4 Imaging of the Shoulder

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Introduction

Radiological examination of the shoulder currently employs different imaging techniques that are used separately or more often in combination, depending on the specific clinical issues. The task of imaging is not only to detect the presence of pathology but also to direct the surgeon towards the most suitable treatment (conservative, arthroscopic, or open surgery). The need to choose between different imaging modalities is in part due to the anatomical complexity of the shoulder and the adjacent soft tissues. The contribution of each method does not always answer the specific clinical question posed by the specialist. Conventional radiographic examination (CR) performed with standard and complementary views is often deemed crucial for the biplanar evaluation of bone structures of the glenohumeral and acromioclavicular joint, as well as to exclude calcifications or bone lesions; however, when no explanation is identified for the "pain" in the shoulder, given the absence of lesions detected by radiography, it becomes necessary to integrate second-level exams.

Ultrasound (US) examination of the shoulder is a technique used to study myotendinous components and other periarticular soft tissues with the aim of assessing the tendinous components at their tuberosity insertions, detecting the presence of articular and periarticular fluid (bursae and synovial recesses), and excluding traumatic and non-traumatic lesions of the rotator cuff. US examination has proved a reliable method to document the presence of calcifications that are undetectable on standard radiographical exams, as well as ultrastructural alterations of the tendon and the fibrochondral junction of the entheses. Moreover, in experienced hands, it can document any compression of the suprascapular nerve in the homonymous notch or in the spinoglenoid groove. US examination plays an important role as a guide in minimally invasive surgery, such as the drainage of superficial fluid collections, calcific tendonitis, space-occupying lesions, and in the symptomatic treatment of a painful shoulder (to guide the injection of hyaluronic acid and steroidal and nonsteroidal anti-inflammatory drugs).

Computed tomography (CT) is a radiological technique that employs ionizing radiation. It applies different reconstruction algorithms and the possibility to perform, by means of the latest technological devices (volumetric CTs), 2D multiplanar and 3D volumetric reconstructions in multiple planes. This exam is especially indicated in traumatic pathology. It is not normally used in cases of clinical suspicion of rotator cuff tears, given its low contrast resolution compared to MRI examination. CT finds another important application in the study of the glenoid bone in shoulder instability to exclude avulsion lesions of the glenoid bone itself (quantification of the glenoid bone defect).

Magnetic resonance imaging (MRI), a second-level methodology, is now an indispensable technique for the diagnosis of disorders of the shoulder. Since its clinical introduction, it has played an important role in neuro- and musculoskeletal radiology. Its constantly increasing use is currently justified in more complex diseases of the shoulder. MRI is considered a preliminary examination to the surgical/arthroscopical approach, since it allows traumatic and atraumatic myotendinous, capsuloligamentous, and fibrocartilaginous lesions, as well as alterations in the other peri-skeletal soft tissues to be documented.

Contrast medium imaging techniques (CT arthrography and MR arthrography) deserve a separate discussion; their questions are aimed at studying capsuloligamentous and fibrocartilaginous structures. Particularly, they are suitable for analysis of articular cartilage and anatomical structures that may be injured in cases of subluxation or dislocation. Such minimally invasive techniques are also employed to confirm the presence of subtle rotator cuff tears or in patients who have undergone rotator cuff repair, for whom MR-based examinations are difficult to interpret due to the presence of

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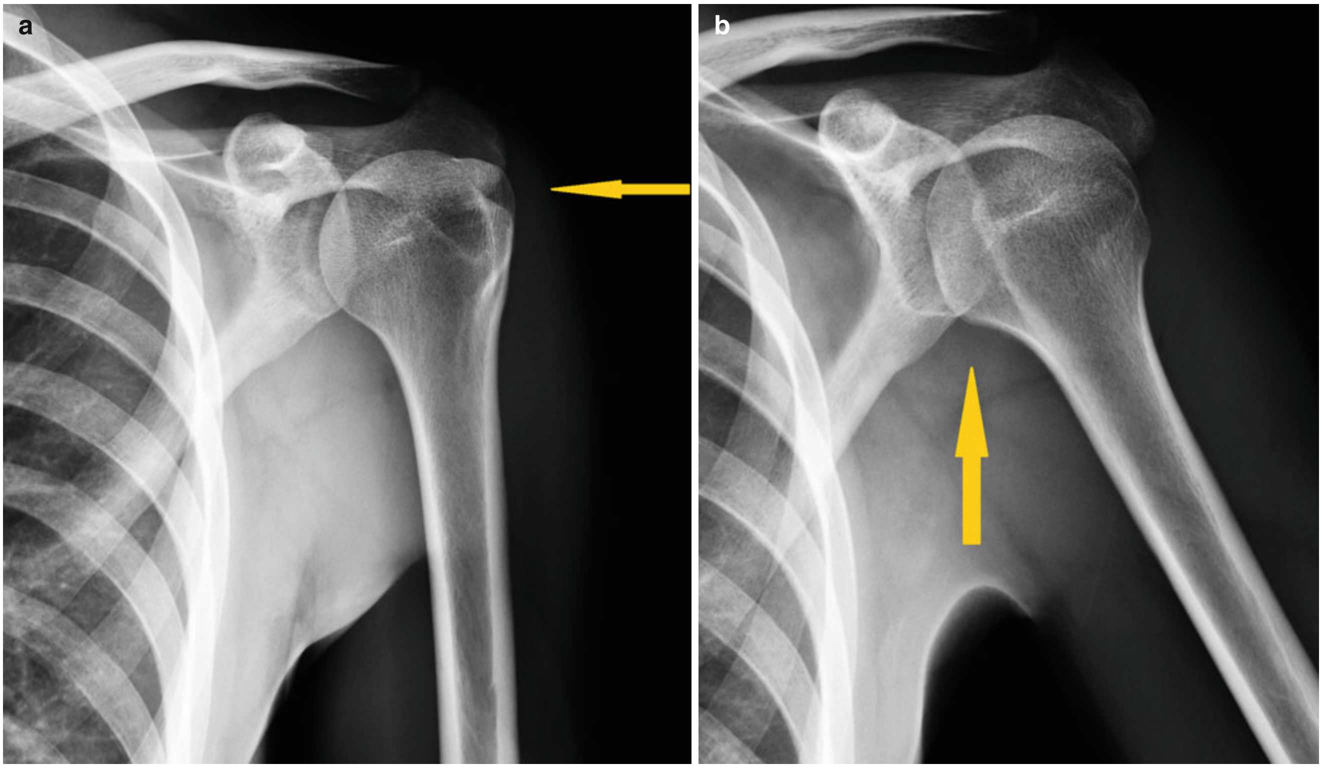

Fig. 4.1 (**a**) Radiographic anteroposterior (AP) view of the left shoulder performed with external rotation of the arm. The greater tuberosity of the humerus can be visualized (*arrow*). (**b**) Radiographic AP view of the same shoulder performed with internal rotation of the arm. On this view, the lesser tuberosity of the humerus can be visualized (*arrow*)

local ferromagnetic artifacts (metal anchors) or reactive subacromial-deltoid (SAD) bursitis. Moreover, clinical diagnosis of a frozen shoulder can be confirmed by MR arthrography, which assesses joint "capacity." Sometimes the individual methods are applied in combination when the clinical question or the result of a single method has identified benign or malignant space-occupying lesions. Only the combination of these methods allows a better characterization of the lesions and their relationships with surrounding neurovascular structures.

