

MRI is valuable for mass localization and evaluation because of its multiplanar capabilities and soft-tissue detail. While in many instances the imaging findings may not be specific, MRI can be very sensitive. The technique used plays a vital role in the pathway to the differential diagnosis and staging of a mass lesion by defining the precise anatomic involvement, relationships, and intrinsic characteristics.

IMAGING OF THE ELBOW

As in routine imaging of the elbow, a dedicated extremity coil is preferred. The sequences should include T_1 - and T_2 -weighted sequences for tissue characterization. Fat-suppression images should also be included to increase sensitivity as well as for possible fat tissue characterization. Images should be obtained in at least two and preferably all three planes for anatomic demonstration and involvement. The transverse plane should always be included. Additional long axis planes would include sagittal for antero-posterior masses and coronal for medio-lateral masses; if possible, both are generally helpful. T_1 -weighted images are vital in tumor evaluation because of the anatomic soft tissue and cortical detail and for demonstration of fat or hemorrhage components. It is this anatomic and tissue definition that may aid the diagnosis or in determining the diagnostic category, in addition to providing a map for possible surgical management. A fat-saturated T_2 -weighted or STIR (short-tau inversion recovery) sequence is also recommended. STIR sequences should be substituted for the fat-saturated sequences to achieve more homogeneous fat suppression when field uniformity may be poor. With lower-field scanners, where fat saturation sequences may not be available, STIR sequences generally still provide good fat suppression. The fat-suppressed longer T_E (T_2 -weighted) and STIR sequences are highly sensitive to marrow edema. A T_2 -weighted sequence without fat suppression in one of the three planes is helpful to assist in demonstrating true high-signal fluid in a cystic or necrotic lesion (Kneeland, 1997; Steinbach et al., 1997a).

Table A27.2.1 lists the hardware necessary to perform the procedure, along with appropriate parameters. The available gradient strength will depend on the scanner, and the echo times given in other tables below may be varied accordingly (the smaller the gradient strength, the longer the echo time for a particular scan).

In summary, our standard protocol consists of coronal and sagittal T_1 -weighted and fat-saturated T_2 -weighted (or STIR) images, transverse proton density- and T_2 -weighted images, as detailed below. Total exam time is ~25 min.

NOTE: Be sure that technologists and nurses have immediate access to any emergency equipment that may be relevant to a given study, or that may be needed for a particular patient, such as crash carts or oxygen.

Table A27.2.1 Equipment Parameters for MRI of the Elbow

Coil type	Phased array extremity coil
Gradient coil strength	25 mT/m (or whatever the system permits)
Cardiac gating	No
Peripheral gating	No
Respiratory gating	No
Oxygen	No
Motion cushions	Useful
Use of contrast agent	No (but used in Alternate Protocol)

BASIC PROTOCOL

Contributed by Jana Crain and Charles Ho

Current Protocols in Magnetic Resonance Imaging (2003) A27.2.1-A27.2.10

Copyright © 2003 by John Wiley & Sons, Inc.

Elbow

A27.2.1

Supplement 9

Set up patient and equipment

1. Interview (screen) the patient to ensure that there are no contraindications for the MRI exam such as cardiac pacemakers, cerebral aneurysm clips, biostimulators, and metallic bodies within the orbit, or other electronic devices sensitive to magnetic fields. Question the patient regarding medical conditions that may require emergency care or equipment, in addition to conditions that would inhibit the patient from being able to complete the exam.

Generally, standard screening forms (see APPENDIX 1) are used for all patients scanned in a magnetic resonance system.

The presence of any ferromagnetic metals may be a health hazard to the patient when he or she is inside the magnet, and will also affect the imaging. If in doubt as to the exact composition of the items, it is best to exclude patients with any metal implants; see Shellock (2001) for discussion of what implants may be safely scanned using magnetic resonance. Orthopedic hardware is not a contraindication. However, ferromagnetic and even nonferromagnetic material in this hardware will produce artifacts that may degrade the exam. Adjustments to the technique may be made as discussed below.

