# Cranial Nerves III to VI



Cranial nerves III, IV, V, and VI are small structures that travel in a reproducible manner from the midbrain and pons to the cavernous sinus and then to the orbit. While there are branches that course through other foramina of the skull, the emphasis in MR is to evaluate the brainstem, the cavernous sinus, and the pericavernous regions for pathology. Because the nerves run from a posterior to an anterior position, coronal scanning is ideal for seeing the nerves in cross-section. Thin sections and contrast enhancement are required to best visualize the diseases that affect these nerves (Castillo and Mukherji, 1996a, 1996b).

Terminology used in this unit is defined under the Index of Terms (see Commentary).

## IMAGING OF CRANIAL NERVES III TO VI

*BASIC PROTOCOL*

The cranial nerves that supply the oculomotor muscles (III, IV, and VI) emanate from the brainstem and proceed through the cavernous sinus to enter the superior orbital fissure. Cranial nerve IV is unique in that it decussates in the midbrain and then exits the brainstem from the posterior surface of the midbrain (all others remain ipsilateral and leave the brainstem from its anterior surface). One branch of cranial nerve V, the ophthalmic branch (V-1), also traverses the superior orbital fissure with the other cranial nerves while the maxillary nerve (V-2) and mandibular nerve (V-3) escape to the head and neck via foramina rotundum and ovale respectively. While cranial nerves III and V are routinely visualized on standard brain scans, visualization of cranial nerves IV and VI requires a dedicated effort. Fortunately, isolated lesions of these nerves are uncommon.

Table A7.2.1 lists the hardware necessary to perform the procedure, along with appropriate parameters. Standard head coil imaging is sufficient to obtain adequate scans on these cranial nerves. Anatomic imaging with high-quality fast spin echo $T_2$-weighted scan with fat suppression should yield dark nerves outlined by bright cerebrospinal fluid (CSF). This is required to see the cisternal portions of these nerves. In the cavernous sinus, the nerves are best seen as filling defects in the gadolinium-enhanced cavernous sinus walls on coronal scans (Yousem et al., 1989, 1990a). Field strength considerations are not critical, although field strength is directly proportional to signal-to-noise ratio (SNR). Adjustments in maximizing overall SNR should be taken into account with small FOV's and reduced slice thicknesses. No monitoring is required.

### *Materials*

Normal saline (0.9% NaCl), sterile
Gadolinium-based MR contrast agent (e.g., Magnevist, Omniscan, or Prohance)

*NOTE:* Be sure that technicians 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.

**Table A7.2.1** Equipment Parameters for Cranial Nerve Imaging

| | |
|---|---|
| Coil type | Head |
| Gradient coil strength | 25 mT/m |
| Flow compensation pulse | As needed |
| Peripheral gating | NA |
| Motion cushions | Useful |
| Use of contrast agents | Yes |



**Contributed by Robert W. Evers and David M. Yousem**
*Current Protocols in Magnetic Resonance Imaging* (2001) A7.2.1-A7.2.12
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***Set up equipment and patient***

1. Interview (screen) the patient to ensure that he or she has no contraindications 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.

   *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 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 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. 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's head within the head coil and use the laser light to ensure symmetry (for most brain scans, placing the center landmark at the eyebrow level allows full coverage of the relevant regions of anatomy). 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.*

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

9. 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.

   *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.*

10. Use the centering light to center on the nasion and advance the patient 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.

***Sequence 1: Sagittal $T_1$-weighted spin echo scan***

Although a pilot scan can be acquired, it is not necessary here, because the first scan covers almost the entire brain in a sagittal fashion. These sagittal images can then be used as localizers for the application of saturation pulses when the transverse images are acquired.

12. Run sagittal $T_1$-weighted scan using the imaging sequence given in Table A7.2.2.

    *Spatial saturation pulses are applied inferiorly within the field of view. This will significantly reduce the propagation of blood flow–related artifacts and will demonstrate the full course of the third cranial nerve seen emanating from the midbrain and heading to the cavernous sinus. Since aneurysms may cause cranial nerve III (and VI) deficits, this scan may demonstrate vascular compression of the nerve to best advantage.*

***Sequence 2: Transverse fast spin echo (FSE) scan***

13. Run transverse fast spin echo (turbo spin echo) $T_2$-weighted scan using the imaging sequence given in Table A7.2.3.

