Brain Abscess

Magnetic resonance imaging (MRI) in cerebral abscess, as with most other forms of intracranial inflammatory or infectious diseases, is a powerful though largely nonspecific diagnostic tool. This unit presents a variant of a previously published (Castillo, 1998) standard imaging protocol, to include gadolinium-enhanced sequences, for imaging of these patients. Several optional sequences, including diffusion (dMRI), perfusion (pMRI), and spectroscopic (MRS) sequences are outlined that can be employed should patient tolerance allow and if specific clinical situations exist to be further clarified. The parameters given here are derived from experience at 1.5 T and may need to be altered slightly depending on the field strength available and the specific equipment manufacturer.

IMAGING OF CEREBRAL ABSCESS

BASIC PROTOCOL

This unit presents what amounts to the authors' routine MR head examination for patients with intracranial inflammatory disease, with gadolinium contrast agent sequences. The total number of sequences presented is seven—scout, T_1-weighted sagittal and transverse, fluid-attenuated inversion recover (FLAIR) and fast spin-echo (FSE) T_2-weighted transverse, and post-contrast T_1-weighted transverse and coronal. This examination may be shortened considerably by limiting the use of two planes for post-contrast imaging to a single transverse plane for exams with a lower clinical suspicion for disease, or if review of the images obtained through the transverse gadolinium-enhanced images proves unremarkable. The sequences described herein are based on the authors' experience with a Marconi Medical Systems 1.5 T scanner, but are expected to be equally applicable to machines from other manufacturers.

Table A4.1.1 lists the hardware necessary to perform the examination, 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. Also ensure only magnetic field compatible oxygen tanks are utilized if wall-source oxygen is unavailable.

Materials

Intravenous MRI contrast agent: gadolinium chelate (e.g., Magnevist, Omniscan, or Prohance)
Normal sterile saline (0.9% NaCl)

Table A4.1.1 Equipment Parameters for Contrast-Enhanced Head Imaging Sequences

Coil type	Head
Gradient coil strength	25 mT/m (or whatever the system permits)
Gating (cardiac, respiratory, peripheral)	No
Respirator or oxygen	If required by patient
Motion cushions	Recommended
Contrast agents	Yes

Contributed by Andrew E. Auber and Clifford Belden
Current Protocols in Magnetic Resonance Imaging (2001) A4.1.1-A4.1.19

Set up patient and equipment

1. Interview (screen) the patient to ensure that he/she has no contraindication for MR scanning such as cardiac pacemaker 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 that necessitate other special precautions. Screening forms are often employed for all patients before scanning in an MRI system.

   Generally standard screening forms 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 (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 remove any mascara or other metal-containing makeup to avoid local tissue heating and image artifacts.
5. Inform the patient about what will occur during the procedure, what he/she will experience while in the magnet, and how to behave, to include the following:
   a. If earphones/headphones are used to protect the ears from loud sounds produced by the scanner, the patient will be asked to wear these, but will be able to communicate with the technologist at any/all times during the procedure.
   b. The patient will be given a safety squeeze-bulb or similar equipment to request assistance at any time (demonstrate how this equipment works).
   c. For optimum results the patient should not talk, and should avoid/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 in these instances.
   d. Nevertheless, the patient may call out at any time if he/she feels it necessary.
6. Have the patient lay supine on the scanner table. Either before or directly after the patient is positioned on the table, set up any triggering devices or other necessary monitoring equipment.
7. Establish an i.v. line 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. This allows no intervening motion between those scans performed before and those run after the contrast agent injection.

8. Center the patient in the head coil. Make sure that the head and neck are constrained to prevent unnecessary motion, especially if high-resolution scans are to be run.
9. If needed, place a pillow or other support under the knees to make the patient more comfortable.

10. Use the centering light to position the patient and place them into the center of the magnet. The nasion is the landmark and utilized here.

    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, either provide an appropriate sedative, or arrange with anesthesiology for conscious or general anesthesia.

    Alternatively, a low-field open magnet may be sought for scanning the claustrophobic patient. There are also fast scanning techniques that may be employed for imaging of these patients (see Chapter A5).

    This Basic Protocol can be performed in less than 30 min.

Sequence 1: Rapid three-plane pilot

12. Run the three-plane pilot (Table A4.1.2) sequence to evaluate the patient positioning in the magnet.

    This sequence runs in less than 10 sec and is used to position the remainder of the sequences. It is particularly useful to correct off-axis positioning in the coronal plane.

Sequence 2: T_1-sagittal head

13. This sequence serves as a true T_1-weighted sagittal study of the head. Bring the sequence for a sagittal T_1-weighted scan up onto the console and utilize the parameters in Table A4.1.3.

14. Use the pilot sequence to set up the scan levels.

15. Let the patient know you are ready, and begin the scan.

Table A4.1.2 Primary Clinical Imaging Parameters for Sequence 1: Rapid Three-Plane Pilot

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Sagittal, transverse, and coronal
Central slice or volume center	Midline head
Echo time (T_E)	3.7 msec
Repeat time (T_R)	16 msec
Flip angle (FA)	20°
Fields of view (FOV_x, FOV_y)	300 mm, 300 mm
Resolution (Δx, Δy)	2.34 mm, 2.34 mm
Number of data points collected (N_x, N_y)	128, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	10 mm
Number of slices	3
Slice gap	NA
Number of acquisitions (N_{acq})	1
Read direction	Left–right
Slice location	At isocenter, 3 orthogonal planes
Saturation pulses	None
RAM[a]	2×
Scan time	6 sec

[a]Zero padded from 128 by 128 points to 256 by 256 points.

Sequence 3: T_1-transverse head

16. Bring the sequence for a transverse T_1-weighted scan up onto the console. Set the imaging parameters as shown in Table A4.1.4.
17. Use the pilot sequence to set up the scan levels.
18. Let the patient know you are ready, and begin the scan.

