Shoulder ultrasound: current concepts and future perspectives

Francesca Serpi[1], Domenico Albano[2,3], Santi Rapisarda[2], Vito Chianca[4,5],
Luca Maria Sconfienza[2,6], Carmelo Messina[2]

[1] Postgraduate School of Radiodiagnostics, Università degli Studi di Milano, Milan, Italy
[2] IRCCS Istituto Ortopedico Galeazzi, Milan, Italy
[3] Sezione di Scienze Radiologiche, Dipartimento di Biomedicina, Neuroscienze e Diagnostica Avanzata, Università degli Studi di Palermo, Palermo, Italy
[4] Clinica di Radiologia EOC, Istituto di Imaging della Svizzera Italiana (IIMSI), Lugano, Switzerland
[5] Ospedale Evangelico Betania, Napoli, Italy
[6] Dipartimento di Scienze Biomediche per la Salute, Università degli Studi di Milano, Milan, Italy

Correspondence: Francesca Serpi, e-mail: francesca.serpi@unimi.it

Abstract

Ultrasonography is an established and effective imaging technique that can be used to evaluate articular and periarticular structures around the shoulder. It has been shown to be useful in a wide range of rotator cuff diseases (e.g. tendon tears, rotator cuff calcific tendinopathy and bursitis) as well as non-rotator cuff abnormalities (instability, synovial joint diseases and nerve entrapment syndrome). A scanning protocol is highly recommended to reduce the rate of operators' errors by following a standardized scheme including a list of main structures. Shoulder ultrasound has several advantages: it is a relatively cheap and widely available technique, free from ionizing radiation, that can reach excellent diagnostic accuracy even compared to magnetic resonance imaging. Moreover, it is the only imaging technique that allows dynamic evaluation of musculoskeletal structures, which is important for the evaluation of impingement. Also, due to the shoulder's superficial anatomical position, ultrasound can also be helpful in guiding interventional percutaneous procedures, both for diagnostic (e.g. magnetic resonance arthrography) and therapeutic purposes (e.g. percutaneous treatment of calcific tendonitis). Contrast-enhanced ultrasound and speckle tracking offer complimentary evaluations of shoulder anatomy and biomechanics. Moreover, the advent of ultra-high-frequency US, with probes up to 70 MHz allowing for a resolution as low as 30 μm, is a promising tool for further evaluation of the shoulder anatomy, and diagnostic and therapeutic strategies.

Main shoulder anatomy

The shoulder girdle comprises three bones (the proximal humerus, the scapula, and the clavicle) that articulate in three joints: the glenohumeral, acromioclavicular, and sternoclavicular joints. The head of the humerus is much larger than the glenoid fossa, giving the glenohumeral joint a wide range of movement at the cost of instability. Static (glenoid labrum, capsule, glenohumeral and coracoacromial ligaments) and dynamic stabilizers (rotator cuff tendons) maintain the joint congruence during movement[(1–3)].

The rotator cuff is composed of four muscles with relative tendons attaching onto the humerus: the subscapularis, the supraspinatus, the infraspinatus, and the teres minor. The long head of the biceps tendon (LHBT) has a proximal insertion at the apex of the glenoid (bicipital-labral complex), courses laterally and anteriorly through the so-called rotator interval (between the subscapularis and supraspinatus tendons), and turns down vertically through the bicipital groove of the humerus (Fig. 1). The LHBT is the only tendon around the shoulder with a synovial sheath, which communicates with the glenohumeral joint space.
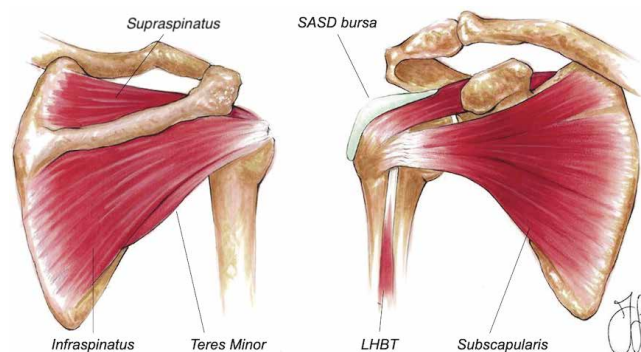
Fig. 1. *The rotator cuff is composed of four muscles with relative tendons attaching onto the humerus: the subscapularis, the supraspinatus, the infraspinatus, and the teres minor. The long head of the biceps tendon (LHBT) is located in the humeral groove, stabilized by the subscapularis tendon. The subacromial-subdeltoid (SASD) bursa is a large synovial space that lies between the coracoacromial arch and the supraspinatus tendon*

The subacromial-subdeltoid (SASD) bursa is a large synovial space between the coracoacromial arch and the supraspinatus tendon (1–2 mm in normal thickness) which facilitates motion and dissipates the friction caused by complex shoulder movements[4].

