US Appearance of the Rotator Cable with Histologic Correlation: Preliminary Results[1]

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Purpose: To characterize the ultrasonographic (US) appearance of the rotator cuff cable in asymptomatic shoulders and in cadaveric specimens, with histologic comparison for the latter.

Materials and Methods: The cadaveric portion of this study was approved by the institution's Anatomical Donations Department. Institutional review board approval and informed consent were obtained from asymptomatic volunteers and clinical patients for the HIPAA-compliant portion of the study. Four fresh cadaveric shoulder specimens (two male subjects, 40 and 50 years old) were dissected, assessed for the presence of the rotator cable, and imaged with 12-MHz US. Histologic slides (hematoxylin-eosin stain) from three resected rotator cuff tendons were inspected for fibers in the expected location and orientation of the rotator cuff cable. The shoulders in 17 asymptomatic volunteers (seven men, two women; age range, 27–66 years; mean, 41 years) and contralateral asymptomatic shoulders in 10 patients (six men, four women; age range, 24–78 years; mean, 49 years) were scanned and evaluated for the presence and appearance of the rotator cable.

Results: The rotator cable was identified at gross dissection. Histologic examination and US of the cadaveric shoulders demonstrated an articular-sided fibrillar structure perpendicular to the rotator cuff tendon (average thickness and width, 1.2 mm and 4.5 mm, respectively). US of asymptomatic shoulders depicted a similar fibrillar structure in three (11%) shoulders up to 1.1–1.5 cm medial to the greater tuberosity (average thickness and width, 1.2 mm and 4.5 mm respectively).

Conclusion: The rotator cable can be depicted with US.

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The rotator cuff is composed of intimately associated tendons that form a single functional unit. There exists a relatively hypovascular crescentic region of the distal supraspinatus and infraspinatus tendon, termed the rotator crescent, which is prone to injury (1,2). At the medial aspect of this crescent, a thick bundle of fibers perpendicular to the supraspinatus tendon has been described and called the rotator cable (Fig 1) (3). Important biomechanical and clinical implications have been attributed to this structure (4).

It has been suggested that the relatively avascular crescent tissue of the distal rotator cuff undergoes progressive thinning with aging, with an increasing mechanical reliance on the rotator cable (4). When a tear involves the rotator crescent, an intact rotator cable may allow tension dispersion through the remaining cuff, thereby minimizing the biomechanical consequences of the tear. Therefore, accurate characterization of a rotator cuff tear and its relationship to the rotator cable may be important.

While there are a limited number of peer-reviewed publications dealing with the rotator cable and only a single example of a rotator cable with use of magnetic resonance (MR) imaging (5), we have noted in our clinical practice the appearance of a cablelike structure perpendicular to the supraspinatus tendon fibers. To our knowledge, the ultrasonographic (US) appearance of the rotator cable has not been previously described. The purpose of our study, therefore, was to characterize the US appearance of the rotator cuff cable in asymptomatic shoulders and in cadaveric specimens with histologic comparison for the latter.

Materials and Methods

The cadaveric portion of this study was approved by our institution's Anatomical Donations Department. Institutional review board approval and informed consent were obtained from asymptomatic volunteers and clinical patients for the Health Insurance Portability and Accountability Act–compliant portion of our study.

Cadaveric Specimens, Imaging, and Histologic Examination

Two pairs of fresh cadaveric shoulders (male, 40 and 50 years old) were dissected by an experienced orthopedic surgeon (B.M.) with fellowship training in shoulder surgery. After the skin and the underlying deltoid muscle were removed, the rotator cuff was identified and inspected. After confirmation that the rotator cuff was intact, the supraspinatus and infraspinatus tendons were excised proximally from the musculotendinous junction to the distal attachment. Tendon excision included the superior segment of the greater tuberosity, the superior-most border of the distal subscapularis tendon, and a segment of the long head biceps brachii tendon. After tendon excision, the orthopedic surgeon inspected the rotator cuff for the presence of the rotator cable.