Patients may be accompanied into the magnet room by a friend or family member, who can sit in the room during the scan and comfort the patient as needed. This companion must be screened as well to ensure the absence of loose metal objects on the body or clothing.

2. If the procedure is a research protocol, have the patient sign any necessary consent forms.
3. Have the patient remove all jewelry and clothing items or accessories that may contain metal and change into a gown to eliminate the presence of any metal that might be found in clothing. Remove pants due to the positioning of the arm adjacent to the hip.
4. Have the patient wash off any mascara and other makeup to avoid local tissue heating and image artifacts.
5. Inform the patient about what will occur during the procedure, what he or she will experience while in the magnet, and how to behave, including the following:
 - a. If earplugs or headphones are used to protect the ears from the loud sounds produced by the gradients, the patient will be asked to wear these, but will be able to communicate with you at any time during the imaging.
 - b. Establish a method of communication with the patient using either an intercom or signaling device.
 - c. In order to obtain good results, the patient should not talk, and should avoid or minimize other movement, during each scan—i.e., as long as the banging sounds continue. Between scans, talking is allowed in most cases, but should be avoided when comparative positional studies are being performed; the patient will be informed when this is the case.
 - d. Nevertheless, the patient may call out at any time if he or she feels it necessary.
6. Tape a surface marker (a cod liver oil or vitamin E pill) over the symptomatic site or palpable abnormality. Do not compress a superficial mass.

The cod liver oil pill shows up better on STIR sequences.

7. Have the patient lie supine with the forearm in supination at his or her side. Place the elbow in full extension into the RF coil with the antecubital fossa in the center of the coil; the patient's arm (not necessarily the body) should be straight and parallel to the scanning table; the arm will be parallel to the main field for a cylindrical magnet and

Table A27.2.2 Primary Clinical Imaging Parameters for Sequence 1 (Localizer)

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Three planes (if unavailable use transverse plane)
Central slice or volume center	Center of mass
Echo time (T_E)	5 msec
Repeat time (T_R)	15 msec
Flip angle (FA)	40°
Fields of view (FOV_x , FOV_y)	200 mm, 200 mm (varies with the mass)
Resolution (Δx , Δy)	0.78 mm, 1.56 mm
Number of data points collected (N_x , N_y)	256, 128
Slice thickness (Δz)	5 mm
Number of slices	9 (3 per plane)
Slice gap	1.5 mm
Number of acquisitions (N_{acq})	1
Scan time	23 sec

