Metastatic Extra-Axial Neoplasia

There are a multitude of tumors which may spread to the extra-axial compartment (i.e., meninges, skull base, and calvarium). The role of imaging in the search for metastases is to detect the full extent of and to correctly localize the disease. This unit presents the set of MR sequences (see Basic Protocols 1, 2, and 3) used for imaging extra-axial metastatic tumors, and specific modifications will be discussed where necessary. The sequences described in this unit are based on the authors' experience with a 1.5 T scanner (Echospeed GE Medical Systems, Milwaukee, Wisconsin), but can be expected to be equally applicable to other field strengths and scanners from other manufacturers.

RULE OUT (R/O) LEPTOMENINGEAL CARCINOMATOSIS

BASIC PROTOCOL 1

Spread of tumor to the leptomeninges is frequently seen in association with any adenocarcinoma (i.e., breast, lung, gastrointestinal tumors) and lymphoma or leukemia (Goldberg et al., 1996). MR imaging in suspected leptomeningeal carcinomatosis is essential not only to demonstrate the disease, but also to assess for potential complications including hydrocephalus. The post-gadolinium T_1-weighted images and fluid-attenuated inversion recovery (FLAIR) images are most useful when evaluating spread of tumor, particularly along the subarachnoid space (leptomeninges; Singer et al., 1998). Sequences 1 to 5 comprise the preferred protocol.

Table A3.2.1 lists the hardware necessary to perform the procedure, along with appropriate parameters.

NOTE: Be sure that technologists and nurses have immediate access to any equipment such as crash carts or oxygen that may be necessary in the event of an emergency. Contrast reactions are rare, but the resources are necessary.

Materials

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

Set up equipment and patient

1. Interview (screen) the patient to ensure that he or she has no contraindications to the MRI examination, such as a cardiac pacemaker or other implants or foreign bodies containing ferromagnetic materials. Question the patient regarding any health conditions that may require the presence of specific emergency equipment during the scanning procedure, or necessitate any other precautions.

   Generally standard screening forms are used for all patients scanned in a magnetic resonance system.

Table A3.2.1 Equipment Parameters for Imaging Brain Tumors

Coil type	Quadrature head coil
Gradient coil strength	25 mT/m (or whatever the system permits)
Cardiac gating	No
Peripheral gating	For safety only
Respiratory gating	No
Respirator	If required by patient
Oxygen	If required by patient
Motion cushions	No

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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 in the magnet, and how to behave, including the following:
   a. Ear protection will be provided (earphones, headphones, earplugs) to dampen the sounds from the gradients, but the patient will be able to communicate with you 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. Help the patient mount onto the table and lie in the supine position. Set up all monitoring equipment or any triggering devices before or right after the patient lies down.
7. Center the patient in the head coil at the region where the key information is desired. Make sure the head and neck are constrained to prevent motion.

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

Sequence 1: Localizer

11. Run sequence 1 according to Table A3.2.2. The sagittal scout view is used to prescribe the transverse and coronal sequences.

Table A3.2.2 Primary Clinical Imaging Parameters for T_1-Weighted Scan (Sequence 1 Localizer)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	11 msec (or select "minimum full" echo time)
Receiver bandwidth (RBW)	10 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.25 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	20 or as many as needed to cover the region of interest
Slice gap	2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	Not applicable
Scan time	1 min, 28 sec

Table A3.2.3 Primary Clinical Imaging Parameters for T_1-Weighted Scan (Sequence 2)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	11 msec (or select "minimum full" echo time)
Receiver bandwidth (RBW)	10 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.25 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	20 or as many as needed to cover the region of interest
Slice gap	2.5 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	Yes
Saturation pulses	Not applicable
Scan time	1 min, 28 sec

Table A3.2.4 Primary Clinical Imaging Parameters for T_2-Weighted Scan (Sequence 3)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	102 msec (effective)
Receiver bandwidth (RBW)	16 kHz
Echo train length (ETL)	8
Repeat time (T_R)	3600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.25 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	20 or as many as needed to cover the region of interest
Slice gap	2.5 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	Yes
Saturation pulses	Not applicable
Scan time	~2 min

Table A3.2.5 Primary Clinical Imaging Parameters for Fast FLAIR Scan (Sequence 4)

Patient position	Supine
Scan type	Inversion recovery fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	120 msec (effective)
Receiver bandwidth (RBW)	16 kHz
Echo train length (ETL)	8
Repeat time (T_R)	10000 msec
Inversion time (T_I)	2200 msec
Flip angle (FA)	180°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.25 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	20 or as many as needed to cover the region of interest
Slice gap	2.5 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	Yes
Saturation pulses	Not applicable
Scan time	~5 min

Sequence 2: T_1-weighted scan

12. Run sequence 2 according to Table A3.2.3. The pre-contrast T_1-weighted scan should be acquired in the same plane as the post-contrast T_1-weighted scan to look for intra-lesional enhancement.

