MRI of the Post-Operative Meniscus and ACL Graft

BASIC PROTOCOL

Conventional MR imaging has proven valuable in the diagnosis of knee injuries (Carmichael et al., 1997; Maurer et al., 1997). Standard imaging protocols have been less reliable in imaging the postoperative knee than in an unoperated knee, especially for the diagnosis of meniscal tears and the postoperative anterior cruciate ligament (ACL).

Postsurgically, intra-articular injection of contrast media allows improved visualization of recurrent meniscal tears and of meniscal repairs (Applegate et al., 1993). In situations where an ACL graft is not optimally visualized in a conventional MR imaging study and its radiological evaluation is important for the clinical follow-up, an intravenous gadopentate dimeglumine administration is sometimes helpful. A post-contrast sagittal T_1-weighted sequence with fat saturation (Sequence 2) may help to distinguish an ACL graft from the enhancing periligamentous soft tissue synovium. These aforementioned cases represent two indications for application of either intra-articular or intravenous contrast media in a postoperative diagnostic setting.

In the postoperative setting where a metal artifact distorts the image, an artifact-reducing sequence may be helpful (generally a fast spin echo technique with multiple refocusing pulses, i.e., a large-number echo train length).

The parameters provided in this unit apply to a 1.5-T machine and may need to be altered slightly depending on the main magnetic field strength and the equipment manufacturer.

Magnetic resonance imaging scans can be run at a range of different field strengths. The lower signal-to-noise ratio (SNR) inherent in low-field systems means that trade-offs must be made in the field of view, number of excitations (or number of acquisitions), slice thickness, and acquisition matrix size to maintain adequate signal. Whenever the spatial resolution is kept constant, the lower SNR of a low-field system generally results in the need to increase the receiver bandwidth (or increase the number of data points, N_x) and to increase the number of excitations in order to increase the signal. These alterations in protocol result in a longer acquisition time. On high-field systems, a general protocol of four sequences will result in a comprehensive evaluation of the postoperative knee generally in <30 min.

In general, protocols utilizing a short T_E sequence (T_1 or proton density–weighted) and a long T_E sequence (T_2-weighted), especially with fat saturation, are useful in the musculoskeletal system as described below.

Spin-echo imaging techniques (especially fast spin echo with the multiple refocusing pulses) are less prone to artifacts, because the refocusing pulse(s) decreases the field inhomogeneity produced by the metal in and about the postoperative knee. Gradient-echo images are the most sensitive to metallic artifacts, and therefore are infrequently used to evaluate the postoperative knee unless one is specifically searching for loose or foreign bodies where the "blooming"artifact caused by the bodies helps in their detection.

Regardless of the primary disease process suspected clinically, the end result, anatomically and pathologically, of acute injuries is a T_2-weighted prolongation (edema and/or hemorrhage). Therefore, a sensitive T_2-weighted examination is needed, and it is generally felt that a fast spin echo T_2-weighted sequence with fat saturation or short tau inversion recovery (STIR) sequence works best. It should be noted the STIR images are not recommended in the arthrography setting, as a variable degree of contrast saturation can occur.

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Table A23.2.1 Equipment Parameters for Postoperative Knee Imaging

Coil type	Circumferential extremity coil with a send-receive, quadrature, or phase array design
Gradient coil strength	25 mT/m (or whatever the system permits)
Motion cushions	Helpful
Use of contrast agents	Yes

For the diagnosis of postoperative pathology such as recurrent meniscal tear, MR imaging can be performed after the intra-articular injection of paramagnetic contrast (gadopentate dimeglumine–saline mixture as described below) to obtain direct MR arthrography. In the knee after meniscal repair or meniscectomy, this procedure can better verify the presence of recurrent meniscal tears or the presence of mensical healing. Fat saturation techniques are applied because they increase the conspicuity of the contrast in the joint and potential extravasations into relevant locations. These images provide a high signal-to-noise ratio, and offer an excellent separation of the intra-articular gadolinium mixture from the menisci, cartilage, and surrounding soft tissue. Some radiologists obtain standard images before injecting contrast agents, but many, including the authors, do not.

