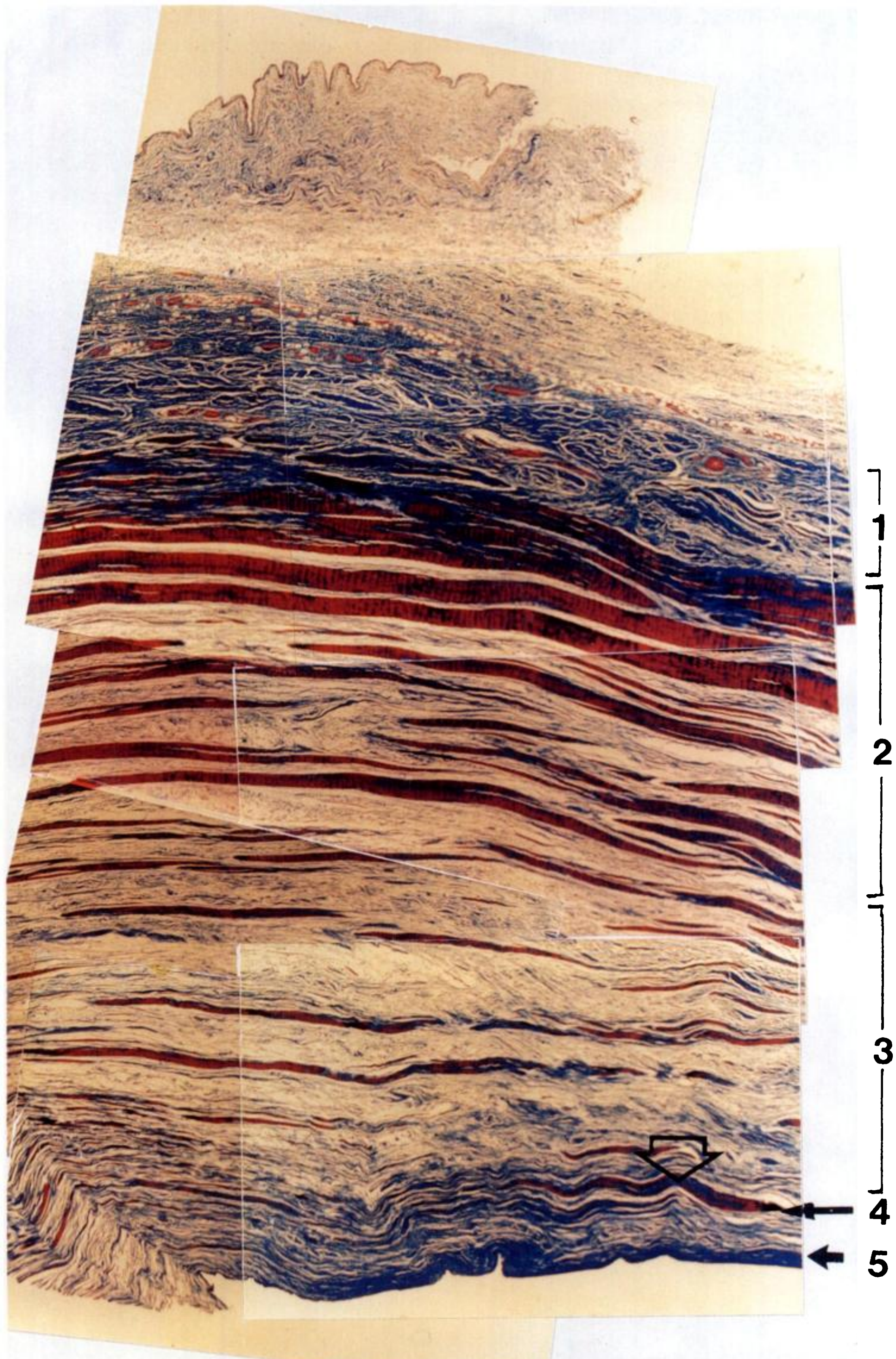

FIG. 5-A

Figs. 5-A through 5-D: Histological sections made vertically through the rotator cuff and capsule of the shoulder in various locations.

