Introduction

Shoulder pathologies in the anterolateral region of the rotator cuff of the shoulder are common in clinical practice. Frequently encountered pathologies in this region are listed in Table 1. Detailed knowledge of the anatomy of this region and its ultrasound appearance is essential to recognize possible pathologies that correlate with the clinical presentation [1]. The focus of this pictorial essay is to review and discuss the anatomical details of the rotator interval of the shoulder, correlate the anatomy with normal ultrasound images and present selected pathologies.

Diagnostic musculoskeletal ultrasound (MSUS) is an excellent tool in the detection of rotator cuff (RC) pathologies [2, 3] with an accuracy compared to magnetic resonance imaging (MRI) and arthroscopy in the hands of experienced sonographers [4–8]. RC lesions are even more frequent in inflammatory patients (e.g., in rheumatoid arthritis (RA), crystal deposition diseases or polymyalgia rheumatica) with the result that a painful shoulder is not always related to active synovitis [9].

The rotator cuff interval (RI) is a roughly triangular region created by the interposition of the coracoid process, the base of the triangle, between the subscapularis muscle/tendon (SSC) medialy and the supraspinatus muscle/tendon (SSP) anteriorly forming the two sides. The RI is a complex anatomic region that plays a relevant role in the stability and function of the shoulder joint. The structure of the RI supports the tendon of the long head of the biceps muscle to prevent dislocation antero-medially and antero-inferiorly (e.g., in external rotation and abduction). In addition, RI structures contribute to inferior glenohumeral joint stability by limiting glenohumeral motility [10, 11]. The added value of the ultra-
sound assessment is to provide a dynamic complementary tool to help in the clinical approach of a patient with RI injuries [12, 13].

Anatomy

The RC is composed of the tendons of the supraspinatus (SSP), infraspinatus (ISP), subscapularis (SSC) and teres minor (Tm) muscles. The RC is an important dynamic stabilizer of the glenohumeral joint; it compresses the humeral head into the glenoid and thus prevents superior migration of the humeral head triggered by deltoïd muscle contraction during abduction and elevation [14]. It may also prevent excessive anterior translation of the humeral head in abduction and external rotation [15]. The triangular shaped RI forms a unique gap in the anterior part of the RC and may vary in size [16]. The RI is actually the anterosuperior aspect of the glenohumeral joint capsule that is reinforced externally (laterally) by the coracohumeral ligament (CHL), internally (medially) by the superior glenohumeral ligament (SGHL) and capsular fibers which blend together and insert medially and laterally to the bicipital groove (Fig. 1–4).

CHL (Coracohumeral Ligament)

The CHL originates at the proximal third of the dorsolateral aspect of the base of the coracoid [17]. The CHL consists of a lateral and medial bundle arranged like two pillars of a bridge. The smaller medial bundle (MCHL) crosses the intraarticular part and surrounds the medial and inferior part of the intraarticular portion of the LBT to insert at the lesser tubercle together with the superior fibers of the SSC tendon and the SGHL [18–21]. This part communicates with the glenohumeral ligament and the superior part with the SSC tendon and forms the medial-pulley-complex (MPC) [21]. This anatomical relationship explains why the LBT tends to become dislocated antero-medially with a subscapularis tendon tear. The larger lateral bundle (LCHL) surrounds the superior and lateral part of the intraarticular LBT. The LCHL inserts at the greater tubercle of the humerus and on the anterior border of the SSP and forms the lateral-pul-