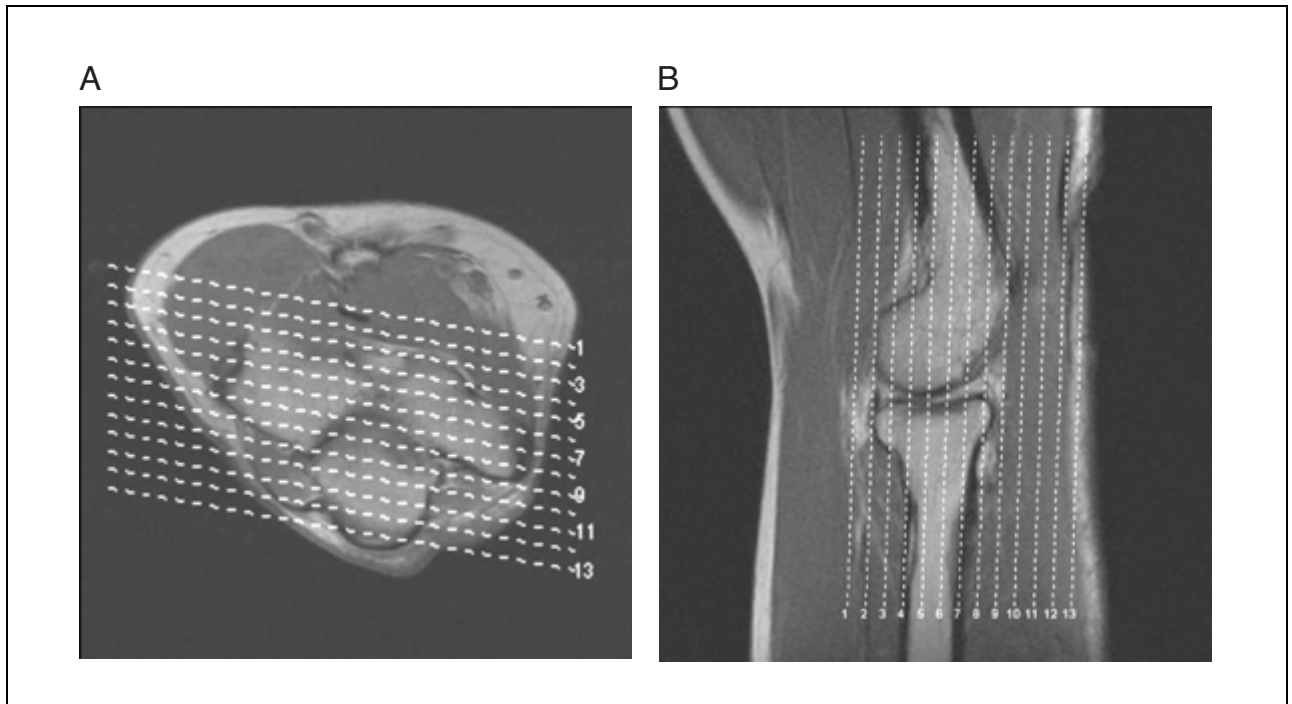


Figure A27.2.1 (A) Transverse scout for coronal images. Oblique coronal images are obtained parallel to a line connecting the humeral condyles anteriorly. (B) Sagittal scout for coronal images. Oblique coronal images are obtained parallel to a line along the long axis of the upper arm and forearm in the sagittal plane.

perpendicular to the main field for a vertical-field magnet. Place sandbags on the arm and lateral to the arm in order to prevent potential motion of the arm.

A small-angle sponge may be placed under the hand/forearm for very slight flexion of the elbow joint, which may allow for more comfort and therefore reduce potential motion.

- Advance the scan table until the centering light is at the center of the RF coil. Evaluate for right/left and anterior/posterior offsets and use these values for localizer setup. Advance the patient to the isocenter of the magnet.

Elbow

A27.2.3

Table A27.2.3 Primary Clinical Imaging Parameters for Sequence 2 (Coronal T_1 -Weighted)

Patient position	Supine
Scan type	Fast spin echo (FSE)
Imaging plane (orientation)	Coronal oblique
Central slice or volume center	Center of mass
Echo time (T_E)	17 msec
Echo train length (ETL)	3
Repeat time (T_R)	493 msec
Flip angle (FA)	180 ^{°a}
Fields of view (FOV _x , FOV _y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.54 mm
Number of data points collected (N_x , N_y)	256, 204 ^b
Slice thickness (Δz)	3.5 mm
Number of slices	16
Slice gap	0.4 mm
Number of excitations (NEX)	2 ^c
Number of acquisitions (N_{acq})	2
Scan time	3 min, 24 sec

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

^bAn additional 50% phase oversampling is applied.

^cThe number of concatenation is set to be 2. This means that only half of the total slices will be excited during a given repeat time.

Table A27.2.4 Primary Clinical Imaging Parameters for Sequence 3 (Coronal STIR)

Patient position	Supine
Scan type	Inversion recovery, fast spin echo
Imaging plane (orientation)	Coronal oblique
Central slice or volume center	Center of mass
Echo time (T_E)	30 msec
Echo train length (ETL)	7
Repeat time (T_R)	4100 msec
Inversion time (T_I)	140 msec
Flip angle (FA)	180°
Fields of view (FOV _x , FOV _y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.54 mm
Number of data points collected (N_x , N_y)	256, 205 ^a
Slice thickness (Δz)	3.5 mm
Number of slices	16
Slice gap	0.4 mm
Number of acquisitions (N_{acq})	1
Scan time	3 min, 45 sec

^aAn additional 80% phase oversampling is applied.

