MRI of the Elbow: How to Do It

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Abstract

The diagnostic cascade for elbow complaints starts with the physical examination and radiographs that already can clarify or rule out many causes. Depending on the suspected pathology, additional imaging is necessary. Magnetic resonance imaging (MRI) has the advantage of accurately demonstrating a broad spectrum of diseases. The main indication for noncontrast MRI of the elbow is chronic epicondylitis. For magnetic resonance (MR) arthrography, it is suspected chondral and osteochondral abnormalities. Indirect MR arthrography is an option when direct arthrography is not practicable. MR arthrography of the elbow with traction is feasible, with promising results for the assessment of the radiocapitellar cartilage.

Keywords

- elbow magnetic resonance imaging
- elbow arthrography
- elbow imaging

Clinical examination is essential to initially evaluate patients with elbow complaints. Both acute and chronic elbow complaints are primarily evaluated by an orthopaedic surgeon, rheumatologist, or family practitioner based on a thorough case history and the physical examination as well as radiographs.[1–4] According to the American College of Radiology (ACR) Appropriateness Criteria for chronic elbow pain, radiography is most helpful for assessing bony structures, may be adequate to reveal the definitive cause of the complaints, and also serves as a useful adjunct to interpretation if magnetic resonance imaging (MRI) is subsequently performed.[5,6]

Depending on the clinically suspected underlying pathology and in cases where the radiographs did not facilitate a diagnosis, conventional radiography may be followed by another diagnostic imaging modality. Computed tomography (CT) and ultrasonography (US) can be used for specific indications such as mechanical symptoms (locking, clicking, limited motion, elbow stiffness), palpable mass, or a suspected nerve abnormality.[5,7–9] MRI demonstrates a wide spectrum of abnormalities of the elbow accurately, depicting both soft tissue and osseus abnormalities, and is therefore an important diagnostic tool.[10–13]

MRI Indications

The main indications to perform MRI of the elbow (without intra-articular injection of gadolinium) are suspected and treatment-refractory epicondylitis due to chronic repetitive microtrauma and overuse by repetitive valgus stress (in pitchers, golfers, and tennis players) or varus stress (the classic "tennis elbow"). In such cases, MRI is performed as an additional diagnostic tool to confirm the suspected diagnosis and to evaluate potential associated tendon and collateral ligament tears.[10,14–18]

MRI is also useful to evaluate the cartilage status of the elbow (with limitations in the diagnosis of early stages of chondromalacia) (►**Fig. 1**) and to assess osteochondral fractures.[19,20] In the setting of acute trauma or elbow dislocation (►**Fig. 2**), MRI is also commonly performed, and as with other joints, it can reveal an occult fracture.[13,21] It is valuable for the assessment of the three main nerves in the elbow depicting the anatomy if a nerve compression syndrome is suspected, such as cubital tunnel syndrome (►**Fig. 3**) or anterior interosseous nerve syndrome (Kiloh-Nevin syndrome).[22–26] For dynamic assessment of ulnar nerve subluxation and dislocation, as well as for confirmation of snapping triceps syndrome, MRI can provide valuable information. However, according to the ACR Appropriateness Criteria, US is preferred.[5] If in the clinical examination a biceps tendon tear is suspected and the radiograph was not expedient, MRI can be used for further diagnostic assessment.[5,27,28]

A potential concomitant bone marrow edema at the radial tuberosity and bicipitoradial bursitis can also be assessed by MRI.[29] Elbow pain at the terminal extension could indicate