In the diagnostic setting of an ACL reconstruction, the intravenous application of gadopentate dimeglumine along with fat suppression techniques may help to better distinguish an ACL graft from the enhancing periligamentous soft tissue. The intravenous injection adds ~5 min to the time of the procedure. The entire protocol including patient setup takes ~35 to 40 min.

The following four sequences encompass the authors' preferred Basic Protocol.

Table A23.2.1 provides a list of the hardware necessary to perform the procedure, along with appropriate parameters.

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 a crash cart or oxygen.

Materials

Normal saline (0.9% NaCl), sterile
Paramagnetic contrast agent: gadopentate dimeglumine

Set up patient and equipment

1. Interview the patient to ensure that there are no contraindications for the MRI exam such as contrast media allergy, cardiac pacemakers, or other ferromagnetic materials. Find out if the patient has any health conditions that may require the presence of any special emergency equipment during the scanning procedure, or necessitate any other precautions.

   Standard screening forms (see APPENDIX 1) are generally used for all patients scanned in MRI systems.

   Any ferromagnetic metals may be a health hazard to the patient inside the magnet, and may also affect the imaging. If in doubt as to the exact composition of the devices, it is the best to exclude patients with any metal implants; see Shellock (1996) for discussion of what implants may be safely scanned using magnetic resonance.

The patient or volunteer may be accompanied into the magnet by another person, who can sit during the scan and comfort the patient as needed. This accompanying person must be screened as well to ensure the absence of loose metal objects on the body or clothing.

2. If the scan is a research protocol, have the patient sign any necessary consent forms.

3. Ask the patient to remove all jewelry and change into a gown to eliminate any metal that might be found in clothing.

4. Have the patient wash off any mascara and other makeup in order to avoid local tissue heating.

5. Inform the patient of what will happen during the procedure, what he or she will experience while in the magnet, and how to behave, including the following:

   a. If earphones or headphones are used to protect the ears from the loud sounds produced by the magnet, the patient will be asked to wear these, but will be able to communicate with you at any time during the examination.

   b. The patient will be given a safety bell or similar equipment to request assistance at any time (demonstrate how it works).

   c. In order to get good results, the patient should not move or talk during each scan—i.e., as long as the banging sound continues. Between the 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 is necessary.

6. Have the patient positioned comfortably on the table with feet toward the scanner. Inject the appropriate contrast agent:

   a. *For postoperative meniscus imaging (direct, intra-articular):* Dilute paramagnetic contrast agent (gadopentate dimeglumine) with saline in a ratio of 1:100. Inject the mixture into the knee until mild joint distention is produced (usually 40 to 50 ml).

   b. *For intravenous administration in postoperative ACL imaging:* Administer gadopentate dimeglumine intravenously in a dosage of 0.1 mmol per kg of body weight.

   Flush with 10 ml saline after the injection. Either before or right after the patient lies down, set up any monitoring equipment that is to be used.

7. Center the patient in a knee coil at the region where the key information is needed. Make sure that the knee is constrained to prevent motion, especially if high-resolution scans are to be run.

   Generally the patient's knee is fixed in a straight, horizontal, neutral position. For a better visualization of the ACL, some physicians recommend 10° to 15° of outer rotation (Lee et al., 1988). This is less critical as slice thickness decreases (≤4mm).

8. If needed, place a pillow under the patient's head to make him or her more comfortable.

   The comfortable installation of the patient at the beginning of the study is important to limiting motion artifacts. Care should be exercised in positioning the cushions and pads around the knee in the extremity coil to make the examination as comfortable as possible.

9. Use the centering (laser) light to position the injured knee to the lower third of the patella and put the patient into the center of the magnet.