US imaging (Logic 9; GE Medical Systems, Milwaukee, Wis) of the resected supraspinatus and infraspinatus tendons was performed by a fellowship-trained musculoskeletal radiologist (Y.M., 4 years of experience in musculoskeletal US) using a 12-MHz linear transducer. A liberal amount of transmission gel was used. Images were obtained longitudinal to the supraspinatus and infraspinatus tendons by using the greater tuberosity as a landmark. Transverse images were obtained by using the intraarticular portion of the long head biceps brachii tendon as a landmark. Subsequent images were reviewed by this individual and a second fellowship-trained musculoskeletal radiologist (J.A.J., 10 years experience in musculoskeletal US) for the presence of a hyperechoic bundle of fibers running perpendicular to the supraspinatus tendon in the expected anatomic location of the rotator cable. Measurements of the rotator cable thickness (craniocaudal dimensions) and width (mediolateral dimensions) were obtained. Given the lax state of the resected tendon, reliable measurements from the greater tuberosity to the cable could not be obtained.

After fixation in 10% formalin, three resected rotator cuff tendons were dissected in transverse and longitudinal planes into rectangular segments approximately 2 cm long along the course of the rotator cable. The fourth specimen was extremely friable after formalin fixation and could not be properly dissected. The bursal surface of the dissected portions was marked with India ink and was labeled according to location and orientation as anterior, midline, posterior, transverse, or longitudinal. The dissected segments were made into paraffin blocks, and 4-μm sections were cut. The sections were stained with hematoxylin-eosin, and selected specimens were also stained with Masson trichrome. Histologic slide interpretation was performed by a pathologist (D.L., 14 years of experience) subspecializing in musculoskeletal pathology. Slides were inspected for tendon or collagen fibers coursing perpendicular to the supraspinatus and infraspinatus tendons in the expected location of the rotator cable.

Asymptomatic Volunteers and Imaging

Seventeen asymptomatic shoulders in nine healthy volunteers (seven men, two women; age range, 27–66 years; mean, 41 years) were imaged. Volunteers with shoulder pain, limited range of motion, or history of symptomatic

Advance in Knowledge

- Identification of the rotator cable is possible at US.

Published online
10.1148/radiol.2412050800

Radiology 2006; 241:485–491

Author contributions:
Guarantor of integrity of entire study, Y.M.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; approval of final version of submitted manuscript, all authors; literature research, all authors; clinical studies, Y.M., J.A.J.; experimental studies, Y.M., D.L., B.M.; and manuscript editing, all authors

Authors stated no financial relationship to disclose.

shoulders were excluded from the study. Asymptomatic shoulders were imaged with a US unit (ATL HDI 5000; Philips Medical Systems, Bothell, Wash) and a 12-MHz linear transducer by a fellowship-trained musculoskeletal radiologist (Y.M.). Subsequent images were reviewed by this individual and a second fellowship-trained musculoskeletal radiologist (J.A.J.), for the presence of a hyperechoic bundle of fibers running perpendicular to the supraspinatus or infraspinatus tendons in the expected location of the rotator cable. Identification of the rotator cable relied on demonstration of cable fibers in both transverse and the longitudinal orientations. Cases where fibers were identified in only one plane were not considered sufficient to prove the presence of a rotator cable. Measurements of the rotator cable thickness (craniocaudal dimensions) and width (mediolateral dimensions) were performed. The maximal distance in the sagittal plane from the point of insertion of the medial-most supraspinatus tendon fibers on the greater tuberosity to the cable was also performed.

Clinical Patients and Imaging

In an attempt to diversify our study group with regard to age and sex, we imaged asymptomatic contralateral shoulders in patients presenting for unilateral rotator cuff evaluation. Patients with bilateral shoulder pain, limited range of motion, or history of bilateral symptomatic shoulders were excluded from the study. After evaluation of the symptomatic shoulder, US of the asymptomatic contralateral shoulder and evaluation of the images were performed in 10 patients (six men, four women; age range, 24–78 years; mean, 49 years) in a similar fashion to that described for the asymptomatic volunteers.

Results

Cadaveric Specimens

At the time of dissection, the rotator cuffs were grossly intact to visual inspection by the orthopedic surgeon. After excision, the rotator cable was identified in two specimens by means of palpation and direct visualization and by means of palpation alone in the two remaining specimens. Examination of the resected specimens showed a variable-sized cordlike thickening extending along the articular surface of the rotator cuff proximal to the greater tuberosity. The structure extended from the lateral aspect of the rotator interval in an archlike fashion toward the infraspinatus tendon.