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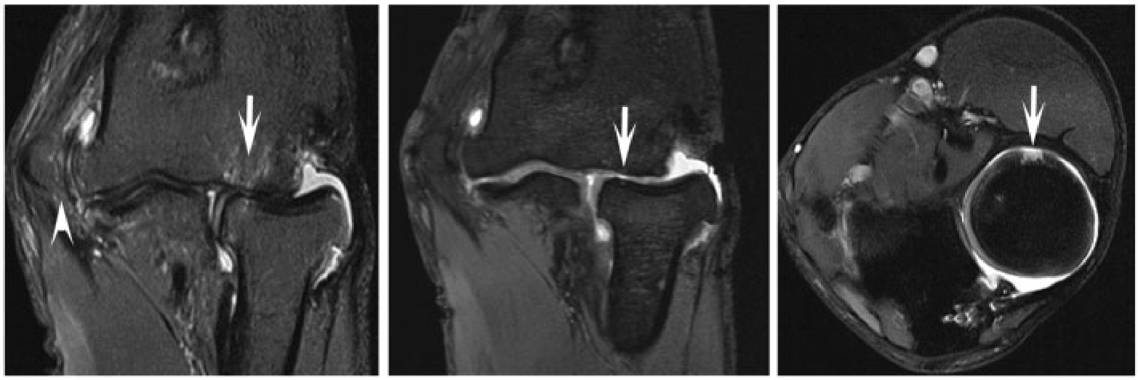
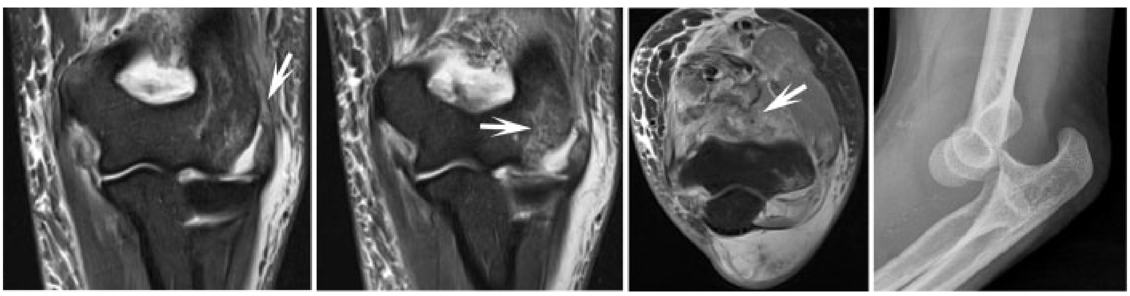


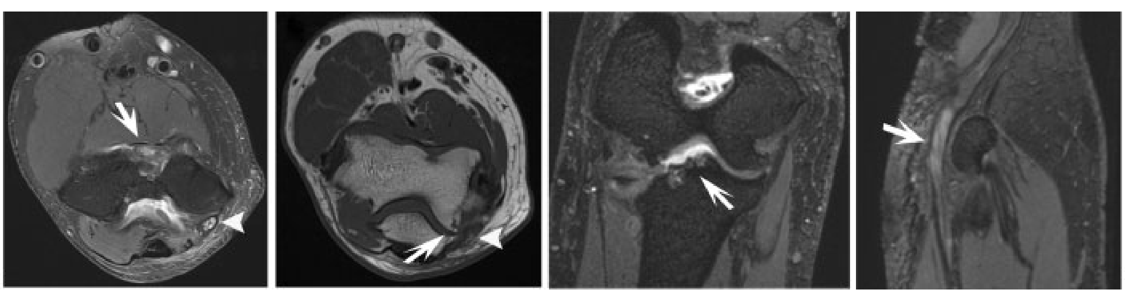
a, b c

Fig. 1 Posttraumatic osteoarthritis of the elbow. (**a**) The coronal short tau inversion recovery image shows a fibrous pseudarthrosis (arrowhead) of a detached and distally dislocated ulnar epicondyle of the humerus as well as subchondral edema in the capitulum (arrow). (**b**) The coronal true fast imaging with steady-state free precession depicts deep cartilage defects of the capitulum (arrow) with corresponding cartilage injuries also of the radial head. (**c**) A transverse proton-density fat-saturated image depicts the cartilage defect of the radial head (arrow).



a, b c, d

Fig. 2 (**a–c**) Images after reduction of a dislocated elbow caused by a fall during cross-country skiing. (**d**) Lateral radiograph before joint reduction. (a, b) Coronal short tau inversion recovery images show a partial tear of the aponeurosis of the extensor tendons on the radial epicondyle of the humerus (a, arrow), as well as a pronounced bone bruise of the epicondyle due to contusion (b, arrow). (c) Transverse proton-density fat-saturated image visualizing an extensive hematoma in the brachial muscle (c, arrow).



