Pituitary

Benefiting from superior tissue contrast, multi-planar capability and lack of bone artifact, MRI readily depicts complex anatomy in and about the pituitary gland. This unit presents three basic protocols for common indications relating to pathology of the sella and parasellar region. The protocols differ in emphasis, more than in concept, and share a basic theme of thin slice high-resolution imaging including the use of gadolinium. With the possible exception of dynamic imaging, all protocols may be readily performed on any MR scanner.

MACROADENOMA

BASIC PROTOCOL 1

Imaging of suspected or known pituitary macroadenoma focuses on evaluation of tumor extension into adjacent structures, specifically the suprasellar space and cavernous sinus. Identification of the lesion itself, essentially by definition, is not a taxing problem. The protocol is quite simple and focuses on demonstrating anatomy in the most useful planes. The T_1-weighted spin echo coronal sequence is the cornerstone of the exam, providing the majority of useful information.

Table A5.2.1 lists the four sequences which comprise the Basic Protocol. Two optional sequences are listed. A T_2-weighted TSE (turbo spin echo)/FSE (fast spin echo) coronal sequence is suggested as an option, to provide better characterization of intrasellar pathology, such as differentiating cyst versus tumor. An optional sixth sequence consisting of a PD (proton density)/T_2-weighted whole brain transverse sequence should be used in those cases in which sellar pathology is not necessarily the only consideration. Table A5.2.2 lists the hardware necessary to perform the procedure. Next, stepwise instructions for performing the protocol are provided. The protocol is not terribly demanding of scanner hardware and may be performed well on most clinical systems. Basic Protocol 1 generally requires 30 to 45 min to complete.

Table A5.2.1 Basic Pituitary Protocol: Macroadenoma

Sequence and type of weighting	Imaging plane
1. Pilot scan (scout)	
2. T_1-weighted spin echo	Sagittal
3. T_1-weighted spin echo	Coronal
4. Post-gadolinium T_1-weighted spin echo	Coronal
Optional sequences	
5. T_2-weighted TSE/FSE	Coronal
6. Dual echo PD/T_2-weighted TSE/FSE whole brain	Transverse

Table A5.2.2 Equipment Parameters

Coil type	Quadrature head coil
Gradient coil strength	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	Useful

Contributed by Danial K. Hallam
Current Protocols in Magnetic Resonance Imaging (2001) A5.2.1-A5.2.20

Materials

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

Set up equipment and patient

1. Interview 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 or special precautions during the scanning procedure.

   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 mascara or 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 be instructed not to talk unless absolutely necessary and to avoid or minimize swallowing and other movements during each scan—i.e., as long as the banging sounds continue. Between scans, talking and swallowing are acceptable 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. Set up any triggering devices or other monitoring equipment that is to be used either before or just after the patient lies down.

7. Center the patient in the head coil. Make sure that the head and neck are constrained to limit motion, especially if high-resolution scans are to be run.

   Generally the patient's head is fixed so that it 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.

   This step may be performed prior to entering the magnet room if necessary to save scanner time. 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 and after contrast agent injection.

10. Use the centering light to position the patient's nasion and put him or her into the center of the magnet.

    Once this step has been performed, so long as the patient does not move on the table, the table itself can be moved and then replaced in the same position as before without jeopardizing the positioning of one scan relative to another.

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

Sequence 1: Rapid three-plane positioning pilot

12. To validate the patient's position, run the system's pilot (or scout) scan to ensure correct location of the head in three dimensions, using the imaging sequence given in Table A5.2.3 or similar parameters.

    This sequence usually consists of three orthogonal planes to allow localization. The images are often also used later to determine where to place the saturation pulses and to set up total coverage of the volume of interest.

Sequence 2: T_1-weighted spin echo sagittal

13. Using images generated in sequence 1, sagittal images are planned to provide thin slice midline coverage. Set the parameters as indicated in Table A5.2.4.

    The scan is best positioned first on the transverse pilot scan. Some angulation may be needed to provide for true sagittal anatomic imaging. The coverage provided should then

Table A5.2.3 Parameters for Pilot Scan (Scout; Sequence 1)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	3 planes
Central slice or volume center	Run initially at magnet isocenter
Echo time (T_E)	Minimum
Repeat time (T_R)	Minimum
Flip angle (FA)	20°
Fields of view (FOV_x, FOV_y)	300 mm, 300 mm
Resolution (Δx, Δy)	1.17 mm, 1.56 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	3, one in each of 3 cardinal planes
Slice gap	Not applicable
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Not applicable
Saturation pulses	Not applicable
Scan time	A few seconds

be checked on the sagittal scout. A small field of view (FOV) is used to improve in-plane resolution. In order to avoid aliasing, the (read) oversampling and the no-phase-wrap or the phase oversampling option should be chosen. Occasionally, large sellar masses may necessitate increasing the FOV—this should be apparent from the pilot scan. Appropriate FOV modifications can then be made for all scans focused on the sella. This sequence is used to accurately position subsequent scans. It provides excellent visualization of midline structures.