Technique and scanning protocol

Due to their superficial location, soft tissue structures of the shoulder can be easily scanned. Nevertheless, the expertise of the operator performing the ultrasonography (US) examination is a relevant aspect which may significantly impact diagnostic accuracy. In fact, several pitfalls related to the ultrasound technique may mislead inexperienced US operators, such as anisotropy artefacts, causing an artifactually hypoechoic tendon appearance that may simulate pathology. Therefore, a scanning protocol is highly recommended in order to reduce the rate of operator errors by following a standardized scheme that includes a list of primary structures. This method is crucial for an exhaustive and efficient examination, also because focal shoulder symptoms do not always correlate with the location of the disease[2].

Several technical guidelines have been issued throughout the years by different scientific societies. The three main guidelines are: EULAR (European League Against Rheumatism), ESSR (European Society of Musculoskeletal Radiology), and the American College of Radiology (ACR)/American Institute of Ultrasound in Medicine (AIUM)/Society of Pediatric Radiology (SPR)/Society of Radiologists in Ultrasound (SRU)[5]. They propose relatively uniform approaches, with some differences related to the position of the examiner (standing in front or behind the patient) and patient positioning (Crass or modified Crass) for supraspinatus tendon assessment[2].

The shoulder US examination is typically performed using high-frequency (6–15-MHz) linear broadband array transducers. The patient is preferably imaged while seated, with the radiologist either seated in front of or standing behind the patient. In general, each anatomic structure is evaluated in orthogonal planes by asking the patient to perform specific positional maneuvers, as needed. An exhaustive examination should include evaluating the LHBT, rotator cuff tendons, acromioclavicular joint and SASD bursa. Moreover, dynamic scans may allow the assessment of possible shoulder impingement. Detailing shoulder scanning technique is beyond the purpose of this article, but in our practice we usually refer to the ESSR Technical Guidelines[6].

Indications

LHBT and rotator cuff evaluation

All shoulder tendons are examined in short and long axis, sometimes with gentle toggling of the transducer to eliminate the anisotropy artefact that may mimic tendinopathy or a tear. The LHBT is usually scanned from the proximal
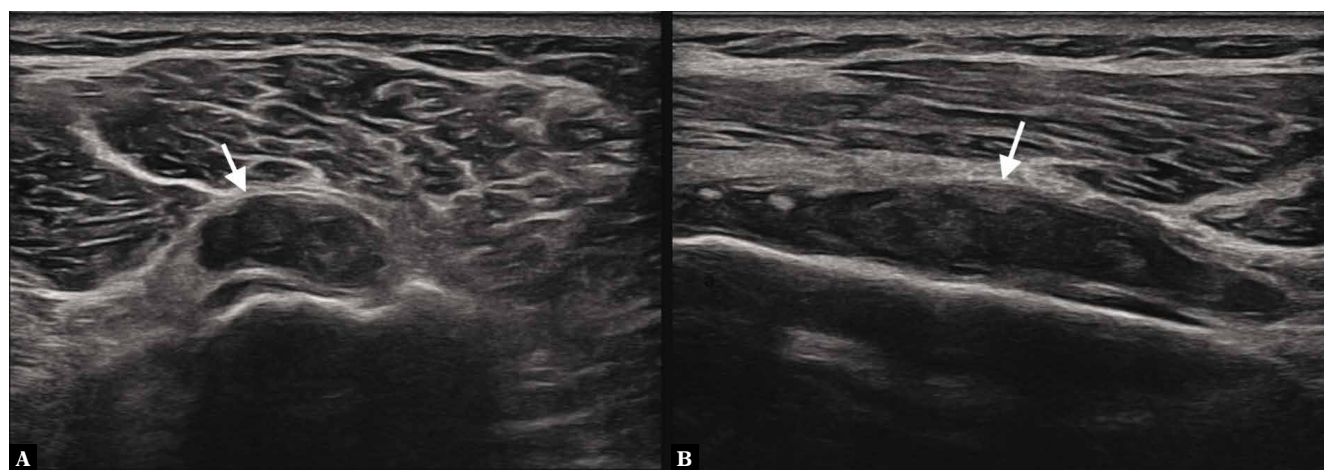