**Table A7.2.2** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 1; $T_1$ Sagittal)

| | |
|---|---|
| Patient Position | Supine |
| Scan type | Spin echo |
| Imaging plane (orientation) | Sagittal |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | Minimum |
| Receiver bandwidth (RBW) | 16 kHz |
| Repeat time ($T_R$) | 400–600 msec |
| Flip angle (FA) | 90° |
| Fields of view ($FOV_x$, $FOV_y$) | 240 mm, 240 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.94 mm, 1.25 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 192 |
| Slice thickness ($\Delta z$) | 5 mm |
| Number of slices | 28 |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 1 |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~2 min |

**Table A7.2.3** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 2; $T_2$ FSE Transverse)[a]

| | |
|---|---|
| Patient position | Supine |
| Scan type | Fast spin echo |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | 90–120 msec |
| Receiver bandwidth (RBW) | 20 kHz |
| Echo train length (ETL) | 12–32 |
| Repeat time ($T_R$) | 3000–4000 msec |
| Flip angle (FA) | 90° |
| Fields of view ($FOV_x$, $FOV_y$) | 240 mm, 240 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.94 mm, 0.94 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 256 |
| Slice thickness ($\Delta z$) | 3 mm |
| Number of slices | Variable (~20) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 2 |
| Flow compensation | Yes |
| ZIP 512 | Yes, changes resolution to 0.47 mm by 0.47 mm |
| Chemical saturation | Yes, fat |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~4–5 min |

[a]FSE, fast spin echo.

*Echo train length is 12 to 32, depending on slices allowed and minimum echo spacing. Saturation pulses inferiorly and gradient moment nulling (flow compensation) are applied. The sections should be from the top of the midbrain to the mid medulla to encompass the origins of the cranial nerves. We now routinely apply frequency selective fat suppression pulses to produce a better dynamic range of contrast and to null the skull base fat. This is of particular advantage when studying lesions or structures that traverse fatty areas such as the orbit (for cranial nerves III, IV, V-1, and VI) and the skull base foramina (for V-2, V-3). Acquisition time will be 4 to 5 min in length. For details on improvements in fat suppression techniques, see Troubleshooting.*

### *Sequence 3: Transverse FLAIR scan*

14. Run transverse fluid attenuation inversion recovery (FLAIR) scan using the imaging sequence given in Table A7.2.4.

*Echo train length is 12 to 32 depending on slices allowed and minimum echo spacing. Saturation pulses inferiorly, tailored radiofrequency pulses, and gradient moment nulling (flow compensation) are applied. The sections should be through the entire brain. Acquisition time will be 4 to 5 min in length. Since demyelinating disorders are a common cause of cranial neuropathies, one needs to utilize FLAIR imaging because of its ability to display white matter lesions in the brainstem and supratentorial compartment in patients who have cranial nerve III to VI deficits.*

### *Sequence 4: Transverse echo planar/diffusion weighted scan*

15. Run transverse echo planar/diffusion weighted imaging using the imaging sequence given in Table A7.2.5.

**Table A7.2.4** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 3; FLAIR Transverse)[a]

| | |
|---|---|
| Patient position | Supine |
| Scan type | FLAIR |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | 133 msec |
| Receiver bandwidth (RBW) | 16 kHz |
| Echo train length (ETL) | 12–32 |
| Repeat time ($T_R$) | 8800 msec |
| Inversion time ($T_I$) | 2200 msec |
| Flip angle (FA) | 180° |
| Fields of view ($FOV_x$, $FOV_y$) | 240 mm, 240 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.94 mm, 0.94 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 256 |
| Slice thickness ($\Delta z$) | 5 mm |
| Number of slices | Variable (~20) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 1 |
| Flow compensation | Yes |
| ZIP 512 | Yes, changes resolution to 0.47 mm by 0.47 mm |
| Tailored RF | Yes |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~4–5 min |

[a]FLAIR, fluid attenuation inversion recovery.