Layer 1 is composed of fibers of the coracohumeral ligament obliquely oriented with respect to the axis of each muscle. Large arterioles are commonly present throughout this layer. Layer 2 is composed of closely packed parallel tendon fibers grouped in large bundles. Arterioles from the first layer cross into this second layer between the fascicles. Layer 3 has a tendinous structure in which the fascicles are smaller than those in Layer 2, but they lack a uniform orientation. The individual fascicles are smaller than those in Layer 2 and are not as tightly packed together. Blood vessels are also present in this layer but are smaller than those in Layers 1 and 2. Larger arteries that pass through the first and second layers turn and run in the interval between the second and third layers. Layer 4 is composed of loose connective tissue in which there are thick bands of collagen fibers. The only blood vessels in this layer are capillaries, found adjacent to the extra-articular surface of the capsule of the shoulder. Layer 5 is a thin, continuous sheet of interwoven collagen fibrils which usually insert on the humerus as Sharpey fibers within the bone.

The photomicrographs were made with a 1/4 lambda filter. The collagen fibers are blue and red, the vessels are red, and the loose areolar tissue is blue. The use of the filter enhances the detail.

Fig. 5-A: Composite photomicrograph of a vertical, longitudinal section through the supraspinatus tendon and joint capsule near the insertion of the tendon. The open arrowhead in Layer 4 identifies one of the transverse fibers in this layer. At this location, Layer 1 is relatively thick and the fibers in Layer 4 are attenuated (hematoxylin and eosin, × 19).