Conventional Radiology

Standard anterior-posterior (AP) views of the shoulder are obtained with internal and external rotation of the arm (Fig. 4.1). In the first case, the purpose is to evaluate the cortical bone of the greater tuberosity, while the second makes the lesser tuberosity visible. Moreover, standard AP views can be obtained by tilting the X-ray tube in a craniocaudal direction by 20° in order to better estimate the subacromial space. The external-rotation AP view identifies the presence of calcifications at the supraspinatus insertion, while internal-rotation AP view shows calcifications in the infraspinatus, teres minor, and subscapularis. As a normal finding, the external-rotation AP view can document the presence of an area poor in trabeculae at the level of the greater tuberosity called "pseudocyst of the humerus" [1]. Another normal finding is the identification in the external-rotation AP view of a hyper-diaphanous lamellar ridge projecting in correspondence with the joint cavity [2]. In addition to standard exams, complementary views can be performed according to the clinical question, each one with different purposes: (1) true AP view: this view is obtained by inclining the patient by approximately 40° in order to have the shoulder blade parallel to the sensitive plane and the beam angled medial to lateral by 45°; the purpose of this projection is to scan the joint line avoiding overlaps; (2) "outlet" view: a posterior-anterior view with the patient in the upright or supine position with the side under scrutiny on the sensitive surface inclined by about 60° without or with craniocaudal inclination of the X-ray tube at 20°; this view shows, inscribed in the glenoid, the humeral head which must project between the coracoid process anteriorly and the acromion posteriorly; (3) axillary views, including the West Point view: this exam is performed with the patient prone on the X-ray table with the limb to be examined raised by 8 cm, the head and neck are rotated in the opposite side, the radiographic cassette is maintained on the top portion of the shoulder, and the X-ray tube centered on the axilla with a 25° medial inclination; the resulting image is a tangential view of the anteroinferior glenoid; (4) Stryker notch view: this is performed with the patient supine on the table with the radiographic cassette positioned under the shoulder, the palm of the hand of the side to be examined is placed on the head, the X-ray tube is tilted by 10° cranially and centered on the coracoid; (5) double oblique or apical oblique view, in which the patient is sitting so as to make the scapular blade parallel to the sensible plane with the X-ray tube tilted mediolaterally by 45° and craniocaudally by 45° in order to project the anteroinferior surface of the glenoid [3]. Complementary views are usually performed when the clinical question concerns the instability of the shoulder, as they identify lesions in the posterior cortex of the humeral head (Hill-Sachs fracture) (Stryker notch view), fragmented bony avulsions of the glenoid (bony Bankart lesion) (West Point and double oblique views), or humeral dislocations (outlet view). The outlet view is also used to provide further images of the functional acromioclavicular arch without bone overlaps. In this way, the presence of calcifications in the cuff structures, and in particular of the supraspinatus and infraspinatus tendons, is identified along with the calcifications in the SAD bursa. Furthermore, this view allows examination of possible osteophytes of the undersurface of the anterior part of the acromion and acromioclavicular joint responsible for subacromial impingement. Radiographic studies of the shoulder are used as preliminary step of minimally invasive examinations such as CT arthrography (CTA) and MR arthrography (MRA). Radiography of the shoulder is performed only in the AP view to evaluate the proper position of the needle into the joint cavity and the initial filling of the same.

Echotomography

Over the years, US examination of the shoulder has gained importance because of its ease of execution and because, according to some clinical indications, it could be the ultimate exam. This method has many advantages, including the fact that it does not use ionizing radiation, making it harmless and repeatable at any time.

The patient is seated in front of the operator and is informed of the different arm positions required during the examination of each tendon. The supraspinatus tendon is investigated by bringing the patient's arm behind her/his back, in order to prevent the shadow of the acromion from covering the greater tuberosity of the humerus (Fig. 4.2). The ultrasound probe explores the tendon in an oblique coronal plane. Then, the probe is oriented in a plane orthogonal to the previous one and shows, from front to back, the supraspinatus and the posterior rotator cuff (infraspinatus and teres minor). At this point, the patient is asked to bring her/his arm to the front, with the forearm at a 90° angle

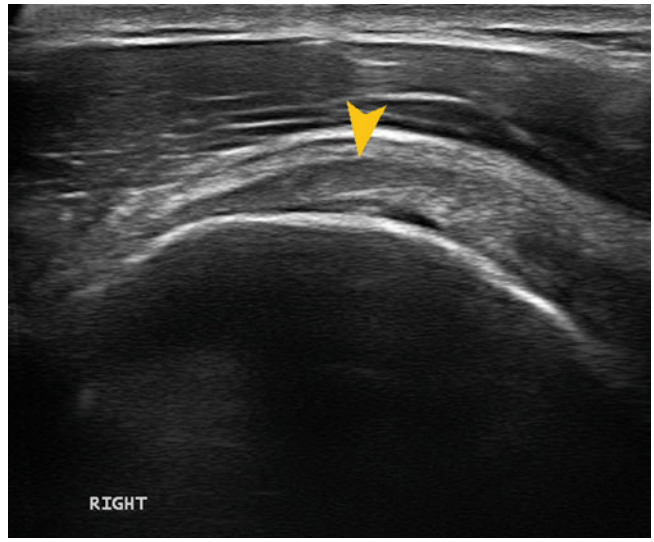

Fig. 4.2 Echotomographical oblique coronal scan for the evaluation of the tendon of the supraspinatus tendon (*arrowhead*)

with the upper arm and with the palm of the hand upwards. The front and upper surface of the humerus is imaged in axial planes, in order to show the subscapularis tendon, which is composed of approximately 4–5 tendon units and, more laterally, the intertuberosity groove of the humerus where the long head of the bicep (BLH) is visible. During this scan, it is possible to study the tip of the coracoid process, from which the coracoacromial originates, as well as the coracohumeral and coracoclavicular ligaments, the short head of the biceps brachii and, more medially, the coracobrachial muscle. Axial scans can document effusions in the subcoracoid bursa, in the synovial sheath of the LHB, and in the subscapularis recess. More caudal axial scans allow visualization of the pectoralis major tendon. Bringing the probe to longitudinal planes allows the examination of the tendon units of the subscapularis and LHB along their major axis.