**Table A7.2.5** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 4; Echo Planar/Diffusion Weighted Image Transverse)

| | |
|---|---|
| Patient position | Supine |
| Scan type | Echo planer/diffusion weighted image |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | Minimum |
| Receiver bandwidth (RBW) | 62 kHz |
| Repeat time ($T_R$) | 10,000 msec |
| Flip angle (FA) | 90° |
| Fields of view ($FOV_x$, $FOV_y$) | 240 mm, 240 mm |
| Resolution ($\Delta x$, $\Delta y$) | 1.88 mm, 1.88 mm |
| Number of data points collected ($N_x$, $N_y$) | 128, 128 |
| Slice thickness ($\Delta z$) | 5 mm |
| Number of slices | Variable (~10) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 1 |
| Slice series | Interleaved |
| Scan time | 1 min |

*The minimum diffusion weighting should have a "b" value of at least 1000 sec/mm$^2$. These sections should be applied through the entire brain, and aid in the detection of acute stroke processes.*

### *Sequence 5: Transverse $T_2$-weighted spin echo scan*

16. Run transverse fast spin echo (turbo spin echo) thin cut imaging should also be employed using the imaging sequence given in Table A7.2.6.

    *Selective chemical (fat) suppression should be utilized to decrease the signal from skull-base fat.*

### *Sequence 6: Transverse post-contrast $T_1$-weighted scan*

17. Leave the patient in the magnet, inject the contrast agent, and flush the line with 10 ml saline.

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

18. Run transverse post-gadolinium $T_1$-weighted scans using the imaging sequence given in Table A7.2.7.

    *Saturation pulses inferiorly placed and gradient moment nulling (flow compensation) are applied. Again these scans should be focused on the brainstem and cavernous sinus region and thus will also include parts of the orbit (though a separate orbit protocol may be necessary to best visualize orbital pathology). It is imperative to utilize an inferior spatial saturation pulse in conjunction with gradient moment nulling. Although the addition of gradient moment nulling may slightly increase your overall effective $T_E$, we have not found this slight increase to be of any real clinical significance in altering the $T_1$ of the tissue examined.*

**Table A7.2.6** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 5; Thin $T_2$ FSE with Fat Saturation)

| | |
|---|---|
| Patient position | Supine |
| Scan type | Fast spin echo |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | 90–120 msec |
| Receiver bandwidth (RBW) | 20 kHz |
| Echo train length (ETL) | 12–32 |
| Repeat time ($T_R$) | 3000–4000 msec |
| Flip angle (FA) | 90° |
| Fields of view ($FOV_x$, $FOV_y$) | 200 mm, 200 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.78 mm, 0.78 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 256 |
| Slice thickness ($\Delta z$) | 3 mm |
| Number of slices | Variable (~20) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 2 |
| Flow compensation | Yes |
| ZIP 512 | Yes, changes resolution to 0.39 mm by 0.39 mm |
| Chemical saturation | Fat saturation |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~4 min |

**Table A7.2.7** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 6; Thin Transverse $T_1$ Post-Contrast)

| | |
|---|---|
| Patient position | Supine |
| Scan type | Spin echo |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | Minimum |
| Receiver bandwidth (RBW) | 16 kHz |
| Repeat time ($T_R$) | 400–600 msec |
| Flip angle (FA) | 90° |
| Fields of view ($FOV_x$, $FOV_y$) | 200 mm, 200 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.78 mm, 0.78 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 256 |
| Slice thickness ($\Delta z$) | 3 mm |
| Number of slices | Variable (~20) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 2–3 |
| Flow compensation | Yes |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~4 min |