Sequence 3: T_1-weighted spin echo coronal

14. Set parameters as indicated in Table A.5.2.5. Using sequence 2, position coronal images orthogonal to floor of sella or planum sphenoidale.

The center slice should be placed in the middle of the sella. Sequence 3 is the most valuable sequence of the protocol. It provides excellent visualization of sellar contents and their

Table A5.2.4 Parameters for T_1-Weighted Spin Echo Sagittal (Sequence 2)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Midline
Echo time (T_E)	14 msec
Repeat time (T_R)	500 to 600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.98 mm, 0.86 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	3 mm
Number of slices	11
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	2
Read direction	Cranio-caudal
Saturation pulses	Inferior may be used
Scan time	4 to 5 min

Table A5.2.5 Parameters for T_1-Weighted Spin Echo Coronal (Sequence 3)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	14 msec
Repeat time (T_R)	500 to 600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.98 mm, 0.86 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	3 mm
Number of slices	11
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	2
Read direction	Cranio-caudal
Saturation pulses	Inferior may be used
Scan time	4 to 5 min

relationship to the cavernous sinus. It also provides visualization of the optic apparatus in the neighborhood of the pituitary (Figure A5.2.1). Invasion by pituitary adenoma of the clivus is demonstrated due to the intrinsic contrast afforded by fatty clival marrow (Figure A5.2.2).

15. Inject the contrast agent, then flush the intravenous line with 10 ml saline. It is preferable to perform the contrast injection while leaving the patient in the magnet.

    A dose of 0.1 mmol/kg is usually given.

Sequence 4: Post-contrast T_1-weighted spin echo coronal

16. Repeat sequence 3 with nearly identical parameters and positioning.

    Flow compensation is recommended to minimize phase encoding artifact from the cavernous internal carotids. This will increase the T_E to ~17 msec. If a mass is present, this sequence further characterizes the lesion by demonstrating its enhancement pattern (Figure A5.2.3).

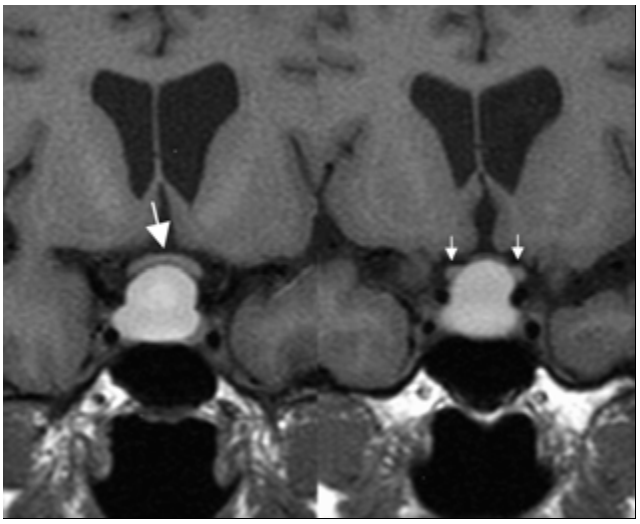

Figure A5.2.1 Displacement of optic apparatus by suprasellar extension of a Rathke's cleft cyst is demonstrated on T_1-weighted coronal image.

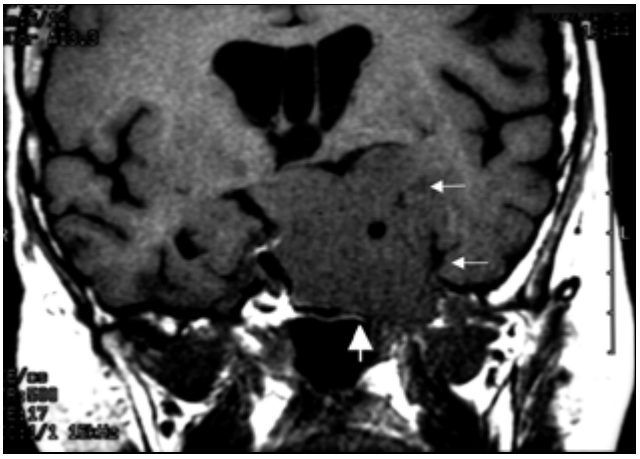

Figure A5.2.2 Invasive pituitary adenoma. Involvement of clivus and clear invasion of left cavernous sinus demonstrated by pre-contrast T_1-weighted coronal image.