a, b c, d

Fig. 3 Osteoarthritis of the elbow and symptoms suggestive of a cubital tunnel syndrome (tingling sensation by flexion of the elbow and tenderness over the ulnar sulcus with positive Hoffmann-Tinel phenomenon), as well as pathologic electroneurography with a conduction block distal of the ulnar sulcus. (**a**) Transverse proton-density fat-saturated image shows a thickened ulnar nerve in the ulnar sulcus (arrowhead) and loose joint bodies in the coronoid fossa (arrow). (**b**) Transverse T1-weighted image shows osteophytes arising from the olecranon and the epicondyle (arrow), probably compromising the ulnar nerve in the ulnar sulcus (arrowhead). (**c**) Coronal true fast imaging with steady-state free precession (TRUFI) image demonstrates large cartilage defects of the coronoid process (arrow). (**d**) Reconstructed parasagittal secondary reconstructions of the three-dimensional TRUFI sequence shows the swollen and hyperintense ulnar nerve in its course through the ulnar sulcus.

enlarged synovial plicae that MRI can visualize nicely.[30] It is also used for preoperative planning and for the assessment of postoperative results as in case of metallic implants, using special metal artifact reducing sequences.[19,31]

In case of a soft tissue mass or suspicious osseous tumor, MRI without and with intravenous (IV) contrast media may be helpful, particularly in hemorrhagic soft tissue masses or when a vascular mass is suspected. It provides information about lesion vascularity and local staging. Additionally, MR angiography can be an adjunct to assess adjacent neurovascular structures, which is useful for biopsy or surgical planning.[5,32,33] Contrast-enhanced sequences also provide information about the extent and distribution of synovitis or other synovial processes, such as pigmented villonodular synovitis or bursitis.[34,35]

Positioning in the MR Scanner

MRI of the elbow is ideally performed in the prone position with the arm extended overhead and the forearm in pronation, the so-called superman position[34] (►**Fig. 4**). Another possible position is supine with the arm held in the

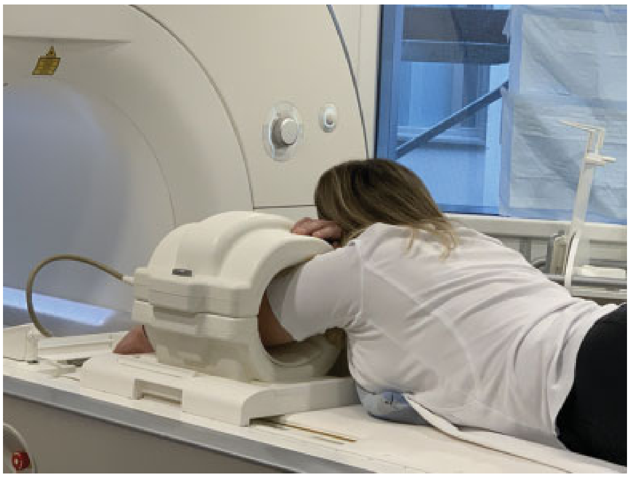


Fig. 4 Optimal position for elbow magnetic resonance (MR) imaging, the so-called superman position, with the arm extended overhead and the forearm in pronation. Note that the elbow is centered in the multichannel surface coil of a 3-T MR system.

anatomical position at the side (patient position on the scanner: feet first supine). This patient position could be disadvantageous because the elbow is positioned at the periphery of the magnetic field, out of the isocenter of the magnet, resulting in a suboptimal signal-to-noise ratio and reduced effectiveness of spectral fat saturation techniques.[36,37] However, it is more comfortable and an acceptable alternative for patients who cannot tolerate the arm raised above the head position. To reduce movement artifacts, sandbags can be placed on the forearm and wrist.

Multichannel extremity coils are recommended, such as a multichannel knee coil or a small flex multichannel coil to improve image quality for elbow MRI.[31,38]

MRI Protocol

A standard MRI protocol of the elbow at 3 T is described in ►**Table 1**. The 1.5-T MR systems are also sufficient, with possibly a slightly longer examination time. An efficient MR protocol consists of five sequences sensitive for both osseous and soft tissue pathologies and, if required, one sequence enhanced with contrast. Coronal short tau inversion recovery (STIR) sequences and transverse proton density with fat saturation (PDFS) sequences are fluid sensitive and mainly useful for depicting overall texture irritation, joint effusion, bone bruise, and tendon or ligaments tears. The three-dimensional true fast imaging with steady-state free precession (TRUFI) sequence can be used to assess the cartilage status and for reformation in any necessary plane. The transverse T1-weighted sequence is fast, causing fewer motion artifacts and provides a high signal-to-noise ratio for optimal visualization of fractures, osteophytes, and muscle quality, as well as the nerves, and to show the elbow anatomy. The sagittal T2-weighted sequence is mainly performed to visualize extra-articular structures and pathologies (e.g. injuries of the biceps and triceps tendon), as well as joint effusion.[34]