**Table A7.2.8** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 7; $T_1$ Coronal Post-Contrast)

| | |
|---|---|
| Patient position | Supine |
| Scan type | Fast spin echo |
| Imaging plane (orientation) | Coronal |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | Minimum |
| Receiver bandwidth (RBW) | 16 kHz |
| Echo train length (ETL) | ≤4 |
| Repeat time ($T_R$) | 400–600 msec |
| Flip angle (FA) | 90° |
| Field of view ($FOV_x$, $FOV_y$) | 200 mm, 200 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.78 mm, 0.78 mm |
| Number of data points collected ($N_x$, $N_y$) | 256, 256 |
| Slice thickness ($\Delta z$) | 3 mm |
| Number of slices | Variable (~20) |
| Slice gap | 0 mm |
| Number of excitations (NEX) | 2–3 |
| Flow compensation | Yes |
| ZIP 512 | Yes, changes resolution to 0.39 mm by 0.39 mm |
| Chemical saturation | Fat saturation |
| Spatial saturation | Inferior |
| Slice series | Interleaved |
| Scan time | ~4 min |

***Sequence 7: Coronal post-contrast $T_1$-weighted scan***

19. Run coronal post-gadolinium spin echo $T_1$-weighted scan using the imaging sequence given in Table A7.2.8.

*Saturation pulses inferiorly placed and gradient moment nulling (flow compensation) is encouraged. The sections should begin at the posterior brainstem margin (where cranial nerve IV leaves) and extend anteriorly to include the orbits. The field of view should be at least 20 cm, to include parts of the skull base and head and neck supplied by the branches of the trigeminal nerve. Frequency-selective fat suppression is useful. The sequence can be performed as a fast spin echo $T_1$-weighted scan, but the matrix should be ZIPed to 512 by 512, no more than an echo train length of 4 should be used, and fat suppression should be applied. Acquisition time will be 2 to 4 min in length.*

***ALTERNATE PROTOCOL***

## DEMYELINATING ETIOLOGIES: ANEURYSMS

If demyelinating etiologies for the cranial nerve deficits are considered, then a more extensive $T_2$-weighted evaluation of the brain may be indicated. The post-gadolinium scans should be extended to cover the whole brain. If one identifies lesions that enhance and lesions that do not, it would imply a polyphasic disease such as multiple sclerosis.

As indicated previously, aneurysms of nearby vessels may impinge on cranial nerves, thereby causing deficits. In the case of cranial nerve III, these are usually posterior communicating artery aneurysms although the nerve also courses between the posterior cerebral and superior cerebellar arteries. Cranial nerve V may be impacted by branches of the basilar artery as well and lead to trigeminal neuralgia ("tic doulereux"; Chong, 1996; Hutchins et al., 1989). Cavernous sinus aneurysms may lead to cranial nerve VI palsies, as this nerve is in close proximity to the cavernous carotid artery. For these reasons, one should scrutinize the spin echo scans for any signs of unusual flow voids that might indicate an aneurysm, and have a very liberal threshold for performing an MR angiogram of the intracranial vessels. We have found that the utilization of a MOTSA (multiple overlapping thin slice acquisition) proves to be a very predictable and homogeneous time-of-flight technique. With the addition/employment of MOTSA, we often find it necessary to ramp the RF pulse across the imaging volume.

***Sequence 8: MRA (MR angiography) scan***

An optional MRA using the imaging sequence given in Table A7.2.9 to evaluate aneurysms and/or other pathologies may be required in conjunction with conventional imaging. The decision to complete the optional MRA should be made prior to the administration of intravenous contrast medium. A 3-D vascular time-of-flight (TOF) utilizing a technique known as MOTSA (multiple overlapping thin slice acquisition) typically provides the clinician with a very good assessment of the vascular anatomy. A $T_R$ of 35 msec, $T_E$ = 6.9 msec should be used so that fat and water are out of phase with one another. This "out of phase" $T_E$ should reduce the contribution of orbital fat signal overlapping structures such as the ophthalmic arteries. Take note that the $T_E$ will vary with field strength in order to have fat and water out of phase. At 1.5 T, every 2.3 msec, fat and water go out of phase and back in phase, respectively. The slice thickness is 1.2 mm with a ZIP 2 (50% overlap slice interpolation) and an imaging matrix of 512 by 256 that is ZIPed to 512 by 512. A maximum field of view (FOV) should be (24 cm, 18 cm) and it is suggested to utilize magnetization transfer and a ramped RF pulse as imaging options to improve the angio quality.