Another important advantage of US is the ability to perform dynamic scans that are useful for assessing tendon's movement and possible bone or calcified formations involving tendons that limit or prevent their regular movement. On the axial plane, it is possible to assess the depth of the bicipital groove and the position of the LHB in the groove itself. The transverse ligament is identified, which closes the intertubercular sulcus anteriorly, thus preventing dislocation of the LHB. By instructing the patient to place her/his hand onto the contralateral shoulder and running a posterior oblique coronal plane scan, it is possible to evaluate the teres minor and infraspinatus tendons at the same time, which are frequent sites of calcification. On the contrary, a posterior medial vertical plane serves to distinguish the individual muscle bellies. Another crucial plane is the posterior axial one, which documents glenoid fibrocartilage and the scapular notches where the neurovascular bundle can be identified (nerve, artery, and suprascapular veins). US examination is concluded with the evaluation of the acromioclavicular joint (ACJ). This joint is studied by placing the transducer on its upper surface and identifying the two bone heads separated by a fibrocartilaginous disc. In pathological conditions, this space can contain fluid expanding the capsule; ACJ may also appear swollen because of marginal osteophytes which alter bone profiles, narrow the joint, and compress the interposed articular disc (degenerative changes). Under physiological conditions, the subacromial bursa appears as a hyperechogenic structure between the deltoid muscle and the supraspinatus tendon (oblique coronal scan); this aspect depends on the attachment of the bursal wall: in the presence of fluid, the attached walls separate showing an anechogenic layer between the deltoid and the supraspinatus. US study of the rotator interval deserves a special mention. Located between the tendon of the supraspinatus and the most cranial fibers of the subscapularis, it contains the superior glenohumeral ligament (SGHL), the LHB, and the coracohumeral ligament (CHL). The SGHL is difficult to explore with an ultrasound probe, while the LHB and the CHL can be scanned by ultrasound probe without interpositions. This ligament is an important stabilizer of the LHB, which has a conical shape with its apex at the coracoid. Its base, consisting of a medial and a lateral heads, encloses the LHB together with the transverse ligament of the subscapularis, preventing its dislocation.

The presence of clinically evident swelling localized in the subcutaneous adipose tissue in a muscle, adjacent to a joint cavity, or in continuity with it, gives further indication for the execution of US examination. In these cases, thanks to the structural study of the lesion, it is possible to take into account space-occupying solid benign diseases, such as lipomas and fibro-lipomas, primary or secondary malignant lesions, or fluid-containing lesions, such as arthrogenous ganglia. Finally, US examination can document an alteration in the size and structure of muscular masses surrounding the shoulder girdle, such as neuromuscular disease, in which the muscle belly appears hyperechogenic due to fatty infiltration. In these cases, the examination can be useful for muscle biopsy.

In normal conditions, the anterior glenoid labrum cannot be explored due to the lack of an adequate acoustic window; therefore, US is not indicated in shoulder dislocation. However, an indirect sign of the occurred dislocation is the depression found on the posterolateral surface of the humeral head (Hill-Sachs lesion).

Computed Tomography

Computed tomography (CT) of the shoulder is performed in the axial planes with multi-detector devices. The choice between prone or supine position depends on the patient's comfort and on the clinician's specific indication: standard examination of the glenohumeral joint; CTA approach (in which the distribution of air or radiopaque contrast is affected by the patient's position); examination of multiple-trauma patients (where the position is mandatory); or CT-guided biopsy. In most CT examinations, the patient is positioned at the center of the gantry, but there are skeletal segments for which the use of small fields of view is required and the patient has to be positioned obliquely to avoid the acquisition of unnecessary volumes [4].

During the examination of the shoulder, the patient is positioned at the center of the gantry so that the two shoulders are scanned simultaneously, unless there are different indications. A volumetric acquisition is performed in order to limit motion artifacts and to ensure a better 2D and 3D reconstruction in multiple planes. In addition, two different reconstruction algorithms are chosen in order to highlight the bone structures (high resolution) or soft tissues (standard or soft algorithm). The technical parameters are summarized in the Table 4.1.

The images thus obtained are visualized in the bone and soft tissue window. Several studies have been published on the use of CT in patients with shoulder dislocation, and new methods for the evaluation of bone defects have been proposed [5–7]. In this case, volumetric acquisition is required in the axial plane, as well as subsequent 2D MPR and 3D reconstructions in oblique sagittal planes to obtain "en face" views of the glenoid. A comparison between 2D and 3D acquisitions in patients with shoulder instability was carried out to assess whether the 2D could replace the 3D technique, which is considered the reference method and, furthermore, to assess whether it would be sufficient to scan only the injured shoulder to avoid any unnecessary radiation exposure [8] (Fig. 4.3). The actual role of CT in the study of the shoulder has been recently reconsidered, since MRI replaced CT in many fields; a case in point is the study of rotator cuff, in which only CTA still has diagnostic value in those patients who cannot undergo MRI. The choice between MRI and CTA of the shoulder is controversial. They have the same sensitivity for the diagnosis of full-thickness rotator cuff tears, but MRI appears to have greater sensitivity than CTA in the diagnosis of partial-thickness cuff tears [9]. CT is often used in neuromuscular diseases, because it allows the

Table 4.1 CT technical parameters of the shoulder

Speed (slice-ms)	Interval (mm)	FOV	Acquisition technique	kV	mA	Acquisition mode	Reconstruction (mm)
1.25	0.6	Large	Elicoidal	140	400–600	Standard	0.6–0.6 bone

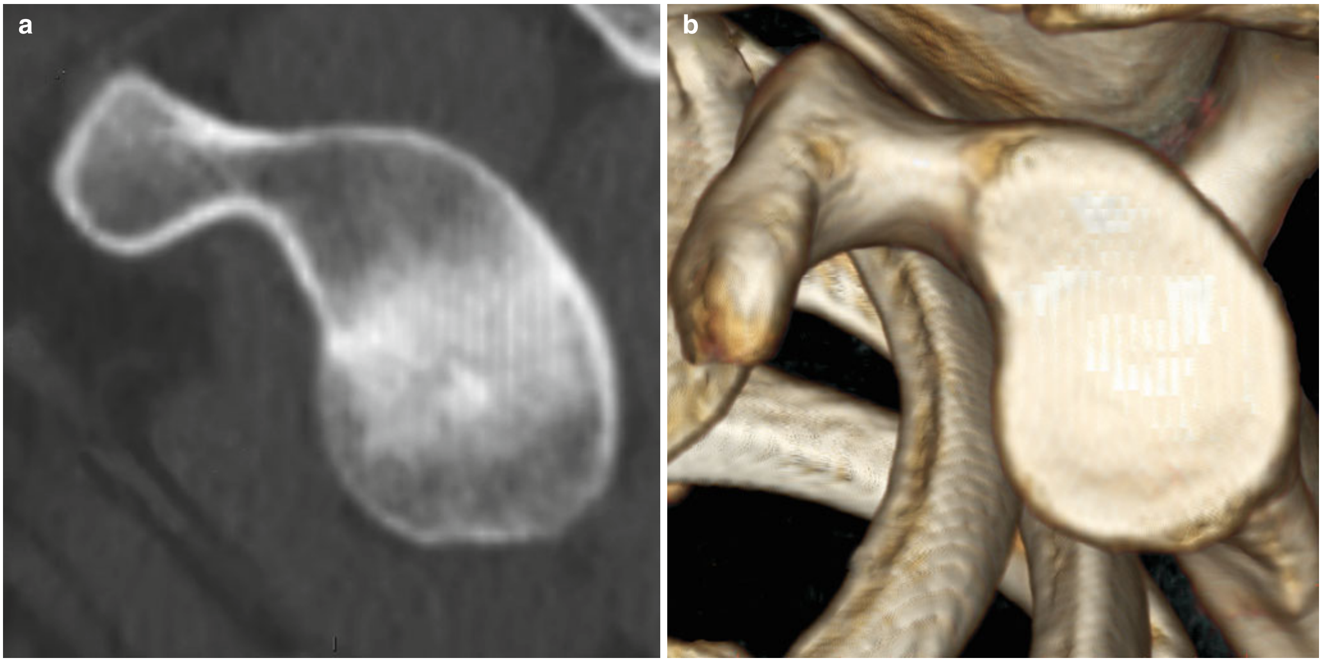

Fig. 4.3 (**a**) MPR 2D reconstruction in oblique sagittal planes for the evaluation of the articular surface of the left shoulder glenoid ("en face" view). (**b**) Volume rendering reconstruction in oblique sagittal planes for the evaluation of the articular/joint surface of the left shoulder glenoid ("en face" view)

densitometric analysis of shoulder girdle muscles; in fact, a reduction of muscle tissue density and a gradual replacement with adipose tissue can occur.