At histologic examination, a fibrillar structure distinct from the rotator cuff was identified, consistent with the rotator cable. The orientation and appearance of the fibrillar structure differed from those of the rotator cuff tendon fibers. Samples from the rotator cuff midline demonstrated a cablelike structure situated on the articular surface of the cuff tendons (Fig 2). This fibrillar structure could be identified as oriented perpendicular to the orientation of the rotator cuff tendon fibers (Fig 3). In addition, a fibrillar Y-shaped structure arose from the lateral aspect of the rotator interval, also perpendicular to the supraspinatus tendon (Fig 4). The two limbs of this Y extended along the articular and bursal surface of the anterior aspect of the supraspinatus tendon, with the articular component more substantial.

US scans of the dissected specimens demonstrated similar findings. A fibrillar structure distinct and perpendicular to the rotator cuff tendons (Fig 5), which appeared to arise from the lateral rotator interval in a Y-shaped fashion encompassing the rotator cuff tendons and assuming a cablelike appearance arching from anterior to posterior, was identified along the articular surface of the supraspinatus and infraspinatus tendons (Fig 6). The bursal component was diminutive and was clearly identified only in the anterior-most portion of the rotator cuff. Thickness of the identified cables varied 1.1–1.3 mm (mean, 1.2 mm) among shoulders, and width varied 2.6–7.0 mm (mean, 4.5 mm).

Asymptomatic Volunteers and Clinical Patients

By using the described criteria, the rotator cable was identified in three male (34, 40, and 66 years old) volunteer shoulders among all shoulders evaluated (11%). Review of the US images showed a cord of fibers perpendicular to the supraspinatus tendon fibers adjacent to the articular surface in the expected location of the rotator cable. In the approximately midsagittal plane, this structure was located 1.1–1.5 cm medial to the greater tuberosity. This structure appeared hyperechoic and fibrillar, especially when imaged longitudinally (anterior to posterior) (Figs 7, 8), and demonstrated anisotropy (Fig 9). Thickness of the identified cables varied 1.1–1.3 mm (mean, 1.2 mm) among shoulders, and width varied 2.6–7 mm (mean, 4.5 mm). The cable appeared thicker near the origin at the rotator interval, thinning deep to the supraspinatus tendon.

Discussion

The rotator cuff is composed of intimately associated tendons that intersect and interdigitate in the region of the

Figure 1

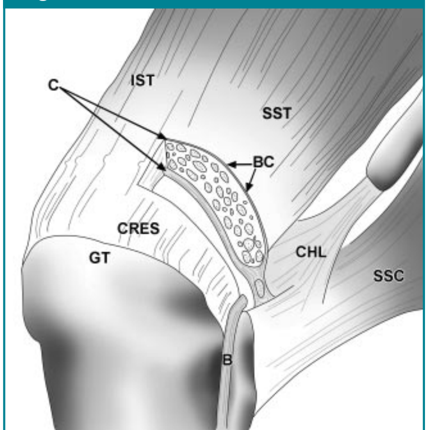


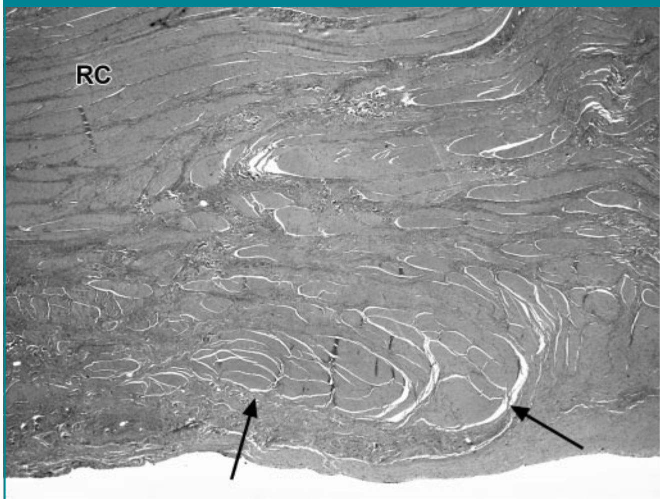
Figure 1: Illustration demonstrates relationship between rotator cable and rotator cuff. For purpose of illustration, the acromion and clavicle were not drawn, and an anterior segment of distal supraspinatus tendon, adjacent rotator interval, and long head biceps brachii were removed to reveal anterior portion of rotator cable *(C)*. Rotator cable arises from coracohumeral ligament *(CHL)*, encompassing anterior portion of rotator cuff with a more robust deep component. Cable tracks posteriorly along the undersurface of supraspinatus *(SST)* and infraspinatus *(IST)* tendons. Note biceps tendon *(B)* adjacent to lesser tuberosity. *BC* = bursal portion of cable, *CRES* = crescent, *GT* = greater tuberosity, *SSC* = subscapularis.