Sequence 3: T_2-weighted scan

13. Run sequence 3 according to Table A3.2.4.

Sequence 4: Fast fluid-attenuated inversion recovery (FLAIR) scan

14. Run sequence 4 according to Table A3.2.5. FLAIR images are useful when evaluating spread of tumor, particularly along the subarachnoid space (leptomeninges).

Sequence 5: Post-contrast imaging

15. Remove the patient from the scanner. The patient should not move on the table. Establish an intravenous line from 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. Move the patient back into the scanner.

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

16. Leaving the patient in the magnet, inject the contrast agent, flush the line with 10 ml saline.

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

    A delay in scanning may actually be beneficial when evaluating for metastases, which is one of the reasons we scan in multiple planes after intravenous contrast administration.

17. Acquire the post-contrast images using the same parameters as in sequence 2 (T_1-weighted), Table A3.2.3. In addition to the transverse plane, the coronal plane is routinely obtained, with the following changes to the parameters in sequence 2: (a) flow compensation is on; (b) T_E is 15 msec (prolonged due to flow compensation gradients); and (c) it is not necessary to swap read and phase encoding directions. We also routinely obtain a third post-contrast plane of imaging (sagittal) in patients requiring sedation and in all pediatric patients.

R/O BASE OF SKULL METASTASIS

BASIC PROTOCOL 2

Metastases to the base of the skull frequently arise from the local spread of pharyngeal tumor, or from hematogenous spread to the bone. The main purpose of imaging is to demonstrate disease and determine the full extent of spread of the lesion (i.e., cranial nerve or meningeal involvement). Fat-suppressed high-resolution imaging (including T_2-weighted imaging and post-contrast T_1-weighted imaging) is essential when evaluating tumor involvement of skull base structures.

Set up patient and equipment

1. Use the same equipment and perform equipment and patient setup as for the previous method (see Basic Protocol 1).
2. Obtain sequences 1, 2, 3 outlined in Basic Protocol 1 to evaluate the entire brain.
3. For high-resolution imaging of the skull base, perform transverse pre-contrast sequences 6 and 7 outlined in Tables A3.2.6 and A3.2.7. The entire extent of the lesion must always be included.

Table A3.2.6 Primary Clinical Imaging Parameters for T_2-Weighted Scan (Sequence 6)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	102 msec (effective)
Receiver bandwidth (RBW)	16 kHz
Echo train length (ETL)	16
Repeat time (T_R)	4000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.70 mm, 0.70 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	3 mm
Number of slices	20 or as many as needed to cover entire skull base
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	3
Swap read and phase encoding	Yes
Saturation pulses	Fat
Fat suppression	Yes
Scan time	~5 min

Table A3.2.7 Primary Clinical Imaging Parameters for T_1-Weighted Scan (Sequence 7)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	11 msec (or select "minimum full" echo time)
Receiver bandwidth (RBW)	10 kHz
Repeat time (T_R)	600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.70 mm, 0.94 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	3 mm
Number of slices	20 or as many as needed to cover entire skull base
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	3
Swap read and phase encoding	Yes
Saturation pulses	None
Fat suppression	No
Scan time	~5 min

Table A3.2.8 Primary Clinical Imaging Parameters for Post-Contrast T_1-Weighted Scan (Sequence 8)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse *and* coronal
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	20 msec
Receiver bandwidth (RBW)	10 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.70 mm, 0.94 mm
Number of slices	20 or as many as needed to cover the area of interest
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	3 mm
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	3
Swap read and phase encoding	Yes if it is a transverse scan
Saturation pulses	Fat
Fat suppression	Yes
Scan time	~5 min

Sequence 6: T_2-weighted scan

4. Run sequence 6 according to Table A3.2.6. Fat-suppressed high-resolution imaging is essential to clearly delineate the full extent of disease in the skull base.