The choice of a specific contrast medium depends on the clinical indication; in the different scenarios of shoulder disorders, the radiologist can perform CTA using a single dose of iodinated water-soluble contrast or a mixture of iodine contrast and air in order to obtain the double contrast. If the purpose is to adequately "contrast" the glenoid rim or the articular surface of the cuff tendons, or when the clinical suspicion is an inflammatory, degenerative, or pseudotumoral synovial disease, such as rheumatoid arthritis (RA), pigmented villonodular synovitis, and synovial chondromatosis, the single-contrast technique may be indicated [10]. The pathology of the ACJ also takes advantage of CT study, as it identifies articular surfaces and periarticular soft tissues. This joint is often affected by degenerative changes with the presence of subchondral cysts and osteophytes which alter the profile of the undersurface of the joint and imping against the rotator cuff tendons during arm elevation; in addition, subacromial space can be reduced by joint effusion and swelling.

In case of chronic inflammatory diseases, CT can document periarticular osteopenia up to the erosion phenomena typical of the most aggressive forms or erosion of the distal end of the clavicle as in chronic renal failure (secondary hyperparathyroidism). Moreover, joint pain exacerbated by pressure on the distal end of the clavicle can be associated with a fuzzy osteopenic area of the clavicle that can be related to reflex sympathetic dystrophy syndrome (Fig. 4.4). The window of visualization of bone tissue can show calcification of the fibrocartilaginous disc of the ACJ, which is typically observed in metabolic diseases such as hydroxyapatite crystal deposition disease [11].

CT is also useful in the evaluation of coracoid impingement. Distance between the apex of the coracoid process and the lesser tuberosity of the humerus can be measured in the axial planes. This distance changes depending on the rotation of the arm (internal or external rotation). The coracohumeral distance can also be subjected to change resulting from fractures of the coracoid process and lesser tuberosity, calcification of the subscapularis tendon, or surgical procedures (transposition of the coracoid process).

A CT scan is performed when bone lesions undetected at standard examinations lead to disabilities. These include acute fractures of the humeral tuberosities; osteochondritis dissecans of the glenoid or humeral head; stress fractures of the clavicle, scapula, and ribs; and post-traumatic osteolysis of the distal end of the clavicle [12]. Finally, CT also plays an important role in benign or malignant tumors affecting the scapular-humeral girdle. An example of this is differential diagnosis between osteochondroma and peripheral chondrosarcoma; in fact, CT can accurately assess the nature of the lesion by detecting the mineralization pattern and thickness of the cartilaginous cap, even though MRI has a more significant role in the last case due to its inherently higher contrast resolution.

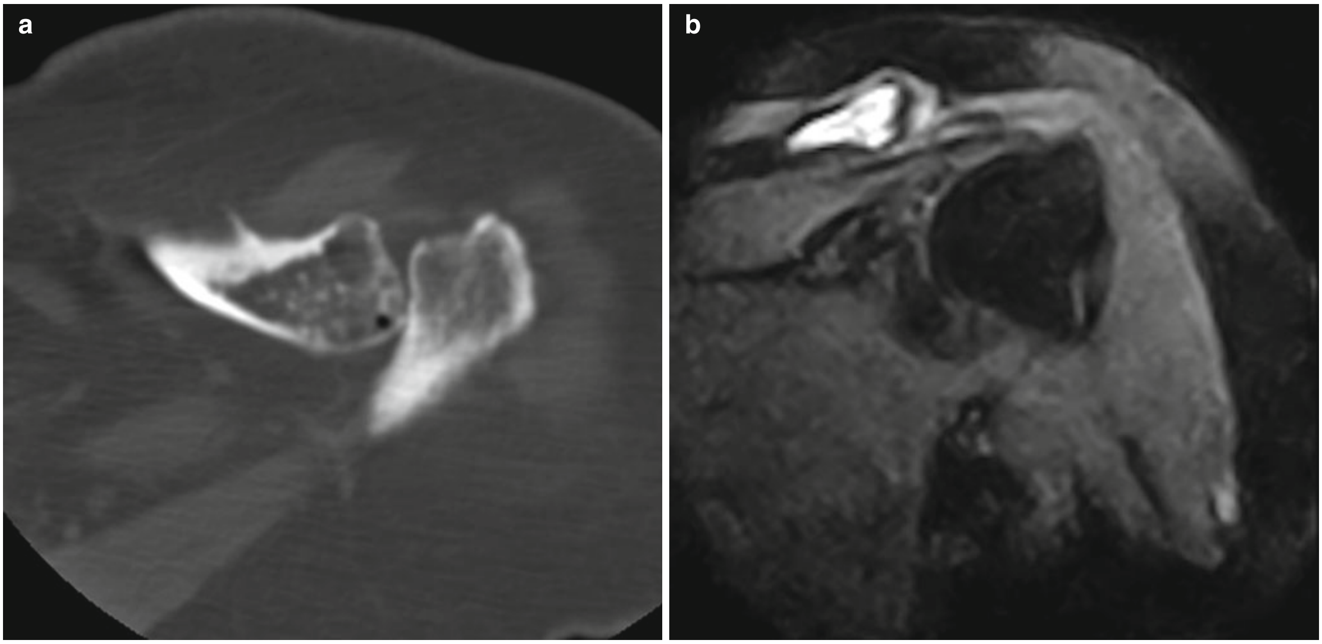

Fig. 4.4 (**a**) Algodystrophic focus in a 63-year-old woman with pain at finger pressure of the distal end of the left clavicle. Axial CT scan of the acromioclavicular joint. (**b**) Same patient: MR image performed with suppressed signal from adipose tissue in a coronal oblique plane. It documents widespread edema of the distal end of the clavicle

Magnetic Resonance Imaging

The ability of MRI to obtain multiplanar acquisitions and soft tissue contrast with multiple parameters allows a detailed study of the shoulder and helps to identify the complex anatomical structures and variants as well as pathologies of these structures. Among the characteristics that make MRI an important diagnostic method for musculoskeletal system are the high sensitivity to physical differences between tissues and fluids, the ability to show these differences as tissue contrast, the ability to highlight these differences working with specific parameters, and the ability to highlight vascular and neural structures without the administration of a contrast medium (CM) [13]. Since MRI does not use ionizing radiation, it has an important value in the study of pediatric patients.

Since its introduction, industries improved the performance of MRI devices and dedicated coils over years. Updated software for fast sequences have been recently introduced, which allow the evaluation of the shoulder in about 30 min, thereby reducing motion artifacts due to patient's fatigue from maintaining the same position for a long time. Dedicated phased array coils with high spatial resolution are now used which allow optimal visualization of the different structures to be evaluated: tendons, muscles, capsuloligamentous and bone structures, and neurovascular bundles.