supraspinatus and infraspinatus tendons (6,7). Through this arrangement of fibers, loads from contraction are not isolated to a single muscle but are dispersed among neighboring cuff muscles (7,8). Anatomic dissections of rotator cuffs (6) have demonstrated a thick fibrous sheath called the rotator cable, which arises from the coracohumeral ligament and envelopes the anterior margin of the supraspinatus tendon. In the setting of a full-thickness rotator cuff tear, an intact rotator cable may disperse tension and reduce the biomechanical effects of the tendon tear (4). The results of our study show that the rotator cable can be visualized at US.

Microscopic dissections (8) have demonstrated that the rotator cable is a defined cablelike extension of the coracohumeral ligament along the articular surface of the supraspinatus and infraspinatus tendons, perpendicular to the cuff fibers. A less robust extension of the coracohumeral ligament extends along the supraspinatus tendon bursal surface. The cable bounds the distal supraspinatus and infraspinatus tendons surrounding the area described by Codman (1) as the “critical zone,” a zone with a propensity for tearing (2). The cable and crescent are thought to represent the fourth layer of the shoulder (7).

Histologic specimens in our study revealed the rotator cable as a distinct fibrillar structure enveloping the anterior margins of the supraspinatus and forming a bandlike structure that extends anteriorly to posteriorly in an archlike fashion along the articular surface of the superior rotator cuff tendons. This finding is in concordance with previous descriptions of the rotator cable (8). US of the cadaveric specimens was able to depict the fibrillar structure composing the cable oriented perpendicular to the rotator cuff, which is similar in appearance to previously published MR images of the rotator cable (5). US of asymptomatic volunteer’s and patient’s shoulders successfully de-

Figures 2–4



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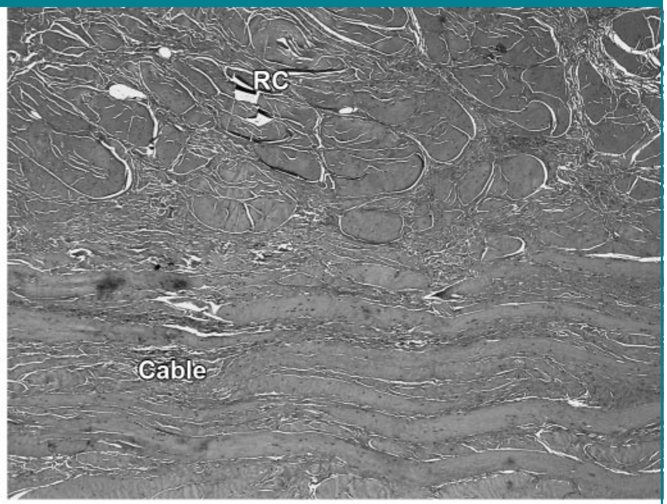

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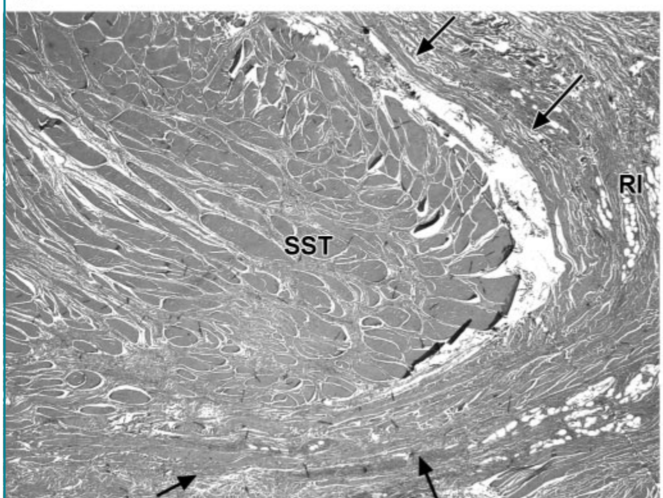