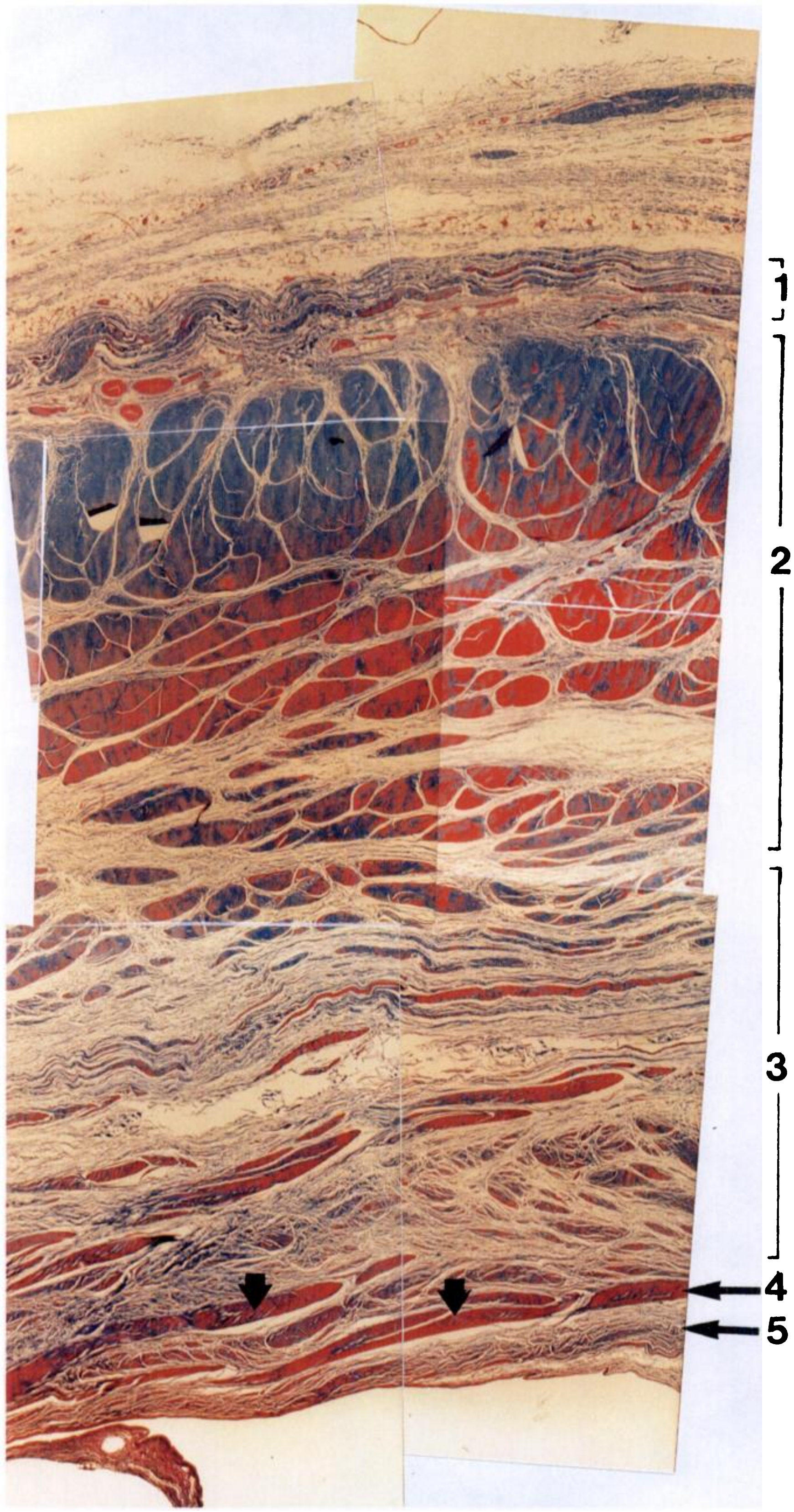

FIG. 5-B

Vertical, transverse section through the supraspinatus tendon and capsule, midway between the musculotendinous junction and insertion of the tendon. The thick fibers of Layer 2 are cut perpendicular to their long axes, and their rounded profiles are evident. Layer 1 is thin at this level, and the fibers in Layer 4 (arrows) are numerous.

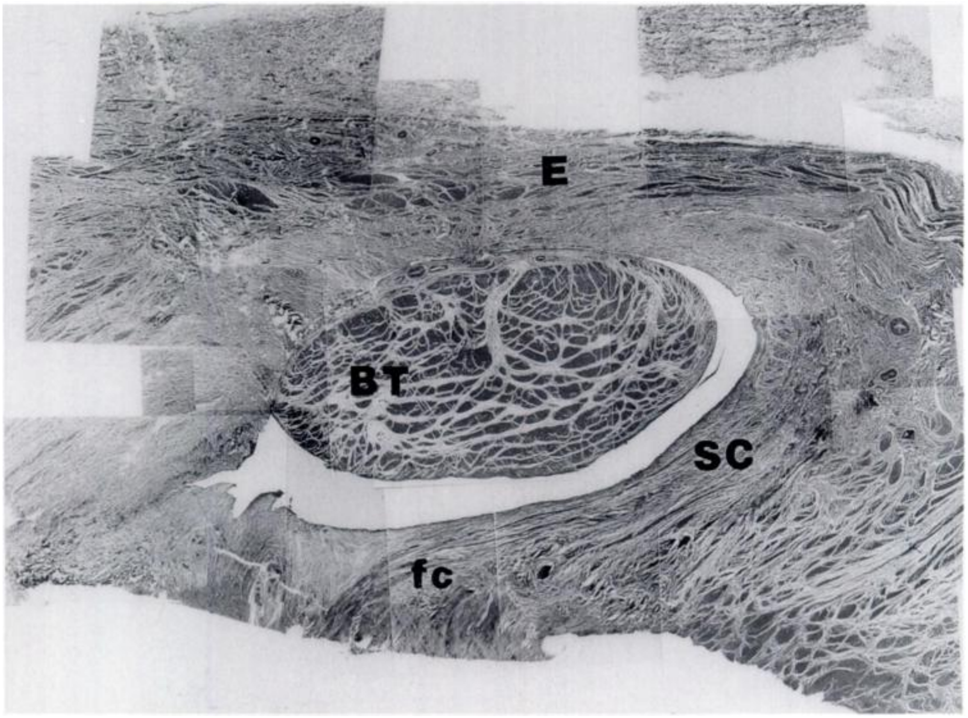

FIG. 5-C

Vertical, transverse section through the biceps tendon and its sheath near the proximal opening of the bicipital groove (Masson trichrome, × 38). The section, made after these structures had been dissected off the bone, shows the thick fibrous tissue that encircles the tendon (BT). In this segment of the sheath, the floor is formed primarily by a slip from the subscapularis (SC) and has the appearance of fibrocartilage (fc) where it lies close to the bone. The fibers crossing horizontally over the tendon are an extension (E) from the supraspinatus tendon.