Standard coronal slices of the elbow are planned parallel to the epicondyle axis as the reference plane, whereas sagittal and transverse slices are planned orthogonal to the coronal one. Conventional coronal, transverse, and sagittal imaging planes enable sufficient assessment of all soft tissue structures of the elbow, classically divided into anterior and posterior as well as medial und lateral compartments, along with the osseous structures of the elbow joint.[39]

MR images should have a maximum slice thickness of 3 mm. The field of view of the transverse sequences should extend at least 5 cm proximal as well as 5 cm distal to the humeroradial joint, so not to miss the biceps tendon attachment at the radial tuberosity. Care should be taken to ensure the sequences extend anteriorly far enough to cover the distal biceps tendon completely as well as the lacertus fibrosus (aponeurosis of the biceps muscle).

Specific MR Imaging of the Biceps Tendons

Transverse planes are commonly used to image the biceps tendon, which provides short-axis images of the tendon and allows accurate assessment of distal biceps tendon anatomy and pathology. With clinical examination, the differentiation of complete tears from partial tears may be difficult, particularly when the lacertus fibrosus remains intact.[1] Long-axis images of the tendon may be useful for a precise evaluation of the extent of the rupture.[40] Considering that the distal biceps tendon is a flattened cord and has an oblique course, which may cause partial volume averaging on sagittal images,

Table 1 Standard MR protocol for the elbow at 3 T

Sequence	TR, ms	TE, ms	NEX	Matrix	Slice thickness, mm	FOV	ETL
Coronal TRUFI 3D	9	3–4	1	448 × 246	3	12	1
Coronal STIR	4,000–6,000	30–60	1	320 × 256	3	12	15
Sagittal T2	3,000–6,000	70–100	1	384 × 269	3	12	14
Transverse T1	400–650	8–15	1	384 × 307	3	12	2
Transverse PDFS	3,000–6,000	30–60	1	320 × 288	3	12	8
Contrast-enhanced transverse T1 FS	400–600	8–15	1	384 × 307	3	12	2

Abbreviations: 3D, three-dimensional; ETL, echo train length; FOV, field of view; FS, fat saturation; NEX, number of examinations; PDFS, proton density with fat saturation; STIR, short tau inversion recovery; TE, echo time; TR, repetition time; TRUFI, true fast imaging with steady-state free precession.
Note: Intravenous contrast is only administered in selected cases.

Giuffrè and Moss described the flexion, abduction, and supination (FABS) view that allows the longitudinal depiction of the tendon from the musculotendinous junction to its insertion on the radial tuberosity. For this view the patient lies prone with the arm overhead, the shoulder abducted, the elbow bent at 90 degrees, and the forearm supinated.[41] Although the FABS view allows a good depiction of the biceps tendon insertion, it is not widely used.

Indications for Direct MR Arthrography

The most important indication for MR arthrography, according to the ACR Appropriateness Criteria, is to assess chondral and osteochondral abnormalities.[5]

Direct MRA of the elbow improves the diagnostic performance of conventional MRI in detecting and grading cartilage injuries.[19,42–45] The intra-articular contrast agent facilitates the detection of articular pathology by delineating the articular structures, by distension of the joint capsule, allowing a better visualization of individual anatomical structures localized close to each other, and by filling potential spaces that originate in or communicate with the joint. Furthermore, MRA may provide additional information about the integrity of the articular structures, especially cartilage, fibrocartilage, and ligaments. Subtle partial-thickness ligament tears and an early focal osteochondral lesion may be better visualized compared with noncontrast MR examinations.[46–50] Additionally, the study of Magee with 79 patients and surgical correlation found that the direct MR arthrography technique was more precise in visualizing fibrous tear healing compared with conventional MRI, in which these changes appeared as false-positive ligament tears.[51] MR arthrography could be more sensitive, detecting joint capsule injuries and synovial-based or adherent processes as well as nonossified or cartilaginous intra-articular bodies.[38,52]

