Rule Out (R/O) Migraine

When imaging patients with headaches, the goals are (1) to rule out a more ominous etiology for their headaches and, when atypical or complicated migraine is suspected, (2) to assess the degree of hemodynamic and parenchymal involvement. The standard images allow other etiologies such as mass lesions to be excluded and an MR venogram can rule out venous sinus thrombosis. Contrast may be helpful in differentiating multiple small metastases, demylinating lesions with inflammatory components, and subcortical infarcts from the nonspecific foci of increased T_2 associated with migraines that do not enhance. Perfusion-weighted imaging allows detection assessment of hemodynamic compromise. Diffusion-weighted imaging, in combination with the standard MR images, allows assessment of parenchymal involvement. The following Basic Protocol can be used for the evaluation of patients. The Alternate Protocol is used for the assessment of cerebral perfusion in patients with visual auras.

STANDARD IMAGING FOR MIGRAINE

BASIC PROTOCOL

In order to perform the optional sequences, perfusion and diffusion studies, a scanner with echoplanar capabilities is required (Table A1.7.1). The standard anatomical MR imaging sequences included in the protocols do not require these faster gradients. The parameters given here are optimized for a 1.5T GE LX system with 11.0 software and may need modification for different software versions, field strengths, or manufacturers.

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. Reactions to contrast agents are rare, but the resources are necessary.

Table A1.7.1 Equipment Requirements for Cerebral Vascular Assessment

Type of system	LX EchoSpeed
Field strength	1.5 T
Software level	11
Magnet type	CX K4
Polarity	Positive
Active gradient shielding	No
Passive gradient shielding	No
Gradient strength (amplitude)	2.4 mT/cm
Slew rate	12 mgauss/cm
SAR (average)	2 W/kg
SAR (max)	8 W/kg
Superior conductive shimming	45 cm
Resistive shimming	No
Active magnetic shielding	No
Maximum noise level	100 db
Type of body coil	High pass
TPS recon system memory	386
Array processor (TPS)	Reflex 100
Computer	LX Octane
Weight limit	350 lb (130.6 kg)

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Materials

Gadolinium-DTPA contrast agent (e.g., Magnevist, Omniscan, Prohance)

Set up patient and equipment

1. Interview (screen) the patient to ensure that he or she has no counterindications such as cardiac pacemakers or other implants containing ferromagnetic materials. Also be sure to find out if the patient has any health conditions that may require the presence of special emergency equipment during the scanning procedure, or necessitate any other precautions. Do not forget to ask if the patient has any drug allergies and document them.

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

   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 (1996) for discussion of what implants may be safely scanned using magnetic resonance.

   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 form.

3. Have the patient 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 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 earphones 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 the technologist at any time during the imaging.
   b. The patient will be given a safety squeeze-bulb or similar equipment to request assistance at any time (demonstrate how this works).
   c. For good results, the patient should not talk, and should avoid or minimize swallowing or other movement, during each scan—i.e., as long as the banging sounds continue. Between scans, talking and swallowing are 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. Have the patient mount onto the table. Either before or right after the patient lies down, set up any triggering devices or other monitoring equipment that is to be used.

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

   Generally the patient's head is fixed so that the head is horizontal (not tilted) and the neck and head lie along the axis of the patient table; other positions may be appropriate depending on the needs at hand.

Table A1.7.2 Rapid Sagittal T_1-Weighted Scout

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Nasion
Echo time (T_E)	Minimum (at least 4.1msec)
Receiver bandwidth (RBW)	15.6 kHz
Repeat time (T_R)	100 msec
Flip angle (FA)	60°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.87 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	128, 128
Slice thickness (Δz)	7 mm
Number of slices	7
Slice gap	2 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	1
Read direction	Anterior–posterior
Scan time	16 sec

8. If needed, place a pillow or other support under the knees to make the patient more comfortable.
9. Use the centering light to position the patient and put him or her into the center of the magnet.

   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 replaced in the same position as before without jeopardizing the positioning of one scan relative to another.

10. If the patient is unable to hold still, provide an appropriate sedative.

Sequence 1: Rapid sagittal T_1-weighted scout

11. To determine the patient's position, a fast sagittal scout scan is performed using the imaging sequence in Table A1.7.2.