Sequence 7: T_1-weighted scan

5. Run sequence 7 according to Table A3.2.7.

Sequence 8: T_1-weighted scan (post-contrast)

6. Repeat steps 15 and 16 in Basic Protocol 1.
7. Post-contrast T_1-weighted sequence 8 (Table A3.2.8) are obtained in two planes (transverse and coronal). The entire extent of the lesion must always be included. Fat-suppressed T_1-weighted images are critical to evaluate for abnormal enhancement of cranial nerves, since high signal intensity from fat found along the skull base or chemical shift artifact from fat-containing structures can obscure enhancement of cranial nerves.
8. In addition, post-contrast images (sequence 8 outlined in Table A3.2.8) of the entire brain should be obtained.

R/O HEMORRHAGIC METASTATIC DISEASE/MELANOMA

BASIC PROTOCOL 3

The MR appearance of hemorrhage will vary according to the stage of the hemorrhage (acute-chronic) on the T_1-weighted and T_2-weighted images. On the other hand, gradient-echo images not uncommonly demonstrate evidence of hemorrhage that may not be seen with conventional spin-echo images (Atlas et al., 1987, 1988; Thulborn et al., 1990; Thulborn and Atlas, 1996). Intracranial metastatic melanoma (if melanotic) exhibits the typical imaging appearance of any paramagnetic lesion (Atlas et al., 1987), causing shortening of T_1 and T_2. However, the imaging appearance may be quite variable depending on melanin content and hemorrhage.

Table A3.2.9 Primary Clinical Imaging Parameters for Gradient Recalled Echo (GRE) Scan (Sequence 9)

Patient position	Supine
Scan type	2-D gradient recalled echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Laser light centered on nasion
Echo time (T_E)	30 msec
Receiver bandwidth (RBW)	4 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	15°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.25 mm
Number of data points collected (N_x, N_y)	256, 192
Slice thickness (Δz)	5 mm
Number of slices	20 or as many as needed to cover the region of interest
Slice gap	2.5 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	Yes
Saturation pulses	Not applicable
Scan time	~2 min

Set up equipment and patient

1. Use the same equipment and perform patient setup as in Basic Protocol 1. Obtain sequences 1 to 4.

In addition, gradient echo (GRE) images (sequence 9; Table A3.2.9) should be obtained.

Sequence 9: Gradient echo scan

2. Run sequence 9 according to Table A3.2.9.

Sequence 10: Post-contrast imaging

3. Run sequence 5 (see Basic Protocol 1, steps 15 to 17).

COMMENTARY

Background Information

Metastatic extra-axial disease is common in clinical practice and lesions are frequently numerous and infiltrative. Obtaining detailed information regarding the entire extent of disease is critical to the planning of appropriate treatment. MRI with intravenous contrast is essential for documenting meningeal disease and spread along cranial nerves.

High-resolution computed tomography (CT) of the skull base is often an integral part of the work-up of a skull base lesion. CT provides important information regarding the integrity of bone architecture and depicts bone irregularity, erosion, intra-tumoral calcification or hyperostosis.

Critical Parameters and Troubleshooting

The MR evaluation for extra-axial spread of tumor to the meninges (leptomeningeal carcinomatosis) should always include FLAIR or post-contrast T_1-weighted images to provide the greatest sensitivity in disease detection. When evaluating the skull base, fat-suppressed high-resolution imaging (including T_2-weighted and post-contrast T_1-weighted) is essential to clearly delineate the full extent of disease. With a resolution of less than 1 mm in the *x* and *y* directions, there is superb visualization of the fine, intricate structures of the skull base (foramina and cranial nerves). Fat-suppressed T_1-weighted images are critical to

evaluate for abnormal enhancement of cranial nerves, since high signal intensity on the T_1-weighted images from fat found along the skull base or chemical shift artifact from fat-containing structures can obscure enhancement of cranial nerves. Inhomogeneities in the magnetic field can result in incomplete fat suppression or unintended suppression of water. With experience this does not usually represent a concern.

Anticipated Results

The goal of imaging when evaluating for extra-axial metastases is to accurately localize and detect the full extent of disease. Magnetic resonance imaging offers the necessary contrast and high resolution to fully evaluate the extra-cranial compartment for tumor spread.

Time Considerations

The majority of these protocols should take ~30 min to complete.

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