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PRACTICE GUIDELINE FOR THE PERFORMANCE AND INTERPRETATION OF MAGNETIC RESONANCE IMAGING (MRI) OF THE ELBOW

PREAMBLE

These guidelines are an educational tool designed to assist practitioners in providing appropriate radiologic care for patients. They are not inflexible rules or requirements of practice and are not intended, nor should they be used, to establish a legal standard of care. For these reasons and those set forth below, the American College of Radiology cautions against the use of these guidelines in litigation in which the clinical decisions of a practitioner are called into question.

The ultimate judgment regarding the propriety of any specific procedure or course of action must be made by the physician or medical physicist in light of all the circumstances presented. Thus, an approach that differs from the guidelines, standing alone, does not necessarily imply that the approach was below the standard of care. To the contrary, a conscientious practitioner may responsibly adopt a course of action different from that set forth in the guidelines when, in the reasonable judgment of the practitioner, such course of action is indicated by the condition of the patient, limitations of available resources, or advances in knowledge or technology subsequent to publication of the guidelines. However, a practitioner who employs an approach substantially different from these guidelines is advised to document in the patient record information sufficient to explain the approach taken.

The practice of medicine involves not only the science, but also the art of dealing with the prevention, diagnosis, alleviation, and treatment of disease. The variety and complexity of human conditions make it impossible to always reach the most appropriate diagnosis or to predict with certainty a particular response to treatment.

Therefore, it should be recognized that adherence to these guidelines will not assure an accurate diagnosis or a successful outcome. All that should be expected is that the practitioner will follow a reasonable course of action based on current knowledge, available resources, and the needs of the patient to deliver effective and safe medical care. The sole purpose of these guidelines is to assist practitioners in achieving this objective.

I. INTRODUCTION

This guideline was developed and written collaboratively by the American College of Radiology (ACR) and the Society of Skeletal Radiology (SSR).

Magnetic resonance imaging is a proven, established imaging modality for the detection, evaluation, staging, and follow-up of disorders of the elbow. Properly performed and interpreted, MRI not only contributes to diagnosis but also serves as an important guide to treatment planning and prognostication. However, it should be performed only for a valid medical reason, and only after careful consideration of alternative imaging modalities. The strengths of MRI and other modalities should be weighed against their suitability in particular patients and in particular clinical conditions.

Radiographs should be the first imaging test performed to evaluate the elbow [1,2], especially for trauma in both adults and children [3,4]. Radiographs can screen for osteochondritis dissecans (OCD) and osseous loose bodies [5,6,7], although they are less sensitive than MRI for these entities [8]. Nevertheless, there are soft tissue conditions such as heterotopic ossification for which radiographs may be more sensitive than MRI [9]. Radiographs taken during valgus stress can aid in the

diagnosis and management of ulnar collateral ligament injuries [10,11]. While conventional arthrography can help diagnose internal derangements in the elbow joint, computed tomography (CT) arthrography and MR arthrography have largely replaced it [12]. Bone scintigraphy is sensitive to early osseous diseases, which may be radiographically occult, but bone scans lack specificity, often necessitating additional imaging studies for complete evaluation [1]; in the elbow, scintigraphy may be used evaluating athletes with suspected stress injuries [13], although MRI is a more comprehensive examination in this population.

Elbow sonography can image many of the soft tissues of the elbow [14,15]. Ultrasound can show elbow effusions [16], bursitis [17,18], nerve abnormalities [19,20], and tendon abnormalities [3,4,21,22] in adults, as well as cartilage and soft tissue abnormalities in the infant elbow [23]. However, MRI is probably more sensitive than sonography for demonstrating elbow effusions [16] and lateral epicondylitis [24]. Dynamic ultrasound examination may be useful for elbows with torn ulnar collateral ligaments [25,26] or snapping of the distal triceps [19], and arthrosonography following intra-articular saline injection can be used to search for loose bodies [27]. Furthermore, sonography can guide diagnostic and therapeutic injections [18].

Elbow CT is most frequently used to evaluate and prognosticate complex fractures in children and adults [28-30], to visualize the articular surfaces [31], and for surgical planning [3], especially with multiplanar and surface-rendered reformatting of the data. When combined with single-contrast or double-contrast arthrography, CT is an effective test for intra-articular bodies [7,32-34], symptomatic synovial folds [32], and the staging of chondral and osteochondral infractions [1,33].

Lastly, arthroscopy, an invasive procedure, provides direct visualization of the internal structures of the elbow joint [35, 36], and can be use for therapeutic as well as diagnostic purposes [37].