10. If the patient is not able to hold still, provide an appropriate sedative.

Table A23.2.2 Primary Clinical Imaging Parameters for Sequence 1

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Laser light centered on the lower third of the patella
Echo time (T_E)	42 msec
Receiver bandwidth (RBW)	±13.89 kHz
Echo train length (ETL)	8
Repeat time (T_R)	3000 msec
Flip angle (FA)	90°
Field of view (FOV_x, FOV_y)	130 mm, 130 mm
Resolution (Δx, (Δy)	0.51 mm, 0.51 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	4 mm
Number of slices	20
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Tailored RF	Yes
No phase wrap (NPW)	Yes
Fat suppression	Yes; frequency-selective fat saturation, superior and inferior
Scan time	3 min, 23 sec

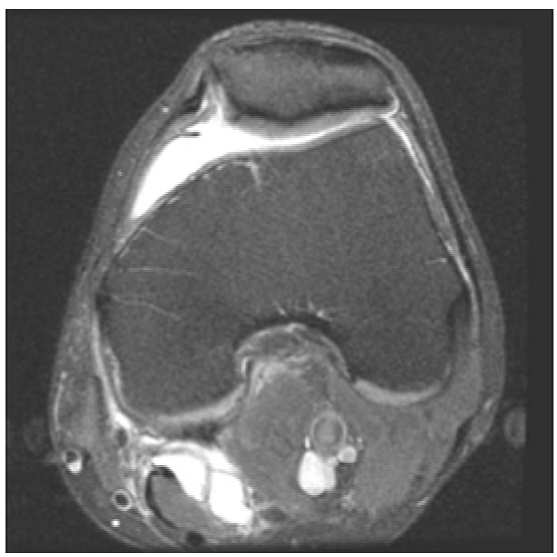

Figure A23.2.1 Fast spin-echo T_2-weighted image with fat saturation (localizer).

Table A23.2.3 Primary Clinical Imaging Parameters for Sequence 2

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Variable bandwidth	Yes
Central slice or volume center	Laser light centered on the lower third of the patella
Echo time (T_E)	Minimum (e.g., 11 msec)
Receiver bandwidth (RBW)	±17.86 kHz
Repeat time (T_R)	650 msec
Flip angle (FA)	90°
Field of view (FOV_x, FOV_y)	140 mm, 140 mm
Resolution (Δx, Δy)	0.55 mm, 0.55 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	4 mm
Number of slices	20–23
Slice gap	0 mm
Number of acquisitions (N_{acq})	2
ZIP 512	Yes
Tailored RF	Yes
No phase wrap (NPW)	Yes
Fat suppression	Yes; frequency-selective fat saturation
Scan time	5 min, 38 sec

Figure A23.2.2 Sagittal spin-echo T_1-weighted image with fat saturation, with intra-articular gadolinium.

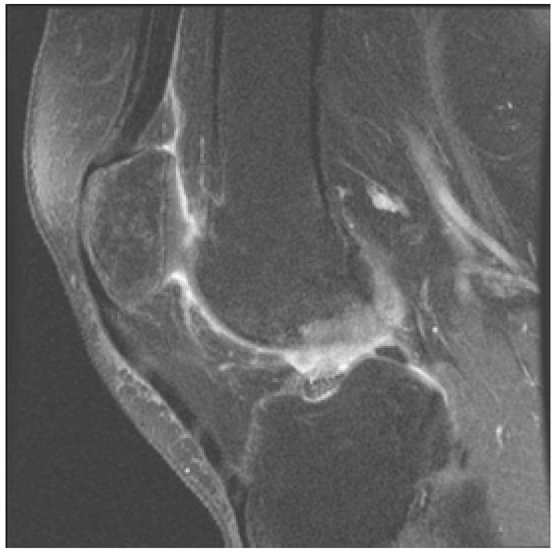

Figure A23.2.3 Sagittal spin-echo T_1-weighted image with fat saturation, with intravenous gadolinium.