Sequence 5: T_2-weighted TSE/FSE coronal (optional)

17. Set parameters as indicated in Table A5.2.6.

The scan is positioned identically to the T_1-weighted coronal studies. This sequence allows further characterization of sellar lesions and is particularly helpful in the setting of hemorrhage and in differentiating cyst from neoplasm (Figure A5.2.4). Rarely, it will demonstrate a lesion not otherwise detected. As implemented, the scan will result in some right-to-left aliasing. This may be solved by employing the no-phase-wrap or the phase-oversampling option available on many scanners. Such measures will increase the imaging

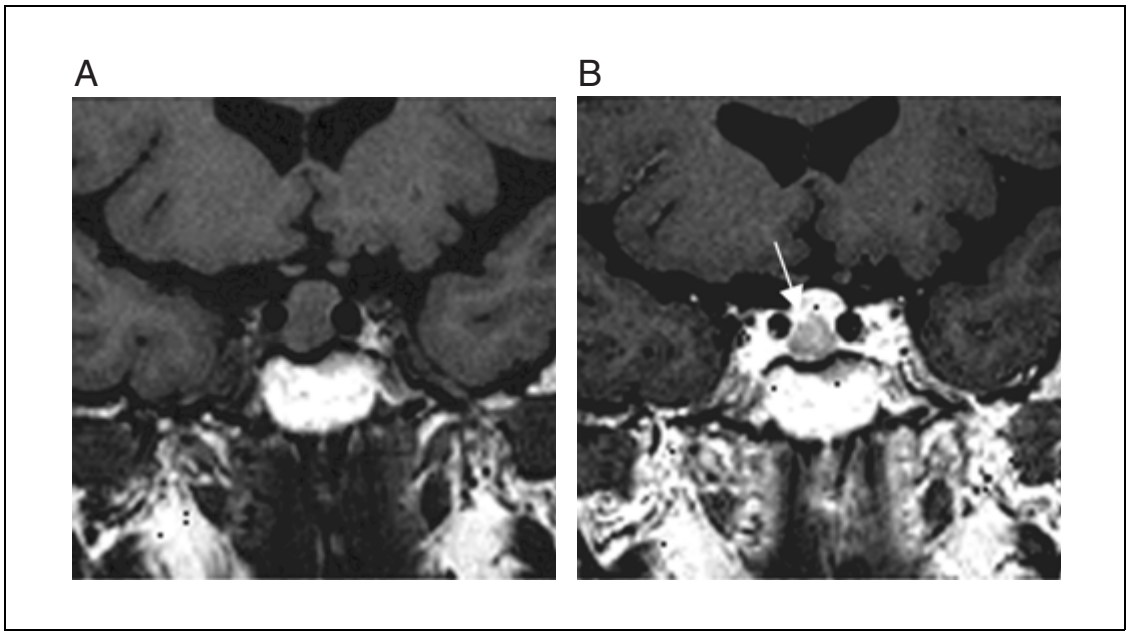

Figure A5.2.3 (**A**) The presence of an ademona is suggested by possible mass effect and hypointensity on non-contrast T_1-weighted coronal image. (**B**) Following contrast, adenoma is clearly demarcated by decreased enhancement relative to normal pituitary gland.

Table A5.2.6 Parameters for T_2-Weighted TSE/FSE Coronal (Sequence 5)

Patient position	Supine
Scan type	TSE/FSE
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	102 msec
Echo train length (ETL; turbo factor)	8 to 11
Repeat time (T_R)	3000 msec
Flip angle (FA)	180°[a]
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.70 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	3 mm
Number of slices	11
Slice gap (distance factor)	1 mm (0.33)
Number of acquisitions (N_{acq})	3 to 4
Read direction	Cranio-caudal
Saturation pulses	Inferior may be used
Scan time	3.5 to 5 min

[a]The system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

time of an already lengthy scan. Alternatively, one may simply accept the aliasing artifact as it does not overlap the sella.