While MRI is often the most sensitive, noninvasive diagnostic test for detecting anatomic abnormalities of the elbow, its findings may be misleading if not closely correlated with the clinical history, physical examination, physiologic tests such as nerve conduction analysis and electromyography, and other imaging studies. Adherence to the following guidelines will enhance the probability of detecting clinically important abnormalities.

II. QUALIFICATIONS AND RESPONSIBILITIES OF PERSONNEL

See the [ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#).

III. INDICATIONS

A. Primary indications for MRI of the elbow include, but are not limited to, diagnosis, exclusion, and grading of suspected:

1. Ligament disorders (ulnar collateral, lateral ulnar collateral, radial collateral, and annular ligaments): strains, partial and complete tears [12,38-48]. †
2. Disorders of the flexor and extensor tendon origins (epicondylitis): partial and complete tears, tendonopathy [24,48-52]. *
3. Distal biceps tendon disease: partial and complete tears, tendonopathy [46,48,53-56].
4. Distal triceps tendon disease: partial and complete tears, tendonopathy, snapping, subluxation [46,48,57-59].
5. Muscle and myotendinous injuries [46].
6. Occult fractures [60-62].
7. Osteochondritis dissecans [5,6,12,44,46,62-66]. *†
8. Cartilage lesions: chondral fractures and flaps, chondromalacia, degenerative chondrosis [12,46,65,67]. †
9. Joint effusions and inflammatory or proliferative synovitis [16,42,68-70]. *
10. Intra-articular bodies: chondral, osteochondral, osseous [7,12,34,44,46,64-66]. †
11. Symptomatic plicae, synovial folds, and elbow menisci [12,71]. †
12. Olecranon and bicipitoradial bursitis: septic, traumatic, crystal-induced, inflammatory [17,42,46,70,72,73]. *
13. Marrow abnormalities: bone contusions, osteonecrosis, marrow edema syndromes, stress fractures [13,62,64,74]. *
14. Peripheral nerve disorders: entrapment, compression, cubital tunnel syndrome, muscle denervation [46,48,75-80]. *
15. Congenital and developmental abnormalities [81].
16. Neoplasms of bone, joint, or soft tissue [82]. *
17. Infections of bone, joint, or soft tissue [42]. *
18. Proximal forearm disorders [78,83].

B. MRI of the elbow may be indicated to further clarify and stage conditions diagnosed clinically and/or suggested by other imaging modalities, including but not limited to:

1. Arthritides: inflammatory, infectious, neuropathic, degenerative, crystal-induced, post-traumatic [42,68]. *
2. Primary and secondary bone and soft tissue tumors [82].* See also the [Practice Guideline for the Performance and Interpretation of Magnetic](#)

Resonance Imaging (MRI) of Bone and Soft Tissue Tumors.

3. Fractures and stress fractures [4,47,60,61,62,65,84,85].

C. MRI of the elbow may be useful to evaluate specific clinical scenarios, including but not limited to:

1. Prolonged, refractory, or unexplained elbow pain. †
2. Sports injuries, especially in throwing athletes [13,38,39,45,46,62,74,86,87]. †
3. Elbow instability: acute, recurrent, chronic [41,47,88]. †
4. Painful elbow snapping or mechanical symptoms [15,58,59,71].
5. Refractory tennis elbow [48,50,52].
6. Limited or painful range of motion, or contracture [89].
7. Unexplained elbow swelling, mass, or atrophy [82]. *
8. Patients for whom diagnostic or therapeutic arthroscopy or elbow surgery is planned [45]. †
9. Patients with recurrent, residual, or new symptoms following elbow surgery. †

* Conditions in which intravenous (IV) contrast may be useful.

† Conditions in which intra-articular contrast (performed by direct intra-articular injection or indirect joint opacification following IV administration) may be useful.

IV. SAFETY GUIDELINES AND POSSIBLE CONTRAINDICATIONS

See the [ACR Practice Guideline for Performing and Interpreting Magnetic Resonance Imaging \(MRI\)](#) and the ACR White Paper on Magnetic Resonance Safety¹.

Peer-reviewed literature pertaining to MR safety should be reviewed on a regular basis [90,91].

V. SPECIFICATIONS OF THE EXAMINATION

The supervising physician must have complete understanding of the indications, risks, and benefits of the examination, as well as alternative imaging procedures. The physician must be familiar with potential hazards associated with MRI, including potential adverse reactions to contrast media. The physician should be familiar with relevant ancillary studies that the patient may have undergone. The physician performing MRI

¹ In 2007 the following updated version was published: ACR Guidance Document for Safe MR Practices. AJR 2007;188:1-27.

interpretation must have a clear understanding and knowledge of the anatomy and pathophysiology relevant to the MRI examination.

