Cranial Nerve I

The olfactory bulbs and tracts mediate the sense of smell from the nasal cavity to the brain. Unfortunately they are located in a precarious position for MR imaging, above the air-filled nasal cavity and ethmoid sinuses at a bone-air-soft tissue interface. This creates problems with susceptibility artifact. This issue, plus the very small size of the structures to be studied and the superimposed eye motion artifact makes imaging of the olfactory system a technical challenge.

IMAGING OF CRANIAL NERVE I

BASIC PROTOCOL

The olfactory bulb and tract is actually a second order neuron with the primary sensory (ciliary) nerves in the ethmoid and nasal cavity vault. Lesions in the sinonasal cavity as well as the anterior cranial fossa can affect the sense of smell (Li et al., 1993, 1994; Yousem, 1993). The most common diseases to affect olfaction are sinonasal bacterial and viral infections and neurodegenerative disorders such as multiple sclerosis, Alzheimer's disease, and Parkinson's disease (Doty et al., 1998, 1999; Li et al., 1994). Primary entities to affect the olfactory bulbs and tracts include traumatic shearing or contusional injuries, congenital disorders such as Kallmann's disease and holoprosencephaly, and tumors such as meningiomas and olfactory neuroblastomas (Doty et al., 1997; Li et al., 1994; Yousem, 1993; Yousem et al., 1996a, 1996b). Because the olfactory bulbs and tracts are very tiny structures oriented in an anteroposterior plane, they are best evaluated with thin-section coronal scanning (Yousem et al., 1997a). However the proximity of these structures to the air containing sinonasal cavity makes the use of gradient echo scanning prohibitive.

Imaging of the cranial nerves requires a focused approach based on clinical symptomatology and signs. Thin section imaging and high resolution are essential components to this evaluation. Table A7.1.1 lists the hardware necessary to perform the procedure, along with appropriate parameters.

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.

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.

Table A7.1.1 Equipment Parameters for Cranial Nerve Imaging

Coil type	5-in. surface coil
Gradient coil strength	25 mT/m
Flow compensation pulse	Yes
Peripheral gating	N/A
Respiratory gating	N/A
Respirator	PRN
Oxygen	PRN
Motion cushions	Useful

Contributed by Robert W. Evers and David M. Yousem
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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. Help 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 surface coil over the nasion (the region where the key information is desired). Make sure that the head and neck are constrained to prevent motion, especially if high-resolution scans are to be run.

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

   Surface coil imaging is required to visualize the olfactory bulbs and tracts. A 5-in. round general purpose coil can be used, suspended one inch over the nasion, without touching the patient. Instructions to the patient to refrain from excessive eye or head movement are critical. The gaze should be fixed on a single spot. Anatomic imaging with high-quality spin echo T_1-weighted scan is the mainstay of the evaluation. Field strength considerations are not critical. No monitoring is required.
8. If needed, place a pillow or other support under the knees to make the patient more comfortable.
9. Use the centering light to center on the nasion in the center of the 5-in. round surface coil 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.

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

Sequence 1: Coronal scout scan

11. Run coronal 2-D FMPSPGR (sequence 1; fast multi-planar spoiled gradient echo) scout using the imaging sequence given in Table A7.1.2.

At 1.5 T, fat and water will precess in and out of phase respectively every 2.3 msec. Thus, utilizing a T_E of 4.6 msec will maximize the contributory signal within each voxel. The primary reasoning for a quick gradient echo localizer is to assess the maximum dimension that the 5-in. coil provides in regard to SNR (signal-to-noise ratio) and anatomic coverage. We have found that the utilization of a T_1 weighted FMPSPGR quickly provides the imaging personnel with an above average survey with regard to coverage and SNR.

Sequence 2: Sagittal T_1-weighted spin echo scan

12. Run sagittal T_1-weighted scan (sequence 2) using the imaging sequence given in Table A7.1.3.

Spatial saturation pulses and gradient moment nulling (flow compensation) are not necessary. Ideally, one's area of coverage should maximize the useful signal dimensions of the 5-in. surface coil.