Once this step has been performed, so long as the patient does not move on the table, the table itself can be moved and then returned to the same position as before without jeopardizing the positioning of one scan relative to another.

- If the patient is unable to lie still, provide an appropriate sedative.

Sequence 1: Localizer

- Run the localizer (scout) to ensure the correct location of the elbow in three orientations using the imaging parameters in Table A27.2.2.

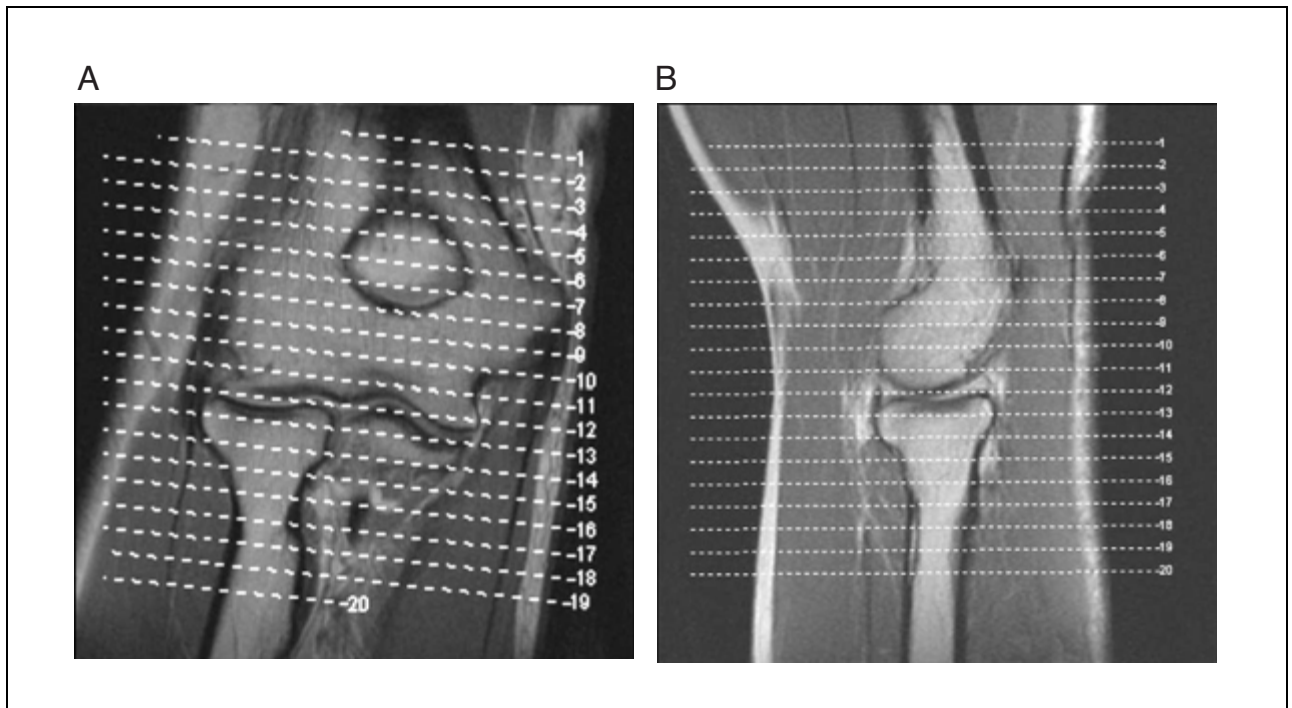


Figure A27.2.2 (A) Coronal scout for setting up transverse images. Transverse images should be obtained tangentially to the humeral condyle surface. Images may need to extend beyond routine parameters to include the entire mass lesion. (B) Sagittal scout for planning transverse images, which should be obtained orthogonally to the long axis of the elbow in the sagittal plane.