<p>| Table 1 adapted from [42–1], frequently encountered pathologies related to anatomical regions. |</p>
<table>
<thead>
<tr>
<th>Anatomical region</th>
<th>Pathologies</th>
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</thead>
<tbody>
<tr>
<td>Long biceps tendon (LBT)</td>
<td>Tendinosis, tears, effusion in the LBT recess, calcifications, (sub-)luxation</td>
</tr>
<tr>
<td>Supraspinatus and subscapularis tendon</td>
<td>Tendinosis, tears, enthesopathy, calcifications, etc.</td>
</tr>
<tr>
<td>Ligaments, labrum and joint capsule</td>
<td>Tears, thickening, contraction (e.g., in capsulitis), anteromedial or anterosuperior impingement, secondary instability, etc.</td>
</tr>
<tr>
<td>Bursa</td>
<td>Bursitis (subdeltoid, subcoracoid, subscapularis communicating with the anterior gleno-humeral recess)</td>
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See Fig. 1 Drawings of the rotator interval. Superior glenohumeral ligament (SGHL), middle glenohumeral ligament (MGHL), anterior inferior glenohumeral ligament (IGHL), coracohumeral ligament (CHL), medial coracohumeral ligament (MCHL), lateral coracohumeral ligament (LCHL), subscapularis tendon (SSC), long biceps tendon (LBT) and supraspinatus tendon (SSP).
ley-complex (LPC) [22, 23]. This lateral part has been called the rotator cable, a thin fibro-osseous band continuous with the coracohumeral ligament (and some fibers of the SGHL) that arcs along the undersurface of the SSP and ISP fibers and superficial to the joint capsule. The CHL may be hypoplastic or absent in up to 6% of shoulder dissections [24]. The tension of the CHL has an important effect on the stability and range of motion of the glenohumeral joint, particularly in external rotation [10, 22]. The CHL consists of loose connective tissue and is therefore relatively flexible. Histological studies demonstrate that the CHL contains irregular and sparse fibers with a higher proportion of type III collagen compared to the LBT or the intramuscular SSC tendon [25, 26]. Selected histological studies even suggest that the superior glenohumeral ligament may be a defined part of the CHL, adherent to the tendinous slip of the SSC [27].

SGHL (Superior Glenohumeral Ligament)

The SGHL is a reinforcement of the anterosuperior glenohumeral joint capsule. Some anatomical details and variations of the SGHL need to be explained in more detail due to their relevance in imaging studies. The SGHL may be absent in up to 3% of patients based on arthroscopy findings [28]. The proximal attachment of the SGHL can be quite variable: originating from the LBT only; from the LBT and the superior part of the labrum; or from the middle glenohumeral ligament, the LBT, the superior part of the labrum and partially from the superior glenoid tubercle of the scapula [29, 30]. It inserts near the lesser tubercle at the fovea capitis of the humerus [10]. The SGHL crosses the floor of the RI and may fuse with the MCHL [23].

LBT (Long Biceps Tendon) and Borders of the RI (Rotator Interval)

The RI contains the intraarticular portion of the tendon of the long head of the biceps muscle (LBT) as it passes through the joint capsule [17–20]. The LBT may originate from the postero-superior labrum, the superior glenoid tubercle, or from both [31–31]. At this level, the LBT functions as a humeral head depressor and stabilizer of the glenohumeral joint. In 207 examined shoulders, the mean width of the long head of the biceps tendon was 6.0 mm (range: 3–10 mm) [32]. The distal anterior roof of the RI expands anteriorly to form the transverse humeral ligament, which covers the LBT in the bicipital groove. Some authors propose that the transverse ligament is only a minor contributor to stabilization of the LBT in the bicipital groove [33, 20, 34], while others describe no distinct transverse ligament, characterizing it as a combination of fibers from the SSC tendon and the posterior lamina of the tendon of the pectoralis major muscle [35]. Furthermore, the supraspinatus tendon has an aponeurotic tendon-like expansion which courses anteriorly and laterally to the LBT tendon reaching the cranial insertion of the pectoralis major. It may be identified with MRI or ultrasound in about one-half of shoulders [36]. Fibers from the coracohumeral ligament, SSP and SSC contribute to the anterior roof proximal to the transverse ligament, forming a sling around the biceps tendon at the level of the proximal bicipital groove while forming the distal end or the apex of the RI [37]. Thus the RI contains parts of the CHL (posterior roof and lateral wall together with

▶ Fig. 2 Anatomical section through the rotator interval showing the superior glenohumeral ligament (SGHL), the medial (MCHL) and lateral (LCHL) coracohumeral ligament (CHL), the long biceps tendon (LBT), the supraspinatus tendon (SSP) and the subscapularis tendon (SSC).

▶ Fig. 3 Arthroscopic image showing the long biceps tendon (LBT), the superior glenohumeral ligament (SGHL) and the lateral bundle of the coracohumeral ligament (LCHL).