Injures affecting the shoulder can be traumatic and non-traumatic. Indications for MRI include tendon (rotator cuff/LHB), bone (tumors, systemic diseases), capsuloligamentous, and articular cartilage pathologies. Thanks to the signal intensity and operator's choice of the sequences to be used, the radiologist is directed towards any pathology. The sequences used in a standard MRI exam of the shoulder are shown in Tables 4.2 and 4.3.

The images are acquired on three anatomical planes: axial, oblique coronal, and oblique sagittal, with 3–4 mm sections for 2D acquisitions and 0.6–1 mm sections for 3D acquisitions. The study on these three planes allows to evaluate the different structures of the shoulder (Table 4.4).

Technical parameters are variable and are chosen by the operator depending on his skills and experience; however, acquisition planes are dictated by the different anatomical structures to be evaluated. For the study of the rotator cuff, all three acquisition planes are necessary so that it is possible to visualize not only the tendons at their bony insertions but also the myotendinous junction and the capsuloligamentous and bony cartilaginous structures.

In high-field closed systems, the patient lies supine on the table with the limb under examination in a neutral position along the body; the external rotation of the arm would impinge the visualization of the LHB, while internal rotation would result in capsular redundancy and difficult discernment between supraspinatus and infraspinatus tendons in the axial plane. Another position which is extremely useful to complement the standard positions, especially in MRA, is the abduction external rotation (ABER) position, since it assesses the inferior capsule and centering of the humeral head in the glenoid cavity [14].

Table 4.2 Sequences for standard MRI of the shoulder (GE)

MRI sequences (1.5 T GE)	TR/TE (ms)	Thickness (mm)	Matrix	ETL	NEX	FOV (cm)
Axial PD	2,000/26	3	224×256	4	3	12–14
Axial T2 FS	3,000/50	3	224×256	8	3	12–14
Coronal T1	600/20	4	224×256	4	3	12–14
Coronal T2 FS	3,000/50	4	224×256	8	3	12–14
Sagittal T2 FS	3,000/50	4	224×256	8	3	12–14
Sagittal PD FS	2,000/26	4	224×256	4	3	12–14

Table 4.3 Sequences for standard MRI of the shoulder (Philips)

MRI sequences (1.5 T PHILIPS)	TR/TE (ms)	Thickness (mm)	Matrix	TEF	NEX	FOV (cm)
Axial T2 FFE	463/14	3	292×164	–	2	16
Sagittal TSE T1w	1,205/20	3	256×160	5	2	14
Coronal DPw TSE	1,207/30	3	256×140	5	3	14
Coronal PDw SPAIR	3,000/30	3.5	352×224	5	2	14.3
Axial 3D WATS C3	20/8.1	0.6	160×162	–	2	9.7

Table 4.4 Scan planes and anatomical structures detectable

Coronal oblique plane	Sagittal oblique plane	Axial plane
Longitudinal Infraspinatus muscle and tendon Supraspinatus muscle and tendon	Transverse Supraspinatus muscle and tendon Teres minor muscle and tendon Long head biceps tendon (proximal portion)	Long head biceps tendon (bicipital groove)
Acromioclavicular joint	Subscapularis tendon and muscle	Longitudinal Subscapularis tendon and muscle
Acromion	Rotator interval	Glenoid labrum (anterior and posterior portion)
Glenohumeral joint	Acromion	Joint
Subacromial-subdeltoid bursa	Coracoacromial ligament	Glenohumeral joint
Glenoid labrum (superior and inferior portion)	Coracoacromial arch Glenohumeral ligaments	Glenohumeral ligaments

MRI is very accurate in the study of full-thickness rotator cuff tears, which are associated with indirect signs, such as the elastic retraction of the tendinous stump and the presence of fluid which extends in the subacromial-deltoid bursa. Partial-thickness rotator cuff tears are slightly more difficult to visualize because they can affect the articular, bursal, or interstitial aspect of the tendons without tendon retraction. In addition, the “false” hyperintensity signal at the distal third of the supraspinatus tendon due to the “magic angle” artifact is responsible for a linear signal alteration involving the structures located at 55° from the static magnetic field (B0). A radiologist skilled in musculoskeletal MRI will of course recognize the artifact and avoid it using sequences that are not subjected to it (sequences with TE >30 ms). On the axial plane it is possible to follow the rotator cuff tendons inserting onto the greater tuberosity posteriorly to the supraspinatus, the infraspinatus, and the teres minor. On the axial plane, it is also possible to identify complete or partial lesions of the subscapularis tendon and its relationship with the tip of the coracoid process.

The sagittal plane allows to evaluate the supraspinatus and infraspinatus fossae occupied by the supraspinatus, infraspinatus, and teres minor muscles, respectively; the morphology of the acromion is also assessed, which can contribute to rotator cuff tear by subacromial impingement. Furthermore, in the sagittal plane it is possible to identify anteriorly the rotator interval (RI) (the space between the supraspinatus and subscapularis tendon), occupied by the superior glenohumeral ligament, the LHB, and the coracohumeral ligament.

MRI has an undisputed role in the study of diseases involving the glenoid labrum and capsuloligamentous structures. In this way, when the clinical suspicion of shoulder instability is supported by capsulo-labral-ligamentous or bone injures, MRI becomes necessary as its high contrast resolution allows complete assessment of the individual stabilizing structures. However, some structures, such as the superior glenohumeral ligament – whose role in the stabilization of the shoulder is not very clear – and some anatomical variations cannot be seen at basic examination; therefore, one must refer to the MRI examination after articular injection of CM (MRA).

Intrinsic power of contrast resolution of MRI, higher than in any other radiological techniques, makes it essential in the study of tumors and cysts involving the shoulder girdle (Figs. 4.5 and 4.6). Determination of the extension of the tumor enables the surgeon to choose the most adequate