Table A4.1.3 Primary Clinical Imaging Parameters for Sequence 2: T_1-Sagittal Head

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Midline head
Echo time (T_E)	12 msec
Repeat time (T_R)	300 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 0.94 mm
Number of data points collected (N_x, N_y)	192, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	4 mm
Number of slices	15
Slice gap	1 mm
Number of acquisitions (N_{acq})	1
Read direction	Superior–inferior
Slice location	Cover brain parenchyma
Saturation pulses	None
Scan time	1 min, 55 sec

Table A4.1.4 Primary Clinical Imaging Parameters for Sequence 3: T_1-Transverse Head

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse (planum sphenoidale line)
Central slice or volume center	Mid-cranium
Echo time (T_E)	12.1 msec
Repeat time (T_R)	500 msec
Flipe angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.94 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Slice location	Foramen magnum to vertex
Saturation pulses	None
Scan time	2 min, 36 sec

Sequence 4: FLAIR transverse head

19. Bring the sequence for a transverse FLAIR scan up onto the console. Set the imaging parameters as shown in Table A4.1.5.
20. Use the pilot sequence to set up the scan levels and a caudal saturation pulse.
21. Let the patient know you are ready, and begin the scan.

Sequence 5: FSE transverse head

22. Bring the sequence for a transverse FSE scan up onto the console. Set the imaging parameters as shown in Table A4.1.6.
23. Use the pilot sequence to set up the scan levels.
24. Let the patient know you are ready, and begin the scan.

Sequence 6: T_1-transverse post-gadolinium head

25. Bring the sequence for a transverse T_1-weighted scan up onto the console. Set the imaging parameters as shown in Table A4.1.7.
26. Use the pilot sequence to set up the scan levels.
27. Leaving the patient in the magnet, inject the contrast agent either by hand, or using a mechanical injector. Observe the injection to insure there is no extravasation of the contrast agent. Flush the line with 10 ml of sterile normal saline. Begin the scan as soon as the injection is completed.

    Alternatively, the scanning table may be advanced out of the magnet for the injection, but the patient must remain in place.

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

Table A4.1.5 Primary Clinical Imaging Parameters for Sequence 4: FLAIR Transverse Head

Patient position	Supine
Scan type	FLAIR-FSE
Imaging plane (orientation)	Transverse (parallel to AC-PC line)
Central slice or volume center	Mid-cranium
Echo time (T_E)	125 msec (effective)
Echo train length (ETL)	Fixed (generally 12)
Repeat time (T_R)	6000 msec
Inversion time (T_I)	1900 msec
Flip angle (FA)	180°
Fields of view (FOV_x, FOV_y)	240 mm, 197 mm
Resolution (Δx, Δy)	0.94 mm, 0.97 mm
Number of data points collected (N_x, N_y)	256, 204
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of acquisitions (N_{acq})	1
Read direction	Anterior–posterior
Slice location	Foramen magnum to vertex
Saturation pulses	Caudal to saturate arterial flow
Scan time	2 min, 48 sec

Table A4.1.6 Primary Clinical Imaging Parameters for Sequence 5: FSE Transverse Head

Patient position	Supine
Scan type	Fast spin echo (FSE)
Imaging plane (orientation)	Transverse (planum sphenoidale line)
Central slice or volume center	Mid-cranium
Echo time (T_E)	105 msec (effective)
Echo train length (ETL)	16
Repeat time (T_R)	5616 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 180 mm
Resolution (Δx, Δy)	0.63 mm, 0.70 mm
Number of data points collected (N_x, N_y)	384, 256
Display matrix (D_x, D_y)	384, 384
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Slice location	Foramen magnum to vertex
Saturation pulses	Caudal to saturate arterial flow
Scan time	3 min, 22 sec

Table A4.1.7 Primary Clinical Imaging Parameters for Sequence 6: T_1-Transverse Post-Gadolinium Head

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse (planum sphenoidale line)
Central slice or volume center	Mid-cranium
Echo time (T_E)	12.1 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.94 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Read direction	Anterior–posterior
Slice location	Foramen magnum to vertex
Saturation pulses	None
Scan time	2 min

Table A4.1.8 Primary Clinical Imaging Parameters for Sequence 7: T_1-Coronal Post-Gadolinium Head

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal (perpendicular to planum sphenoidale line)
Central slice or volume center	Mid-cranium
Echo time (T_E)	12.1 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 178 mm
Resolution (Δx, Δy)	0.86 mm, 0.93 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Read direction	Left–right
Slice location	Frontal to occipital cerebral poles
Saturation pulses	None
Scan time	2 min, 36 sec

This is essentially the same sequence as the pre-gadolinium scan, but can be performed with the addition of a flow compensation (FC) pulse to better delineate the cerebral vessels, and a magnetization transfer (MT) pulse to optimize enhancing lesion detection.

Sequence 7: T_1-coronal post-gadolinium head

28. Bring the sequence for a T_1-weighted scan up onto the console. Set the imaging parameters as shown in Table A4.1.8.
29. Use the pilot sequence to set up the scan levels.
30. Let the patient know you are ready, and begin the scan.

Small abscesses may be much better delineated with a smaller field of view (FOV; i.e., FOV_x = 200 mm, FOV_y = 150 mm) and higherresolution, thinner slice thickness (3 mm). Please note that this modification should be performed with one acquisition, and limited to the area of abnormality to avoid prolonged scan times.

When scanning pediatric patients (i.e., under 24 months) modify the transverse and coronal sequences by placing the FOV at 200 mm, and the slice thickness and gap at 4 mm and 1 mm, respectively. For neonates, premature infants, and other extremely small patients, an extremity coil may be used.

This sequence may be performed with the addition of a flow compensation (FC) pulse to better delineate the cerebral vessels, and a magnetization transfer (MT) pulse to optimize enhancing lesion detection.

SPECIAL SITUATIONS

ALTERNATE PROTOCOL 1

The two sequences that follow are presented here for consideration by the radiologist in those patients suspected of significant intracranial inflammatory conditions for whom the basic protocol has failed to elucidate a clearly defined abnormality. For instance, in patients with microabscesses related to septic emboli that may be associated with pseudoaneurysm formation, the gradient-echo sequence is extremely useful for demon-

strating the microhemorrhage. This can lead not only to the helpful diagnostic clue of a hemorrhagic lesion but also can bring other lesions to the attention of the radiologist. This can impact patient prognosis, or guide more effective follow-up imaging. The second optional sequence, the 3-dimensional gradient-echo post-contrast sequence, is usually reserved for higher resolution of small lesions or adjacent structures that may be affected by the pathology. It can also be an effective aid in operative planning, and may indeed serve as the base MRI sequence for several of the commercially available image-guided surgery tools presently on the market and utilized by many neurosurgeons. This sequence can be utilized in lieu of the transverse and coronal post-gadolinium sequences outlined in the Basic Protocol, if desired. It is easily manipulated in post-processing to yield a desired projection of a lesion, or simply to give a multiplanar assessment of the brain in a given patient.