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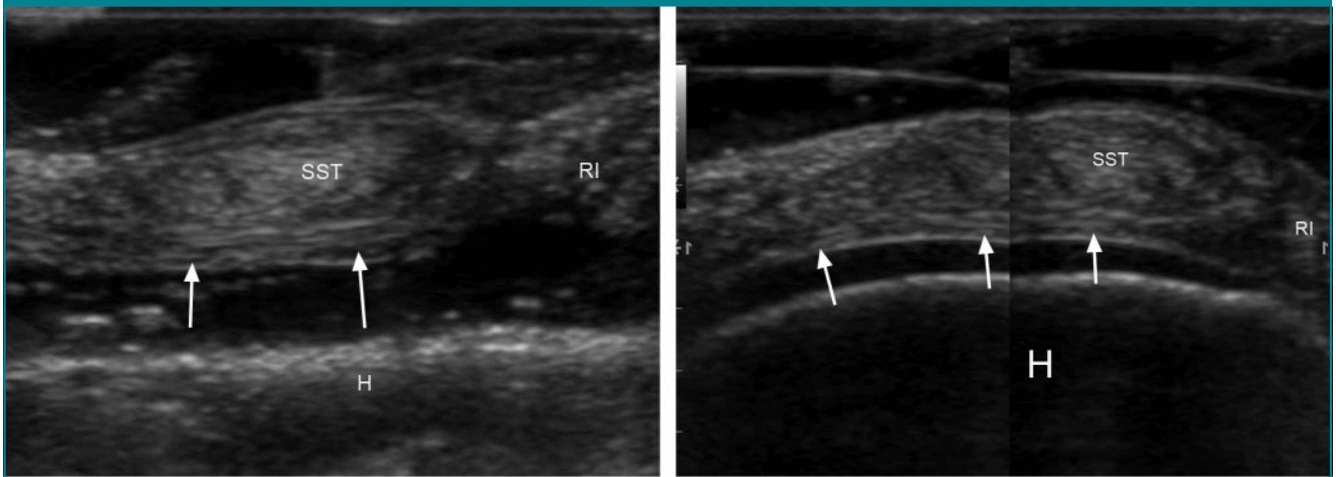
Figure 2: Histologic slice of specimen dissected longitudinal to rotator cuff *(RC)*. Deep to rotator cuff fibers is a bundle of fibers (arrows) perpendicular to the rotator cuff, consistent with the rotator cable. (Hematoxylin-eosin stain; original magnification, x20.)

Figure 3: Histologic slice of specimen dissected transverse to rotator cuff. Deep to rotator cuff fibers *(RC)* are longitudinal fibers consistent with the rotator cable. (Hematoxylin-eosin stain; original magnification, x20.)

Figure 4: Histologic slice of specimen dissected transverse to rotator cuff at anterior aspect of supraspinatus tendon *(SST)* and adjacent rotator interval *(RI)* shows rotator cable fibers (arrows) arising from the rotator interval to encompass anterior border of the supraspinatus tendon. (Hematoxylin-eosin stain; original magnification, x20.)

Figures 5, 6



5a. **5b.**

Figure 5: **(a, b)** Transverse US scans of two specimens perpendicular to orientation of the supraspinatus tendon *(SST)* (anterior to posterior). Deep to the rotator cuff is a bundle of fibers (arrows) oriented along the plane of scan perpendicular to cuff fibers, consistent with the rotator cable. *H* = humerus, *RI* = rotator interval.

6.

Figure 6: US scan of specimen obtained longitudinal to supraspinatus tendon fibers *(SST)* (proximal on right, distal on left) shows rotator cable at articular surface of rotator cuff as distinct oval bundle of fibers (arrowheads), which appears mildly hypoechoic due to anisotropy. *H* = humerus.

picted a hyperechoic fibrillar structure deep to the supraspinatus tendon tracking in a perpendicular fashion relative to the rotator cuff fibers, which is similar to the US appearance of cadaveric specimens in three (11%) shoulders. This hyperechoic and fibrillar rotator cable demonstrated anisotropy and therefore appeared artifactually hypoechoic when not imaged perpendicular to the ultrasound beam.