Sequence 3: Coronal T_1-weighted scan

13. Run coronal spin echo T_1-weighted scan (sequence 3) using the imaging sequence given in Table A7.1.4.

Saturation pulses and gradient moment nulling are not necessary. The sections should begin at the nasion and extend posteriorly to the level of the optic chiasm, visualized on the coronal "scout" image. Fast spin echo scanning may be used, however, it may be helpful to increase the matrix size or zero fill interpolate (ZIP) to more easily visualize small details. Echo train lengths ≤4 should then be used.

Table A7.1.2 Clinical Imaging Parameters for 2-D FMPSPGR Coronal Scout Scan (Sequence 1)

Patient position	Supine
Scan type	Fast multi-planar spoiled gradient echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Middle optic nerve
Echo time (T_E)	4.6 msec
Receiver bandwidth (RBW)	16 kHz
Repeat time (T_R)	100 msec
Flip angle (FA)	70°
Field of view (FOV_x, FOV_y)	300 mm, 300 mm
Resolution (Δx, Δy)	0.58 mm, 1.17 mm
Number of data points collected (N_x, N_y)	512, 256
Slice thickness (Δz)	5 mm
Number of slices	Variable (~20)
Slice gap	1 mm
Number of excitations (NEX)	1
Scan time	~1 min

Sequence 4: Coronal T_2-weighted scan

14. Run coronal fast spin echo (FSE) T_2-weighted scan using the imaging sequence given in Table A7.1.5.

Saturation pulses and gradient moment nulling are not necessary. The sections should be the same as those for the T_1-weighted scans. Acquisition time will be 4 to 5 min in length. Manual chemical fat saturation techniques should be employed to ensure a homogeneous "fat suppressed" image (see Troubleshooting for additional information on the advantages of manual chemical saturation).

Table A7.1.3 Clinical Imaging Parameters for Sagittal T_1

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Middle optic nerve
Echo time (T_E)	Minimum
Receiver bandwidth (RBW)	16 kHz
Repeat time (T_R)	400–600 msec
Flip angle (FA)	90°
Field of view (FOV_x, FOV_y)	160 mm, 160 mm
Resolution (Δx, Δy)	0.63 mm, 0.63 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	3 mm
Number of slices	Variable (~20)
Slice gap	0 mm
Number of excitations (NEX)	1
Extended dynamic range (EDR)	Yes
Slice series	Interleaved
Scan time	~3 min

Table A7.1.4 Clinical Imaging Parameters for Coronal T_1 Spin Echo

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Middle optic nerve
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)	160 mm, 160 mm
Resolution (Δx, Δy)	0.63 mm, 0.63 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	2–3 mm
Number of slices	Variable (~20)
Slice gap	0 mm
Number of excitations (NEX)	2–3
Flow compensation	Yes
Extended dynamic range (EDR)	Yes
Slice series	Interleaved
Scan time	4–5 min

Table A7.1.5 Clinical Imaging Parameters for Coronal T_2 FSE Fat Saturation[a]

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Middle optic nerve
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°
Field of view (FOV_x, FOV_y)	160 mm, 160 mm
Resolution (Δx, Δy)	0.63 mm, 0.63 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	2–3 mm
Number of slices	Variable (~20)
Slice gap	0 mm
Number of excitations (NEX)	2
Flow compensation	Yes
ZIP 512	Yes, changes resolution to 0.31 mm by 0.31 mm
Extended dynamic range (EDR)	Yes
Chemical saturation	Yes
Slice series	Interleaved
Scan time	~4–5 min

[a]FSE, fast spin echo.

COMMENTARY

Background Information

It was not until the introduction of surface coils that adequate evaluation of the olfactory bulbs and tracts became possible. The improved signal-to-noise ratio is what is needed to evaluate these structures, which measure ~20 mm by 4 mm in size. Cutting the bulbs and tracts in cross-section, i.e., in the coronal plane, is necessary, as neither the sagittal nor transverse plane is reliable in reproducibly visualizing the olfactory apparatus. Because it is the morphology of the bulbs and tracts which is critical rather than signal intensity, one should rely most heavily on the T_1-weighted scans. These will tell if the bulbs and tracts are there, if they are hypoplastic or encephalomalacic, and if they have been traumatized.