The written or electronic request for MRI of the elbow should provide sufficient information to demonstrate the medical necessity of the examination and allow for its proper performance and interpretation.

Documentation that satisfies medical necessity includes 1) signs and symptoms and/or 2) relevant history (including known diagnoses). Additional information regarding the specific reason for the examination or a provisional diagnosis would be helpful and may at times be needed to allow for the proper performance and interpretation of the examination.

The request for the examination must be originated by a physician or other appropriately licensed health care provider. The accompanying clinical information should be provided by a physician or other appropriately licensed health care provider familiar with the patient's clinical problem or question and consistent with the state's scope of practice requirements. (ACR Resolution 35, adopted in 2006)

The supervising physician must also understand the pulse sequences to be employed and their effect on the appearance of the images, including the potential generation of image artifacts. Standard imaging protocols may be established and varied on a case-by-case basis when necessary. These protocols should be reviewed and updated periodically.

A. Patient Selection

The physician responsible for the examination shall supervise patient selection and preparation and be available in person or by phone for consultation. Patients shall be screened and interviewed prior to the examination to exclude individuals who may be at risk by exposure to the MR environment.

Certain indications require administration of intravenous (IV) contrast media. IV contrast enhancement should be performed using appropriate injection protocols and in accordance with the institution's policy on IV contrast utilization. (See the [ACR Practice Guideline for the Use of Intravascular Contrast Media](#).)

Patients suffering from anxiety or claustrophobia may require sedation or additional assistance. Administration of moderate sedation may be needed to achieve a successful examination. If moderate sedation is necessary, refer to the [ACR Practice Guideline for Adult Sedation/Analgesia](#) or the [ACR Practice Guideline for Pediatric Sedation/Analgesia](#).

B. Facility Requirements

Appropriate emergency equipment and medications must be immediately available to treat adverse reactions associated with administered medications. The equipment and medications should be monitored for inventory and drug expiration dates on a regular basis. The equipment, medications, and other emergency support must also be appropriate for the range of ages and sizes in the patient population.

C. Examination Technique

Elbow MRI can be performed using a variety of magnet designs (closed or open) and field strengths (low, medium, or high), including dedicated, extremity-only scanners [51, 92]. On lower field systems, however, the lower signal-to-noise ratio (SNR) may necessitate modifications in the imaging parameters to prevent image degradation [93, 94]. For example, the number of signals averaged can be increased, at the expense of longer imaging times and increased risk of involuntary patient motion [94,95]. Alternatively, the voxel size can be increased (by a combination of larger field of view (FOV), thicker slices, and/or decreased matrix) at the expense of spatial resolution. Fat suppression techniques that rely on the difference between fat and water frequencies (chemical shift) are unreliable at low field strength, and substituting short-TI inversion recovery (STIR) images may be necessary.

Regardless of system design, a local receiver coil is mandatory to maximize the SNR [96]. In general, the coil size should closely approximate the size of the elbow [97]. Thus, a wrist coil may be appropriate for a small child's elbow, while an adult who cannot completely straighten the elbow may require a knee coil [62]. Circumferential, cylindrical coils — constructed in saddle, birdcage, or phased array configurations — provide the most homogenous receptive field [47,98]. However, many cylindrical coils are too large to fit at the side of a supine patient [98]. Other choices include an anterior neck, shoulder, or flexible coil, or a pair of surface coils joined in a Helmholtz configuration [12,47,62,98]. Because it must be oriented perpendicular to the B_0 magnetic field, elbow MRI can only utilize a solenoid coil on a low field system with a vertically oriented B_0 field [94].

Patient positioning for elbow MRI is more difficult than for other joints [99]. The position chosen for the patient and arm also limits the available coil choices. Lying prone with the affected arm overhead allows the elbow to be placed near the magnet isocenter, where the field is most homogeneous. Additionally, the prone position may be easier to tolerate for some patients with severe claustrophobia [100]. Nevertheless, this position is uncomfortable for many patients, resulting in involuntary