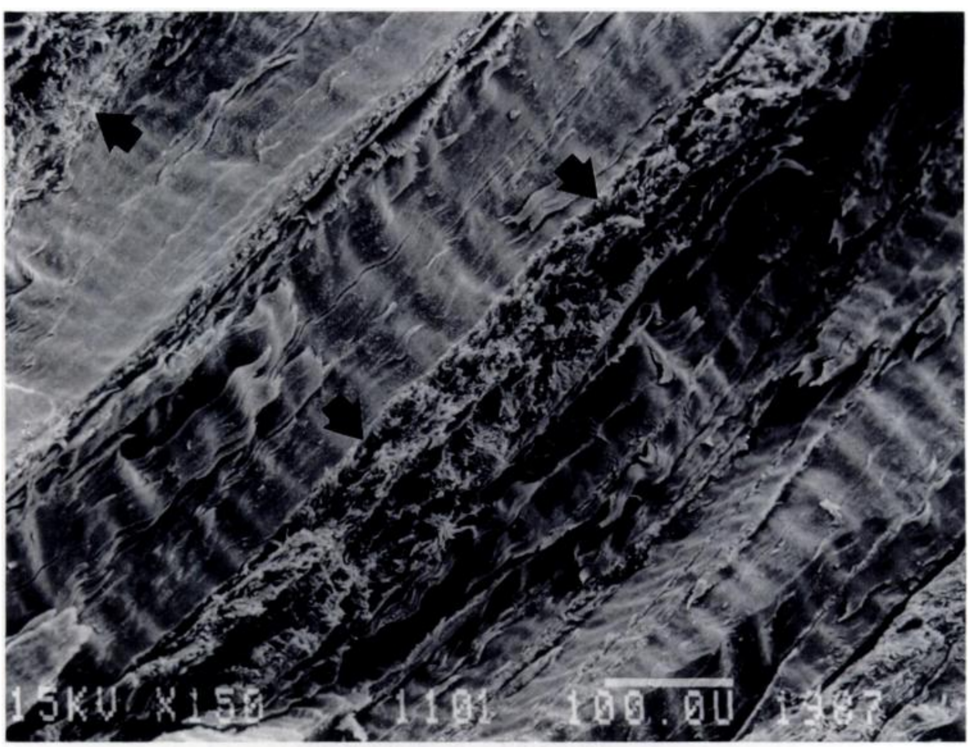

FIG. 5-D

Scanning electron micrograph showing the cryofractured surface of a supraspinatus tendon after it was fractured in the vertical longitudinal plane (× 320). The fascicles shown are in Layer 3. The fascicles form distinct layers due to variations in their orientations. The fascicles that are not parallel to the plane of fracture project from the surface (arrows). The bar indicates 100 micrometers.