Fig. 2. *Full-thickness rupture of the LHBT. Transverse short axis (**A**) over the bicipital groove shows anechoic effusion and hemorrhage in the synovial sheath (arrow). Sagittal long axis (**B**) shows large effusion with a thicker sheath wall (arrow). No tendon fibers are recognized at these points, with the muscle belly and the distal stump being retracted inferiorly*
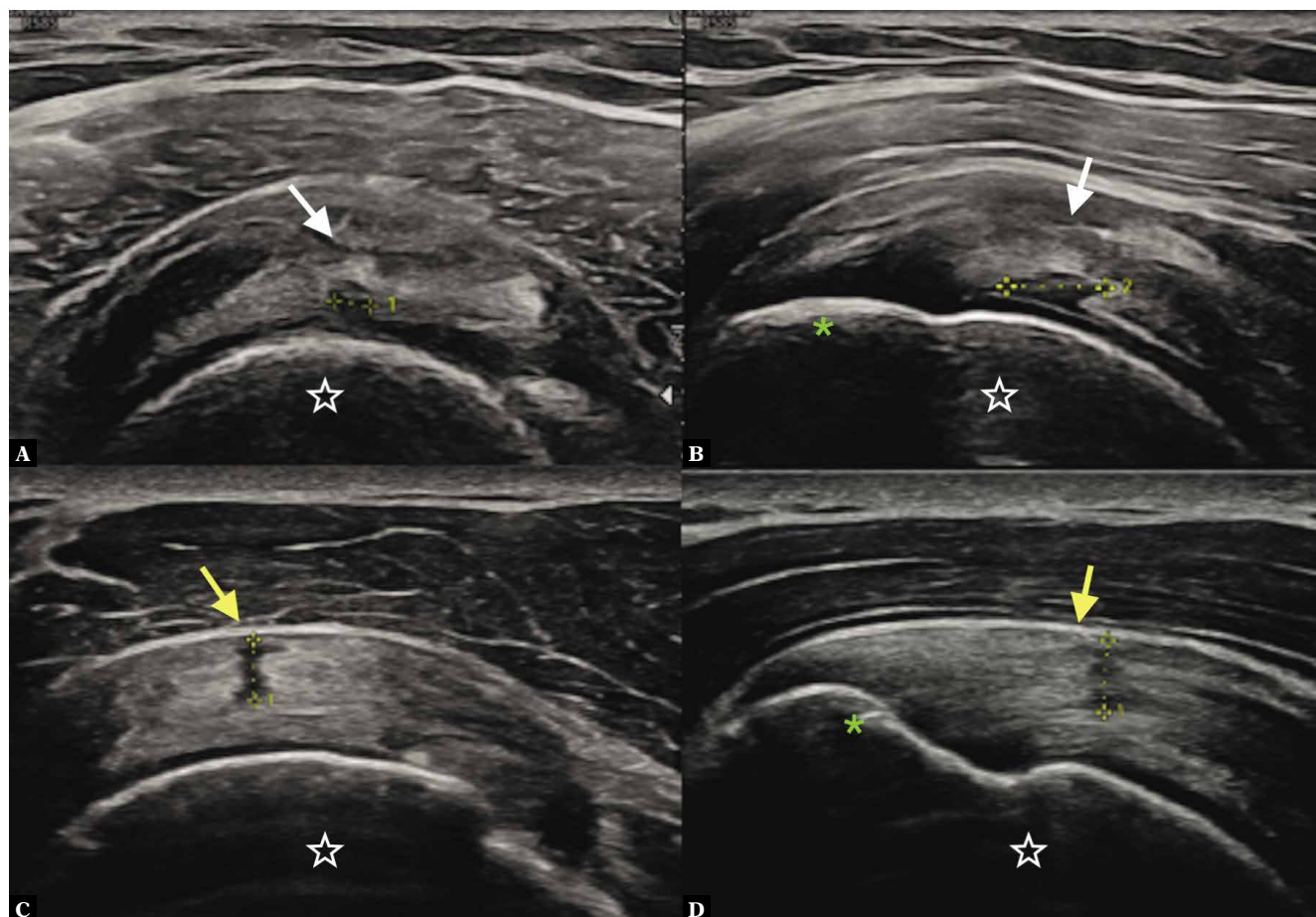
Fig. 3. *Partial-thickness supraspinatus tear of the articular surface (white arrows) on the short (**A**) and long (**B**) axis, and of the bursal surface (yellow arrows) on the short (**C**) and long (**D**) axis. The tear is displayed as a hypoechoic area with loss of normal fibrillar pattern, involving only one side of the tendon. Star: humeral head. Asterisk: greater tuberculum at the supraspinatus footprint*

(superior aspect of the bicipital groove) to the distal (pectoralis major tendon-humerus attachment) aspect, firstly in the transverse plane. Dynamic US of the LHBT is performed to evaluate for possible tendon subluxation or dislocation[7]. The main clinical indications for LHBT include tendinosis/tenosynovitis, rupture, and subluxation or dislocation.