▶ Fig. 4 Histological image (toluidine blue) of the rotator interval showing the long biceps tendon (LBT), the superior glenohumeral ligament (SGHL) and the lateral (LCHL) and medial (MCHL) coracohumeral ligament (CHL).
the SSP tendon) and the SGHL (medial wall together with fibers of the SSC tendon) (Fig. 2). They form the sling-like capsulo-ligamentous biceps pulley (CHL, SGHL, capsule) [38] (Fig. 3). All of these structures together are also referred to as the superior-complex layer (SCL) [39]. Superiorly and posteriorly, the RI border is formed by fibers of the SSP, inferiorly by fibers of the SSC. Between the rotator cable and the insertional region of the distal portion of the SSP at the greater tubercle, there is a zone known as the rotator crescent which is a poorly vascularized but clinically highly stressed section of the rotator cuff. The crescent of the rotator cuff becomes thinner with age. Tears involving the rotator crescent with an intact rotator cuff cable may have minimal biomechanical consequences [12] [40]. The rotator cable has been described as the suspension bridge of the shoulder joint providing stress dispersal to the rotator cuff tendons and is a stabilizer of the glenohumeral joint [12]. Morag et al. measured the different rotator cuff structures around the cable on cadaveric specimens by ultrasound [41, 42]. Ultrasound demonstrates the rotator cable on essentially all normal shoulders consistent with the articular-sided fibrillary structure perpendicular to the rotator (SSP, ISP) noted in histologic studies [42].

Ultrasound Technique and Ultrasound Findings

Before focusing on the RI, the full extent of the biceps tendon (LHBT) and its associated structures are initially examined in transverse and longitudinal axes from the RI distal to the superior aspect of the tendon of the pectoralis major [43].
For the examination of the rotator interval, one preferred position to examine the patient is supine on the examination table with the upper extremity to be examined hanging off the side of the table (allowing for posterior flexion which opens the interval, stretches the LHBT and tightens the CHL) and in neutral rotation ▶ Fig. 5a–c. Alternatively, the patient sits on a revolving chair with the examiner sitting or standing behind or in front of the patient according to personal preference (▶ Fig. 5d–f).

We begin by placing the probe in short axis over the superior aspect of the bicipital groove. The probe is then moved upward to a position just above the most proximal aspect of the groove (and the trans-humeral ligament). It is now in the most distal aspect of the RI where the CHL and SGHL coalesce into an annular sling around the LHBT as it enters the glenohumeral joint. The sling is hypoechoic when compared to the hyperechoic LHBT and the probe must be angulated from side-to-side to eliminate this anisotropy ▶ Fig. 6. Remember that the LHBT is much more sensitive to the angulation of the probe than the CHL. The LHBT/CHL are followed superiorly as they enter the joint and with the LHBT turning sharply and disappearing into the joint towards its origin on the supra-glenoid tubercle ▶ Fig. 7. It is possible to visualize the LHBT/CHL over the most distal cartilaginous surface of the humeral head. It is important to toggle the probe slightly to utilize the different anisotropies of the LHBT and CHL to distinguish them as distinct structures separated by the joint capsule ▶ Fig. 8.
Returning to the starting point for transverse imaging of the RI, the dependent arm is slightly rotated internally and externally and the proximal pole of the probe is rotated approximately 30° in the direction of the deep aspect of the lateral coracoid process and the CHL origin. The oblique probe is now longitudinal to the CHL and essentially transverse to the distal SSP tendon close to its insertion into the medial aspect of the greater tuberosity. One should visualize the trajectory of the fibers of the CHL originating at the base of the lateral coracoid process as they pass over the LHBT into the inferior portion of the SSP. 

Fig. 9 [44].

Fig. 11 Arthroscopy of the rotator cable and ultrasound image of the supraspinatus tendon longitudinal in a modified Crass position: peribursal structures (b), layer I = superficial layer, measuring 1 mm in thickness and composed of fibers from the coracohumeral ligament (LCHL) which extends posteriorly and obliquely, infraspinatus and supraspinatus tendon layer (ISP and SSP, respectively) composed of 3 layers: layer II = densely packed fibers of the tendon, 3–5 mm in thickness, layer III = 3 mm thick and composed of smaller bundles of collagen which are loosely organized at an approximately 45 degree angle to the long axis of the tendon, layer IV = loose connective tissue and thick collagen bands and merges with fibers from the coracohumeral ligament), layer V (LCHL/capsule) = capsule and glenohumeral ligament, 2 mm in thickness, cartilage (c). Note the anisotropy effect at the insertion due to the different trajectories of the different layers. Anisotropy artifacts typically affect the insertional area at the level of the footprint of the humeral head. To avoid these artifacts, try to tilt the probe laterally to have the ultrasound beam as perpendicular as possible to the tendon or the ligament fibers.