Table A27.2.5 Primary Clinical Imaging Parameters Sequence 4 (Transverse PD- and T_2 -Weighted)

Patient Position	Supine
Scan type	Fast spin echo, dual echo (PD- and T_2 -weighted)
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of mass
Echo time (T_E)	15 msec and 92 msec
Echo train length (ETL)	5
Repeat time (T_R)	3000 msec
Flip angle (FA)	150° ^a
Fields of view (FOV_x , FOV_y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.43 mm
Number of data points collected (N_x , N_y)	256, 256 ^b
Slice thickness (Δz)	3 mm
Number of slices	16
Slice gap	0.3 mm
Number of acquisitions (N_{acq})	1
Scan time	~5 min

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90° .

^bAn additional 80% phase oversampling is applied.

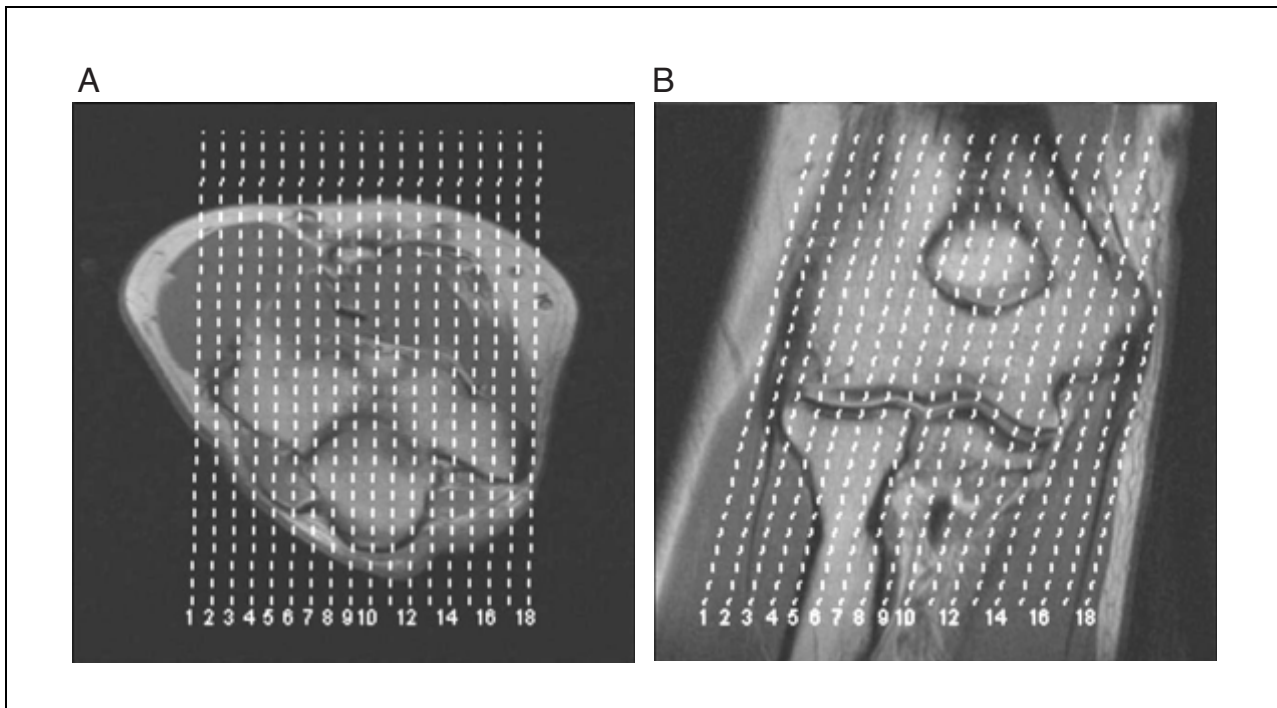


Figure A27.2.3 (A) Transverse scout for setting up sagittal images. Sagittal images are obtained perpendicular to coronal plane. The first and last images should include the epicondyle tips. (B) Coronal scout for planning sagittal images. Sagittal images should be parallel to the long axis of the elbow in the coronal plane of the scout image.

