Rule Out (R/O) Vasculitis

When imaging patients for vasculitis, the goals are (1) to determine if there is evidence of acute or subacute cerebral injury and (2) to assess the contour of the major intracranial arteries. An additional but still experimental goal is (3) to determine if there are areas of altered perfusion that suggest active small vessel disease. Standard MR images and diffusion-weighted imaging are used to detect and determine the age of parenchymal lesions. The 3-D TOF MRA helps evaluate the large and medium vessels. Perfusion-weighted imaging may detect regions of altered relative blood flow and blood volume. The following Basic Protocol can be used for the evaluation of stable patients; an Alternate Protocol is provided for evaluation of unstable patients.

STANDARD IMAGING FOR VASCULITIS

BASIC PROTOCOL

In order to perform the optional sequences with perfusion and diffusion studies, a scanner with echoplanar capabilities is required (Table A1.6.1). MR angiography and 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.

Data processing is required for the 3-D TOF MRA sequences described in this unit. For optimal assessment of the volumetric 3-D TOF MRA data, separate volumes of interest (VOI) of the left anterior, right anterior, and posterior circulation should be created. Images from 15° rotations about the vertical axis should be saved. An additional anterior circulation volume of interest should include both anterior cerebral arteries and the region of the anterior communicating artery for visual inspection. Images from 15° rotations about the horizontal axis should be saved.

Table A1.6.1 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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Although maximum intensity projections are used. All of the authors' MRA data is processed on a General Electric (GE) Advantage Windows Workstation version 3.1P using standard GE Advantage Windows software or FuncTool version 1.9M. In the hands of an experienced technologist, the post-processing will require ~5 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. Reactions to contrast agents are rare, but the resources are necessary.

Materials

Gadolinium-DTPA contrast agent (e.g., Manevist, Omniscan, Prohance)
Normal saline (0.9% NaCl), sterile
Injection pump

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 forms.

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 optimum 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. Establish an intravenous line using an 18-G angiocatheter through which the contrast agent can be injected, and attach this line securely to the patient so that movement into or out of the magnet will not pull at the patient's 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.

8. 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.

   Most scanners have a special neck coil for MRA; otherwise, a head coil should be used and the patient placed as far in as possible so that the bifurcation of the main carotid artery into the internal and external carotid arteries can be imaged.

9. If needed, place a pillow or other support under the knees to make the patient more comfortable.

10. Place the patient such that the laser light is centered over the patient's nasion, 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.

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

12. 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.

13. Program the 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.

Sequence 1: Rapid sagittal T_1-weighted scout

14. To validate the patient's position, perform a fast sagittal scout scan using the imaging sequence in Table A1.6.2.

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

Sequence 2: Transverse diffusion

15. 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 A1.6.3.

16. 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 diffusion-weighted imaging (DWI). In order to obtain apparent diffusion coefficient

Table A1.6.2 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 4.1 msec)
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

Table A1.6.3 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 sec
Scan time	3 min, 5 sec

Table A1.6.4 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 A1.6.5 Transverse T_2-Weighted FSE

Patient position	Supine
Scan type	Fast spin echo
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

(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 1.9M.

Sequence 3: Transverse FLAIR

17. 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 A1.6.4.

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

Sequence 4: Transverse T_2-weighted FSE

19. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse T_2-weighted FSE. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.6.5.

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

Table A1.6.6 Transverse 3-D TOF MRA

Patient position	Supine
Scan type	3-D vascular TOF SPGR
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Central slice or volume center	Nasion
Echo time (T_E)	6.9 msec
Receiver bandwidth (RBW)	10.42 kHz
Repeat time (T_R)	50 msec
Flip angle (FA)	20°
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.357 mm, 0.468 mm
Number of data points collected (N_x, N_y)	384, 224
Display matrix (D_x, D_y)	384, 224
Slice thickness (Δz)	1.4 mm
Number of slices/slab	40
Number of slabs	2
Slab overlap	4
Slice gap	0
Number of excitations (NEX)	1
Number of acquisitions (N_{acq})	1
Read direction	Anterior–posterior
Flow compensation	Yes
ZIP 512/ZIP 1024	ZIP 512
ZIP 2/ZIP 4	ZIP 2
Extended dynamic range (EDR)	Yes
Saturation pulses	Inferior
Magnetization transfer	Yes
Vascular options	Reprojections = 19, collapse = on, ramp pulse = inferior to superior
Scan time	6 min, 32 sec

Sequence 5: Transverse 3-D TOF MRA

21. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse 3-D TOF MRA. Set up the imaging parameters as shown in Table A1.6.6. Two slabs are posted on the midline sagittal image, centered at the top of the sella tursica.