    Some centers may prefer a rapid three-plane scout instead of this multislice sagittal scout.

Sequence 2: Transverse FLAIR

12. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse FLAIR. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.7.3.
13. Warn the patient that this sequence is starting and begin the scan.

Sequence 3: Transverse T_2-weighted FSE

14. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse T_2 FSE. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.7.4.
15. Warn the patient that this sequence is starting and begin the scan.

Table A1.7.3 Transverse FLAIR

Patient position	Supine
Scan type	Inversion recovery FSE
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	120 msec
Receiver bandwidth (RBW)	20.83 kHz
Repeat time (T_R)	10,000 msec
Inversion time (T_I)	2200 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.86 mm, 1.14 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Saturation pulses	Inferior
Scan time	4 min, 44 sec

Table A1.7.4 Transverse T_2-Weighted FSE

Patient position	Supine
Scan type	Fast spin echo XL
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	FSE-XL
Central slice or volume center	Nasion
Echo time (T_E)	102 msec
Receiver bandwidth (RBW)	11.36 kHz
Echo train length (ETL) or shots (SH)	12
Repeat time (T_R)	6000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 165 mm
Resolution (Δx, Δy)	0.86 mm, 0.86 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	320, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	2
Number of acquisitions (N_{acq})	1
Read direction	Anterior–posterior
Flow compensation	Yes
Extended dynamic range (EDR)	Yes
Saturation pulses	Inferior
Scan time	3 min, 19 sec

Table A1.7.5 Transverse Diffusion

Patient position	Supine
Scan type	SE-EPI
Imaging plane (orientation)	Transverse
Central slice or volume center	Nasion
Echo time (T_E)	Minimum (80.9 msec)
Echo train length (ETL) or shots (SH)	1 SH
Repeat time (T_R)	5000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	1.72 mm, 1.72 mm
Number of data points collected (N_x, N_y)	128, 128
Display matrix (D_x, D_y)	128, 128
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	3
Number of acquisitions (N_{acq})	1
Read direction	Right–left
Saturation pulses	Fat saturation (automatic with EPI)
Control variables (CV)	Ramp sampling = 1, burst sampling = 0
b-value	1000 sec/min^2
Direction	6
Scan time	3 min, 5 sec

Sequence 4: Transverse diffusion

16. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse diffusion. The transverse images should begin at the foramen magnum and end at the top of the brain. Set up imaging parameters as shown in Table A1.7.5.

17. Warn the patient that this sequence results in loud beeping noises and begin the scan.

    Most diffusion sequences will perform a minimum of four sequences: three with orthogonal diffusion gradient directions and one with a minimal or no diffusion gradient. Often, a fifth set of images is also provided, which combines the three orthogonal gradient images to produce a set of images whose signal intensity is not affected by the diffusion direction. This is the DWI. In order to obtain apparent diffusion coefficient (ADC) maps, the images may need further processing. On a GE system, the ADC maps can be obtained by processing on the Advantage Window Workstation using FuncTool version 3.1P using FuncTool version 1.9M.

Sequence 5: Coronal 2-D TOF MR venogram (optional)

18. From the sagittal scout, select the image through the center of the brain to set up the locations for the coronal TOF MR venogram. The entire brain should be included. Set up the imaging parameters as shown in Table A1.7.6.

19. Warn the patient that this sequence is starting and begin the scan.

Table A1.7.6 Coronal 2-D TOF MR Venogram

Patient position	Supine
Scan type	Vascular TOF SPGR
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	Minimum
Receiver bandwidth (RBW)	15.6 kHz
Repeat time (T_R)	40 msec
Flip angle (FA)	60°
Fields of view (FOV_x, FOV_y)	220 mm, 165 mm
Resolution (Δx, Δy)	0.86, 1.14
Number of data points collected (N_x, N_y)	256, 144
Display matrix (D_x, D_y)	256, 192
Slice thickness (Δz)	1.5 mm
Number of slices	Variable (depends on area of coverage)
Slice gap	0
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	Variable (depends on area of coverage)
Read direction	Superior–Inferior
Saturation pulses	Inferior
Scan time	12 sec/slice

Sequence 6: Transverse T_1-weighted spin echo (optional)

20. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse T_1. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.7.7.