Table A23.2.4 Primary Clinical Imaging Parameters for Sequence 3

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Central slice or volume center	Laser light centered on the lower third of the patella
Echo time (T_E)	Minimium (e.g., 14.2 msec)
Receiver bandwidth (RBW)	±15.63 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	130 mm, 130 mm
Resolution (Δx, Δy)	0.41 mm, 0.51 mm
Number of data points collected (N_x, N_y)	320, 256
Slice thickness (Δz)	4 mm
Number of slices	14
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Tailored RF	Yes
No phase wrap (NPW)	Yes
Fat suppression	Yes; frequency selective fat saturation
Scan time	4 min, 20 sec

Figure A23.2.4 Coronal spin-echo T_1-weighted image with fat saturation, with intra-articular gadolinium.

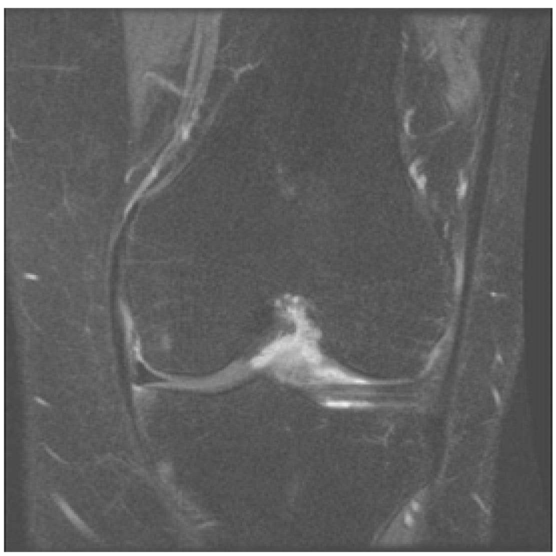

Figure A23.2.5 Coronal spin-echo T_1-weighted image with fat saturation, with intravenous gadolinium.

Table A23.2.5 Primary Clinical Imaging Parameters for Sequence 4

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Central slice or volume center	Laser light centered on the lower third of the patella
Echo time (T_E)	42 msec
Receiver bandwidth (RBW)	±11.36 kHz
Echo train length (ETL)	10
Repeat time (T_R)	3000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	130 mm, 130 mm
Resolution (Δx, Δy)	0.51 mm, 0.51 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	4 mm
Number of slices	14
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Tailored RF	Yes
No phase wrap (NPW)	Yes
Fat suppression	Yes; frequency selective fat saturation
Scan time	2 min, 42 sec

Figure A23.2.6 Coronal fast spin echo T_2-weighted image with fat saturation.

Sequence 1: Transverse fast spin-echo T_2-weighted sequence with fat saturation (localizer)

11. To validate the patient's position, run the localizer (scout scan) to ensure the correct location of the knee and plan the perpendicular (sagittal and coronal) orientations using the imaging sequence given in Table A23.2.2, or similar parameters.

    An example image is shown in Figure A23.2.1.

Sequence 2: Sagittal spin-echo T_1-weighted sequence with fat saturation

12. Bring the sagittal spin-echo T_1-weighted sequence with fat saturation up onto the console. Set the imaging parameters as shown in Table A23.2.3.
13. Let the patient know you are ready, and begin the scan.

    Example images are shown in Figures A23.2.2 and A23.2.3.

Sequence 3: Coronal spin-echo T_1-weighted sequence with fat saturation

14. Bring the coronal spin-echo T_1-weighted sequence with fat saturation up onto the console. Set the imaging parameters as shown in Table A23.2.4.
15. Let the patient know you are ready, and begin the scan.

    Example images are shown in Figures A23.2.4 and A23.2.5.

Sequence 4: Coronal fast spin-echo T_2-weighted sequence with fat saturation

16. Bring the coronal fast spin-echo T_2-weighted sequence with fat saturation up onto the console. Set the imaging parameters as shown in Table A23.2.5.
17. Let the patient know you are ready, and begin the scan.