With the utilization of smaller fields of view (FOVs) to improve spatial resolution, there is often a decrease in signal-to-noise ratio (SNR). Taking the time to complete a dedicated examination with a surface coil will yield better results for those structures close to the coil. The smaller surface coil will tend to improve the overall SNR because of its inherent ability to provide more signal within a smaller voxel. In general, to improve the overall SNR of an image, the operator has a great number of parameters to alter. Maximizing the signal received within each voxel is one of the best ways to improve the image quality/SNR while maintaining the spatial resolution.

Critical Parameters

The most common reason why an inadequate study is obtained is the presence of motion artifact from eyeball movement and inhomogeneous fat suppression. Often the globes are at the same coronal plane as the bulbs and bulb-tract junction. The motion of the globes will cause artifacts in a transverse plane that obscures the bulbs and tracts. For this reason, one must tell the subject to fix his or her gaze on a single point, reduce blinking, and to refrain from head movement. Having scan times as short as possible without losing SNR is essential. For this reason, fast spin echo T_2-weighted imaging is advantageous.

Incompletely fat-suppressed images will impair and reduce overall confidence with a differential diagnosis and often confuse the referring clinicians. Due to the inherent diffi-

culties with air/tissue interfaces in regard to fat suppression, it is essential that the imaging professional know some tricks of the trade to overcome this disability. Beginning with an automatic pre-scan and moving on to a manual spectral suppression should help identify where to accurately place the chemical saturation pulse. If there is an improper centering of the center frequency, typically the suppression pulse that was intended to suppress fat will also be at the wrong frequency.

Troubleshooting

It is important to make sure that the slice locations and surface coil placement are optimal. Improper "tilting" or centering of the 5-in. surface coil may render one side of the anatomy to appear to have a higher SNR than the other.

Helpful hints in regard to complete fat suppression over your imaging volume include the following. (1) Prior to beginning any examination, the patient should be required to remove all make-up and remove all metallic objects (i.e., dental work, earrings, hairpins, etc.). This simplistic idea will pay off in the long run by significantly improving the magnetic field homogeneity to the imaging volume that is being evaluated. (2) Having a visual spectrum that allows the user to identify the water peak and the fat peak improves the chemical suppression of the imaging volume on selective fat suppression series. However, even when utilizing proper automatic and manual suppression techniques to suppress fat, there are often additive disabilities that lead to an overall poor image. We are referring to the presence not only of the air-tissue interface but also dental work that cannot be removed. In the case of excessive diamagnetic properties, a STIR (short tau inversion recovery) would be in order. STIR takes the "guesswork" out of the chemical saturation process by utilizing the null point of fat to give the clinician a "fat suppressed image" (see "optional sequence" for STIR parameters in lieu of FSE T_2 with fat saturation in Table A7.1.6).

In the event that a congenital cause for anosmia is suspected, one should perform an unenhanced scan through the brain to evaluate the septum pellucidum (septo-optic dysplasia is associated with aplasia of the olfactory bulbs) and the cerebral hemispheres (to evaluate for holoprosencephaly).

Anticipated Results

When imaging has been done appropriately, you should see the olfactory bulbs arise in a narrow groove on either side of the crista galli at the mid ethmoid level. Evidence of sinusitis or sinonasal masses should be apparent, particularly on the T_2-weighted scans. You should be able to follow the bulbous bulbs to the slit-like tracts as they proceed posteriorly in the olfactory sulcus lateral to the gyrus rectus. The tracts enter the brain at the medial and lateral olfactory septal nuclei lateral to the optic chiasm. The full course of these structures should be demonstrated.

Time Considerations

This is a quick protocol once the proper placement of the patient, coils, and slices are determined. Extra time instructing the patient on eye movement is worth the investment. If the head needs to be examined, allot time accordingly; you will have to switch coils. If there is a need to implement an additional sequence such as an STIR, please understand that in order to maintain the same SNR as the FSE T_2 you will need to decrease your effective T_E and quite possibly may have to increase your NEX. Typically STIRs will yield a lower overall SNR in comparison to FSE T_2 with all other parameters remaining consistent.