**Table A7.2.9** Magnetic Resonance Imaging of Cranial Nerves III to VI (Sequence 8; Optional MOTSA MRA)[a]

| | |
|---|---|
| Patient position | Supine |
| Scan type | 3-D gradient echo |
| Imaging plane (orientation) | Transverse |
| Central slice or volume center | Mid-brain |
| Echo time ($T_E$) | 6.9 msec |
| Receiver bandwidth (RBW) | 16 kHz |
| Repeat time ($T_R$) | 35 msec |
| Flip angle (FA) | 30° |
| Field of view ($FOV_x$, $FOV_y$) | 240 mm, 180 mm |
| Resolution ($\Delta x$, $\Delta y$) | 0.47 mm, 0.70 mm |
| Number of data points collected ($N_x$, $N_y$) | 512, 256 |
| Slice thickness ($\Delta z$) | 1.2 mm |
| Number of slices | Variable (~50) |
| Slice gap | 0 |
| Number of excitations (NEX) | 1 |
| Flow compensation | Yes |
| ZIP 512 | Yes, changes resolution to 0.23 mm by 0.35 mm |
| ZIP 2 | Yes |
| Extended dynamic range (EDR) | Yes |
| Chemical saturation | Fat saturation |
| Spatial saturation | Superior |
| Magnetization transfer | Yes |
| Slice series | Interleaved |
| Scan time | ~8 min |

[a]Utilize ramped RF pulse in the direction of arterial blood flow. Utilize an overlap of ~10 mm in between adjacent slabs (completed as needed).

## COMMENTARY

### Background Information

There are a plethora of lesions that may cause cranial nerve III to VI pathology, and therefore these studies often require more clinical input and physician monitoring to tailor the evaluation to the clinical and imaging findings. A pupil-sparing third-nerve palsy might suggest an aneurysm, so one must add an MR angiography (MRA). Add an optic neuritis history to the mix and the study becomes a search for demyelinating plaques. Add pain and one might be looking at a vascular compression syndrome. The key here is to evaluate the individual slices of the MRA searching for bright vessels impacting dark nerves. If there are multiple cranial nerve deficits, one might be dealing with neurofibromatosis, subarachnoid seeding on nerve roots, sarcoidosis, Lyme disease, granulomatous infections, or other conditions, all of which require greater scrutiny of the post-contrast scans (Yousem et al., 1990b). The whole brain should be evaluated for a source of such drop metastases.

With the advent of a ramped RF pulse and the utilization of MOTSA, the resultant angiogram is very homogeneous and there is an overall reduction in the apparent dephasing of blood across the imaging volume. "Ramped RF" actually adjusts the flip angle of the pulse sequence to take into account the normal dephasing pattern of blood as it traverses through the transverse imaging slab. Thus, this should minimize an artifact that typically occurs during 3-D TOF imaging in which there is sufficient SNR on one aspect of the slab, and, as you get to the opposite side there is a drastic drop in SNR. Evaluation of the raw data is often critical, especially where vascular compression is a possible etiology for the symptoms. The addition of the MRA should be made prior to the administration of intravenous contrast medium (MRA is the subject of *UNIT B7.3*). Angiograms that are done in the reverse order

will yield an overall appearance of not having a suppressed venous flow. This can make it difficult to access subtle lesions/pathologies that are simply overlapped by large prominent veins. If the decision to perform an MR angiogram is made after contrast medium has already been given, it may be advantageous to the physician interpreting the exam to have the patient return the next day for a non-contrast-enhanced MRA of the area in question. If the patient is not able to return for the conventional TOF (time-of-flight) angiography, then the imaging professional should make attempts to utilize an angiographic technique that does not employ TOF effects. Phase-contrast angiography (PCA) employs techniques that are unique because it is based on velocity-induced phase shifts to produce an image. Thus your success with PCA depends largely on selecting the correct $V_{enc}$ (velocity encoding) within the vessel you are attempting to image. One major difference that you will note between TOF imaging and PCA imaging is the significant improvement in background suppression with PCA. PCA employs two bipolar gradients in which there is essentially a subtraction of signal from stationary tissue. Only flowing spins against the gradient will be demonstrated.