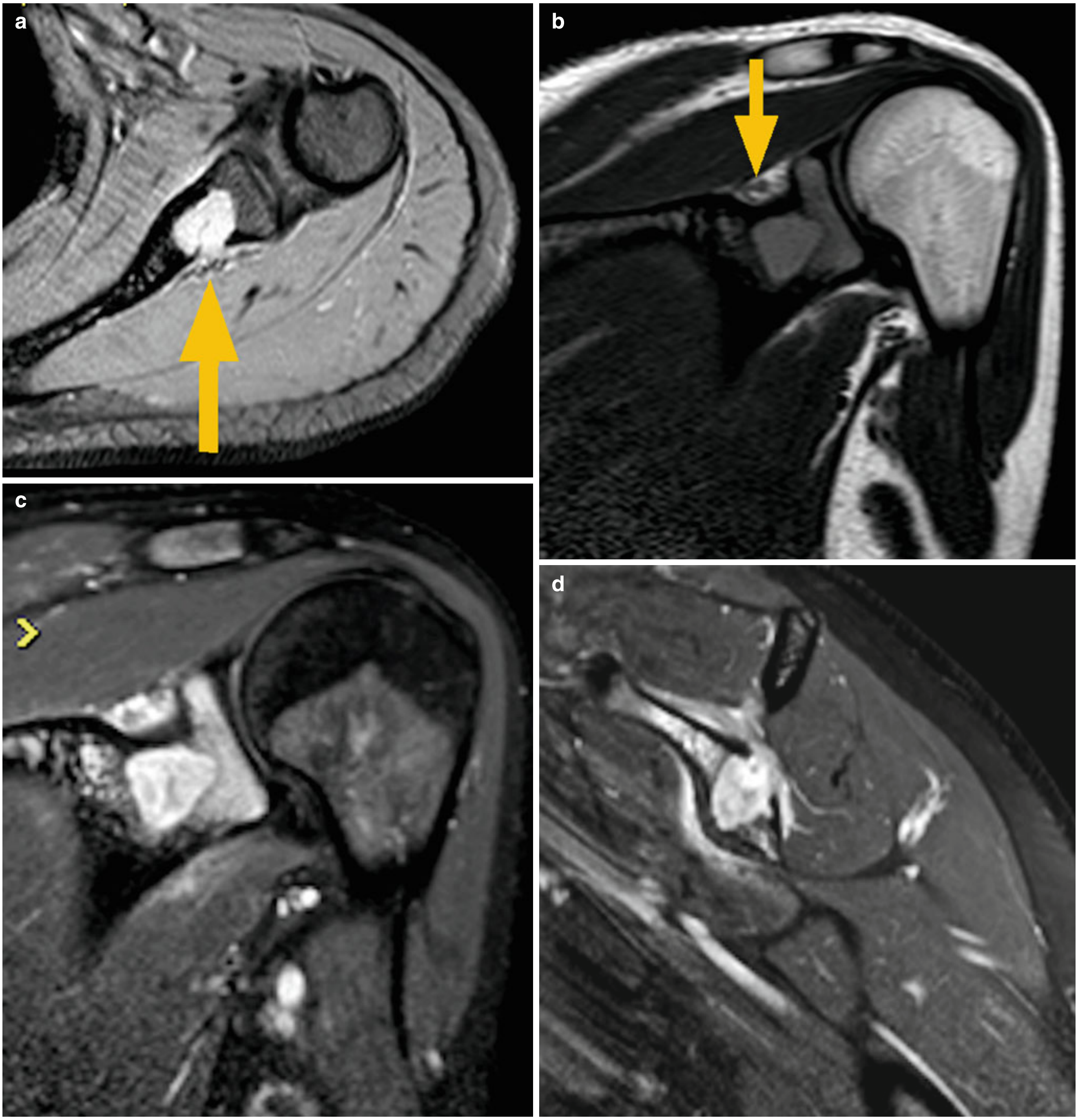

Fig. 4.5 18-year-old patient with painful symptomatology in the left shoulder. (**a**) Axial T2* GRE. Lytic lesion (*arrow*) at the body of the scapula with interruption of the posterior cortex. (**b**) T1w coronal scan, documenting lytic lesion with sclerotic rim and peripheral edema. Immediately above the lesion, the suprascapular notch and nerve are shown (*arrow*). (**c**) Coronal oblique FS T2 scan. Lytic lesion with hyperintense contents. (**d**) Oblique sagittal T2 FS scan. The scan confirms pathological interruption of the posterior cortex of the glenoid neck and edema of the surrounding soft tissue

surgical procedure, such as limb preservation surgery [13]. With regard to systemic diseases, MRI allows the evaluation of the replacement of the normal signal intensity of the bone marrow (medullary shift) by metabolically active tissue; in fact the signal is nonspecific as it could be related to a reactivation (e.g., physiological conditions of hypoxemia) or changes in the hematopoietic system (anemia, leukemia, multiple myeloma, lymphomas, etc.).

In the shoulder, as in other joints, sequences with fat tissue saturation are routinely used in order to enhance the