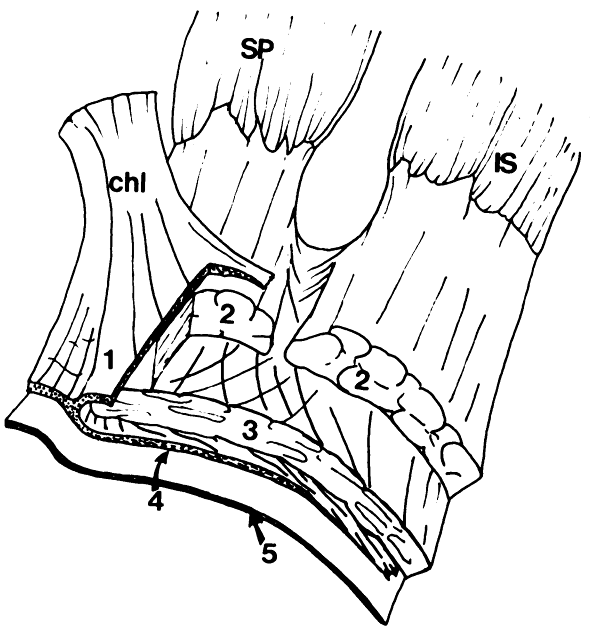

FIG. 6

Schematic diagram of a dissection sectioned transversely at various sites in the supraspinatus and infraspinatus tendons and capsule of the shoulder, comparable with that shown in Figures 5-A and 5-B. The orientations of the fascicles in the numbered layers are indicated by the lines on their upper surfaces. Layer 1 is composed of superficial fibers that overlie the cuff tendons and extend from the coracoid process to the greater tuberosity. These fibers form an extension of the coracohumeral ligament (chl). Layers 2 and 3 contain the fibers of the supraspinatus (SP) and infraspinatus (IS) tendons. The fibers in Layer 2 are oriented parallel to the axes of the supraspinatus and infraspinatus tendons. The fibers of Layer 3 are smaller and are obliquely oriented with respect to the fibers of Layer 2. Within Layer 3, the fibers of the supraspinatus tendon fan out and intermingle with the fibers of the adjacent infraspinatus and subscapularis tendons. This intermingling between the infraspinatus and supraspinatus creates the variation in alignment of the fibers observed in Layer 3 and shown here diagrammatically. In Layer 4, the fibers make up the deep extension of the coracohumeral ligament (Fig. 4-A). These fibers branch off the main body of the ligament at the anterior border of the supraspinatus tendon and then course between the tendon and capsule as far as the junction between the infraspinatus and supraspinatus. Layer 5 is the true joint capsule of the shoulder, which forms a continuous fibrous cylinder extending from the glenoid labrum to the neck of the humerus. The synovial lining of the capsule is in direct contact with the articular surface of the humeral head. The orientation of the fibers within the capsule is quite variable and is not identified in this diagram.

nective tissue in which there are thick bands of collagen fibers. These bands, for the most part, are located on the external (extra-articular) surface of the capsule. However, along the anterior edge of the supraspinatus, they merge with those of the coracohumeral ligament and form a ligamentous envelope that encases the anterior part of the supraspinatus tendon (Fig. 4-B). The previously described fibrous band that is visible beneath the supraspinatus (Figs. 2-A and 2-B) is composed of fibers that branch off from the body of the coracohumeral ligament at the anterior edge of the supraspinatus tendon. The only blood vessels in this layer are capillaries found adjacent to the extra-articular surface of the shoulder capsule.

Layer 5: The fifth and deepest layer is a thin (1.5 to 2.0 millimeters thick), continuous sheet of interwoven collagen fibrils (Fig. 5-A). This layer, which is the capsule of the shoulder joint, extends from the glenoid labrum medially to the humerus laterally where the fibrils insert on the humerus as Sharpey fibers within the bone.

In the regions of the supraspinatus and infraspinatus, the tendinous segment of the cuff is thickened along the axes of the principal musculotendinous units. The cuff is thinner (three to five millimeters thick) in the interval between the supraspinatus and infraspinatus tendons, because Layer 2, composed of the fibers that extend directly from the two muscle bellies to the humerus, is not present.

The grossly apparent fusion of the tendons of the supraspinatus and infraspinatus muscles (Figs. 1-B and 1-D) is due to the extensive interdigitation of the tendon fibers in the third layer (Figs. 3-A, 3-B, and 3-C). This cross-over is best appreciated in the tangential sections that were cut through the third layer in the specimens that had been fixed while pinned flat. It is apparent that both tendons splay as they approach their insertions into the greater tuberosity.

Subscapularis

The portion of the cuff-capsule complex in the region of the subscapularis tendon is composed of four to six thick bundles of collagen fibers that extend from the muscle belly to the lesser tuberosity. These bundles run parallel to one another but splay before they insert on the lesser tuberosity. They are tightly packed in the superficial part of the tendon, but the deeper bundles adjacent to the capsule are separated by loose connective tissue. The most proximal group of bundles passes under the biceps tendon to form the floor of the bicipital groove together with fibers from the supraspinatus. However, most of the fibers that make up the floor of the groove are derived from the subscapularis (Figs. 2-C and 5-C). Within the groove, these intermingled tendinous elements became fibrocartilaginous, and cuboidal cells and metachromatic ground substance are dispersed among thick collagen fascicles. In all tendon insertions into the tuberosities, there is a fibrocartilaginous zone comparable with the one that Benjamin et al. described in the supraspinatus.