Finally, one should be aware that sellar and clival masses commonly present with cranial nerve VI symptoms (Yousem et al., 1989, 1990a). Sagittal post-gadolinium scans may be useful to demonstrate the meningeal or extracranial extent of such lesions as chordomas, meningiomas, and nasopharyngeal carcinomas that may lead to such symptoms.

## Critical Parameters

The accurate prescription of the slice locations is the most important step in this process. If one uses the sagittal scan and prescribes transverse slices from the top of the midbrain to the mid-medulla, one should have appropriate coverage. Cranial nerve VI courses from the pontomedullary junction superiorly to enter the inferior petrosal sinus, crosses Dorello's canal, and then runs within the cavernous sinus. One must be able to see all these segments well. In the end it is usually the post-gadolinium scans that are the most revealing, so one should take the time to repeat these if they are of poor quality.

## Troubleshooting

One of the most difficult tasks to accomplish is homogenous fat saturation within your imaging volume. Typically the overall fat suppression is at its worst when the imaging volume is adjacent to an air/tissue interface and local magnetic field inhomogeneities (i.e., secondary to metallic dental work). Although the scanners of today can often complete this task automatically, there is no better way of improving your fat suppressed image than by manually adjusting the center frequency and the position of the RF pulse that will impose the fat suppression.

When imaging post contrast, more often than not there will be a significant increase in flow artifacts over your imaging volume. This will make it difficult to assess very subtle lesions. What the authors have found is that, with the simultaneous addition of gradient moment nulling and inferior spatial saturation pulses, a drastic improvement of the image quality and directly decreased motion across the anatomy have been achieved. It should be noted that with the addition of gradient moment nulling, there typically will be an increase in the minimum $T_E$ that may slightly (in theory) adjust the $T_1$ weighting of your image. The authors have not found this slight increase in the effective $T_E$ to be of any real clinical significance.

When there is a need to perform an MRA to exclude aneurysm and you are utilizing a technique such as MOTSA, take note of two very real pitfalls that can significantly hamper your results. First make sure that the ramped RF pulse is in the direction that the flow is going. "Go with the flow" is an easy way to remind one's self which way to utilize this unique tool. If it is prescribed in the opposite direction, it will give results that are not conducive to good angiographic imaging. The next thing to remember while utilizing an MOTSA technique is the key word "overlapping." There must be an adequately applied overlap between adjacent slabs in order to insure an even flowed appearance. Adequate overlapping of ~10 mm between slabs is usually sufficient.

## Anticipated Results

You should always see cranial nerves III and V in the cisterns. Cranial nerve IV may be seen as a fine line emanating from behind the midbrain and traversing the ambient cistern. The foramen ovale and rotundum are usually outlined by enhancing perneural vascular plexi. The cavernous sinus should enhance brightly along with the pituitary stalk. If it is not enhancing, check your intravenous access, as you may have infiltrated the contrast dye.

## Time Considerations

Since the post-contrast and the $T_2$-weighted scans are the most valuable in this scenario, you can skimp on some signal averages if necessary to complete the uncooperative patient's study. Sequences such as fast recovery, fast spin echo have been developed to create $T_2$ contrast with much shorter $T_R$ values. These sequences incorporate additional RF pulses that will drive up longitudinal magnetization. This allows the user to "tip" the protons back into the transverse plane in a relatively shorter period of time, thereby decreasing the overall imaging time without sacrificing $T_2$ contrast.

## Index of Terms

The clinical imaging instructions and terminology utilized in this unit are primarily geared towards General Electric equipment. An Index of Terms is provided that should bridge the gap of vendor specific terminology.

**Chemical saturation** A technique that applies an additional radiofrequency (RF) pulse (at a desired distance from the center frequency) to selectively suppress a tissue. This technique can be utilized to suppress the signal from water, fat, or silicone.

**Echo time ($T_E$)** The time that is measured from the initiation of the initial RF (radio frequency) pulse and the peak of the echo.