Set up patient and equipment

1. Use the same equipment and the same patient set-up as for the previous method (see Basic Protocol, steps 1 to step 11).
2. Run the pilot scan as sequence 1 in the Basic Protocol (see Table A4.1.2).

Sequence 8: Coronal gradient echo (head)

3. Bring the sequence for a gradient-echo scan up onto the console. Set the imaging parameters as shown in Table A4.1.9.
4. Use the pilot sequence to set up the scan levels.
5. Let the patient know you are ready, and begin the scan.

Sequence 9: 3-Dimensional post-gadolinium transverse gradient echo (head)

6. Repeat Basic Protocol, step 27.

   When surgery is contemplated, or in order to better delineate a smaller lesion, a useful alternative sequence to the post-gadolinium transverse and coronal scans described in the Basic Protocol is a post-gadolinium 3-D gradient-echo sequence.

7. Perform scan with high resolution parameters as described in Table A4.1.10.

   This scan can be reformatted into any desired plane as it is a volume-acquired sequence.

   This scan generates 120 images as a whole brain study, but higher resolution image sets with 32 or 64 images, with a resolution as low as 1 mm can be produced, but may be restrictive in area of coverage.

8. Perform planar reformations of the 3-D data set on-line or off-line using the reformation software.

   One can coordinate with the neurosurgeon to obtain the most useful projections, that can then be saved and/or filmed.

   Note that the cerebral vasculature is quite bright on this sequence as this 3-D gradient echo sequence is the base-sequence for time-of-flight (TOF) magnetic resonance angiography (MRA).

ALTERNATE PROTOCOL 2

IMAGING OF CEREBRAL ABSCESS BY MAGNETIC RESONANCE DIFFUSION, PERFUSION, AND SPECTROSCOPY

The Basic Protocol is quite sufficient in most instances of cerebral abscess imaging and represents the standard for imaging of the patient suspected for cerebral abscess. However, in certain clinical instances there may remain confusion as to the diagnosis, or in order to gain a higher degree of specificity in labeling a lesion as an abscess, further imaging

Table A4.1.9 Primary Clinical Imaging Parameters for Sequence 8: Coronal Gradient Echo Head

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-cranium
Echo time (T_E)	24.6 msec
Repeat time (T_R)	719 msec
Flip angle (FA)	25°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.86 mm, 1.15 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	21
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Read direction	Left–right
Slice location	Frontal to occipital cerebral poles
Saturation pulses	None
Scan time	4 min, 36 sec

Table A4.1.10 Primary Clinical Imaging Parameters for Sequence 9: 3-D Post-Gadolinium Transverse Gradient Echo Head

Patient position	Supine
Scan type	3-D gradient echo
Imaging plane (orientation)	Transverse (option sagittal or coronal)
Central slice or volume center	Mid-cranium for whole brain, or area of abnormality
Echo time (T_E)	5 msec
Repeat time (T_R)	11.2 msec (or minimum)
Flip angle (FA)	35°
Fields of view (FOV_x, FOV_y)	240 mm, 187 mm
Resolution (Δx, Δy)	0.94 mm, 0.97 mm
Number of data points collected (N_x, N_y)	256, 192
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	1.2 mm
Number of slices	120
Slice gap	0 mm
Number of acquisitions (N_{acq})	1
Read direction	Anterior–posterior, if imaging plane is transverse
Slice location	Whole brain
No phase wrap (NPW)[a]	Yes
Saturation pulses	NA
Scan time	4 min, 19 sec

[a]Phase oversampling or anti-aliasing.

can be performed utilizing dMRI, pMRI, or MRS. Recent literature (Ernst et al., 1998; Burtscher and Holtas, 1999; Desprechins et al., 1999) has indicated a clinical benefit in some patients with these new approaches. Higher-field-strength magnets with enhanced gradient packages (e.g., generally >20 mT/m for dMRI and pMRI) are preferred for optimum benefit in the performance of these sequences. Also, magnetic field homogeneity is a crucial factor in the successful performance of these sequences, mandating routine assessment and optimization of magnet shim prior to each acquisition. Indeed, as the hardware and software to obtain these specialized sequences becomes more ubiquitous and further data is gathered, one or more of these sequences may prove invaluable in the work-up of the patient suspected of cerebral abscess. Described here is the authors' experience with a 1.5 T whole-body system with an enhanced gradient system. Note that a detailed presentation on the performance and processing of these complex sequences goes beyond the scope of this unit. For such a discussion, the reader is referred to their respective scanner and workstation manufacturers, as well as the literature cited in this unit. Additionally, having an MRI-trained physicist available to insure the proper quality management of these sequences is highly recommended.

Additional Materials

Enhanced gradient equipped MRI scanner

Specialized post-processing software, especially for pMRI image processing (a separate workstation is preferred for off-line processing of data sets, enabling continuous patient scanning to proceed)

Power injector for dynamic contrast administration (i.e., while scanning)

Set up patient and equipment

1. Perform the patient setup as for the previous method (see Basic Protocol, steps 1 to 11).
2. Run sequence 1 as in Basic Protocol (see Table A4.1.2).

Sequence 10: pMRI of the brain

3. Perform this scanutilizing the parameters outlined in Table A4.1.11 to assess vascular perfusion of the brain and pathologic foci.

   pMRI can help in differentiating abscess from necrotic neoplasm.This is a rapid acquisition with moderate spatial resolution that can yield information on the entire brain and multiple lesions, even in agitated patients.

   This sequence must be the first sequence performed after the gadolinium injection, and is acquired dynamically. After a baseline brain image acquisition is performed, an injection time of <8 sec is used to deliver 0.2 mmol/kg gadolinium chelate with a 10 ml normal saline bolus flush via the injector. This step may be performed by hand, but timing of the sequence is problematic.

4. Perform image analysis visually or off-line on a workstation using commercially available programs.

   Regional cerebral blood volume (rCBV) maps can be reconstructed using an appropriate analysis of the MR signal intensity as a function of time.

   The rCBV maps can be aligned with the anatomic images to obtain region-of-interest (ROI) data.

Sequence 11: Echo-planar imaging (EPI) dMRI of the brain

5. Run this sequence utilizing the parameters outlined in Table A4.1.12 to assess water motion within the brain parenchyma.