Fig. 12 Adhesive capsulitis phase 1. Transverse a and longitudinal oblique b power Doppler images in a modified Crass position obtained over the rotator cuff interval. Images show the normal long head of the biceps tendon (asterisks) that appears thin and hyperechoic. The tendon is surrounded by a hypervascular area related to inflammation of the rotator cuff interval.

Fig. 13 Adhesive capsulitis phase 2. Transverse a and longitudinal oblique b images obtained over the anterior aspect of the shoulder in a relaxed neutral position with flexed elbow and supinated forearm. Images show the coracohumeral ligament (black arrowheads) that is thickened and hypoechoic. The normal coracoacromial ligament is thin and hyperechoic (white arrowheads).
In the modified Crass position ▶ Fig. 5, we have an excellent view to evaluate the supraspinatus (SSP) enthesis (footprint at the greater tubercle), the ligaments and the humeral cartilage. All structures, especially the supraspinatus, should be visualized in the longitudinal and transverse view from anterior (subscapularis tendon, long biceps tendon) to posterior (infraspinatus tendon, teres minor tendon). The hyperechoic fibrillar rotator cable is a thin fibrous band continuous with the coracohumeral ligament that courses along the undersurface of the rotator cuff fibers and superficial to the joint capsule and can be visualized 1.5 cm medial to the greater tubercle [41] ▶ Fig. 10. Different layers of the supraspinatus tendon are shown in ▶ Fig. 11 according to different cadaveric studies [45, 46]. The rotator cable can be visualized in up to 99% of cases [41, 47]. On long axis scans, the rotator cable is visualized in its short axis as a hyperechoic transversely oriented bundle of fibers running perpendicular and deep to the SSP and ISP tendons, located approximately 1 cm medial to the rotator cuff footprint [40]. Medial to the bicipital groove, we identify the subscapularis ten-
don (SSC) and the superior glenohumeral ligament in external rotation.

The RI may reflect the condition of the glenohumeral joint and may be distended due to intra-articular effusion, capsulitis or synovitis [43]. Pathologic changes at the RI are common. A selection of changes is listed in ▶ Table 1. In adhesive capsulitis (▶ Fig. 12, 13), for example, arthroscopy and histological studies revealed thickening of the ligaments of the RI, a shortened antero-superior portion of the capsule with concomitant synovitis [48] or a contraction of the rotator interval [49] with replacement of the normal RI fat by fibrous tissue [50]. Another representative example is the combined pulley and rotator cuff lesion (▶ Fig. 14–16). Arthroscopic studies could demonstrate that for instance of all diagnosed subscapularis tears, 47 % involved the medial pulley (SGHL/MCHL complex) and of all rotator cuff tears involving the supraspinatus tendon, 10 % involved the lateral pulley (LCHL) [32, 49].

**Summary**

This article demonstrates the capability of MSUS to visualize the detailed anatomy of the rotator interval. MSUS has a higher spatial resolution than other imaging techniques, the ability to examine these structures dynamically and to utilize the probe for precise anatomic localization of the patient’s pain by sono-palpation. Obviously, MSUS is limited with respect to visualizing the more proximal intra-articular aspect of the components of the RI and when the structures are obscured by overlying bone such as the acromion. Since pathologic changes are common in this region, it is im-
important to acquire the necessary technical ability. Routine MSUS imaging of the rotator interval will amplify our diagnostic ability in rheumatology patients with shoulder pain and improve our diagnostic accuracy. So, we not only need to consider bursitis, synovitis and tendonitis, but we also need to become proficient in detecting capsulitis and the wide array of rotator cuff tears with or without additional lesions of the ligaments and joint capsule in this critical region.

Conflict of Interest

The authors declare that they have no conflict of interest.

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References

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