However, a survey published in 2018 among the members of the European Society of Musculoskeletal Radiology found that MR arthrographies account for only 5% of all musculoskeletal MR imaging, with the examination more common in orthopaedic hospitals and elbow arthrography performed less commonly than arthrography of the shoulder or the hip.[53] MR arthrography has some advantages over CT arthrography because it does not use ionizing radiation and is therefore preferable for younger patients. It also shows structural alterations of the cartilage (besides the surface also the internal structure as well as subchondral changes) and has higher soft tissue contrast resolution, whereby extra- and periarticular structures can be better assessed.[19,50]

CT and MR arthrography showed no significant difference in their sensitivity and specificity in detecting cartilage lesions or loose bodies, but CT arthrography may show better results in detecting small or low-grade cartilage lesions.[6,19,54] CT arthrography offers fast multiplanar images with higher in-plane spatial resolution less susceptible for motion artifacts as well as for metal artifacts.[19,54] CT arthrography is also an alternative examination technique

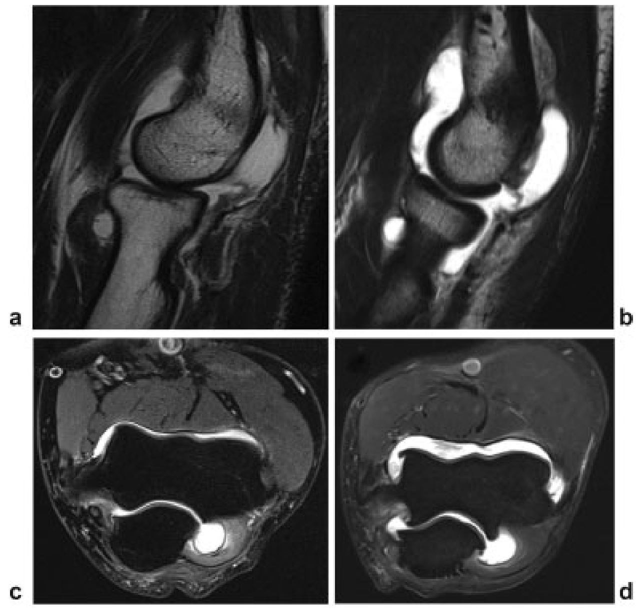


Fig. 5 (**a**) Sagittal T2-weighted image and (**c**) transverse proton-density fat-saturated (PDFS) image of a patient with joint effusion. (**b**) Sagittal T2-weighted image and (**d**) transverse PDFS image of a patient after intra-articular injection of 10 mL contrast medium for the magnetic resonance arthrography with sufficient distension of the joint capsule.

for patients with MRI contraindications, such as MR-incompatible metal devices or pacemakers, acute claustrophobia, severe obesity, or unusually large patient size, as well as, in some cases, for patients who have an allergy to gadolinium-based contrast agents.[44,54]

Local soft tissue infection is considered an absolute contraindication to MR or CT arthrography. In the setting of osteoarthritis with joint effusion, MR arthrography is unnecessary because the intra-articular fluid is likely to serve as a sufficient intrinsic contrast agent on fluid-sensitive sequences (►**Fig. 5a, c**). The joint space typically contains a variable volume of synovial fluid. Many intra-articular pathologies irritate the synovium and increase the synovial fluid, resulting in joint effusion, which can be used as a natural contrast agent and make elbow arthrography often unnecessary. For example, a posttraumatic joint effusion helps highlight pathologic changes of the annular ligament.[55]

Technique of Direct MR Arthrography

For conventional MRI and MR arthrography, the same patient position, coils, and MR sequence parameters are used. For MR arthrography, the intra-articular contrast injection is performed, mostly guided by fluoroscopy under sterile conditions. Intra-articular injection of contrast agents is considered a safe procedure; in particular, the prevalence of joint infections after arthrography is very low at 0.003%.[56] For the intervention, we recommend a 21G and 4-cm-long needle, 5-mL sterile syringe with local anesthesia (lidocaine 20 mg/mL), a 10-mL sterile syringe with nonionic contrast (iopamidol 200 mg/mL), and a commercially purchased

Fig. 6 Patient position on the fluoroscopic table with the elbow flexed to 90 degrees and the hand pronated.

prefilled syringe of an intra-articular gadolinium agent (gadopentetate dimeglumine 2 mmol/L).