Sequence 6: Dual echo PD/T_2-weighted TSE/FSE transverse (optional)

18. The T_1-weighted sagittal image (sequence 2) is used to position these transverse scans.

Set parameters for the PD/T_2-weighted dual echo transverse sequence as given in Table A5.2.7. The scan is positioned graphically to provide whole brain coverage. The slices

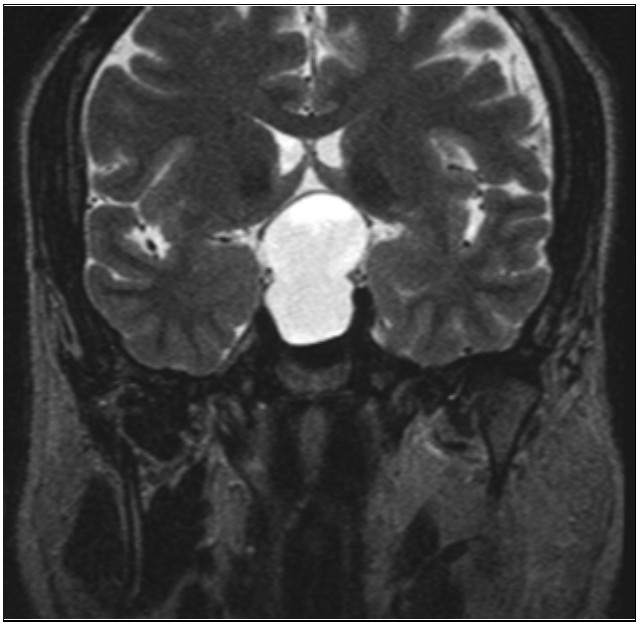

Figure A5.2.4 T_2-weighted TSE image can be helpful to better characterize some lesions, as in this case of an arachnoid cyst.

Table A5.2.7 Parameters for Dual Echo PD/T_2-Weighted TSE/FSE Transverse (Sequences 6 and 18)

Patient position	Supine
Scan type	TSE/FSE
Imaging plane (orientation)	Transverse
Central slice or volume center	Position for whole brain coverage
Echo time (T_E)	14–17 msec for PD weighted image and 85–102 msec for T_2-weighted image
Echo train length (ETL) (turbo factor)	5 to 8
Repeat time (T_R)	2500–3000 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm, 230 mm
Resolution (Δx, Δy)	0.94 mm, 0.9 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	5 mm
Number of slices	23
Slice gap (distance factor)	1.5 mm (0.30)
Number of acquisitions (N_{acq})	2
Read direction	Anterior to posterior
Saturation pulses	Inferior may be used
Scan time	2 to 4 min

should be angled according to an institutional standard for transverse images. The author recommends using "AC-PC" line as such a standard (see UNIT A5.1). The anterior and posterior commissures are identified on the T_1-weighted sagittal midline image. The slices of all transverse scans are positioned parallel to a line drawn between the two landmarks. The sequence provides excellent visualization of the whole brain. It should be used as a quick whole brain screen when the clinical issue being addressed is not necessarily limited to the sella.

ALTERNATE PROTOCOL

STATUS POST TRANSPHENOIDAL SURGERY

This alternate protocol as summarized in Table A5.2.8 should be used in patients who have undergone transphenoidal surgery for pituitary lesions. The protocol differs from the Basic Protocol predominantly by the use of fat saturation on post-contrast images. Also, a second plane post-contrast is helpful in the evaluation of often quite distorted post-surgical anatomy. This Alternate Protocol should include sequences 1 through 3 as discussed in Basic Protocol 1. Then perform post-gadolinium imaging in coronal and sagittal planes with fat saturation. For patient set up and contrast agent injection, see Basic Protocol 1, steps 1 to 15.

Sequences 7 and 8: Post-contrast T_1-weighted spin echo with fat saturation (FS)

1. Set parameters for sequences 7 and 8, as given in Tables A5.2.9 and A5.2.10 respectively.

   The sequences are positioned identically to their pre-contrast counterparts. A reduction in total number of slices (thus T_R) may help to limit a somewhat lengthy scan time. Evaluation of pre-contrast images will determine whether or not this can be done without compromising the diagnostic utility of the scan.

Table A5.2.8 Alternate Protocol (Status Post Transphenoidal Surgery)

Sequence and type of weighting	Imaging plane
7. Post-gadolinium T_1-weighted spin echo FS	Coronal
8. Post-gadolinium T_1-weighted spin echo FS	Sagittal

Table A5.2.9 Parameters for FS Post-Contrast T_1-Weighted Spin Echo Coronal (Sequence 7)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	17 msec
Repeat time (T_R)	600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.98 mm, 0.86 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	3 mm
Number of slices	11
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	3
Read direction	Cranio-caudal
Flow compensation	Yes (if available)
Saturation pulses	Inferior may be used
Fat suppression	Yes
Scan time	5 to 6 min