   Diffusion imaging may help in the differential diagnosis of cerebral abscess versus necrotic neoplasm.

Table A4.1.11 Primary Clinical Imaging Parameters for Sequence 10: pMRI of the Brain

Patient position	Supine
Scan type	Single-Shot Echo Planar Imaging (SS-EPI)
Imaging plane (orientation)	Transverse or coronal
Central slice or volume center	Mid-cranium
Echo time (T_E)	60 msec
Repeat time (T_R)	1400 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	1.28 mm, 1.88 mm
Number of data points collected (N_x, N_y)	188, 128
Display matrix (D_x, D_y)	376, 256
Slice thickness (Δz)	5 mm
Number of slices	10
Slice gap	5 mm
Number of acquisitions (N_{acq})	39 (time resolution 1.4 sec)
Read direction	Left–right
Slice location	Area of interest
Saturation pulses	NA
Scan time	56 sec

Table A4.1.12 Primary Clinical Imaging Parameters for Sequence 11: dMRI of the Brain

Patient position	Supine
Scan type	Diffusion EPI
Imaging plane (orientation)	Transverse
Central slice or volume center	Mid-cranium
Echo time (T_E)	100 msec
Repeat time (T_R)	5629 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	2.96 mm, 3 mm
Number of data points collected (N_x, N_y)	81, 80
Display matrix (D_x, D_y)	81, 80
Slice thickness (Δz)	5 mm
Number of slices	20
Slice gap	1 mm
Number of acquisitions (N_{acq})	1 (see Table A4.1.13 below)[a]
Read direction	Left–right
Slice location	Whole brain or area of interest
Saturation pulses	Fat
Scan time	28 sec

[a]With each slice, the MR machine scans five times (five frames), and each frame has a different *b*-value associated with it (see Table A4.1.13).

Table A4.1.13 Five Frame Preset *b*-Value Results

Image Appearance	Read *b*-value	Phase encoding *b*-value	Slice select *b*-value
Frame no. 1. No diffusion	0	0	0
Frame no. 2. No diffusion	0	0	0
Frame no. 3. Diffusion along read	1000 sec/mm^2	0	0
Frame no. 4. Diffusion along phase encoding	0	1000 sec/mm^2	0
Frame no. 5. Diffusion along slice select	0	0	1000 sec/mm^2

This is a rapid acquisition (scan time 28 sec) with moderate spatial resolution that can yield information on the entire brain and multiple lesions, even in agitated patients.

Optimizing echo-planar scan parameters (phase offset and delay) is important to obtain high-quality diffusion images. For this reason, the scan is often simulated prior to being run to allow optimization of these parameters. This may take 1 to 3 min. The values obtained are then passed to the scanner and the sequence performed. (This is unique to Marconi's system.)

6. Acquire images at *b*-values (diffusion gradients; Table A4.1.13) of both 0 and 1000 sec/mm^2, each applied in three orthogonal directions.

   N_{acq} may range from 1 to 40 depending on required SNR.

   These data provide raw diffusion-weighted multishot echo-planar images and is used to process apparent diffusion coefficient (ADC) maps.

Sequence 12: MRS of the brain

7. Use previously acquired multiplanar sequences to place the single voxel over a region of interest. The voxel is $2 \times 2 \times 2$ cm^3 and should be located in the brain, avoiding contamination of signal and magnetic field inhomogeneities from cerebrospinal fluid, fat, bone, and air (sinuses).

   To assume the proper voxel placement, it is recommended that its position be checked in three planes prior to running the sequence.

8. Before the sequence can be run, two important steps must be completed: shimming over the voxel and water suppression. Many scanners have automated packages to perform these functions. However, these preliminary steps may take 5 min to perform.

9. Run this sequence utilizing the parameters outlined in Table A4.1.14 to provide information as to the specific molecular substrate within a volume of interest that can indicate the presence of abnormal tissue or metabolic processes.

   MRS can be used in the diagnosis and follow-up of cerebral abscesses.

10. Sequence acquisition time is 10 min per T_E performed (including the water suppression and shimming, with the sequence acquisition), making useful results difficult to obtain in agitated patients.

    Spectral post-processing is usually automated within the scanner and may include apodization with a gaussian filter, frequency-shift correction, Fourier transformation, and adjustment of phase relations.

    A tracing of the magnetic spectra of the molecular contents of the voxel is produced for analysis.

    In general, longer T_E sequences (e.g., 270 msec) isolate spectra that are more specific for the most commonly assessed peaks of N-acetyl aspartate (NAA), choline (Cho), and creatine (Cr). Lower T_E sequences provide more complex spectra with greater sensitivity for many other substances of potential interest, such as myoinositol.

Table A4.1.14 Primary Clinical Imaging Parameters for Sequence 12: MRS of the Brain

Patient position	Supine
Scan type	Single voxel Point-Resolved Spectroscopic (PRESS)
Voxel center	Area of abnormality
Echo time (T_E)	35 msec
Repeat time (T_R)	1500 msec
Flip angle (FA)	90°
Voxel size (Δx, Δy, Δz)	2 cm, 2 cm, 2 cm
Number of acquisitions (N_{acq})	8 (reference)[a], 192 (signal)[b]
Saturation pulses	Fat and water

[a]These 8 acquisitions are done without water suppression and are used for phase correction of the free induction decay scans.
[b]These 192 acquisitions are done with water suppression.

COMMENTARY

Background Information

Cerebritis and abscess, though not common diagnoses, remain disturbingly common today despite the advent of, and significant advances in, the field of microbiology. This is primarily related to the increased prevalence of immunocompromised patient populations and resistant strains of microorganisms. The patient with cerebral abscess may present in a nonspecific fashion. The most commonly noted symptom is headache, which may be the only complaint. More disturbing signs and symptoms of fever (i.e., <50% in some series), altered sensorium, focal neurologic deficit, and seizure may also manifest. The primary source of the intracranial infection may be an important clue and should be sought.