A 2017 study showed that the intra-articular capacity of the elbow joint is markedly higher than previously reported, with an average capacity of $\sim 36 \pm 12$ mL measured on patients undergoing elbow arthroscopy.[57] In our institution, a total amount of maximal 7 to 10 mL fluid is injected, thereby obtaining sufficient distention of the joint capsule and adequate separation of individual anatomical structures (►**Fig. 5b, d**), as well as appropriate patient comfort.

As with any invasive procedure, written consent should be obtained before the injection. The patient is positioned prone on the fluoroscopic table with the arm over the head, the elbow flexed 90 degrees, and the hand pronated (►**Fig. 6**). The hand can also be supinated with the thumb up, to maximally open the radiocapitellar joint.[58] Alternatively, the patient could be seated next to the X-ray tube, but the prone position is preferred because vasovagal reactions may occur.

A true lateral approach is then used during the intermittent fluoroscopy to ascertain the correct injection position.[58] In this lateral approach, the anterior aspect of the joint surface of the radial head is the target for the tip of the needle and serves as an osseous abutment (►**Fig. 7**). The joint capsule/soft tissue may be numbed with the local anesthetic. If there is no resistance while injecting the local anesthetic, the intra-articular needle position is confirmed by slowly injecting 1 mL nonionic iodine-based contrast media with a connecting tube attached to the needle. Thus the connecting tube enables an overlay-free view during fluoroscopy and also serves as protection for the radiologist's hands, which can then be held outside the fluoroscopic image. Contrast media should flow freely into the anterior joint recess at the level of the coronoid fossa and ideally also in the radiocapitellar joint space as far as the fossa olecrani (►**Fig. 8**).

Fig. 7 Fluoroscopy image after injection of contrast medium into the joint via a lateral approach with the tip of the needle on the anterior aspect of the joint surface of the radial head.

In case of an initial needle misplacement, the needle position should be corrected, with the tip directed into the anterior joint recess along the radius joint surface (position of the tip of the needle is depicted in ►**Fig. 8**). Once the intra-articular position of the needle is confirmed, the gadolinium-based contrast agent can slowly be injected.

MR images should be performed without time delay to avoid trans-synovial diffusion and imbibition of the contrast

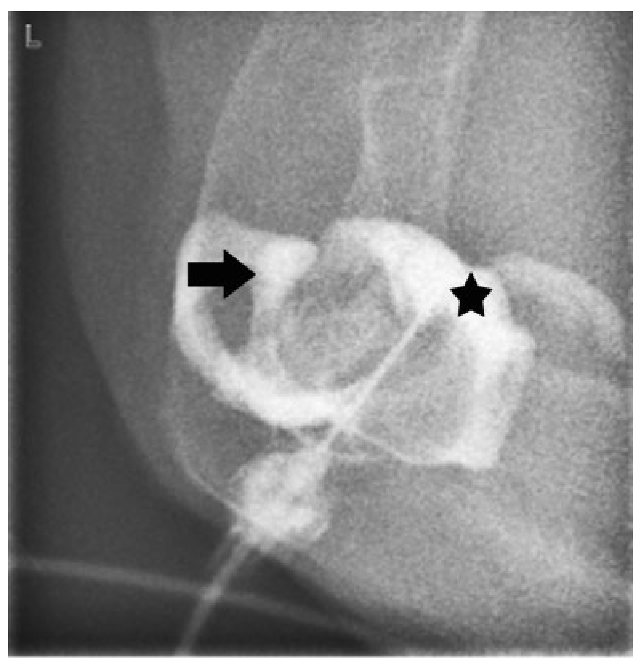


Fig. 8 Lateral fluoroscopy image showing tip of the needle in the anterior joint recess (asterisk). Note the free flow of the contrast medium into the coronoid fossa and the olecranon fossa (arrow). Contrast medium is also evident within the joint recess around the radial neck.