Table A5.2.10 Parameters for FS Post-Contrast T_1-Weighted Spin Echo Sagittal (Sequence 8)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Midline
Echo time (T_E)	17 msec
Repeat time (T_R)	500–600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	220 mm, 220 mm
Resolution (Δx, Δy)	0.98 mm, 0.86 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	3 mm
Number of slices	11
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	3
Read direction	Cranio-caudal
Flow compensation	Yes (if available)
Saturation pulses	Inferior may be used
Fat suppression	Yes
Scan time	5 to 6 min

MICROADENOMA

BASIC PROTOCOL 2

In the MR examination for microadenomas, emphasis shifts from evaluation of the extent of the lesion, primarily to lesion detection. Several approaches exist for meeting this goal. First, the resolution of the T_1 sequences may be increased, with the recognition that the technique used for macroadenomas already represents a reasonably high-resolution exam. Further increases in acquisition matrix and decreases in slice thickness come at predictable costs both in imaging time and in motion-artifact vulnerability. Second, dynamic imaging during contrast injection may be applied. In microadenoma detection, dynamic imaging has received much attention and provides some, albeit limited, increase in sensitivity (Nagele et al., 1993; Davis et al., 1994; Kucharczyk et al., 1994). Addition of a T_2-weighted sequence usually does not improve sensitivity (Peck et al., 1989; Elster, 1993) and so is not included as part of the standard protocol.

The type of thin-slice, high-resolution exams utilized here push the limits of signal-to-noise. Some modification of noise-relevant parameters including slice thickness, N_{acq}, and acquisition matrix may be needed to yield visually satisfactory images, depending on individual scanner capabilities. Many centers do not employ high-resolution T_1-weighted sequences as described here. As an alternative approach, the reader may wish to simply add the dynamic imaging scan to the macroadenoma protocol as their version of a microadenoma exam (see Background Information, Use of Microadenoma Protocol).

Due to higher N_{acq}'s utilized on several sequences, as well as setup for the dynamic exam, total scanning time will be increased 10 to 15 min beyond that required for the macroadenoma protocol.

Optional sequences for the microadenoma protocol are the same as that for the macroadenoma protocol and will not be repeated. Table A5.2.11 lists the five sequences that will be run in Basic Protocol 2.

Set up equipment and patient

1. Use the same equipment and perform patient setup as for the previous method (see Basic Protocol 1).
2. As before (see Basic Protocol 1, step 9), establish an intravenous line.

   For the current protocol, the patient will be scanned while contrast is injected. As such, the i.v. line must be sufficiently long to extend outside the magnet while the patient is being imaged.

Sequence 9: Pilot scan

3. Run a rapid three-plane positioning pilot scan (see Basic Protocol 1, sequence 1).

Sequence 10: T_1-weighted spin echo sagittal

4. Set parameters as indicated in Table A5.2.12.

   Using images generated in the pilot scan, sagittal images are planned to provide high-resolution thin slice midline coverage. The scan is best positioned first on the transverse pilot scan. Some angulation may be needed to provide for true sagittal anatomic imaging. A small FOV is used to improve in-plane resolution. In order to avoid aliasing, the (read) oversampling and the no-phase-wrap or the phase oversampling option should be chosen.

Sequence 11: High-resolution T_1-weighted spin echo coronal

5. Set parameters as indicated in Table A5.2.13.

Table A5.2.11 Basic Pituitary Microadenoma Protocol

Type of weighting and sequence	Imaging plane
9. Pilot scan (scout)	
10. T_1-weighted spin echo	Sagittal
11. T_1-weighted spin echo	Coronal
12. Dynamic T_1-weighted FSE/TSE	Coronal
13. Post-gadolinium T_1-weighted spin echo	Coronal

Table A5.2.12 Parameters for T_1-Weighted Spin Echo Sagittal (Sequence 10)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Sagittal
Central slice or volume center	Midline
Echo time (T_E)	14 msec
Repeat time (T_R)	500-600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.80 mm, 0.70 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	2 to 3 mm
Number of slices	11
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	2 to 3
Read direction	Cranio-caudal
Saturation pulses	Inferior may be used
Scan time	3.5 to 7 min

[a]No-phase-wrap or phase-oversampling.

The scan is positioned on the T_1-weighted sagittal images orthogonal to sellar floor or planum sphenoidale. This is the most important sequence of a protocol geared towards detecting subtle lesions within the pituitary (Figure A5.2.5).

Sequence 12: Dynamic T_1-weighted TSE/FSE coronal

6. Set parameters as indicated in Table A5.2.14.

Microadenomas usually enhance somewhat later than adjacent normal anterior pituitary gland. Fast T_1-weighted scanning performed during contrast injection may allow detection of these subtle abnormalities. The scan is run once before, once during and multiple times after the administration of contrast agent (for 2 to 3 min after injection). Contrast agent

Table A5.2.13 Parameters for High Resolution T_1-Weighted Spin Echo Coronal (Sequences 11 and 13)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	14 msec
Repeat time (T_R)	500–600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.80 mm, 0.70 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	2 to 3 mm
Number of slices	11
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	2 to 3
Read direction	Cranio-caudal
Saturation pulses	Inferior may be used
Scan time	3.5 to 7 min

[a]No phase-wrap or phase-oversampling.