MR has emerged as the study of choice in patients suspected of harboring a cerebral abscess(es), primarily as it is significantly more sensitive for the detection of inflammatory disease in the central nervous system (CNS) than computed tomography (CT) and the other imaging and laboratory studies (Mathisen and Johnson, 1997). The results of the Basic Protocol outlined above are often nonspecific though, yielding a differential diagnosis that also includes primary and metastatic brain tumors, resolving hematoma, infarction, and demyelinating disease. However, MR is crucial for defining not only the presence of disease, but also the extent, and is used in surgical planning (and timing) with these patients. With the recent advancements of diffusion, perfusion, and spectroscopic sequences, and newly available research data, the lack of specificity of the technique is rapidly diminishing. pMRI parallels the published results of nuclear medicine studies differentiating abscess from neoplasm using single-photon emission CT (SPECT) and positron emission tomography (PET; Ernst et al., 1998). However, pMRI is a more convenient and rapid exam (when performed in conjunction with the MR study). In addition, the anatomic information and higher spatial resolution provided by MRI make the technique a powerful tool in these patients. Additionally, MR can be used to follow cerebral abscess patients through their therapy. Not only does MR demonstrate reduced size and number of lesions and mass effect with effective therapy, but also the status of organism activity within abscesses and their response to antibiotics may be assessed (Burtscher and Holtas, 1999). This in turn may lead to earlier intervention with percutaneous or surgical drainage of abscess cavities or more rapid assignment of the proper differential diagnosis of a noninfectious lesion, such as tumor, allowing for directed therapies to be instituted. The sensitive detection and proper classification of infectious lesions and abscess by MR can also provide more timely and directed determination of the source of an infection, with institution of the necessary treatments, as is seen with cardiac valvular disease causing mycotic aneurysm and abscess. Laboratory analysis is still required to determine the specific infectious organism.

Critical Parameters and Troubleshooting

There are several parameters that enhance the sensitivity and utility of the Basic Protocol

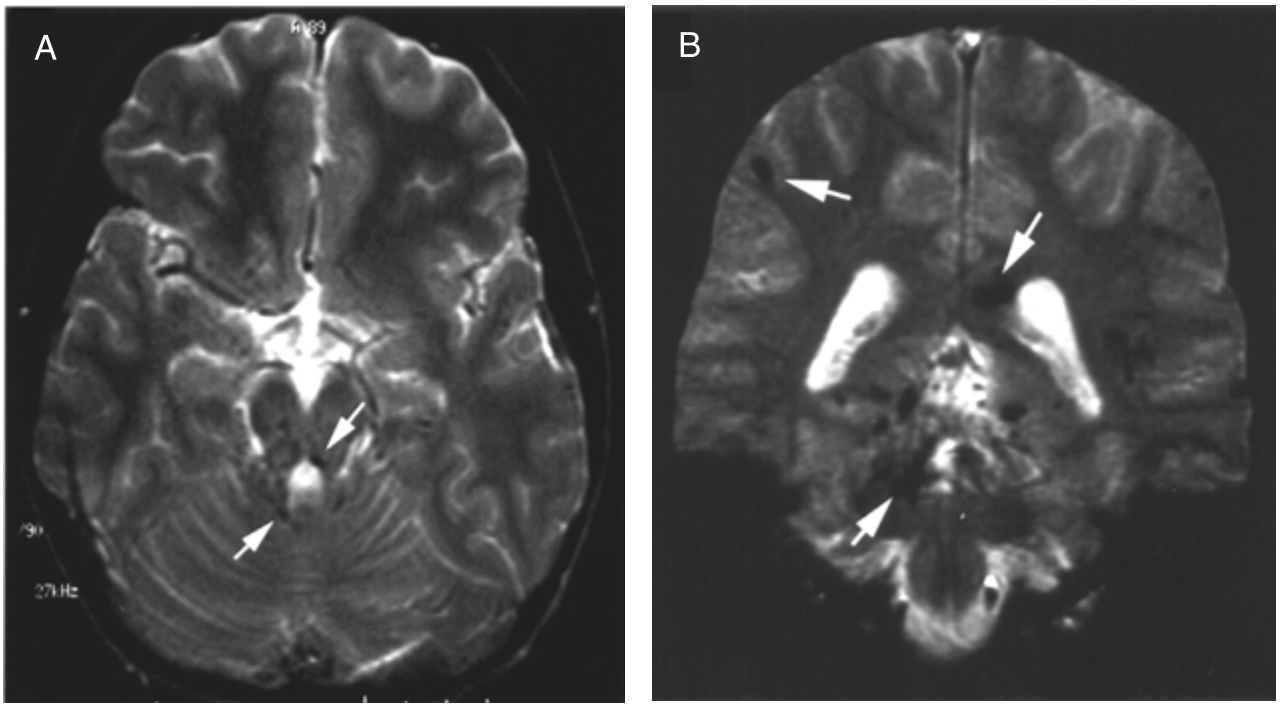

Figure A4.1.1 A T_2-weighted spin-echo transverse (T_R = 2500 msec, T_E = 80 msec, N_{acq} = 0.75) image of the brain (**A**) at the level of the midbrain shows several subtle abnormal foci of low signal intensity in the posterior brainstem and cerebellar peduncles (arrows) that on a gradient-echo coronal (T_R = 500 msec, T_E = 25 msec, N_{acq} = 1) image through the posterior midbrain (**B**) demonstrate marked magnetic susceptibility effect with "blooming" of the lesions (arrows). In addition there are numerous other foci demonstrated at multiple levels consistent with diffuse axonal injury in this 12-year-old boy who had sustained a severe closed head injury 2 months previously.

(Orrison et al., 1995). These include the proper selection of the T_I (inversion time) for the FLAIR images to effect nulling of hyperintense cerebrospinal fluid (CSF) signal, producing dark CSF. This enables the detection of abnormal periventricular high T_2-signal intensity for the important determination of ventriculitis/ependymitis, indicating spread of infection to the ventricles or possibly rupture of the abscess into the CSF spaces. Interestingly, most patients have a thin rim of this hyperintensity in the normal state. Additionally, the use of the MT pulse for the post-gadolinium sequences improves the sensitivity for early detection of subtle foci of abnormal enhancement. The MT pulse works by suppressing overall background signal intensity, thus leaving the high T_1-signal of enhancing tissue more apparent.