Table A27.2.6 Primary Clinical Imaging Parameters for Sequence 5 (Sagittal T_1 -Weighted)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Center of mass
Echo time (T_E)	17 msec
Echo train length (ETL)	3
Repeat time (T_R)	493 msec
Flip angle (FA)	180 ^{oa}
Fields of view (FOV_x , FOV_y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.54 mm
Number of data points collected (N_x , N_y)	256, 204 ^b
Slice thickness (Δz)	3.5 mm
Number of slices	16
Slice gap	0.4 mm
Number of excitations (NEX)	2 ^c
Number of acquisitions (N_{acq})	2
Scan time	3 min, 24 sec

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

^bAn additional 50% phase oversampling is applied.

^cThe number of concatenation is set to be 2. This means that only half of the total slices will be excited during a given repeat time.

Table A27.2.7 Primary Clinical Imaging Parameters for Sequence 6 (Fat-Suppressed T_2 -Weighted)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Center of mass
Echo time (T_E)	44 msec
Echo train length (ETL)	5
Repeat time (T_R)	3000 msec
Flip angle	180° ^a
Fields of view (FOV_x , FOV_y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.43 mm
Number of data points collected (N_x , N_y)	256, 256 ^b
Slice thickness (Δz)	3.5 mm
Number of slices	20
Slice gap	0.4 mm
Number of acquisitions (N_{acq})	1
Fat suppression	Yes
Scan time	4 min, 53 sec

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

^bAn additional 80% phase oversampling is applied.

Sequence 2: Coronal T_1 -weighted

11. Use the localizer images to center at the joint line. Prescribe off transverse or sagittal scout images, in order to obtain coronal images (see Fig. A27.2.1). Run sequence 2 according to the parameters in Table A27.2.3.

Refer to the sample images in Figures A27.2.1A and B.

Sequence 3: Coronal STIR

12. Run sequence 3 according to the parameters in Table A27.2.4.

Sequence 4: Transverse proton density weighted and T_2 -weighted

13. Prescribe off coronal or sagittal scout images in order to obtain transverse images (see Fig. A27.2.2).
14. Run sequence 4 according to the parameters in Table A27.2.5.

Sequence 5: Sagittal T_1 -weighted

15. Prescribe off transverse or coronal scout images in order to obtain sagittal images (see Fig. A27.2.3).
16. Run sequence 5 according to the parameters in Table A27.2.6.

Sequence 6: Sagittal fat-suppressed T_2 -weighted

17. Run sequence 6 according to the parameters in Table A27.2.7.

Also, an STIR sequence may be substituted for the sagittal fat saturated T_2 -weighted sequence. An STIR sequence may be an alternative fat-suppression sequence, e.g., for mid/low-field scanners for which frequency-selective fat-saturation or fat suppression is not available, or for high-field scanners where field homogeneity is suspect and fat saturation is nonuniform.

ADDITIONAL FAT-SUPPRESSED SEQUENCES AND INTRAVENOUS POST-CONTRAST SEQUENCES

Post-contrast images are optional and in many cases do not contribute to the diagnosis. However, intravenous gadolinium contrast agent may help to differentiate cystic or necrotic lesions from solid masses by defining a nodular or peripheral enhancing component in a cystic lesion versus more diffuse enhancement in a solid mass. In some cases, conversely, initial imaging without contrast agents may reveal the diagnosis and exclude the need for post-contrast imaging. Contrast agents may also be helpful in defining extent of a mass, but at times may be misleading for mass margins, as microscopic tumor involvement may extend beyond the macroscopic enhancing region of a mass. In general, the authors do not use contrast agents for evaluation of a mass lesion.

Standard, single-dose gadolinium contrast agent may be administered as an intravenous injection. Post-contrast T_1 -weighted images (with fat suppression if available) can then be performed in transverse and coronal and/or sagittal planes. Pre-contrast T_1 -weighted images should also be performed for comparison.