LHBT *tendinosis* appears as a large and thick tendon, with hypoechogenic geographic areas and loss of normal fibrillar architecture. In *tenosynovitis*, the tendon is usually surrounded by anechoic fluid at the humeral groove (out of proportion to joint fluid), with hypoechoic or echogenic synovial hypertrophy associated to increased signal on Doppler US.

Tears of the LHBT usually occur spontaneously in individuals older than 50 years, at the proximal part, in the setting of preexisting tendon degeneration. A complete rupture is generally associated with pain and palpable retracted muscle belly (known as the "Popeye sign"), possibly followed by pain relief (Fig. 2)[8]. Partial tears are more challenging to detect[7].

They commonly occur at the entrance to the humeral groove and may propagate distally or proximally, where they may extend into the biceps anchor with associated superior labral tears, also known as the SLAP lesion (superior labral tear from anterior to posterior). Of note, although MR arthrography remains the technique of choice for evaluating SLAP lesions, US also showed some potential for detecting SLAP lesions in a pivotal study by Alali *et al*.[9]

In the setting of *subluxation* or *dislocation*, US can reach a 88–100% sensitivity and 96–98% specificity[7]. Commonly, the LHBT dislocates medially, at the entrance to or within the proximal bicipital groove, which is usually associated with subscapular tendon tear, coracohumeral ligament or superior glenohumeral ligament injury.

Rotator cuff

Rotator cuff (RC) is composed of four fibrous tendons (subscapular, supraspinatus, infraspinatus, teres minor), which appear on US evaluation as hyperechoic structures with a convex surface and uniform fibrillar appearance[10]. RF pathologies include a broad spectrum of diseases, including tendinopathy, tendon tears (full- and partial-thickness tears), calcific depositions or calcific enthesopathy[7].

The appearance of RF *tendinopathy* is similar to other tendon pathologies and includes thickening, enlargement,

Fig. 4. *Full-thickness tear of supraspinatus insertional fibers (arrow) with fiber retraction (dashed arrow). Star: humeral head. Asterisk: greater tuberculum at the supraspinatus footprint*

Fig. 5. *Cartilage interface sign. This represents a curvilinear hyperechoic line that courses parallel to the hypoechoic hyaline cartilage of the humeral head (yellow arrow), located at the interface between the hyaline cartilage and the abnormal hypoechoic tendon. It is a result of increased US transmission due to changes in acoustic impedance in cases of articular surface–sided tendon disease, being more pronounced in cases of full-thickness RC tears. White arrow: full-thickness supraspinatus tear. Star: humeral head. Asterisk: greater tuberculum at the supraspinatus footprint*
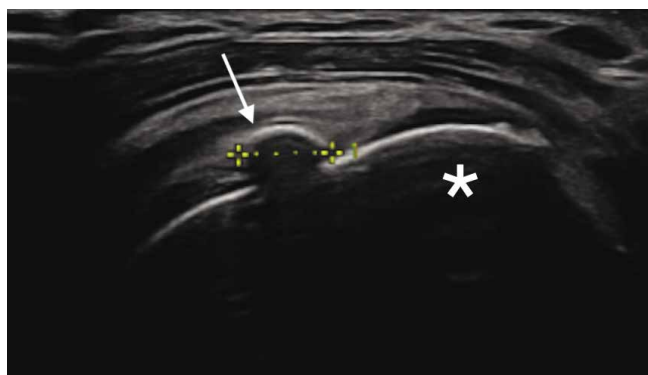

Fig. 6. *Small pre-insertional intratendinous calcification of the supraspinatus, with acoustic shadowing. Asterisk: footprint of the supraspinatus at the greater tuberosity*

focal or diffuse hypoechoic areas, and the loss of the typical fibrillar architecture. The diagnostic accuracy of shoulder US when evaluating RF tears is very high for *full-thickness tears* (it can reach 100%) and slightly lower (91%) for *partial-thickness tears*.

With expert operators, it has been reported to be as accurate as magnetic resonance imaging (MRI)[5,11,12]. Partial thickness tears may involve the articular or bursal surface, and are associated with cortical irregularity ("pitting") at the tendon insertion (Fig. 3).