When considering the optional sequences, the optimal choice of T_E on the gradient-echo coronal sequence is important to allow for detection of foci of microhemorrhage. These foci may indicate the presence of satellite lesions of infection, and their detection may narrow the differential diagnostic possibilities for infectious organism (such as Herpes simplex virus,

Figure A4.1.2 (*on right*) FLAIR (T_R = 6000 msec, T_E = 96 msec, N_{acq} = 1; T_I = 1800 msec) and FSE T_2-weighted (T_R = 5616 msec, T_E = 105 msec, N_{acq} = 1; echo train length = ETL = 12) transverse images (**A**,**B**) of the brain at the level of the corona radiata show an abnormal rounded low T_2 signal intensity lesion (arrow) adjacent the left frontal horn of the lateral ventricle with surrounding edema. Precontrast (**C**) and post-contrast (**D**) transverse images at the same level (T_R = 500 msec, T_E = 12 msec, N_{acq} = 1) show intense enhancement of the lesion. The patient is a 41-year-old male with chronic sarcoidosis being treated with high-dose corticosteroids. The resulting chronic immunosuppression enabled infection and cerebral abscess formation by *Bipolaris* fungus. This patient previously underwent a left frontal lobe biopsy and resulting encephalomalacia is noted (asterisk). Magnetic resonance spectroscopy (PRESS, T_R = 1600 msec, T_E = 135 msec) of one of the abscesses (**E**) demonstrates a decrease in the NAA peak with elevation of the creatine and choline peaks consistent with a loss of neuronal tissue within the lesion.