If a gadolinium i.v. contrast agent is to be used, the standard protocol is as follows: first, pre-contrast coronal or sagittal T_1 -weighted images (depending on orientation of mass), and transverse proton-density- and T_2 -weighted images, then, post-contrast coronal, sagittal, and transverse T_1 -weighted images with fat suppression. The total scan time with contrast sequences is 30 to 45 min, including injection time.

Materials

- Normal saline (0.9% NaCl), sterile
- Gadolinium-based MR contrast agent (e.g., Magnevist, Omniscan, or Prohance)
- 21- to 23-G butterfly needle

Set up patient and equipment

1. Set up patient as in the Basic Protocol, steps 1 to 6.
2. Access a vein in the forearm not being imaged and, using a 21- to 23-G butterfly needle, establish an intravenous line through which the contrast agent can be injected.

It is preferable to insert the line prior to imaging and to leave the patient in the magnet, so that there is no intervening motion between the scans run before contrast agent injection and those run after injection.

3. Finish setting up the patient by performing steps 7 to 9 of the Basic Protocol.
4. Run sequences 1, 2 (or 5), and 4 in the Basic Protocol.
5. Without removing the patient from the magnet, inject the contrast agent and flush the intravenous line with 10 ml saline solution.

A standard single dose of 0.1 mmol/kg of contrast agent is usually given.

Sequence 7: Transverse fat-suppressed T_1 -weighted

6. Run sequence 7 according to the imaging parameters in Table A27.2.8.

Sequence 8: Coronal fat-suppressed T_1 -weighted

7. Run sequence 8 according to the imaging parameters in Table A27.2.9.

Sequence 9: Sagittal fat-suppressed T_1 -weighted

8. Run sequence 9 according to the imaging parameters in Table A27.2.9.

Table A27.2.8 Primary Clinical Imaging Parameters for Sequence 7 (Transverse Fat-Suppressed T_1 -Weighted)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of joint
Echo time (T_E)	19 msec
Echo train length (ETL)	3
Repeat time (T_R)	699 msec
Flip angle (FA)	150 ^{oa}
Fields of view (FOV_x , FOV_y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.43 mm
Number of data points collected (N_x , N_y)	256, 256 ^b
Slice thickness (Δz)	3 mm
Number of slices	16
Slice gap	0.3 mm
Number of excitations (NEX)	2 ^c
Number of acquisitions (N_{acq})	1
Fat suppression	Yes
Scan time	4 min, 2 sec

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

^bAn additional 100% phase oversampling is applied.

^cThe number of concatenation is set to be 2. This means that only half of the total slices will be excited during a given repeat time.

Table A27.2.9 Primary Clinical Imaging Parameters for Sequence 8 (Coronal and/or Sagittal Fat-Suppressed T_1 -Weighted)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal or sagittal
Central slice or volume center	Center of joint
Echo time (T_E)	19 msec
Echo train length (ETL)	3
Repeat time (T_R)	699 msec
Flip angle	180 ^{oa}
Fields of view (FOV_x , FOV_y)	110 mm, 110 mm
Resolution (Δx , Δy)	0.43 mm, 0.43 mm
Number of data points collected (N_x , N_y)	256, 256 ^b
Slice thickness (Δz)	3.5 mm
Number of slices	16
Slice gap	0.4 mm
Number of excitations (NEX)	2 ^c
Number of acquisitions (N_{acq})	1
Fat suppression	Yes
Scan time	4 min, 2 sec

^aThe system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

^bAn additional 50% phase oversampling is applied.

^cThe number of concatenation is set to be 2. This means that only half of the total slices will be excited during a given repeat time.