RC tears should be described in terms of their location and dimensions in short axis (e.g. anterior, middle or posterior fibers) and long axis (e.g. involving the footprint or musculotendinous junction), their shape, and tendon retraction[7]. A massive tear is defined as greater than 5 cm in width and/or involving two or more tendons. Chronic full-thickness tears are commonly associated with tendon retraction and less commonly with joint or bursal effusion, which is typically seen in acute injury (Fig. 4). Other signs suggesting an RC tear include bony cortical irregularities of the footprint, the "cartilage interface sign", glenohumeral joint and SASD bursa effusion, as well as various degrees of SASD bursa wall depression in the location of the tear. Cortical irregularity and joint effusion are the signs with the highest values of sensitivity, specificity, and positive and negative predictive values for US detection of supraspinatus tendon tears[13]. The cartilage interface sign is a curvilinear hyperechoic line that courses parallel to the hypoechoic hyaline cartilage of the humeral head, and is located at the interface between the hyaline cartilage and the abnormal hypoechoic tendon (Fig. 5). It results from an increased US transmission due to changes in acoustic impedance in cases of articular surface–sided tendon disease, and it is most pronounced in full-thickness RC tears[7]. Complete evaluation of RC tears also includes an assessment of muscle trophism. In fact, fatty degeneration in the setting of a tendon tear is a negative prognostic factor in the subsequent tendon repair. US and MR imaging have comparable diagnostic performance in the detection of rotator cuff atrophy; on US, fatty degeneration appears as increased echogenicity and reduced muscle volume[14].

Rotator cuff calcific tendinopathy (RCCT) is a common disease (with a reported prevalence of up to 20% of painful shoulders) characterized by calcium hydroxyapatite crystal deposition within tendons, with the supraspinatus being the most commonly affected[15]. Calcium deposition occurs approximately 10 mm from the supraspinatus insertion on the greater tuberosity, although any portion and the other tendons of the RC can also be involved. The LHBT and SASD bursa can be affected by depositions especially in cases of rupture deposits[7].

Patients of 30–50 years of age are the most prone. Although the exact pathogenesis is still debated, it is probably a multifactorial disease which occurs in multiple stages: the pre-calcific, calcific (including formative and resorptive phases) and post-calcific. Pain is associated with the resorptive phase[16]. US is useful for the detection and localization of calcifications within the tendon, which appear as fluffy or well-defined hyperechoic deposits, with posterior acoustic shadowing in

Fig. 7. *Long-standing full-thickness supraspinatus tear with a degenerative change of the shoulder and inferior acromioclavicular (AC) joint capsule disruption. Fluid erupts superiorly from the SASD bursa and the glenohumeral joint through the AC interval (white arrow), forming a supraclavicular collection known as the geyser sign (yellow arrows). Star: AC joint*
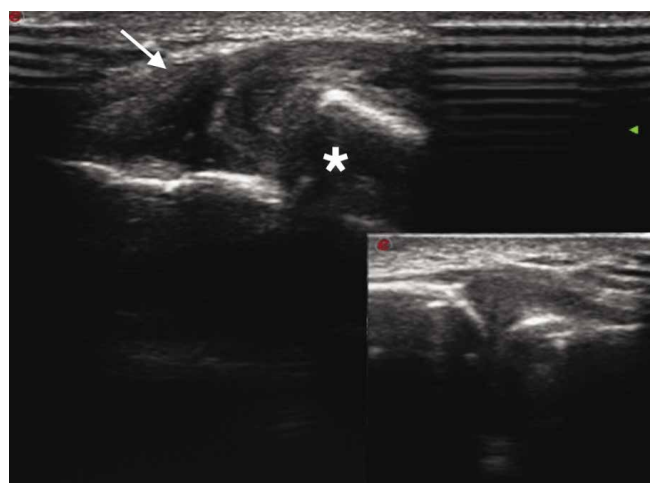

Fig. 8. *Partial dislocation of the AC joint after trauma. US shows widening of the articular space (asterisk) with capsule distension and effusion (arrow). The contralateral normal joint is displayed in the right inferior corner*

cases of hard calcifications (Fig. 6). Color Doppler US is helpful in detecting the resorptive phase, which is associated with an increased Doppler signal. Besides diagnostic purposes, US is also capable of guiding therapeutic needle placement and irrigation for symptomatic calcific tendinitis[17].

SASD bursa

Conditions that can affect the SASD bursa include bursal effusion secondary to rotator cuff disease, infection, and inflammatory bursitis.

Bursal distension can be classified into communicating and non-communicating with the glenohumeral joint[18]. The most common cause of communicating bursal distension is rotator cuff tear, especially the supraspinatus tendon. Non-communicating bursal distension can occur in reactive bursitis, for example in inflammatory arthropathy,

septic bursitis in the setting of immune compromise or intravenous drug use.