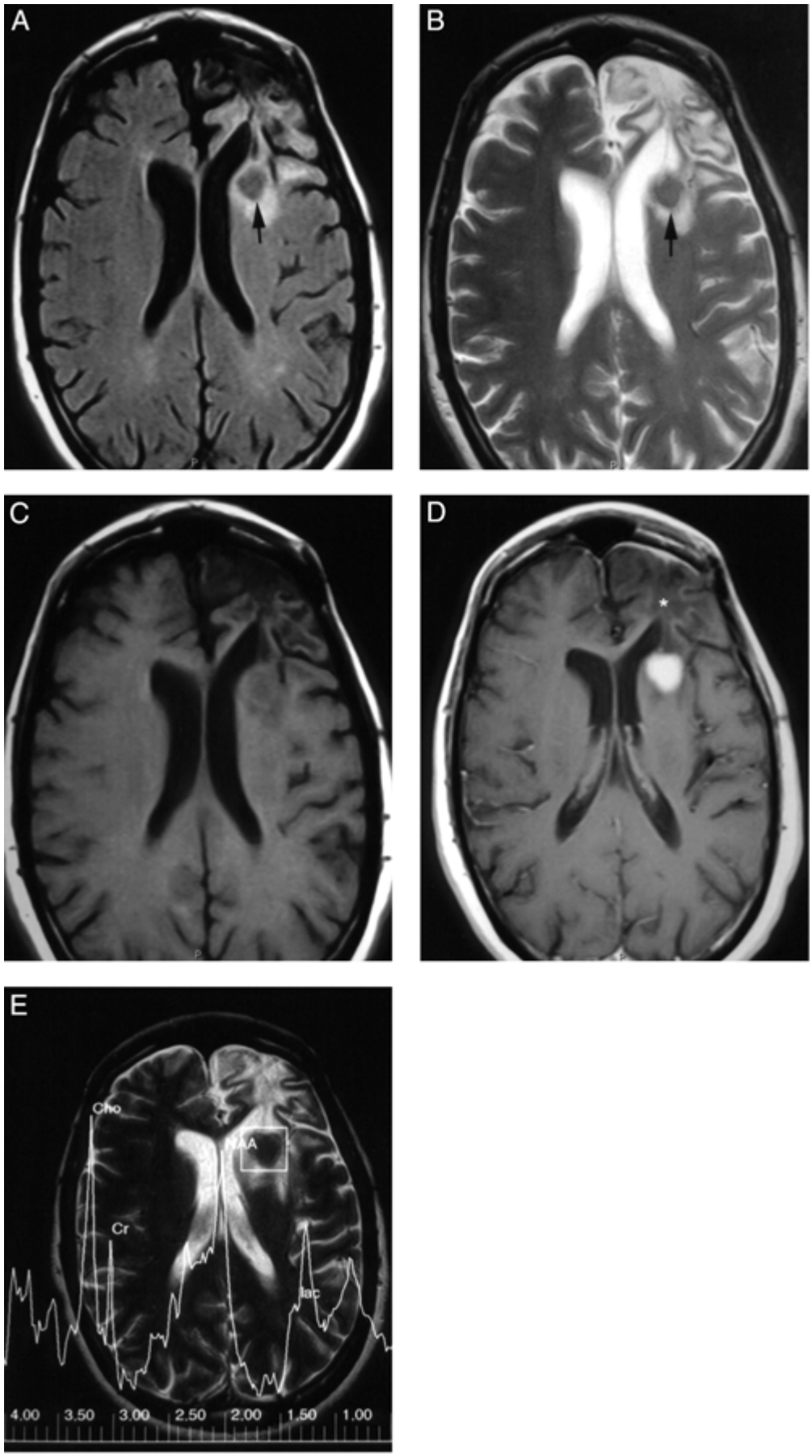

Figure A4.1.2 *(See legend on facing page.)*

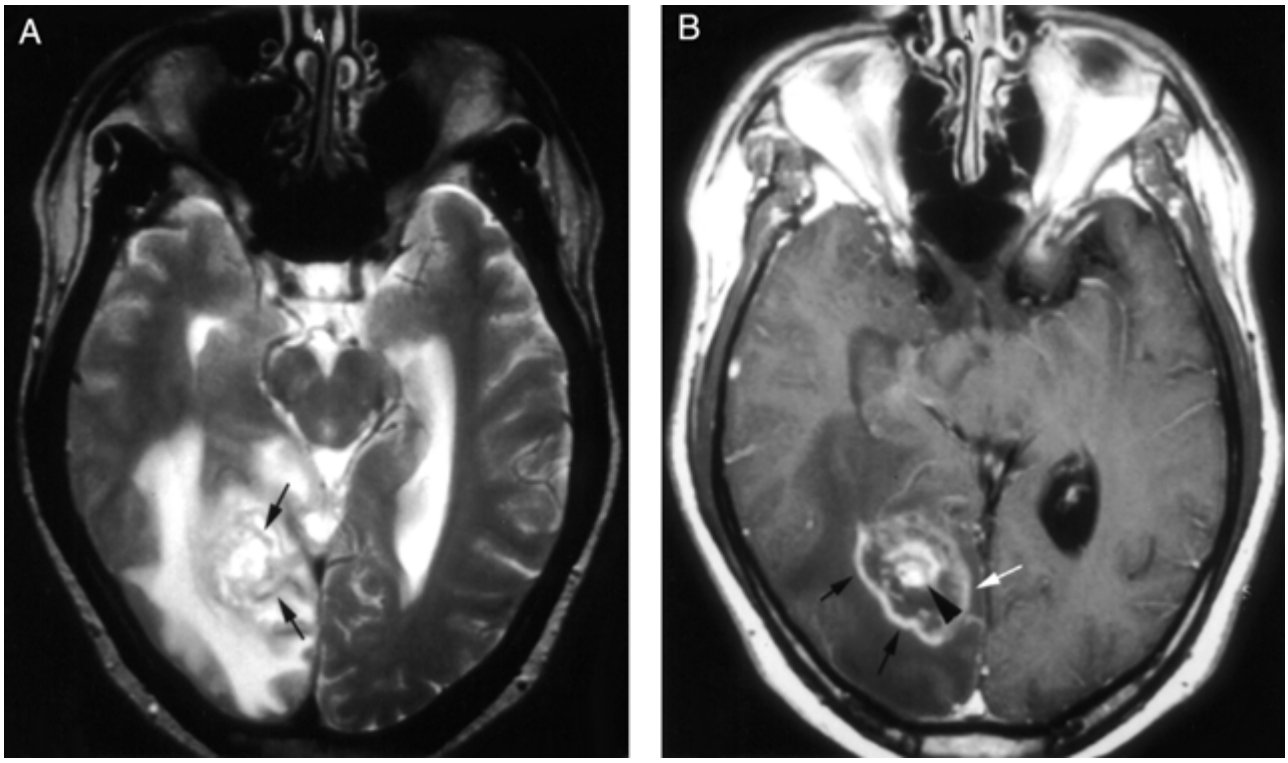

Figure A4.1.3 FSE (T_R = 3380 msec, T_E = 90 msec, N_{acq} = 2; ETL = 8) T_2-weighted (**A**) image through the occipital lobe shows a large heterogeneous lesion with prominent surrounding edema. There are layers of low T_2 signal within its wall (arrows) suggesting not only abscess but possible microhemorrhage. The corresponding post-contrast T_1-weighted (T_R = 600 msec, T_E = 14 msec, N_{acq} = 2) transverse (**B**) image reveals a relatively defined deep wall (arrow) compared to the more superficial wall (white arrow) and a target configuration (arrowhead), as well. This 40-year-old male with AIDS was treated for presumed toxoplasmosis with lesion resolution over the ensuing 8 weeks (not shown).

which is angioinvasive and thus predisposed to causing hemorrhage). A longer T_E will demonstrate increased T_2-based contrast and magnetic susceptibility with more pronounced low signal "blooming" from foci of hemorrhage containing hemosiderin (Fig. A4.1.1), though at the expense of overall tissue signal-to-noise ratio (SNR). Generally, T_E values of <25 msec (the authors use 24.6 msec) are less sensitive for this purpose. For similar reasons, this "blooming" is prominent from densely calcified cortex, such as in the calvarium, and makes for poor evaluation of signal at the skull-brain interface, particularly at the skull base.

An option with speed and utility that can be performed in place of both the gradient-echo coronal and FLAIR/FSE T_2 transverse sequences is a standard proton-density/T_2 dual-echo spin-echo sequence (see *UNIT A5.1*). For a time expenditure similar to that of the Basic Protocol, the sensitivity for magnetic susceptibility (better on T_2 spin-echo than FSE, but best on the gradient-echo coronal sequence) is improved, but at the expense of some sensitivity in the detection of periventricular disease (better with the FLAIR). Also, if detection of brain calcifications is important, this is still best accomplished with CT, as the gradient-echo coronal sequence, though quite sensitive for the magnetic susceptibility of calcified foci, is nonspecific in differentiating calcium from blood products. Additional time savings for imaging critically ill or noncompliant patients can be found by limiting pre-contrast and post-contrast T_1-weighted sequences to one plane each, or performing only one acquisition (N_{acq}) on each sequence, or alternatively by utilizing FSE T_1-weighted sequences rather than routine T_1-weighted sequences. These maneuvers will all limit SNR and sensitivity for detection of abnormal contrast enhancement, but will afford faster protocol scan times (for a more detailed discussion of fast-scan techniques, see chapter A5 of this series).

Anticipated Results

Brain abscesses have been shown to progress through four evolutionary stages on imaging studies, with the first being the acute or cerebritis stage (Taveras and Pile-Spellman,