Fibers of the superior and middle glenohumeral ligaments, which can be identified histologically as separate structures, run along the superficial, non-articular aspect of the capsule. Located along the proximal and distal edges of the subscapularis tendon, these fibers pass between the tendon and the capsule on their way to insert into the lesser tuberosity of the humerus. In these locations, the configuration of the cuff is similar to that observed in Layer 4 in the region of the supraspinatus. Fibers of the superior and middle glenohumeral ligaments can be identified primarily by their location on the superficial aspect of the capsule. In sections through the capsule, from specimens in which the capsule had been separated from the tendons of the cuff, the collagen fibers had a diverse orientation.

General Histological Observations

In the thirty-two shoulders, there was little microscopic evidence of degeneration of tendons because only specimens that had grossly intact myotendinous cuffs had been selected. Small foci of calcification and areas of acellularity were present in the tendons from about half of the cuffs. Also, in the specimens from cadavera of subjects more than fifty-five years old, the cuffs were generally thinner, although this thinning could not be attributed to attenuation of one or more of the specific components of the cuff. The appearance of the collagen fibers and the blood vessels of the tendinous portion of the cuffs were similar in all specimens and did not appear to be affected by age or sex. Signs of degeneration of the cuff, such as hyaline necrosis of collagen, microscopic tears in fibers, calcific deposits, and intimal changes in arterioles, were not exclusively characteristic of one age-group. In general, the diameter of the arteries in the cuff decreased as the distance from the musculotendinous junctions increased. In the transverse sections, the vessels on the outer surface of the cuff followed the longitudinal intervals between the heavy fiber bundles in Layer 2 and branched into the interface between Layers 2 and 3.

Discussion

In most anatomy textbooks, the supraspinatus, infraspinatus, and teres minor tendons are shown as contiguous but distinct structures, with the subscapularis separated from the others by an interval that contains the bicipital tendon and groove[5,11-14,16,23]. Our study showed that all four tendons of the rotator cuff fuse to form a common insertion on the tuberosities of the humerus. Fibers from the subscapularis anteriorly and the infraspinatus posteriorly interdigitate with those of the supraspinatus. The interdigitation of fibers occurs primarily in the deep layers. On gross inspection, the tendons appear to have discrete insertions because the superficial fibers are concentrated along lines that are parallel to the axes of individual muscles and go directly to their insertions. The tendinous portion of the cuff is also confluent with the capsule of the shoulder joint and with the coracohumeral and glenohumeral ligaments. Therefore, at any point, the cuff is composed of layers that can be clearly identified by the orientations and attachments of the constituent fibers.

Initially, defects of the cuff seem to occur in different layers. Codman originally described deep-surface (articular side) failure of fibers. Fukuda et al.[8,9] described tears limited to the superficial (bursal) side; more recently, Tabata and Kida described several patterns of interstitial tears. Without knowledge of the normal anatomy of the fibers and of the arrangement of the layers, it is difficult to explain the different lesions. The more frequent use of magnetic resonance imaging, ultrasonography, and arthroscopy in the diagnosis of shoulder lesions makes it imperative that the interpretation of the findings be based on a detailed knowledge of normal anatomy. It is especially important to know that tears of a cuff tendon may be obscured by the coracohumeral ligament on the superficial surface or by the capsule on the deep surface. Simple sutures seem to hold well in the rotator cuff, perhaps because of the heterogeneous arrangement of the collagen fibers in the tissue. This study is unique because it involved normal specimens and because microscopic examination and dissection were employed together as a means of tracing individual fibrous elements.