The ability of US to depict the rotator cable may have clinical implications. The rotator cable surrounds the critical zone of the supraspinatus tendon, an area with a propensity for tearing (1,2). Burkhart et al (4) described two functional classes of rotator cuff: cable dominant and crescent dominant. In cable-dominant cuffs, the crescent tissue bound medially by the rotator cable is relatively thinned. No thinning of the rotator crescent was noted in crescent-dominant cuffs. On the basis of biomechanical cadaveric studies, Burkhart et al (4) hypothesized that in cable-dominant shoulders, the rotator cable has a role in stress shielding that is similar in fashion to the supporting cables in a suspension bridge. Stress is transferred from the rotator cuff to the cable, with stress shielding of the thin capsular tissue within the crescent. Therefore, small rotator cuff tears within the crescent with an intact cable may manifest clinically without loss of shoulder strength, but a substantial decrease in force transmission through the supraspinatus tendon may occur when there is involvement of the rotator cable (4,9).

The functional type of cuff is age dependent, with cable-dominant cuffs predominantly occurring in older (>60 years) shoulders. Burkhart et al (4) suggested that the relatively avascular crescent tissue undergoes progressive thinning throughout the years, with increasing reliance on the cable. Thus, crescent-dominant cuffs may slowly evolve to cable-dominant cuffs.

The limitations of our study included the small number and relatively young age of cadavers, volunteers, and patients; however, correlation among dissection, US, and histologic findings was achieved. The ability of US to depict

Figures 7, 8

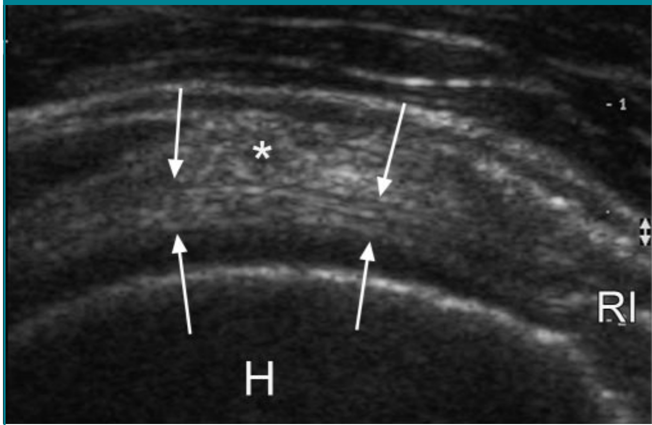


Figure 7: US scan of asymptomatic volunteer's shoulder obtained transverse to the orientation of the rotator cuff shows hyperechoic and fibrillar rotator cable (arrows) at articular surface of the supraspinatus tendon (*) as a bundle of fibers oriented perpendicular to the cuff fibers. *H* = humerus, *RI* = rotator interval.

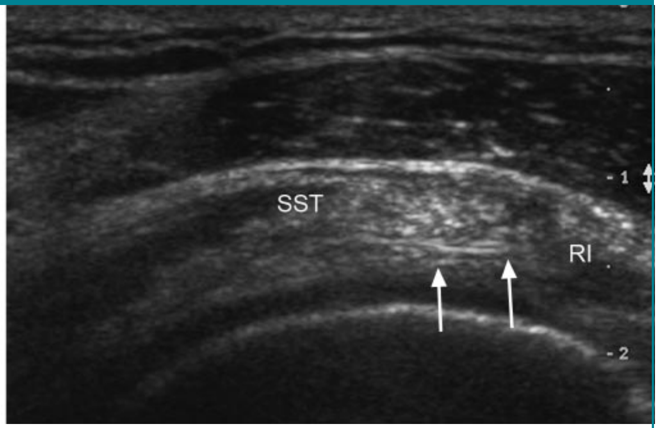


Figure 8: Transverse US scan of asymptomatic volunteer's shoulder, focused on anterior supraspinatus tendon *(SST)*, including the rotator interval *(RI)*. Rotator cable fibers (arrows) are deep and perpendicular to anterior supraspinatus fibers. Long head biceps brachii tendon is not well visualized because of anisotropy.