21. Warn the patient that this sequence is starting and begin the scan.

Sequence 7: Transverse post-contrast T_1-weighted spin echo (optional)

22. Using a small-gauge butterfly, inject a single dose of contrast by weight (usually 20 ml) intravenously.

23. From the sagittal scout, select the image through the center of the brain to set up the locations for the post-contrast transverse T_1. The locations should be the same as those chosen for the transverse precontrast T_1. Set up the imaging parameters as shown in Table A1.7.8.

24. Warn the patient that this sequence is starting and begin the scan.

Sequence 8: Coronal post-contrast T_1-weighted spin echo (optional)

Contrast may be helpful in differentiating multiple small metastases, demylinating lesions with inflammatory components, and subcortical infarcts from the nonspecific foci of increased T_2 associated with migraines that do not enhance.

25. From the sagittal scout, select the image through the center of the brain to set up the locations for the coronal post-contrast T_1. Set up the imaging parameters as shown in Table A1.7.9.

26. Warn the patient that this sequence is starting and begin the scan.

Table A1.7.7 Transverse T_1-Weighted Spin Echo

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	Minimum full (14 msec)
Receiver bandwidth (RBW)	15.6 kHz
Repeat time (T_R)	400 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 165 mm
Resolution (Δx, Δy)	0.86 mm, 1.14 mm
Number of data points collected (N_x, N_y)	256, 144
Display matrix (D_x, D_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Flow compensation	No
Extended dynamic range (EDR)	Yes
Saturation pulses	Inferior
Scan time	2 min, 8 sec

Table A1.7.8 Transverse Post-Contrast T_1-Weighted Spin Echo

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	Minimum full (20 msec)
Receiver bandwidth (RBW)	15.6 kHz
Repeat time (T_R)	400 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 165 mm
Resolution (Δx, Δy)	0.86 mm, 1.14 mm
Number of data points collected (N_x, N_y)	256, 144
Display matrix (D_x, D_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Flow compensation	Yes
Extended dynamic range (EDR)	Yes
Saturation pulses	Inferior
Scan time	2 min, 8 sec

Table A1.7.9 Coronal Post-Contrast T_1-Weighted Spin Echo

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	Minimum full (20 msec)
Receiver bandwidth (RBW)	15.6 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 165 mm
Resolution (Δx, Δy)	0.86 mm, 1.14 mm
Number of data points collected (N_x, N_y)	256, 144
Display matrix (D_x, D_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	26
Slice gap	1 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	2
Read direction	Superior–inferior
Flow compensation	Yes
Extended dynamic range (EDR)	Yes
Saturation pulses	Inferior
Scan time	2 min, 40 sec

ALTERNATE PROTOCOL

ASSESSMENT OF CEREBRAL PERFUSION IN PATIENTS WITH AURAS

Occasionally perfusion weighted imaging may be helpful in patients with migraine to assess for associated perfusion changes. During the aura and the first few hours of headache transient hypoperfusion has been documented whereas others have noted hyperfusion but this may occur at a later phase. Although still controversial, perfusion differences in the setting of migraine do not typically respect vascular territories which help differentiate these changes from stroke related changes.

Materials

Gadolinium-based MR contrast agent (e.g., Magnevist, Omniscan, Prohance)
Normal saline (0.9% NaCl), sterile
18-G angiocatheter and MR-compatible injection pump

Set up patient and equipment

1. Set up patient and equipment as described in Basic Protocol, steps 1 to 10.
2. Establish an intravenous line using an 18-G angiocatheter through which the contrast agent can be injected. Attach this line securely to the patient so that movement into or out of the magnet will not pull at the patients arm.

   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. Connect the MR-compatible injection pump, cleared of air, and loaded with a double dose of contrast agent and saline flush, to the patient. Do a small test injection of normal saline to ensure that the i.v. is working properly.