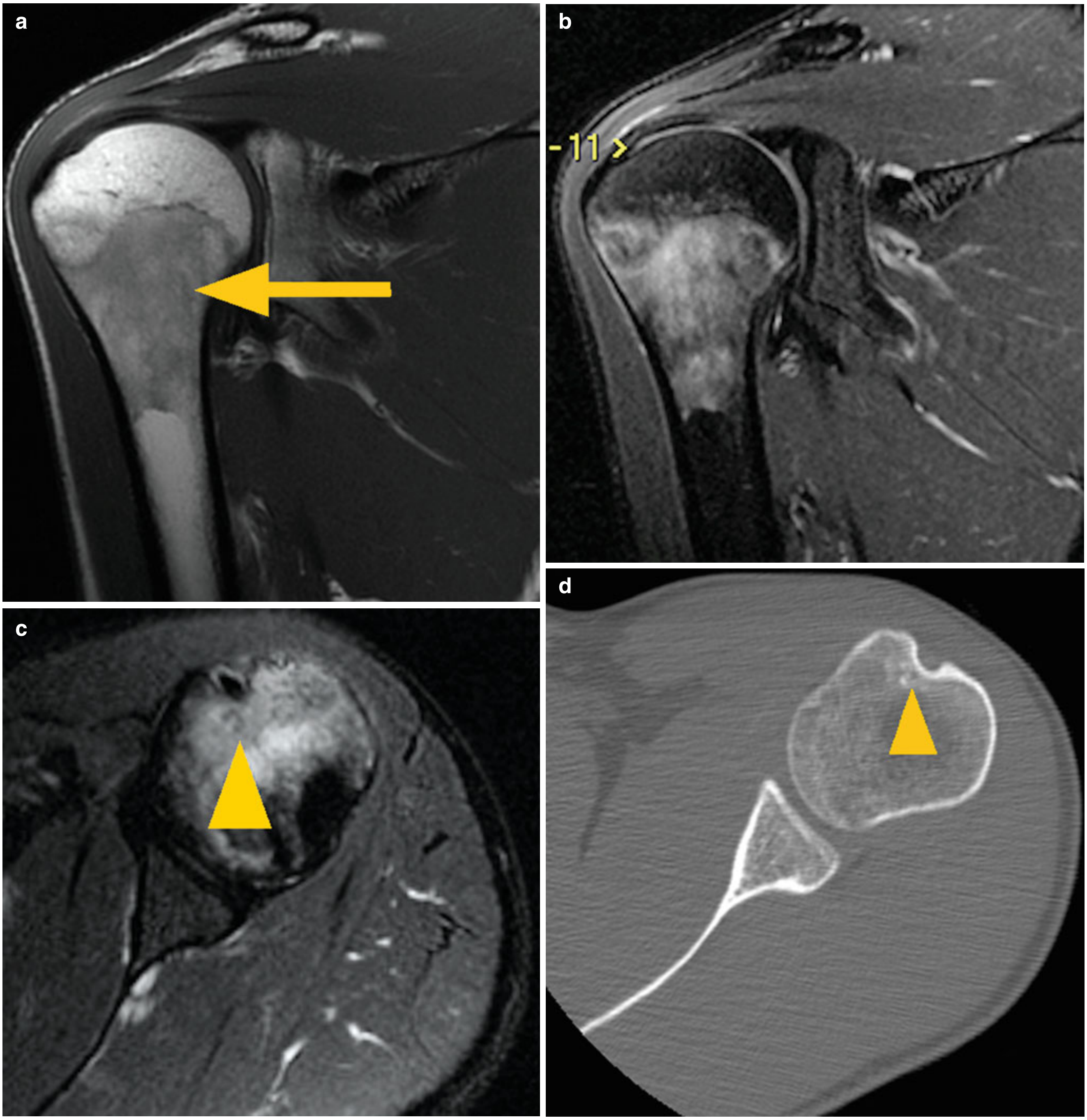

Fig. 4.6 24-year-old patient with predominantly nocturnal pain that lessens with the use of salicylates: clinical suspicion of osteoid osteoma. (**a**) Coronal oblique T1 image shows slight hypointensity at the left proximal humeral metaphysis (*arrow*). (**b**) Oblique coronal T2 FS scan confirms the signal alteration in the proximal humeral metaphyseal region. (**c**) Axial T2 FS. Edema of the spongy bone is documented in the metaphyseal region with small focal hypointense alteration immediately below the bicipital groove (*arrowhead*). (**d**) In order to complete diagnosis, a thin-layer CT scan was performed of the lesion described at MRI. The CT examination documented the presence of "nidus" with central calcification at the same site as the hypointense lesion shown on MRI (*arrowhead*). Examinations confirm the clinical suspicion of osteoid osteoma

contrast of different structures and eliminate the hyperintense signal from the subcutaneous and bone marrow fat. This choice lies mainly in the case of detection of lesions associated with the presence of cellularity or fluid in the form of joint or para-articular effusion or blood serum fluid. Thus the presence of fluid-type signal within a tendon or glenoid fibrocartilage allows the diagnosis of lesions. Moreover, thanks to the contrast between bone and joint fluid, the presence of the latter in the joint cavity allows to evaluate the cartilaginous coating of the joint surfaces, excluding edematous or abrasive-erosive changes. The injection of articular CM facilitates the diagnosis of chondral injures since it increases the sensitivity of the method allowing the early stages of chondromalacia to be identified.

Chronic inflammatory joint diseases, such as RA, are accompanied by joint and bursal effusions and associated with destructive bone erosions. In this case, intravenous (iv) administration of CM during MRI exam allows the radiologist to evaluate the activity of the disease, documenting the hyperintense thickening of the joint and bursal synovial walls and the hyperintensity of the erosive cavities, or the presence of granulomatous tissue, even when subcutaneous. Glenoid labrum undergoes degenerative changes that appear in the form of focal signal abnormalities on long TR sequences and with globular or lamellar morphology; these alterations may lead to the formation of space-occupying mucinous cysts that may extend medially up to the suprascapular notch causing compression on the neurovascular bundle. MRI can document the presence and extension of this cyst, its nature (mucinous tissue: T2 hyperintense signal), and related signs of neurovascular compromise: venous-vascular ectasia and/or atrophy of the shoulder girdle muscles shown by hyperintense signal on T1 and T2 sequences (fibro-fatty replacement of muscle mass and edema). Finally, T1 morphological study of the shoulder allows the documentation of morphological degenerative bone changes ranging from an "inflammatory" chondral phase up to far more serious phases when the joint capacity reduces, resulting in subchondral sclerosis, geodiform cystic lesions, and foci of necrosis.

Another huge advantage of MRI lies in the evaluation of the postoperative shoulder as it can show many potential causes of recurrent symptoms. However, the evaluation of a postoperative shoulder is not always easy, since the magnetic susceptibility artifacts can alter the homogeneity of the field and "disturb" the evaluation of those structures that are normally assessable at presurgical MRI examination. Artifacts in MR depend on many factors such as the type of metal and the size and complexity of the surface (the higher the complexity the greater the artifact). Moreover, material is just as important, because titanium induces a lower local dishomogeneity in the magnetic field, while steel and cobalt-chromium are responsible for a greater dishomogeneity in the field. Metal anchors determine local artifacts that usually do not alter the assessment of the structures to be examined; in addition, the operator knows that sequences affected by field dishomogeneity, such as GRE sequences, are to be avoided in the study protocol. The use of SE, with low TE, a wider bandwidth, a larger FOV, and a larger matrix, can reduce ferromagnetic artifacts compared to the classical protocol. Biodegradable radiolucent implants commonly used in shoulder surgery induce few or no artifacts [15].

Magnetic Resonance Arthrography

MR arthrography (MRA) of the shoulder is generally indicated in clinical suspicions of shoulder instability, SLAP (superior labrum – anterior to posterior) lesions, intra-articular chondral loose bodies, pathology of the rotator interval (RI), adhesive capsulitis, in the postoperative assessment of surgical procedures, and, to a lesser extent, in case of differential diagnosis between full-thickness and partial-thickness tears of the rotator cuff unaddressed at previous ultrasound and/or standard MRI examination [16].

MRA is generally required after the completion of first-level examinations (standard X-ray and ultrasound) and standard MRI exams, following clinical-specialist evaluation. The completion of the investigation with CT is often recommended in patients with suspected osseous lesion of the glenoid (bony Bankart lesion). In addition, MRA carefully studies the RI (Fig. 4.7). RI structures are intracapsular and may be affected by a variety of inflammatory synovial diseases, such as adhesive capsulitis, rheumatic diseases, and septic arthritis. Adhesive capsulitis is a clinical syndrome characterized by pain and severe functional limitations. It can be idiopathic or secondary to trauma, surgery, osteoarthritis, inflammatory diseases, metabolic diseases (diabetes mellitus), and pathology of the cuff/LHB. Characteristic MRA signs of this disease are the reduced capacity of the joint, difficulty in the introduction of contrast medium into the joint, and thickening of the axillary recess and of the coracohumeral ligament. Another anatomic structure of the RI difficult to detect except with MRA is the pulley of the biceps tendon, in proximity to the intertubercular groove. Its injury may cause medial dislocation of the LHB causing injury to the articular surface of the subscapularis tendon and the anterior superior translation of the humeral head. The coracohumeral ligament constitutes the upper edge of the pulley, while the superior glenohumeral ligament constitutes the inferior edge. The coracohumeral and superior glenohumeral connect the supraspinatus and subscapularis with the pulley. The knowledge of this region helps to explain why the lesions of the upper fibers of the subscapularis tendon involve the superior glenohumeral joint and the medial band of the coracohumeral, whereas lesions of the anterior supraspinatus may involve the lateral band of the coracohumeral ligament. MRA is the only examination that can shed light on the anomalies of the biceps pulley in the RI and shows subluxation or dislocation of the LHB and lesions of the subscapularis and supraspinatus tendons around the pulley [14, 17].

The execution of MRA entails two phases: the first is the intra-articular glenohumeral injection of paramagnetic CM under fluoroscopic guidance and the second consists in the execution of MRI with 1.5 T using arthro-sequences (Table 4.5).