    An example image is shown in Figure A23.2.6.

COMMENTARY

Background Information

The knee is one of the most frequently injured regions of the body. Injury to the knee menisci and ligaments are common especially in the younger athletic population. Substantial progress has been made in magnetic resonance imaging since its initial application in 1984. MRI is established as the diagnostic procedure of choice, supporting the physical examination and plain X-ray studies for virtually all suspected disorders of the knee. Moreover MRI may serve as the "second" opinion before any surgical intervention.

Imaging of the postoperative menisci

Difficulty in the image evaluation of the postoperative meniscus comes from multiple factors. The assessment is made more difficult by the spectrum of possible postoperative findings in menisci.

The meniscal morphology is distorted after a partial meniscectomy. Shape irregularity may be misinterpreted as a recurrent meniscal tear because, after an injury, the meniscus may never gain its original preinjury signal intensity on the T_1- and proton density–weighted images (Arnoczky et al., 1994).

Furthermore a healing area within the meniscus may appear as a high signal alteration line reaching the articular surface, and may therefore be misinterpreted as a new meniscal tear (Arnoczky et al., 1994). For that reason one of the most reliable parameters in an acute clinical setting—increased signal extending to the meniscal surface on T_1-weighted or proton density–weighted images—is not as valid in the postoperative knee. An approach to overcome these difficulties after meniscus surgery is to administer intra-articular gadolinium in the knee. (Sciulli et al., 1999), which offers several advantages compared to the imaging without contrast media. On conventional T_2-weighted MR images, joint fluid usually has the same signal intensity as granulation tissue and fibrovascular scar. For that reason, healing tears are sometimes indistinguishable from recurrent tears in the meniscal remnant. On T_1-weighted direct-arthrographic images, contrast solution is not mistaken for scar tissue, because its signal intensity is significantly greater as shown in a study by Palmer (1996).

Gadolinium-based contrast material has a lower viscosity compared to synovial fluid and is therefore more likely to be imbibed into a small cleft and highlight the presence of a meniscal tear. Additionally, the use of gadolinium-based contrast material provides imaging with T_1-weighted pulse sequences, with their inherently favorable signal-to-noise ratio. The increased intra-articular pressure that results from applying the contrast medium provides a distension of normally apposed structures, such as edges of a nondisplaced meniscal tear (Sciulli et al., 1999).

Imaging of the postoperative anterior cruciate ligament (ACL)

The appearance of an intact ACL graft has been the subject of multiple studies (Autz et al., 1991; Howell et al., 1991; Rak et al., 1991; Cheung et al., 1992; Yamato et al., 1992; Maywood et al., 1993; Sanchis-Alfonso et al., 1993; Stockle et al., 1998). In these studies, it is commonly accepted that in the immediate postoperative period the graft is of low signal intensity, comparable to that of the patellar tendon. Another consensus is that intact grafts which are more than two years old are low in signal intensity. However, in the perioperative period the appearance of an intact graft is less well defined. Some studies have stated that these grafts could appear low in signal intensity or attenuated with increased signal intensity. The increased signal intensity was considered to be the result of a graft vascularization. Another study applying intravenous contrast material in nonimpinged ACL grafts did not show any revascularization of the graft within the first two postoperative years, whereas other studies showed increased signal intensity within the graft in the first two postoperative years.

Despite the discrepant reports of the appearance on an intact, nonimpinged ACL, one can draw several conclusions. A homogenous ACL graft of low signal intensity in the first two postoperative years is intact. After the perioperative period, increased signal within the graft may be seen within an unimpinged healthy graft, an intact impinged graft, and disrupted grafts.

The indication to give gadopentate dimeglumine in this context is to help distinguish an ACL graft from the enhancing periligamentous tissue on T_1-weighted images with fat saturation.