COMMENTARY

Background Information

Musculoskeletal tumors of the elbow are unusual. By category, there are benign and malignant soft tissue and osseous masses. More commonly, benign masses occur as a result of acute trauma, chronic overuse, or arthropathy, and may simulate a tumor or more aggressive process. These include a retracted mass of torn tendon tissue, bursal collections, synovial or ganglion cysts, loose bodies, and scar tissue. Post-traumatic myositis ossificans presents as an area of soft-tissue swelling and/or hematoma that eventually undergoes a characteristic ossification pattern and may mimic a tumor. Synovial disorders (such as pigmented villonodular synovitis and synovial chondromatosis), gout, hemophilia, and neuropathic joints frequently present with masses about the joint. The most commonly occurring benign soft tissue tumors include lipomas, vascular tumors such as hemangiomas, and benign neural tumors, all of which often have definitive imaging characteristics and do not require post-contrast imaging. Malignant soft tissue tumors of the elbow are generally sarcomas and include liposarcoma, malignant fibrous histiocytoma, and synovial sarcoma. These tumors have nondefinitive imaging characteristics, but MR imaging may be vital in the evaluation of the extent of soft tissue involvement for tumor staging, as well as post-operative evaluation.

Benign and malignant osseous masses are generally better evaluated on plain film and computed tomography for specificity. However, MR imaging plays an important role in evaluation of soft tissue structures involved and for extent of bone/marrow involvement. The majority of bone tumors (50%) occur in the ulna, with 20% occurring in the radius, 20% in the humerus, and 10% in the soft tissues. Overall, benign osseous tumors are more common. Benign tumors that can occur on the elbow, although unusual, include osteoblastomas, osteochondromas, chondroblastomas, and enchondromas. Additionally, fibrous dysplasia, giant cell tumors, aneurismal bone cysts, and unicameral bone cysts may occur. Subtle MR imaging findings of periostitis, nidus, and marrow edema may diagnose an unsuspected osteoid osteoma. The most common malignant osseous lesion about the elbow is metastasis. Plasmacytomas and multiple myeloma are the most common primary bone tumors, but much more commonly occur in the axial and proximal appendicular skeleton. Other primary malignant bone tumors include osteosarcoma, chondrosarcoma, Ewing's sarcoma, and primary malignant

lymphoma. MR imaging is most useful in delineating and staging these tumors (Ma, 1999; Steinbach et al., 1997a,b).

Critical Parameters and Troubleshooting

Field of view

Masses may extend beyond the normal fields of view (FOV) which may require the FOV to be increased to include all of the abnormality. Alternatively, additional imaging of the proximal humerus or distal forearm may provide the optimal evaluation without the sacrifice of resolution. In these instances, the elbow joint line should be included at the edge of the additional sagittal and/or coronal images to show the extent and location of the mass relative to the joint line.

Contrast

The need for post-contrast imaging is variable, as discussed in the Alternate Protocol.

Anticipated Results

The role of MRI in evaluating masses occurring on the elbow is to define the lesion by its location, intrinsic characteristics, and extent including structures involved. This information will lead the radiologist and the clinician to the diagnosis, differential diagnosis, or diagnostic category. It will also provide preoperative assessment or staging of the elbow when needed.

Acknowledgement

Special thanks to Phillip Becklund, Dr. Rajesh Sethi, and Susan Bybee for their time and contributions.

Literature Cited

- Kneeland, J.B. 1997. MR Imaging of the elbow: Technical considerations. *Magn. Reson. Imaging Clin. N. Am.* 5:439-442.
- Ma, L.D. 1999. Magnetic resonance imaging of musculoskeletal tumors: Skeletal and soft tissue masses. *Curr. Probl. Diagn. Radiol.* 28:29-62.
- Shellock, F.G. 2001. MR Procedures: Health Effects and Safety. CRC Press, Boca Raton, Fla.
- Steinbach, L.S., Fritz, R.C., Tirman, P.F., and Uffman, M. 1997a. Magnetic resonance imaging of the elbow. *Eur. J. Radiol.* 25:223-241.
- Steinbach, L.S., Anderson, S., and Panicek, D. 1997b. MR imaging of musculoskeletal tumors in the elbow region. *MRI Clin. N. Am.* 5:619-653.

Contributed by Jana Crain and Charles Ho
National Orthopedic Imaging Associates
San Francisco, California