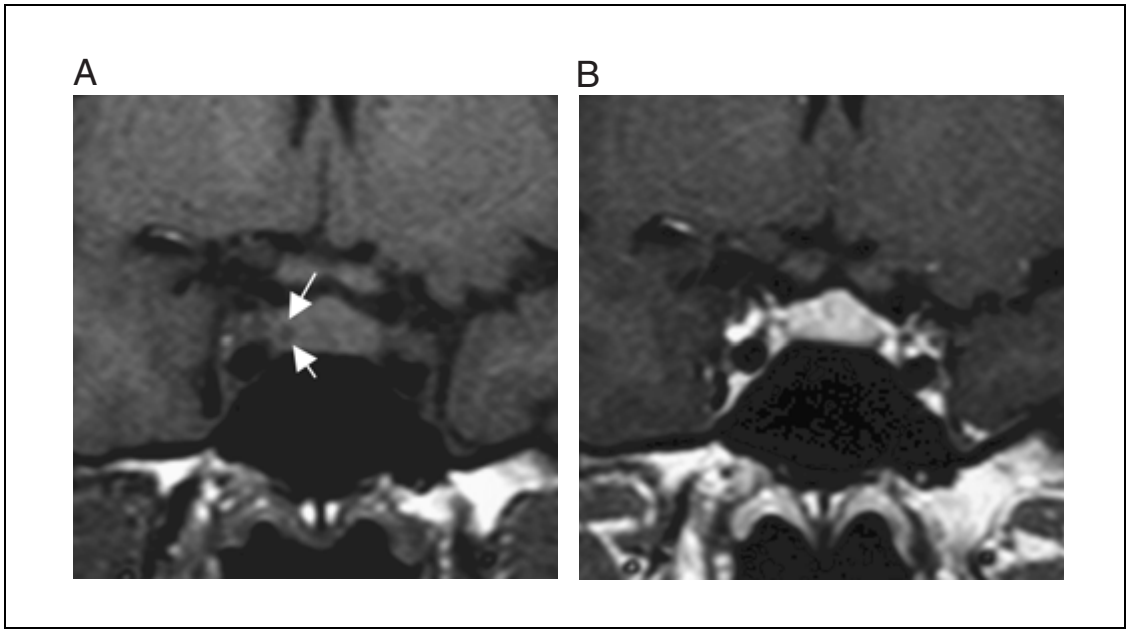

Figure A5.2.5 (**A**) Non-contrast T_1-weighted coronal image demonstrates a 2.5 mm microadenoma in the right side of the sella. (**B**) Following contrast, the lesion is no longer apparent.

Table A5.2.14 Parameters for Dynamic T_1-Weighted TSE/FSE Coronal (Sequence 12)

Patient position	Supine
Scan type	TSE/FSE
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	12 msec
Echo train length (ETL) (turbo factor)	8
Repeat time (T_R)	500 msec
Flip angle (FA)	180°[a]
Fields of view (FOV_x, FOV_y)	180 mm, 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.70 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	3 mm
Number of slices	7
Slice gap	0 to 0.3 mm
Number of acquisitions (N_{acq})	1 to 2
Read direction	Cranio-caudal
Saturation pulses	Not applicable
Scan time	14 to 28 sec per sequential acquisition

[a]The system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

may be administered manually or through the use of an automated injector. Rate of administration is not critical but should be brisk, with a target of at least 1 ml/sec and preferably 2 ml/sec.

A rough survey of techniques used by a few different centers for this particular application disclosed wide variation in parameters. Institutions vary in chosen echo train length (3 to 8), T_R (380 msec to 800 msec), number of slices (3 to 7), slice thickness (2 to 3 mm), and acquisition matrix. The general idea is simply to use a TSE sequence with parameters providing T_1 weighting and run it several times sequentially (Davis et al., 1994). As such, likely many parameter variations will be acceptable.

Sequence 13: Post-gadolinium T_1-weighted spin echo coronal

7. Use parameters as indicated in Table 5.2.13 with identical positioning in sequence 11 and one parameter modification.

Flow compensation option should be used to minimized phase encoding artifact from cavernous carotids. This option will increase T_E to ~17 msec.