Critical Parameters and Troubleshooting

Magnetic resonance imaging of the injured knee is a potent and noninvasive tool. The suggested imaging method provides an approach for acquiring a standard set of images that allows a thorough analysis. Even though a reliable protocol has been chosen, some artifacts may potentially occur during the acquisition. The most common and important artifacts that may pose diagnostic difficulties are outlined in the following paragraphs, together with possible solutions.

Magic angle artifact

Near the notch of the knee, the posterior horn of the lateral meniscus slopes upward. This approximates 55° of the external magnetic field and can lead to the magic angle artifact or diffuse increased signal intensity (Peterfy et al., 1994). To overcome the problem, the knee can be imaged in a slightly different position (the authors choose abduction) in order to confidently exclude meniscal tears.

Truncation artifact

This artifact results from undersampling of data, so that interfaces of high and low signal are incorrectly represented on the image. If utilizing a small matrix, the truncation artifact can result in an increased signal intensity through the meniscus which may appear as a tear. Using a larger acquisition matrix (number of data points collected) can minimize the artifact.

Motion artifact

Alternating increased and decreased signal lines occur with motion and can mimic meniscal tear (Mirowitz, 1994). If this is observed it is highly recommended that the affected portion of the examination be repeated and the patient be asked to hold still. Alternatively, mild sedation and anxiolysis with benzodiazepine (e.g., Lorasepam) is possible.

Vacuum phenomenon and ferromagnetic substances

Magnetic susceptibility of intra-articular gas and ferromagnetic substances may produce a low-signal-intensity void, or blooming, especially on gradient echo images. This artifact may be mistaken for a meniscal tear or articular injury. Normal spin-echo or fast spin-echo sequences are much less vulnerable to these artifacts because of the 180° refocusing pulse.

Pulsation artifact

Popliteal artery pulsation artifacts lead to streaks in the MR image. They can be minimized by swapping the phase-encoding and read directions.

Anticipated Results

The goal in studying the postoperative knee is the detection of clinically suspected abnormalities in the follow-up that could lead to an exacerbation by repeat trauma and/or delay a surgical revision.

Routine MR imaging is not reliable for detecting meniscal re-tears. Applegate et al. (1993) showed in a series study of 37 patients, who had either meniscectomy or meniscal repair and were evaluated with both standard MR imaging and with MR arthrography, that the overall accuracy in the postoperative meniscus was 66% when conventional MR imaging was used and 88% with MR arthrography. In patients with an extensive meniscal resection, accuracy was 65% with conventional MRI and 87% with MR arthrography. In patients with only minimal meniscal resection, both methods provided an accuracy of 89%. When only a small meniscal remnant remained, the accuracy was 50% with routine MR imaging and 100% with MR arthrography.

Sciulli et al. (1999) studied a series of 33 patients after meniscal surgery with four different imaging modalities: conventional arthrography, conventional MR imaging, MR arthrography with iodinated contrast material, and MR arthrography with gadolinium-based contrast material. Twelve patients underwent repeat arthroscopy in their follow-up. The gadolinium-enhanced arthrograms provided the most accurate diagnosis when compared with the arthroscopic images. The evaluation of the postoperative meniscus compared to the gold standard (i.e, arthroscopy) was correct in 92%, using MR arthrography with gadolinium-based contrast media, 77% by conventional MR examination, 75% by MR arthrography, and 58% by conventional arthrography.

These studies support the experiences gained with the protocol described in this unit and emphasize the importance of using MR arthrography with gadolinium-based contrast material in patients who have had significant meniscal resections.

As described above (see Background Information), the MRI evaluation of the postoperative ACL was the subject of several different studies revealing discrepant results with regard to the MRI appearance of the graft during follow-up. The reason for giving intravenous gadopentate dimeglumine is that it helps distinguish an ACL graft from the enhancing periligamentous tissue on T_1-weighted images with fat saturation, thus allowing confirmation of its intactness. This approach is supported by a study from Stockle et al. (1998), who showed that in 50% of their patients an accurate assessment of a reconstructed ligament was only possible in the post-contrast images.

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