Figure 9

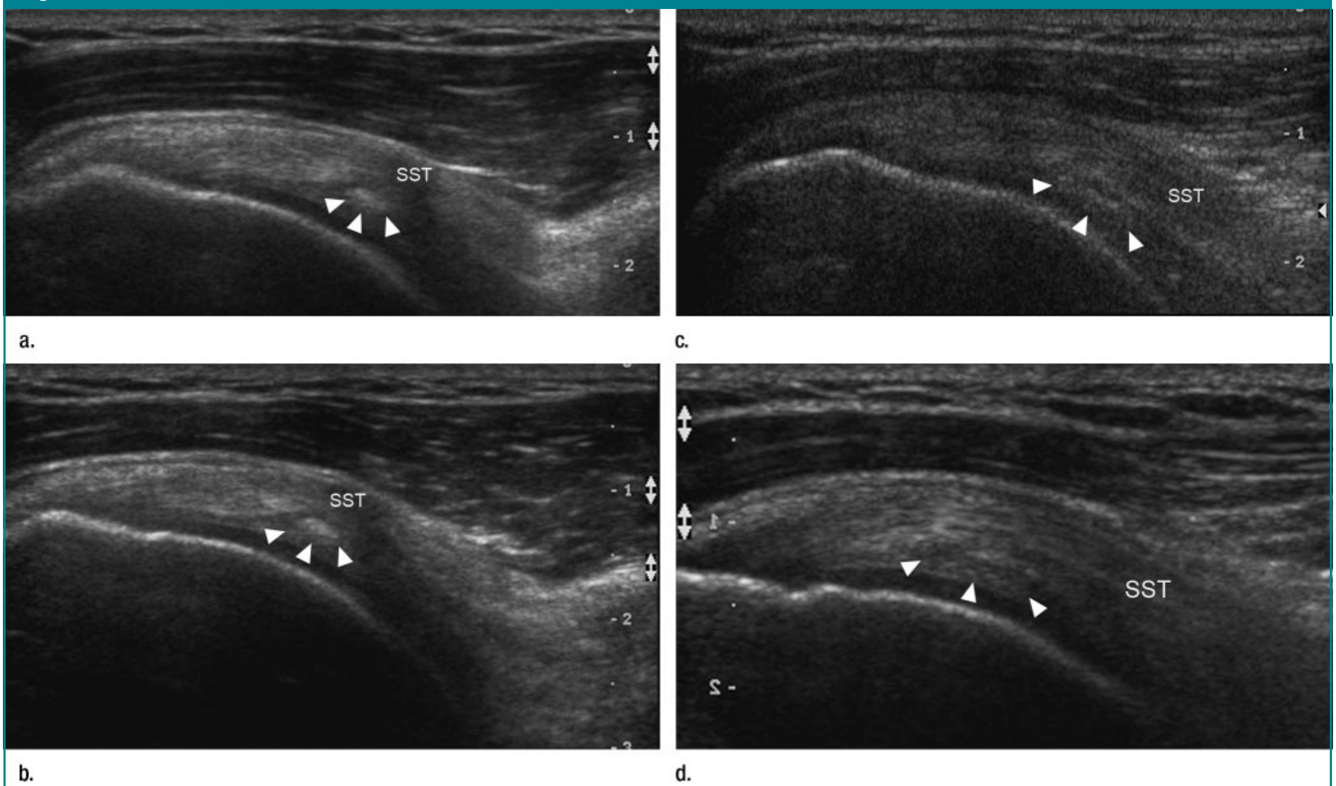


Figure 9: Longitudinal US scans of asymptomatic volunteer's shoulder (proximal on right, distal on left) from anterior to posterior. **(a, b)** Rotator cable (arrowheads) is deep to the supraspinatus tendon *(SST)*, which is oriented along the plane of imaging. **(c, d)** Posterior-most images show relatively flattened rotator cable (arrowheads), demonstrating anisotropy.

the rotator cable in vivo may be underestimated in our study given the relatively strict inclusion criteria, with exclusion of cases where distinct fibers were identified in one plane only. The morphology of the rotator cable may be variable, likely representing a spectrum changing between robust cable to flattened fibers traversing deep to the rotator cuff. The ability of US to depict the rotator cable may be greater in older (>60 years) individuals. Larger studies should be undertaken to assess our ability to consistently identify the rotator cable in large groups of symptomatic and asymptomatic patients and to attempt to correlate between rotator cable morphology and shoulder function after a rotator cuff tear.

In summary, the rotator cable can be identified with US, correlating with findings at gross dissection and histologic examination. The rotator cable is a well-known structure among orthopedic surgeons, often visualized during arthroscopy with proved anatomic correlation. Demonstration of cable integrity with a tear isolated to the crescent may have clinical implications. Further studies are needed to determine if the rotator cable can be uniformly depicted at US and to determine if this information can potentially alter treatment of rotator cuff tears.

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