BASIC PROTOCOL 3

CAVERNOUS SINUS

As with the macroadenoma protocol, evaluation of the cavernous sinus focuses on T_1-weighted imaging in the most useful planes. In this case, transverse imaging is more helpful than sagittal. Also, T_2-weighted imaging is frequently helpful and is included as part of the standard protocol rather than as an option. Because the anatomy to be evaluated is part of the skull base, fat suppression is helpful both for T_1-weighted post-contrast imaging and for T_2-weighted TSE imaging. Finally, if either a cavernous carotid fistula or cavernous carotid aneurism is clinically questioned, then 3-D time-of-flight (TOF) MR angiography is suggested as an option. Table A5.2.15 lists 7 sequences and one optional sequence for Basic Protocol 3. Basic Protocol 1 generally requires 40 to 60 min to complete.

Table A5.2.15 Basic Cavernous Sinus Protocol

Sequence and type of weighting	Imaging plane
14. Pilot scan (scout)	
15. T_1-weighted spin echo	Transverse
16. T_1-weighted spin echo	Coronal
17. T_2-weighted TSE/FSE FS	Coronal
18. Dual echo PD/T_2-weighted TSE/FSE whole brain	Transverse
19. Post-gadolinium T_1-weighted spin echo FS	Coronal
20. Post-gadolinium T_1-weighted spin echo FS	Transverse
Optional sequence	
21. 3-D TOF MR angiography (source images)[a]	Transverse

[a]If CCF is a specific issue, then 3-D short T_R spoiled gradient echo imaging is recommended (should be performed prior to gadolinium administration).

Table A5.2.16 Parameters for T_1-Weighted Spin Echo Transverse (Sequence 15)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Sella
Echo time (T_E)	14 msec
Repeat time (T_R)	500–600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.80 mm, 0.70 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	3 mm
Number of slices	15
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	2
Read direction	Anterior to posterior
Saturation pulses	Inferior
Scan time	4 min

[a]No-phase-wrap or phase-oversampling.

Set up equipment and patient

1. Use the same equipment and perform patient setup as for the previous method (see Basic Protocol 1).

Sequence 14: Pilot scan

2. Run a rapid three-plane positioning pilot scan (see Basic Protocol 1, sequence 1).

Sequence 15: T_1-weighted spin echo transverse

3. Set parameters as indicated in Table A5.2.16.

   Transverse images are planned off the sagittal pilot scan. The images are positioned parallel to the planum sphenoidale and should cover from above the sella to the pons.

Sequence 16: T_1-weighted spin echo coronal

4. Set parameters as indicated in Table A5.2.17.

Table A5.2.17 Parameters for T_1-Weighted Spin Echo Coronal (Sequence 16)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	14 msec
Repeat time (T_R)	500–600 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.80 mm, 0.70 mm
Number of data points collected (N_x, N_y)	224, 256
Slice thickness (Δz)	4 mm
Number of slices	15
Slice gap (distance factor)	1 mm (0.25)
Number of acquisitions (N_{acq})	2
Read direction	Cranio-caudal
Saturation pulses	Inferior
Scan time	4 min

[a]No-phase-wrap or phase-oversampling may be used.

Table A5.2.18 Parameters for T_2-Weighted TSE/FSE Coronal (Sequence 17)

Patient position	Supine
Scan type	TSE/FSE
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	102 msec
Echo train length (ETL) (turbo factor)	8 to 11
Repeat time (T_R)	3000 msec
Flip angle (FA)	180°[a]
Fields of view (FOV_x, FOV_y)	180 mm[b], 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.70 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	4 mm
Number of slices	15
Slice gap (distance factor)	1 mm (0.25)
Number of acquisitions (N_{acq})	3 to 4
Read direction	Cranio-caudal
Saturation pulses	Inferior
Fat suppression	Yes
Scan time	4 min

[a]The system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.
[b]No-phase-wrap or phase-oversampling may be used.

The scan is positioned on the pilot sagittal with images orthogonal to sellar floor or planum sphenoidale. The scan should cover from mid-pons to mid-orbit.

Sequence 17: T_2-weighted TSE/FSE coronal

5. Set parameters as indicated in Table A5.2.18.

The scan is positioned identically to the T_1-weighted coronal study. This scan provides T_2-weighted information about the contents of the cavernous sinus. Fat saturation allows for evaluation of pathology in or adjacent to the skull base.

Sequence 18: Dual echo PD/T_2-weighted TSE/FSE whole brain transverse

6. The scan is identical to that of Sequence 6 of the Basic Protocol 1. Set parameters as indicated in Table A5.2.7.

A quick whole brain screening sequence is often helpful in patients with symptoms related to cavernous sinus pathology.