motion and associated imaging artifacts [62,94,99]. Having the patient pronate the forearm may alleviate some discomfort, but this position may distort the anatomy of the collateral ligaments and tendons in the coronal plane [47,62,94]. Conversely, lying supine with the affected elbow at the side is more comfortable for most patients, but this position places the elbow towards the side of the magnet where the field is less homogeneous, affecting image quality and the ability to achieve effective chemical fat suppression. Furthermore, many cylindrical coils are too large to place alongside a supine patient [98]. A third position for elbow MRI is laying the patient on the side with the elbow overhead [101]. The patient should extend the elbow as much as possible for routine MRI [94]. However, for specific indications, performing part of the examination with the elbow flexed assists in diagnosis. Full elbow flexion is often necessary to demonstrate snapping of the distal triceps or dislocation of the ulnar nerve [59,101]. The contents and size of the cubital tunnel may be easier to visualize with elbow flexion [88]. Lastly, elbow flexion with forearm supination (achievable with the patient prone and the arm overhead) allows imaging of the entire distal biceps tendon in one long-axis plane [102].

Elbow MRI should usually include images in three imaging planes [47,62,88]. Short-axis (transverse) images, perpendicular to the humerus and forearm bones, should extend distally to include the radial tuberosity [62]. Together with the sagittal images, the transverse images are important for grading abnormalities of the distal biceps tendon [54,53]. Coronal and sagittal images need to be prescribed from the transverse images, parallel and perpendicular respectively to the epicondylar axis of the distal humerus [12,47,94]. Some practices will also angle the coronal images posteriorly by 2 to 30 degrees (either by using the sagittal images as a second localizer or by flexing the elbow slightly) to better show the collateral ligaments [40,62,88]. When a severe flexion contracture is present, acquiring separate transverse and coronal images for the humerus and forearm bones may be necessary; alternatively, curved coronal reformatted images can be created from sagittal images 3D gradient-recalled images [89].

Accurate diagnosis of elbow disorders requires high spatial resolution. The FOV should be 10 to 16 cm [47,62,98,99]; if the coil provides a high enough SNR to support it, a FOV at the low end of this range is desirable [98]. Thin slices (1.5 to 4 mm thickness) are also necessary; on most systems, slice thickness less than 2 to 3 mm requires a 3D gradient-echo sequence. For 2D images, an interslice gap no more than 33% of the slice width can increase coverage and decrease signal loss due to cross talk [103] but should not impair complete visualization of the intra-articular structures. The imaging matrix should balance intravoxel SNR with desired in-plane spatial resolution but should be at least 256 steps in

the phase and frequency encoding directions. Smaller pixels are preferred, but the available SNR limits the attainable resolution [94]. High-resolution images are especially important for evaluating the collateral ligaments when the MRI is performed without arthrography [43,104]. Depending on the size of the elbow, using a rectangular FOV can save imaging time without sacrificing in-plane resolution [99].

A wide variety of pulse sequences — conventional spin-echo, fast (turbo) spin-echo, and gradient-recalled — is available for elbow MRI. The choice of sequences, like other aspects of the imaging protocol, can be tailored to optimize the examination to answer the specific clinical questions [94,99], and may vary due to local preferences. A typical imaging protocol will be composed of several pulse sequences. The exact TR, TE, and flip angle chosen will depend on the field strength of the magnet and the desired relative contrast weighting. T1-weighted sequences are useful for characterizing marrow abnormalities [99], various stages of hemorrhage [105], and muscle disorders [106]. T2-weighted images can identify tendon degeneration [50,52,99] as well as muscle and soft tissue edema [99]. Including at least one T2-weighted sequence with fat suppression (or a STIR sequence) will increase the sensitivity of the examination for marrow and soft tissue edema [62]. Some practices use high-resolution long TR, short effective-TE (proton-density-weighted) fast spin-echo images to examine the collateral ligaments [104, 43]. Most elbow imaging protocols will combine short-TE (proton-density-weighted or T1-weighted) images and fluid-sensitive (T2-weighted or STIR) images [88]. An additional option is the use of gradient-recalled pulse sequences. Two-dimensional T2*-weighted images can be used for the diagnosis of intra-articular loose bodies [12,101] and ligament tears [99], or to identify hemosiderin in disorders such as pigmented villonodular synovitis [69]. Gradient-echo imaging performed in 3D mode, with volume acquisition of data, can create thin, contiguous sections. Images with thin slices (2 mm or less) are useful for analyzing the elbow tendons [49], physeal injuries in children [84], and the collateral ligaments in patients with elbow instability or throwing injuries [41,47,84,87,88,99]. However, susceptibility artifacts severely affect gradient-recalled images, limiting their use in postoperative elbows [47,62], where microscopic metal shavings are often present.