material into the extra-articular circulation. Intra-articular injected gadopentetate dimeglumine was shown to be resorbed by the synovium within a few hours.[59] Andreisek et al and Kopka et al investigated the relationship between MRI and the timing of the contrast injection. They found a fast, almost logarithmic decrease of the contrast-to-noise ratio on MR examinations within the first hours after intra-articular gadolinium injections in the shoulder, hip, knee, and wrist with a recommendation to perform the MR scans within 45 to 90 minutes after injection.[60,61]

During the intervention, infilling of gas into the joint should be avoided because it can lead to diagnostic problems. Even a small amount of gas in the joint may lead to a misdiagnosis of intra-articular bodies. However, gas bubbles will rise to upper regions of the joint, whereas loose bodies tend to sink.[62]

Another lateral approach for intra-articular injections is to target the needle by parallel insertion to the fluoroscopy beam into the anterior half of the radiocapitellar joint. However, there is no osseous abutment to ensure correct needle depth. Furthermore, a posterolateral approach can be chosen, pointing above and lateral to the olecranon fossa of the humerus. This approach decreases the possibility of iatrogenic contrast leakage in the lateral compartment of the elbow, potentially avoiding a diagnostic difficulty. This approach should be considered when there is clinical concern regarding the lateral ligament complex.[44,63]

MR Arthrography of the Elbow with Traction

One prospective study with promising results compared MR arthrography of the elbow with and without traction. It found a significant improvement of the visibility of the cartilage surface at the radiocapitellar joint.[64] Using 7 kg for males and 5 kg for females for the traction, the authors measured significantly increased joint space width at both the radiocapitellar and, to a lesser degree, ulnohumeral joint spaces.

Indirect MR Arthrography

Indirect MR arthrography is a less invasive alternative technique for imaging the elbow and can be used in patients when a joint injection is not feasible, there is no fluoroscopy for contrast administration, or in those with severe coagulation disorders.[5,65] This technique is suited to small joints like the elbow and wrist. It is based on the diffusion of intravenous gadopentetate dimeglumine through the vessels of the synovial membrane into the synovial fluid. The arthrographic effect depends on many factors, such as the viscosity of the joint fluid, vascular pressure, and vascular perfusion, as well as a diffusion gradient between plasma and joint fluid.[66] Hyperemia of the synovial membrane due to joint inflammation or physiologic hyperemia after exercise leads to a better and faster diffusion of the contrast into the joint.[66,67] Therefore, it is recommended to exercise the elbow moderately (passive or active) before imaging for 10 to 15 minutes. The signal intensity of the joint fluid will increase up to four times.[68,69] In the case that movement has to be avoided, the images should be performed with a delay of 5 to 10 minutes after the IV administration of contrast material.[70] To improve the contrast-to-noise-ratio, fat saturation is advised.[68,70]

The same indications as for direct MR arthrography apply to the indirect technique.[62] However, the evaluation of the elbow with indirect MR arthrography allows the simultaneous assessment of intra-articular diseases and extra-articular soft tissues or masses.[62] In the setting of epicondylitis, focal enhancement of the tendons and the adjacent bone marrow may be helpful for the diagnostic evaluation.[70] Furthermore, partial tears of ligaments may be identified by focal enhancement due to hyperemia.[70] The ulnar nerve often has a normally high signal on fat-suppressed T2-weighted images, so perineural enhancement in the cubital tunnel provides greater diagnostic confidence for ulnar nerve pathology.[71] Disadvantages of the indirect technique include the lack of controlled capsular distension and interpretative error due to enhancement of extra-articular structures (e.g., vessels, tendon sheaths, and bursae).[70]

Summary

According to the ACR Appropriateness Criteria, initial evaluation of chronic elbow pain should begin with radiographs and be followed by additional imaging (MRI, CT, US). MRI has the advantage of accurately demonstrating a broad spectrum of diseases. Elbow MRI is ideally performed in the so-called superman position, and both 1.5 and 3-T systems are suitable. The MRI protocol should consist of sequences sensitive for both osseous and soft tissue pathologies, and if required, IV contrast medium should be added. For MR arthrography, the intra-articular contrast injection can be performed guided by fluoroscopy using a lateral or posterolateral approach. Indirect MR arthrography is an option when direct arthrography is not practicable.

Conflict of Interest
None declared.

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