When tendons are interwoven and are surrounded by capsule and ligaments, simple dissection with a scalpel does not show their precise relationships. Furthermore, because the cuff curves over the humeral head, it is difficult to trace the various elements of the cuff in serial histological sections. In our study, the tendons were separated from adventitial tissues in stages. Some specimens were examined grossly and microscopically while they were still attached to bone and then were compared with specimens that had been pinned flat before fixation, with and without the adjacent tissues in place. Histological studies confirmed that apparent expansions of the ligaments and tendons were in fact direct fibrous continuations of these elements. Dissection of the tendons off the bone before sectioning eliminated the need for decalcification, thus avoiding distortion of cells and collagen fibers that occur during decalcification.

In contrast with other histological studies, few obvious pathological changes were observed in the tendons of the cuff. Uhthoff et al. studied a group of shoulders that had partial tears or no tears of the tendons of the cuff and reported that fibrillation, necrosis, and so-called microtears were common on histological examination. Similarly, Brewer noted that the tendons of the rotator cuff from older subjects showed more signs of degeneration than those from younger ones and concluded that the cuff deteriorates with age. Brewer included only three shoulders, from cadavera of people who had been twenty, fifty, and seventy years old at the time of death, so it is questionable whether the changes in the older cadavera could be termed representative. These histological abnormalities are commonly believed to result from hypovascularity, particularly in the deeper layers of the supraspinatus tendon[17,21,22]. We found that vessels in the third layer of the cuff were relatively small compared with those in the more superficial layers, but we saw no associated evidence of degeneration and concluded that the blood supply was adequate for the metabolic needs of the tissue. This concept is supported by the observation of Moseley and Goldie[19] that vascular patterns within the cuff do not change with age. In seventy-two shoulders that were studied after injection, those authors found no avascular area in the supraspinatus and concluded that "the tendinous portion is well vascularised and remains so throughout life." Although Rathbun and Macnab maintained that there is an avascular zone in the supraspinatus when the shoulder is adducted, they also noted that the extent of avascularity was greater when the tendons of the cuff were attenuated. Thus, microscopic tears of either the tendons or the capsule may actually cause ischemia or necrosis by secondary disruption of vessels.

As Codman first showed, the prevalence of tears in the rotator cuff increases with age. No specific reason has emerged from subsequent studies. Clearly, age alone does not determine the condition of the tendons; we found no striking age-related differences among our specimens, which were selected because they showed no gross evidence of tears. Generalized thinning of the tendons may reflect the atrophy that is part of normal senescence and subsequent disuse. Some pathological observations, such as microscopic tears and calcification, suggest that biochemical changes may alter the mechanical properties of the tendons. Rather than simply discounting this as related to aging, we should continue to perform research studies to delineate the sequence of causal events in failures of the cuff. Part of this effort is to describe a more detailed picture of normal functional anatomy.

The normal rotator cuff has structural features that should improve its resistance to failure under load. The insertion of the cuff on the tuberosities is wide and continuous. The areas of insertion of the individual tendons are large because they each splay and then interdigitate with each other. Therefore, tension in any one musculotendinous unit is distributed, directly or indirectly, over a wide area. Benjamin et al. have proposed that the splayed insertions protect tendons from excessive stresses induced by bending. DePalma et al.[6,7] and Gagey et al. described the coracohumeral and glenohumeral ligaments as checkreins which become taut in specific positions. Those authors postulated that the ligaments could therefore resist stresses that would otherwise fall exclusively on the tendons of the cuff. In this study, the coracohumeral ligament appeared to reinforce the supraspinatus tendon, to which it is parallel and firmly adherent. The actual function of these structural features can be established only by mechanical testing of normal specimens.