Calcific bursitis or *hydroxyapatite calcification migration* from the tendon into the bursa can also occur. On US examination, one can see anechoic fluid in a simple effusion, or a different sonographic appearance can be seen, based on the underlying mechanism (e.g. internal echoes in hemorrhage or complex fluid with debris and septa in infection). Augmented Color Doppler signal is detected in synovial inflammation with thicker walls[19].

Acromioclavicular joint

The acromioclavicular (AC) joint is a diarthrodial synovial joint. The articular surfaces, encased in a fibrous capsule, are separated by a fibrocartilaginous disk[2]. Common clinical indications for the evaluation of the AC joint include osteoarthrosis, acute trauma (i.e. separation or dislocation), synovitis, synovial cysts, osteolysis, and needle guidance for aspiration or injection[7].

The primary role of US is to evaluate capsular hypertrophy and distension. A capsule-to-bone distance less than 3 mm rules out synovial hypertrophy and joint effusion (Fig. 7)[20].

In contrast, a 2–3 mm comparative difference between AC joints width – bilaterally evaluated – is considered abnormal in the appropriate clinical setting and when symptomatic[21]. In addition, even though US is not primarily used in the setting of trauma, it is more sensitive than radiography for the identification of grade I AC joint injury (soft tissue swelling and capsular distension at US) and has the same accuracy as radiography in more severe injuries (Fig. 8)[7].

Impingement

Impingement is a clinical scenario involving painful functional limitation of the shoulder, thought to be secondary to the compression or altered dynamics that irritate and ultimately damage the tissue around the shoulder joint[22]. External impingement, which relates to abnormal contact between the humeral head and extra-articular structures such as the acromion (subacromial impingement) and the coracoid process (subcoracoid impingement), is better evaluated with dynamic maneuvers[22].