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

    This sequence can also be performed after Sequence 7 (perfusion sequence) to optimize visualization of small vessels.

Data processing and viewing for Sequence 5

23. Once the axial partitions from the 3-D TOF are obtained, select volumes of interest (VOI) that select out the posterior circulation, the right anterior circulation, and the left anterior circulation. Rotate the maximum intensity projections (MIPs) or surface reconstructions of these three VOIs through 360° about the vertical, saving images at 15° intervals. Rotate a fourth VOI that selects out both anterior circulations through 360° about the horizontal, saving images at 15° intervals.

Sequence 6: Transverse T_1-weighted spin echo

24. From the sagittal scout, select the image through the center of the brain to set up the locations for the transverse T_1-weighted spin echo. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.6.7.

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

Table A1.6.7 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 A1.6.8 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)	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
Multiphase	Yes, 46 phases per location, minimum delay between acquisition
Slice series	Interleaved
Control variables (CV)	Ramp sampling = on, burst sampling = off
Scan time	1 min, 10 sec

Sequence 7: Transverse perfusion

26. 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 A1.6.8, set up the transverse images starting at the same location as the MCA were identified on the FSE T_2.

    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.

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

28. Warn the patient that this sequence is starting and that part way through the scan, the i.v. injection will occur. Begin the scan.

29. Process the perfusion images using 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.

Table A1.6.9 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 A1.6.10 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

Sequence 8: Transverse post-contrast T_1

30. 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. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.6.9.

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

Sequence 9: Coronal post-contrast T_1

32. 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. The locations should be the same as those chosen for the transverse diffusion. Set up the imaging parameters as shown in Table A1.6.10.

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

ALTERNATE PROTOCOL

RAPID ASSESSMENT FOR ALTERED PERFUSION AND ACUTE ISCHEMIC INJURY

To evaluate an unstable patient, imaging must be kept to a minimum. In such cases, the following alternate protocol should be followed.

Set up patient and equipment

1. Perform equipment and patient setup as in steps 1 to 11 of the Basic Protocol.
2. Draw up a syringe with a single dose of contrast by weight (typically 20 ml).
3. Perform Sequences 1 to 4 as described in the Basic Protocol.
4. Perform Sequence 8 as described in the Basic Protocol.

COMMENTARY

Background Information

Reports on the sensitivity of standard MR images versus catheter angiography vary and one or both can be normal. Standard MR studies and catheter angiography actually appear to provide complimentary information (Greenan et al., 1992; Harris et al., 1994; Duna and Calabrese, 1995; Cloft et al., 1999; Pomper et al., 1999) Recently, perfusion-weighted imaging has been shown to detect regions of altered hemodynamics, presumably related to microvascular involvement, that were not identified on catheter angiography (Yuh et al., 1999a,b). Diffusion-weighted imaging may also add additional information by identifying regions of acute necrotic change in a nonvascular territory (Yuh et al., 1999b). Although in most cases, 3-D TOF angiography is unhelpful because vascular involvement is limited to small vessels, 3-D TOF angiography may be helpful when medium to large vessels are involved, such as in vasculitis due to fungal invasion. Post-contrast studies are routinely obtained to assess for blood-brain barrier breakdown due to vasculitic involvement that may be reversible, blood-brain barrier breakdown due to subacute ischemic events, and dural pathology. The presence of dural sinus pathology or brain stem atrophy in addition to multifocal parenchymal involvement raises the possibility of Neurological Becet's disease. Dural enhancement has also been reported in temporal arteritis (Joelson et al., 2000). FLAIR images are also included as they may improve detection of subtle subcortical lesions when compared to T_2 FSE images (Jager et al., 1999).

Critical Parameters and Troubleshooting

With FLAIR sequences, it is important to make sure that the T_R and T_I values have not been modified and that vendor-specific recommendations for optimal CSF suppression have been followed. For example in GE FLAIR sequences, at least two interleaved acquisitions are required for optimal CSF suppression.

Important basic parameters in MR angiography are as discussion in *UNIT A1.1*. With the post-contrast MRA, the T_R can be decreased

and the flip angle increased compared to the precontrast study to improve visualization.

Anticipated Results

This combination of sequences should allow the detection and distinction of acute from chronic parenchymal injury. The perfusion-weighted sequence should allow regions with altered hemodynamics to be identified. These regions of altered hemodynamics may indicate acute small vessel involvement prior to the development of acute infarction. In the rare cases that medium or large vessels are involved, the MRA may help identify areas of involvement. The post-contrast studies should allow detection of dural involvement and also allow detection of regions of blood brain barrier breakdown due to either the vasculitis or related ischemic lesions.

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