T1-weighted images are also used when IV contrast is administered, or when MR arthrography is done with gadolinium-based contrast [64,101]. Intravenous contrast may be helpful in the diagnosis of bursitis [70], tendonopathy [51], osteochondritis dissecans [64], and tumors and inflammation [101]. Elbow MR arthrography can be performed by direct injection of saline or dilute gadolinium into the joint [12,101] or by indirect diffusion

of contrast into the joint following IV administration [107]. Exercising the elbow and a delay of 10 to 15 minutes after IV injection will enhance joint opacification for indirect MR arthrography [107]. Direct or indirect MR arthrography can be used to evaluate the elbow ligaments [39,43,44,62,104,108] and articular cartilage [67], and to stage osteochondritis dissecans and identify intra-articular bodies [44,62,101]. While fat-suppressed T1-weighted images are typically used for MR arthrography, at least one additional T2-weighted sequence needs to be performed to detect pathology that does not communicate with the joint [12,39,43,62,107]. Additionally, at least one T1-weighted sequence without fat suppression is useful for evaluating the bone marrow and characterizing soft tissue lesions.

Suppressing the signal from fat may enhance the diagnostic yield of some pulse sequences [97]. Fat suppression can be performed using spectrally selective RF pulses, a phase-dependent method (e.g., the Dixon technique), or a STIR sequence [109-111]. The latter technique may be necessary on low-field systems. Adding fat suppression to T2-weighted images (or using a STIR sequence) increases the conspicuity of subtle marrow and soft tissue edema [62]. Additionally, fat suppression is a useful adjunct to T1-weighted images when IV contrast is used, or when MR arthrography is performed [112], especially indirect MR arthrography, because of the inherently low gadolinium concentration in the elbow joint achieved after IV injection [107].

Various techniques can minimize artifacts that reduce imaging quality. Aliasing is usually not a problem when the elbow is imaged over the head. However, with the elbow at the patient's side, phase-encoding in the left-to-right direction should be avoided; if that is not possible, phase oversampling should be used to prevent wraparound artifact [113]. Presaturation pulses or gradient moment nulling will reduce ghosting artifacts from flowing blood and other periodic motion [113,114]. Chemical shift artifact is most severe at high field strengths and may necessitate an increase in the receiver bandwidth [95,113]. Susceptibility artifacts, which originate from heterogeneity of the local field, are also more severe at higher field strengths, in the presence of metallic implants, and when using gradient-recalled pulse sequences. Reducing the voxel size by increasing the imaging matrix and/or decreasing the slice thickness and FOV will help reduce the magnitude of susceptibility artifacts [113].

It is the responsibility of the supervising physician to determine whether additional or unconventional pulse sequences and imaging techniques confer added benefit for the diagnosis and management of the patient. Examinations that employ techniques not approved by the Food and Drug Administration, such as the intra-articular

injection of gadolinium chelates (direct MR arthrography) [115] can be considered when they are judged to be medically appropriate.

VI. DOCUMENTATION

Reporting should be in accordance with the [ACR Practice Guideline for Communication of Diagnostic Imaging Findings](#).

At a minimum, the report should address the condition of the major elbow ligaments and tendons and the articular surfaces, as well as any abnormalities in the surrounding structures. In selected cases, a description of findings in the bone marrow, synovium, muscles, neurovascular structures, and subcutaneous tissue would be appropriate. The report should use standard anatomic nomenclature and precise terms for describing identified abnormalities, whenever possible.

VII. EQUIPMENT SPECIFICATIONS

The MRI equipment specifications and performance shall meet all state and federal requirements. The requirements include, but are not limited to, specifications of maximum static magnetic strength, maximum rate of change of the magnetic field strength (dB/dt), maximum radiofrequency power deposition (specific absorption rate), and maximum acoustic noise levels.

VIII. QUALITY CONTROL AND IMPROVEMENT, SAFETY, INFECTION CONTROL, AND PATIENT EDUCATION

Policies and procedures related to quality, patient education, infection control, and safety should be developed and implemented in accordance with the ACR Policy on Quality Control and Improvement, Safety, Infection Control, and Patient Education appearing elsewhere in the ACR Practice Guidelines and Technical Standards book.

Specific policies and procedures related to MRI safety should be in place along with documentation that is updated annually and compiled under the supervision and direction of the supervising MRI physician. Guidelines should be provided that deal with potential hazards associated with the MRI examination of the patient as well as to others in the immediate area [90,91,116]. Screening forms must also be provided to detect those patients who may be at risk for adverse events associated with the MRI examination [117].

Equipment monitoring should be in accordance with the [ACR Technical Standard for Diagnostic Medical Physics Performance Monitoring of Magnetic Resonance Imaging \(MRI\) Equipment](#).

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