Subacromial impingement is the most common type, caused by subacromial space narrowing, leading to the entrapment of the supraspinatus tendon and SASD bursa between the humeral head, the acromion, and the coracoacromial ligament. It can be further subdivided into primary, due to abnormal acromial arch morphology, and secondary, caused by abnormal glenohumeral and scapulothoracic movement[23]. US is capable of detecting impingement pathology at SASD bursa (e.g. effusion and inflammation) and supraspinatus tendon (e.g. tendinopathy, tears and calcification). Moreover, during dynamic maneuvers impaired sliding and impingement of the SASD bursa and the supraspinatus under the
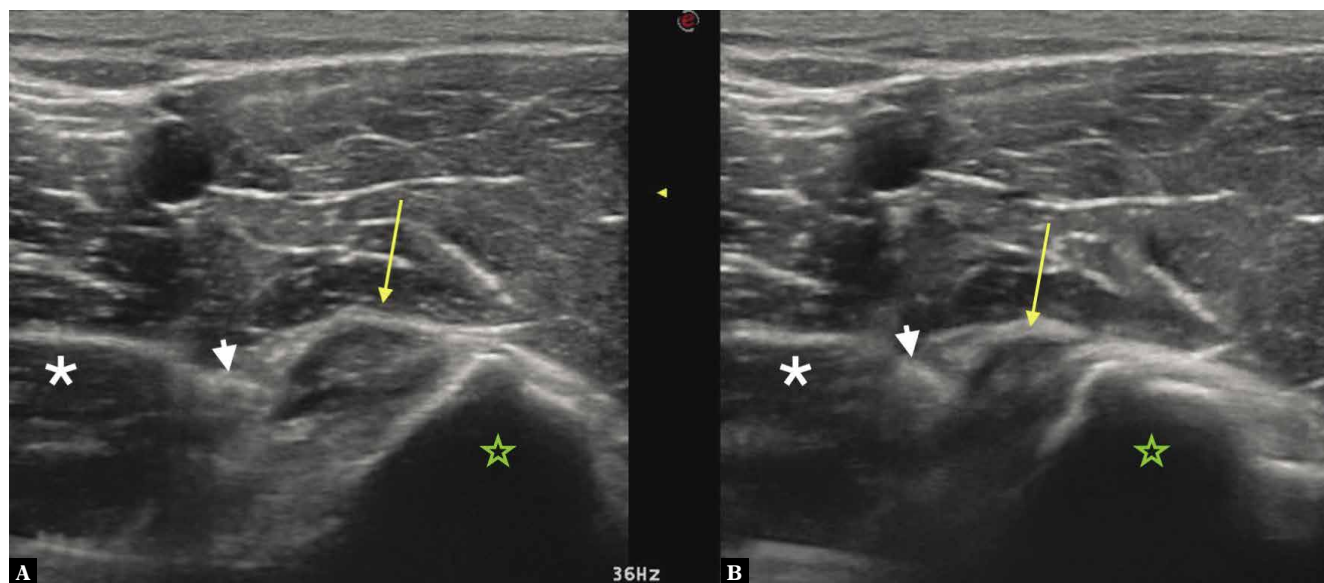
Fig. 9. *Subcoracoid impingement. A synovial hypertrophic nodule (white arrow) and the coracoid (asterisk) determine impaired sliding of the subscapularis (yellow arrow) during dynamic internal rotation on US scan. **A**. initial internal rotation. The belly of the suprascapularis is compressed passing under the coracoid. **B**. with rotation progression, the belly snaps and passes under the coracoid. Star: lesser tuberosity of the humeral head*
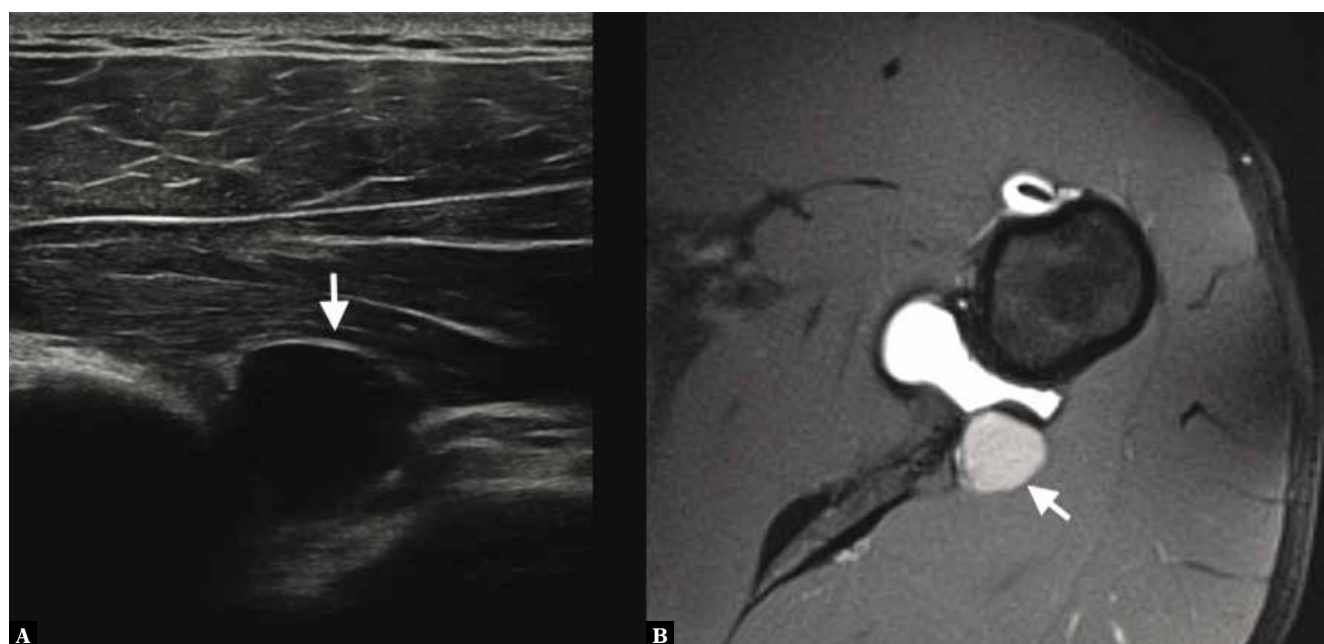

Fig. 10. *US paralabral cyst (arrows) at the SGN (**A**), confirmed with MRI arthrography (**B**). The cyst is located in close proximity to the suprascapular nerve, which may lead to progressive infraspinatus neurogenic muscle atrophy (not affected in this case)*

acromion and coracoacromial ligament can be easily demonstrated, with fluid distending the bursal recesses[2].

Subcoracoid impingement is characterized by impaired sliding of the subscapularis tendon and/or the LHBT under the tip of the coracoid (Fig. 9), when the arm is flexed forward and in maximal internal rotation[2,22,23]. US can reveal indirect signs, such as subscapularis tendinopathy or bursal-sided tears. Dynamic US can also show direct findings of impingement with internal rotation during real-time evaluation[23].

US evaluation of posterior shoulder structures, including nerves

Indications include cysts of the spinoglenoid notch (SGN), glenohumeral joint degeneration, and glenohumeral joint synovitis. The SGN is formed lateral to where the spine extrudes from the scapula and corresponds to the site where the suprascapular nerve passes around the scapula. The nerve can be occasionally compressed at SGN by ganglia arising from the glenohumeral joint (e.g. due to glenoid-labral tears), possibly leading to

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infraspinatus and supraspinatus progressive fatty degeneration (Fig. 10).