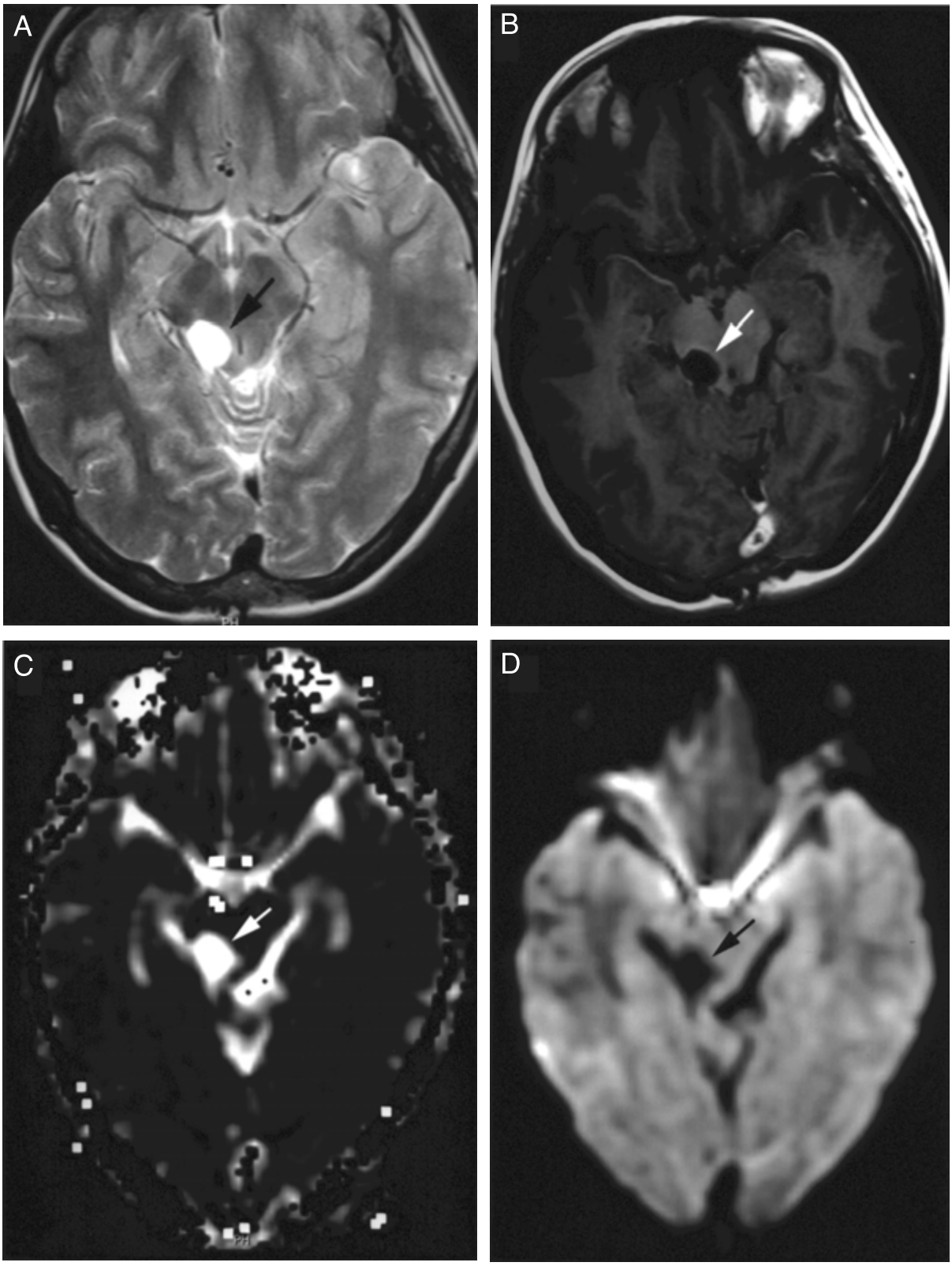

Figure A4.1.4 This 23-year-old female presented with headache and ataxia. (**A**) The FSE-T_2 (T_R = 5616 msec, T_E = 105 msec, N_{acq} = 1; ETL = 8) and (**B**) post-contrast T_1-weighted (T_R = 500 msec, T_E = 12 msec, N_{acq} = 1) transverse images show a heterogeneous rounded lesion of the right posterior midbrain (arrows) without definite enhancement. However, the transverse dMRI sequence (T_R = 3000 msec, T_E = 100 msec; b = 1000 sec/mm^2) discloses corresponding high signal on the ADC map (**C**) and low signal on the diffusion-weighted image (**D**) compatible with a tumoral cyst. A low-grade astrocytoma was subsequently proven at surgical biopsy. This lesion presents a dMRI signal pattern opposite to that expected with cerebral abscess.

1996; Wong and Quint, 1999). This occurs during the first 5 days of the infection and is characterized by a loss of the blood-brain-barrier integrity with edema formation and (rarely) microhemorrhage. Imaging is characteristically normal on CT, though either CT or MR may demonstrate edema without prominent mass effect or contrast enhancement. The late cerebritis stage begins at the end of the first week and is characterized by progression to necrosis with a thin rim of granulation tissue. Imaging will show increased edema and mass effect and minimal, diffuse enhancement. Satellite lesions may emerge (Fig. A4.1.2). Any extension of the process is usually noted within the white matter, and it is in this second stage that rupture into the ventricular system is most likely. By the end of the second week (capsular stage) a capsule can be defined on imaging studies that thickens over time, especially along the more superficial (i.e., gray matter) border. The capsule is now considered complete, with three definable layers: inner granulation layer, middle collagenous layer, and outer gliotic layer. Imaging will show this well defined and prominently enhancing capsule encompassing the liquefied abscess with decreased surrounding edema. Surgery is often delayed until this stage to allow for greater success in lesion resection and to minimize hemorrhage in adjacent structures. Finally, in the chronic stage, abscesses most often continue to grow, eventually resulting in a significant morbid event such as rupture into the ventricular or subarachnoid CSF. However, growth arrest and mineralization of the capsule may occur, as can resolution and resorption, especially with successful antibiotic therapy. Imaging will parallel these changes with continued enhancement of the capsule, while resorbing lesions may lose their necrotic center, eventually becoming small foci of enhancement or mineralization.

At initial presentation, the typical cerebral abscess appears on MR imaging as a well-defined rounded lesion with fluid-signal material centrally and a rim of thin, uniform low signal intensity on T_2-weighted images that demonstrates smooth, homogeneous enhancement (Fig. A4.1.3). This is usually surrounded by a variable amount of parenchymal edema. The lesion is most commonly located in the frontal lobe (adjacent an infected sinus, usually the frontal), the parietal lobe (reflecting hematogenous spread from the infection source, and centering at the gray-white junction), or less commonly in the temporal lobe adjacent an infected temporal bone. On pMRI, a cerebral abscess is expected to demonstrate decreased perfusion relative to normal brain, and markedly decreased perfusion relative to hypervascular tumors that generally show increased perfusion (Ernst et al., 1998). On dMRI, cerebral abscess will typically demonstrate high signal on diffusion-weighted images, with markedly decreased abscess cavity signal on ADC images (Desprechins et al., 1999). This is the opposite of that found in necrotic tumors such as glioblastoma multiforme (Fig. A4.1.4). And finally, MRS tracings may show specific products of infectious organism metabolism (i.e., acetate, lactate, pyruvate and succinate—metabolites not reported in human brain tissue other than in infectious states) in the acute/pretreatment phase, with regression over the course of therapy to a single lactate peak of a "dead" abscess, indicating the cessation of viable infectious organism activity (Burtscher and Holtas, 1999). Also, the presence of a group of resonances at 0.9 ppm on the T_E = 270 msec sequence demonstrating inversion on a 135 msec sequence is diagnostic (95% specific) of bacterial abscess. Several amino acids, including valine, leucine and isoleucine, produce this peak and are found in pus within bacterial abscesses at concentrations 20 to 80 times greater than that found in necrotic tumor cavities. Unfortunately, this relationship is not found in abscesses caused by non-bacterial organisms (Grand et al., 1999).

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Key References

Orrison et al., 1995. See above

Contains lucid explanations for the physics and basic scan parameters of standard and advanced magnetic resonance imaging studies.

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