During the intra-articular injection of paramagnetic CM, the patient is supine, positioned on the table of

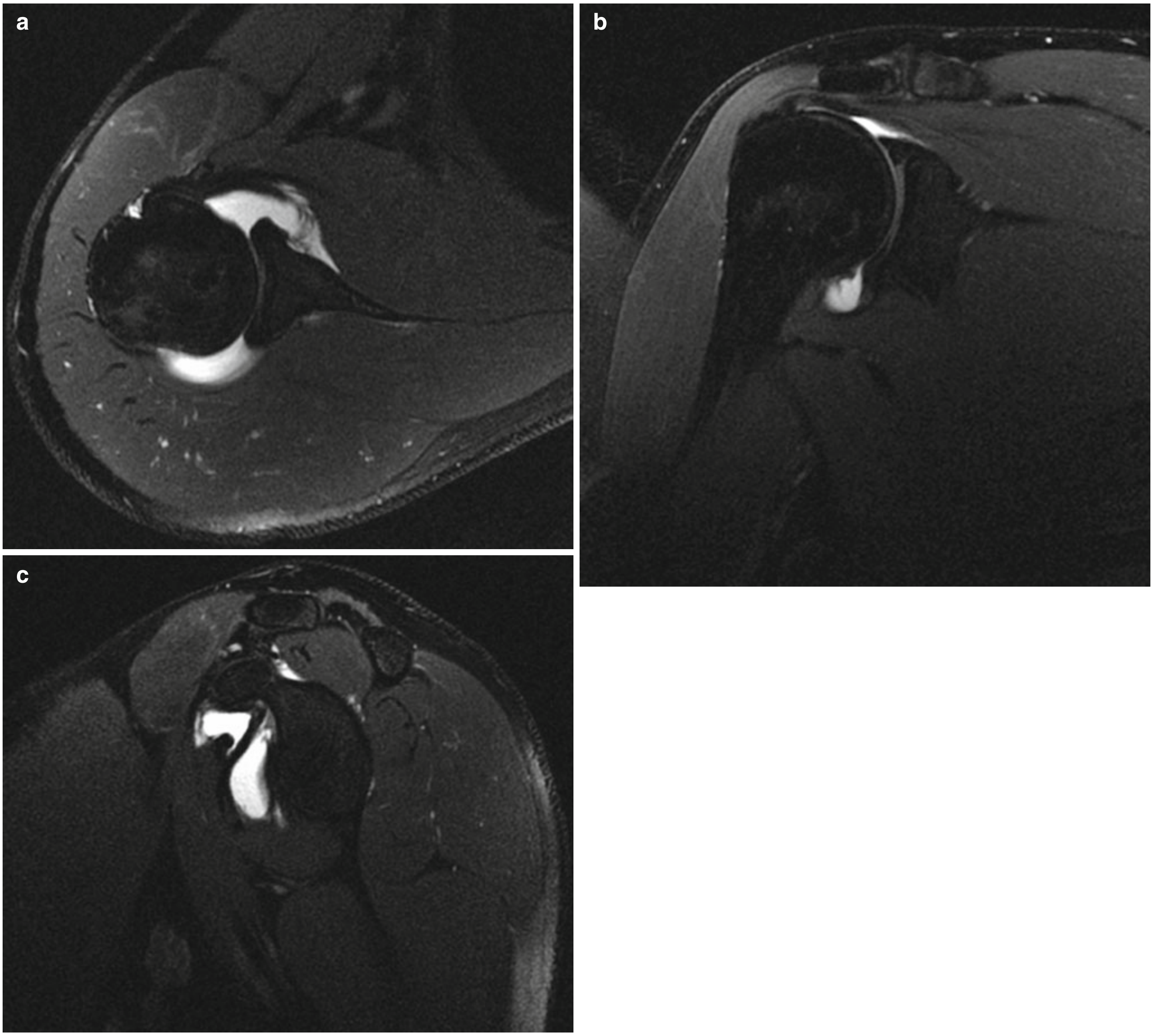

Fig. 4.7 T1w sequences with suppression of fat signal, in the axial (**a**), coronal (**b**), and sagittal (**c**) planes, respectively, after administration of intra-articular paramagnetic contrast medium under fluoroscopic guidance. Good capsular distension can be assessed with involvement of recesses by contrast, relative distension of the LHB sheath and correct view of the capsuloligamentous glenohumeral structures and glenoid labrum

Table 4.5 Sequences for MRA of the shoulder (GE)

MRA sequences (1.5 T GE)	TR/TE (ms)	Thickness (mm)	Matrix	ETL	NEX	FOV(cm)
Axial T1 FS	600/20	4	224×256	4	3	12–14
Coronal oblique T1 FS	600/20	4	224×256	3	3	12–14
Coronal oblique T1	600/20	4	224×256	4	3	12–14
Sagittal oblique T1 FS	600/20	4	224×256	4	3	12–14
ABER T1 FS	600/20	4	224×256	3	4	14

fluoroscopic unit, with her/his arm slightly rotated externally or along the body, in order to make the anterior joint approach quick and easy. The skin is disinfected and the joint is approached under fluoroscopic guidance. A small dose of local anesthetic can be administered (1 % carbocaine) to make the procedure painless. A spinal needle is positioned within the glenohumeral joint having as a radiographic marker the articular margin at the middle-superior

Fig. 4.8 Anteroposterior radiograph of the right shoulder with a spinal needle placement in the intra-articular glenohumeral joint. The ideal entry point of the spinal needle is the superior third of the glenohumeral joint line: linear disposition of radiopaque contrast medium is an X-ray sign of the correct needle placement

third, below and laterally to the coracoid process. About 2 cc radiopaque CM are administered in order to assess the correct intra-articular positioning of the needle, as the joint rim will appear as a radiopaque image between the glenoid and humeral head (Fig. 4.8). We proceed to the administration of 18–20 cc of paramagnetic CM (20:1 dilution). After the procedure, the spinal needle is removed and the skin is disinfected. Finally, the patient is asked to make small movements of the shoulder, in internal and external rotation to facilitate the optimal distribution of the CM introduced. At the end of the procedure, the patient generally refers to a sensation of heaviness and rigidity of the shoulder, in relation to the joint filling of CM. Furthermore, she/he may feel a slight tenderness along the front side of the arm, due to the distension of the LHB sheath, or posteriorly, in correspondence of the scapular region.

In the second phase, the actual implementation of MRI, fat-suppressed T1-weighted sequences are used in the three spatial planes and the investigation can be completed with an oblique scan plane in position of abduction and external rotation (ABER) position. It is useful to complete the MRA using a standard T1-weighted sequence with morphological value.

After the examination, neither functional limitation nor shoulder rest is necessary. In the hours after the examination, mild discomfort in the articulation may persist, which rapidly disappears within 6 h.

The entire procedure must use sterile specialist tools and devices. There is no contraindication to any type of intra-articular injection of paramagnetic CM. There is no need for fasting, nor are blood tests or special precautions required before the procedure. It is sufficient to make sure that the patient is not allergic to iodine, given the albeit minimum administration of iodine contrast agent during the correct positioning of the spinal needle within the intra-articular site.

MRA complications are rare. They include infections, bleeding, allergy, synovitis, and post-procedure pain. Allergic reactions to Gadolinium are rare, although mild/severe reactions have been reported in the literature. A history of adverse reaction to iodine contrast or to anesthetic imposes a premedication or the removal of the substance from the injection. Vasovagal reactions and nausea often occur during the intra-articular injection, whereas bleeding and infection are very rare [18].

In patients carrying pacemaker, MRA can be replaced by CTA examination, which is equally valid for rotator cuff tears but much less sensitive for lesions of the glenoid labrum.

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