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 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 "re-phase 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:

$$\text{Scan time} = (T_R) \times (\text{no. of phase encoding steps/ETL}) \times (\text{NEX})$$

Extended dynamic range (EDR) An imaging-enhancement tool that will allow the

Table A7.1.6 Clinical Imaging Parameters for STIR "Optional Sequence" if Coronal T_2 FSE Fat Saturation is Poor[a]

Patient position	Supine
Scan type	Inversion recovery, spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Middle optic nerve
Echo time (T_E)	50 msec
Receiver bandwidth (RBW)	20 kHz
Echo train length (ETL)	20
Repeat time (T_R)	3000–4000 msec
Inversion time (T_I)	For 1.5 Tesla, 150 msec
Flip angle (FA)	180°
Field of view (FOV_x, FOV_y)	160 mm, 160 mm
Resolution (Δx, Δy)	0.63 mm, 0.63 mm
Number of data points collected (N_x, N_y)	256, 256
Slice thickness (Δz)	2–3 mm
Number of slices	Variable (~20)
Slice gap	0 mm
Number of excitations (NEX)	3–4
Flow compensation	Yes
ZIP 512	Yes, changes resolution to 0.31 mm by 0.31 mm
Extended dynamic range (EDR)	Yes
Chemical saturation	Not needed
Slice series	Interleaved
Scan time	~5–6 min

[a]FSE, fast spin echo.

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 Or sometimes more widely expressed as gradient moment nulling, 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 it does all of the following:

a. NPW doubles the FOV in the phase encoding 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 is 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:

$$\text{Scan time} = (T_R) \times (\text{no. of phase encoding steps}) \times (\text{NEX})$$

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 determined 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 256×256 matrix and then the data are zerofilled to a 512×512 matrix (or 1024×1024, 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.

Literature Cited

Doty, R.L., Yousem, D.M., Pham, L.T., Kreshak, A.A., Geckle, R., and Lee, W.W. 1997. Olfactory dysfunction in patients with head trauma. *Arch. Neurol.* 54:1131-1140.

Doty, R.L., Li, C., Mannon, L.J., and Yousem, D.M. 1998. Olfactory dysfunction in multiple sclerosis. Relation to plaque load in inferior frontal and temporal lobes. *Ann. N.Y. Acad. Sci.* 855:781-786.

Doty, R.L., Li, C., Mannon, L.J., and Yousem, D.M. 1999. Olfactory dysfunction in multiple sclerosis. Relation to longitudinal changes in plaque numbers in central olfactory structures. *Neurology* 53:880-882.

Li, C., Yousem, D.M., Hayden, R.E., and Doty, R.L. 1993. Olfactory neuroblastoma: MR evaluation. *Am. J. Neuroradiol.* 14:1167-1172.

Li, C., Yousem, D.M., Doty, R.L., and Kennedy, D.W. 1994. Neuroimaging in patients with olfactory dysfunction. *Am. J. Roentgenol.* 162:411-418.

Shellock, F.G. 1996. Pocket Guide to MR Procedures and Metallic Objects. Lippincott-Raven, Philadelphia.

Yousem, D.M. 1993. Imaging of sinonasal inflammatory disease: State of the art. *Radiology* 188:303-314.

Yousem, D.M., Geckle, R.J., Bilker, W., McKeown, D., and Doty, R.L. 1996a. MR evaluation of patients with congenital hyposmia or anosmia. *Am. J. Roentgenol.* 166:439-444.

Yousem, D.M., Geckle, R.J., Bilker, W.B., McKeown, D.A., and Doty, R.L. 1996b. Post-traumatic olfactory dysfunction: MR and clinical evaluation. *Am. J. Neuroradiol.* 17:1171-1179.

Yousem, D.M., Geckle, R.J., Doty, R.L., and Bilker, W.B. 1997a. Reproducibility and reliability of volumetric measures of olfactory eloquent structures. *Acad. Radiol.* 4:264-269.

Yousem, D.M., Geckle, R.J., Bilker, W.B., Kroger, H., and Doty, R.L. 1999b. Post-traumatic smell loss: Relationship of psychophysical tests and volumes of the olfactory bulbs and tracts and the temporal lobes. *Acad. Radiol.* 6:264-272.

Yousem, D.M., Maldjian, J.A., Hummel, T., Alsop, D.C., Geckle, R.J., Kraut, M.A., and Doty, R.L. 1999c. The effect of age on odor-stimulated functional magnetic resonance imaging. *Am. J. Neuroradiol.* 20:600-608.

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