Table A1.7.10 Transverse Perfusion

Patient position	Supine
Scan type	GRE-EPI
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	54 msec
Echo train length (ETL) or shots (SH)	1
Repeat time (T_R)	1500 msec
Flip angle (FA)	35°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	1.72 mm, 1.72 mm
Number of data points collected (N_x, N_y)	128, 128
Display matrix (D_x, D_y)	128, 128
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	1
Read direction	Right–left
Slice location	Inferior slice to include MCA
Slice series	Interleaved
Control variables (CV)	Ramp sampling = on, burst sampling = off
Multiphase	Yes, 46 phases per location, minimum delay between acquisition
Scan time	1 min, 10 sec

4. Program a 5 ml/sec injection rate for both contrast and saline, the contrast dose required (double dose by weight), the saline flush required (typically 40 ml), and a 10-sec time delay. Start the saline running at TKVO (to keep vein open) and arm the injection pump.

Sequences 1 to 5

5. Perform sequences 1 to 4 and sequence 6 as described in the Basic Protocol.

Sequence 6: Transverse perfusion

6. Using the transverse T_2-weighted FSE images, find the slice location where the middle cerebral arteries are best seen. Using the imaging parameters as shown in Table A1.7.10, set up the transverse images starting at the same location where the MCA were identified on the T_2 FSE. Typically only ten or eleven slices can be obtained in the given T_R interval. The slice thickness and gap can be modified so that the perfusion study covers any diffusion abnormality.

7. Check that the injection pump is ready to inject and that the injection is set to start after a 10-sec delay.

8. Warn the patient that this sequence is starting and that, partway through the scan, the i.v. injection will occur. Begin the scan.

Data processing and viewing for Sequence 6

9. Process the perfusion images using an appropriate workstation and software to give maps of relative cerebral blood volume (rCBV), relative cerebral blood flow (rCBF), and mean transit time (MTT).

   On a GE system, one can use an Advantage Windows Workstation with FuncTool version 1.9M.

Sequences 7 and 8

10. Perform sequences 7 and 8 as described in the Basic Protocol.

COMMENTARY

Background Information

The incidence of small foci of increased T_2 signal in patients with a history of migraine varies from study to study. Reported incidence rates vary from 13% to 39.6% for migraineurs, dropping to 5.5% to 29.4% for those under 40 compared to the range of 4.3% to 11.2% for controls (Igarashi et al., 1991; Osborn et al., 1991; Robbins and Friedman, 1992; Pavese et al., 1994; De Benedittis et al., 1995; Cooney et al., 1996). Other causes of focal T_2 hyperintensities that should be ruled out include hypertension, athlerosclerotic heart disease, diabetes mellitus, autoimmune disorders, and demyelinating diseases. The increased frequency of T_2 hyperintensities in pediatric migraineurs is controversial, with some stating there is no increase in incidence (McAbee et al., 1993) and others reporting a 50% incidence vs. 17% for age-matched controls (Hamalainen et al., 1996). Perfusion changes have been detected during visual auras with these changes persisting for 2.5 hr into the migraine. These perfusion studies showed decreased cerebral blood flow (16% to 53%), decreased cerebral blood volume (6% to 33%), and increased tissue mean transit time (10% to 54%) in the gray matter of the occipital cortex (Cutrer et al., 1998). Migraines without aura showed no significant hemodynamic changes (Sanchez del Rio et al., 1999). Rarely, as in the case of basilar artery migraine, reversible cortical swelling may be seen (Maytal et al., 1998). Hemiplegic migraine also has uncommon findings with decreased diffusion, decreased blood flow, and leptomeningeal enhancement reported (Crawford and Konkol, 1997, Arnold et al., 1998, Chabriat et al., 2000). In a similar group of patients with visually triggered migraines, neuronal suppression was accompanied by baseline contrast intensity increases on functional MRI that suggested vasodilatation and tissue hyperoxygenation.

Critical Parameters and Troubleshooting

For a discussion of critical parameters and troubleshooting, see *UNITS A1.1 & A1.2*, as well as *UNITS A1.5 & A1.6*.

Anticipated Results

In most cases, the imaging studies in patients with migraines will be normal or show nonspecific foci of increased T_2 signal that are typically more prominent in the frontal regions. It is prudent, however, to rule out other potential causes of multiple foci with increased T_2 signal such as hypertension, athlerosclerotic heart disease, diabetes mellitus, autoimmune disorders, or demyelinating diseases.

In patients with basilar artery migraine, hemiplegic migraine, or visually triggered migraines, other imaging findings (see Background Information) may be observed.

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Contributed by Steven Thibodeau and Ellen Grant
Massachusetts General Hospital
Boston, Massachusetts