References

1. **Benjamin, M.; Evans, E. J.;** and **Copp, L.:** The histology of tendon attachments to bone in man. *J. Anat.*, 149: 89-100, 1986.
2. **Brewer, B. J.:** Aging of the rotator cuff. *Am. J. Sports Med.*, 7: 102-110, 1979.
3. **Clark, John; Sidles, J. A.;** and **Matsen, F. A.:** The relationship of the glenohumeral joint capsule to the rotator cuff. *Clin. Orthop.*, 254: 29-34, 1990.
4. **Codman, E. A.:** *The Shoulder.* Boston, privately printed, 1934.
5. **Cunningham's Manual of Practical Anatomy:** Ed. 13, edited by G. J. Romanes. Vol. 1. Upper and Lower Limbs. London, Oxford University Press, 1966.
6. **DePalma, A. F.:** *Surgery of the Shoulder.* Ed. 2, pp. 206-210, 229. Philadelphia, J. B. Lippincott, 1973.
7. **DePalma, A. F.; Callery, Gerald;** and **Bennett, G. A.:** Shoulder joint. I. Variational anatomy and degenerative lesions of the shoulder joint. In *Instructional Course Lectures, The American Academy of Orthopaedic Surgeons.* Vol. 6, pp. 255-281. Ann Arbor, J. W. Edwards, 1949.
8. **Fukuda, H.:** Rotator cuff tears. *Geka Chiryo. (Osaka)*, 43: 28, 1980.
9. **Fukuda, H.; Ogawa, K.;** and **Mikasa, M.:** Rotator cuff injury with special reference to the "intraoperative color test." *J. Japanese Orthop. Assn.*, 52: 1243-1244, 1978.
10. **Gagey, O.; Bonfait, H.; Gillot, C.; Hureau, J.;** and **Mazas, F.:** Anatomic basis of ligamentous control of elevation of the shoulder (reference position of the shoulder joint). *Surg. and Radiol. Anat.*, 9: 19-26, 1987.
11. **Grant's Atlas of Anatomy:** Ed. 7, edited by J. E. Anderson. Baltimore, Williams and Wilkins, 1978.
12. **Grant's Method of Anatomy by Regions Descriptive and Deductive:** Ed. 7, edited by J. C. B. Grant and J. V. Basmajian. Baltimore, Williams and Wilkins, 1965.
13. **Gray's Anatomy of the Human Body:** American Ed. 29, edited by C. M. Goss. Philadelphia, Lea and Febiger, 1973.
14. **Hollinshead, W. H.:** *Anatomy for Surgeons. Vol. 3. Back and Limbs.* Ed. 3. Philadelphia, Harper and Row, 1982.
15. **Humphreys, W. J.; Spurlock, B. O.;** and **Johnson, J. S.:** Transmission electron microscopy of tissue prepared for scanning electron microscopy by ethanol-cryofracturing. *Stain. Technol.*, 50: 119-125, 1975.
16. **Last, R. J.:** *Anatomy, Regional and Applied.* Ed. 6. New York, Churchill Livingstone, 1978.
17. **McMaster, P. E.:** Tendon and muscle ruptures. Clinical and experimental studies on the causes and location of subcutaneous ruptures. *J. Bone and Joint Surg.*, 15: 705-721, July 1933.
18. **Moseley, H. F.:** *Shoulder Lesions.* Ed. 3, p. 70. Edinburgh, E. and S. Livingstone, 1969.
19. **Moseley, H. F.,** and **Goldie, Ian:** The arterial pattern of the rotator cuff of the shoulder. *J. Bone and Joint Surg.*, 45-B(4): 780-789, 1963.
20. **Neer, C. S., II:** Impingement lesions. *Clin. Orthop.*, 173: 70-77, 1983.
21. **Rathbun, J. B.,** and **Macnab, Ian:** The microvascular pattern of the rotator cuff. *J. Bone and Joint Surg.*, 52-B(3): 540-553, 1970.
22. **Rothman, R. H.,** and **Parke, W. W.:** The vascular anatomy of the rotator cuff. *Clin. Orthop.*, 41: 176-186, 1965.
23. **Sarrafian, S. K.:** Gross and functional anatomy of the shoulder. *Clin. Orthop.*, 173: 11-19, 1983.
24. **Tabata, S.,** and **Kida, H.:** Diagnosis and treatment of partial thickness tears of rotator cuff. *Orthop. Traumat. Surg.*, 26: 1199-1204, 1981.
25. **Uhthoff, H. K.; Loehr, J.;** and **Sarkar, K.:** The pathogenesis of rotator cuff tears. In *Proceedings of the Third International Conference on Surgery of the Shoulder*, pp. 211-212, 1986. Tokyo, N. Takagishi/Professional Post-Graduate Services, 1987.
26. **Watson, Michael:** Rotator cuff function in the impingement syndrome. *J. Bone and Joint Surg.*, 71-B(3): 361-366, 1989.