**Echo train length (ETL)** In fast spin echo or turbo spin echo imaging, the ETL will actually equal the number of echoes prescribed per $T_R$. Successive 180° refocusing pulses are applied to "rephase the dephasing" protons in an effort to maximize the number of lines of *k*-space per $T_R$. The formula for scan time in relation to Fast Spin Echo imaging and ETL is as follows:

Scan time = ($T_R$) × (no. of phase encoding steps/ETL) × (NEX)

**Extended dynamic range (EDR)** An imaging-enhancement tool that will allow the utilization of 32-bit data processing as opposed to the standard 16-bit processor. EDR in this way should improve SNR and resolution, but will utilize twice as much memory as a conventional acquisition.

**Flow compensation** Sometimes more widely expressed as gradient moment nulling, this is a way in which the system places flowing or moving spins into "phase coherence" with stationary spins.

**Inversion time ($T_I$)** With inversion recovery pulse sequences, typically the inversion time is the time from the first 180° RF pulse to the center of the next 90° RF pulse. This inversion time will essentially "null" the desired tissue depending on how long or short the $T_I$ (inversion time) selected is, and the $T_1$ relaxation time of the corresponding tissue.

**No phase wrap (NPW)** Will prevent wrap around artifacts (also known as aliasing artifacts) in the phase encoding direction. NPW should only be used when necessary because of the following:

a. NPW doubles the FOV in the phase direction.

b. NPW essentially doubles the phase encoding steps (to maintain resolution).

c. With NPW, you must reduce the NEX by half in order to maintain scan time.

**Number of excitations (NEX)** is a factor that is utilized to calculate the overall scan time and will directly effect the SNR. NEX is essentially the number of times that data are sampled per acquisition. Note that increasing the NEX to achieve overall better SNR is a rather inefficient way to improve signal. Doubling the NEX from 2 to 4 will only yield a 40% increase in SNR while it doubles scan time. Take note of the formula for scan time:

Scan time = ($T_R$) × (no. of phase encoding steps) × (NEX)

**Receiver bandwidth (RBW)** The range of frequencies that the MRI scanner is actually "tuned" to receive. This will directly affect the overall SNR. This will not be done by increasing or decreasing the signal, but rather there will be an increase and/or decrease in the amount of noise received relative to the alteration of the RBW. An increase in the RBW will increase the range of frequencies that the scanner will evaluate and thus decrease the overall SNR. In comparison, utilizing a narrow bandwidth should yield less noise and improve the overall SNR. The relationship of the receiver bandwidth and SNR can be thought of as inversely proportional to the square root of the bandwidth.

**Rectangular field of view (REC FOV)** Asymmetric field of view (typically in the phase encoding direction). REC FOV is typically utilized when a body part is longer in one direction than another. By utilizing an asymmetric FOV, the system will not collect a portion of the data, thereby decreasing the scanning time.

**Repetition time ($T_R$)** The time in a pulse sequence between successive excitation pulses.

**Spatial saturation** employs an additional RF pulse to cause moving spins within a deter-

mined area to be selectively dephased. This application will reduce motion from flow and/or respiratory artifacts and will limit the number of slices per $T_R$ in general. Since a spatial saturation pulse employs additional RF, which is to be deposited into the patient, special attention should be focused on the SAR (specific absorption rate). Today all MRI scanners have a program that internally monitors how much RF can be applied over a given period of time. This formula takes into account the patient's body weight. This actual body weight needs to be accurately input at all times for patient safety. An inappropriate weight will cause the improper limit of RF to be transmitted relative to a safe period of time in which this is to occur.

**Tailored RF** An imaging option that improves image quality on fast spin echo (FSE) sequences with relatively short $T_E$'s. Tailored RF will improve edge blurring by reducing overall echo spacing.

**ZIP 512/ZIP 1024** Better known as "zerofill interpolation process," this is a reconstruction algorithm that allows the user to scan at a $256 \times 256$ matrix and then the data are zerofilled to a $512 \times 512$ matrix (or $1024 \times 1024$ respectively).

**ZIP 2/ZIP 4** Slice zip essentially is also a "zerofill interpolation process" that will create additional slices through the interpolation procedure. These slices are created with an offset of 50% of the original imaging slice locations.

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