Although US is not the primary modality for evaluating glenohumeral joint degenerative disease, US findings in cases of severe degeneration include severe joint space narrowing, bulky osteophytosis, cortical irregularity, and eventually degenerative tearing of the posterior labrum and echogenic joint bodies or debris[7]. Glenohumeral joint synovitis is seen on US as anechoic joint effusion with synovial thickening involving the posterior and axillary joint recesses, with an associated increase in US signal on Color Doppler[7]. The location of the axillary and suprascapular nerves can be seen with US in limited regions of the shoulder. The more important role of US is detecting indirect signs of nerve pathology, such as muscle atrophy (especially without signs of tendon tear), and possible sources of neuropathy, such as compression from a mass or cyst[24].

Elastography

Elastography is based on the principle of mechanical stress causing changes in stiffness to the underlying tissue. Two techniques are used in clinical practice: strain and shearwave elastography. The latter is the less operator-dependent of the two, allowing a quantitative evaluation based on focused acoustic radiation force, which provides local stress and generates tissue displacement represented a color map[25,26].

Proposed clinical applications of elastography include the detection and quantification of fatty muscle degeneration (especially after a tendon tear), assessment of tendon stiffness, examination of trapezius and deltoid muscles (important for pre- and post-operative evaluations), and assessment of posterior capsule and coracohumeral ligament stiffness[26]. However, there is no standardized guided technique, and in the majority of cases the examination is highly operator-dependent. A minimum distance (usually 1.2 mm) between the skin and examined tissue is needed to place the elastogram box. This may require the application of gel pads or adapters in slim individuals or for the evaluation of very superficial structures. In addition, the exact orientation of the transducer is essential for generating reproducible results. Finally, muscle stiffness is also strongly affected by the grade of muscle contraction[26].

According to the current literature, only limited data are available so far, based on non-controlled studies with small case numbers. Therefore, further investigations are needed.

Other applications

Contrast-enhanced ultrasound (CEUS)

The use of CEUS has been proposed for with the evaluation of adhesive capsulitis[27]. Adhesive capsulitis, also referred to as frozen shoulder, presents with an insidious onset and shoulder pain with a range of motion globally restricted. Accurate diagnosis can be challenging because imaging findings are usually unremarkable[27]. According to the literature, there have been few studies investigating AC with CEUS after the administration of microbubble-based ultrasound contrast agents (SonoVue), both intravenously (to facilitate microcirculation detection) and intraarticularly (US arthrography)[28]. Filling defects and enhanced synovial microcirculation of the joint cavity may be considered a useful sign to indicate AC. However, only limited data are available, and further investigations are needed. Another study reported the use of CEUS for preoperative deltoid assessments, as a predictor of shoulder dysfunction after reverse shoulder arthroplasty (RSA)[29]. The deltoid, in fact, represents the main muscle for elevation and abduction after RSA. CEUS allows dynamic quantification of perfusion in muscle and, therefore, represents a functional real-time biomarker of muscle vitality. Perfusion of the deltoid quantified by CEUS significantly correlated with postoperative shoulder function. Preoperative deltoid dynamic perfusion (PE) revealed a significant correlation with deltoid function after RSA. It might also be useful to detect adaptation processes of the deltoid after RSA, without the drawback of MR metal artifacts[29].

Speckle tracking

Among techniques for characterizing contractile properties of muscle tissue, US technique equipped with automatic speckle-tracking software is a non-invasive method for determining the contractile properties of muscle tissue. It has been used for measuring muscle strain *in vivo* in the asymptomatic adult shoulder during isometric submaximal contractions of the brachial biceps and supraspinatus muscles. The software detects reflected scattered signals (speckles) within the muscle tissue. Based on the unique movement of these speckles, it is possible to calculate muscle strain as the absolute shortening between two speckles divided by the distance between the speckles[30]. However, further studies are needed to explore the potential of the technique.

Conclusion and future perspectives

US is an extremely valuable imaging technique in daily clinical practice, and it is considered as the first-choice technique to assess tendons, burse and capsuloligamentous structures. Moreover, the advent of ultra-high-frequency US (UHFU), with probes up to 70 MHz allowing for a resolution as low as 30 μm,[31] represents a promising possibility for an improved evaluation of the shoulder anatomy and diagnostic and therapeutic strategies.

Conflict of interest

The authors do not report any financial or personal connections with other persons or organizations, which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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