Sequence 19: FS post-contrast T_1-weighted spin echo coronal

7. Set parameters as indicated in Table A5.2.19 and run with identical positioning to the pre-contrast T_1-weighted coronal sequence. Repeat step 15 in Basic Protocol 1.

The time required for the FS pulse will increase T_E and likely require some increase in T_R to provide adequate coverage. The T_R should be kept below ~700 msec to maintain proper T_1 weighting. A decrease in total number of slices is often required and usually acceptable depending upon the anatomy of the patient and any pathology demonstrated on the pre-contrast scan. In exceptional circumstances, it may be necessary to run two separate measurements to provide adequate coverage. An increase in N_{acq} is often needed to maintain high image quality.

Sequence 20: FS post-contrast T_1-weighted transverse

8. Set parameters as indicated in Table A5.2.20 and run with identical positioning to the pre-contrast T_1-weighted transverse sequence.

Table A5.2.19 Parameters for FS Post-Contrast T_1-Weighted Spin Echo Coronal (Sequence 19)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Mid-sella
Echo time (T_E)	17 msec
Repeat time (T_R)	650 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.70 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	4 mm
Number of slices	15 or as allowed
Slice gap (distance factor)	1 mm (0.25)
Number of acquisitions (N_{acq})	3
Read direction	Cranio-caudal
Flow compensation	Yes (if available)
Saturation pulses	Inferior may be used
Fat suppression	Yes
Scan time	6 min

[a]No-phase-wrap or phase-oversampling may be used.

Table A5.2.20 Parameters for FS Post-Contrast T_1-Weighted Spin Echo Transverse (Sequence 20)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Sella
Echo time (T_E)	17 msec
Repeat time (T_R)	650 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	180 mm[a], 180 mm
Resolution (Δx, Δy)	0.94 mm, 0.70 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	3 mm
Number of slices	15 or as allowed
Slice gap (distance factor)	0.5 mm (0.17)
Number of acquisitions (N_{acq})	3
Read direction	Anterior to posterior
Flow compensation	Yes (if available)
Saturation pulses	Inferior may be used
Fat suppression	Yes
Scan time	6 min

[a]No-phase-wrap or phase-oversampling may be used.

Table A5.2.21 Parameters for 3-D Time-of-Flight MR Angiogram (Sequence 21)

Patient position	Supine
Scan type	3-D short T_R spoiled gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Sella
Echo time (T_E)	Minimum (or 6.9 msec)
Repeat time (T_R)	Minimum (or 36 msec)
Flip angle (FA)	25°
Fields of view (FOV_x, FOV_y)	160 mm, 220 mm
Resolution (Δx, Δy)	0.83 mm, 0.86 mm
Number of data points collected (N_x, N_y)	192, 256
Slice thickness (Δz)	1 mm
Number of slices	50–64
Slice gap	0
Number of acquisitions (N_{acq})	1
Read direction	Anterior to posterior
Flow compensation[a]	Yes
Saturation pulses	None
Scan time	~6 to 7 min

[a]Velocity (flow) compensation in read and slice-select directions.

Sequence 21: 3-D TOF MR angiogram (optional)

9. Set parameters as indicated in Table A5.2.21.

The scan is positioned just as prior transverse acquisitions. If this option is chosen, it must be run prior to gadolinium enhancement (before sequence 19). When the presence of a cavernous-carotid fistula (CCF) is questioned, a 3-D TOF angiogram is a helpful step. The exam is interpreted directly from source images where the observation of flow-related enhancement in the cavernous sinus indicates the presence of a CCF. Processing the image data to obtain maximum intensity projections can of course be used to aid evaluation of arterial anatomy in the usual fashion (see Chapter A1).

COMMENTARY

Background Information

Within the modest limits of the sella turcica and environs, an impressive array of anatomy merges, reflecting elements of neural, endocrine, vascular, meningeal and bony tissues. The multi-planar capability and tissue contrast afforded by MRI provides detailed information about the pathology and anatomy of this region. With tumors of the anterior pituitary comprising 10% to 15% of all intracranial neoplasms, careful attention to the MRI evaluation of the sella is paramount (Kovacs and Horvath, 1986).

As a testimony to the tremendous intrinsic soft tissue contrast demonstrated by MRI, the simplest of sequences—a T_1-weighted spin echo sequence performed in the coronal plane—provides much of the desired information. The T_1-weighted coronal sequence identifies most, but not all, microadenomas. The sequence also evaluates suprasellar extension of sellar lesions and the presence of optic apparatus compression. Despite the use of T_2 weighting and various contrast enhancement techniques, the two limitations of this sequence, incomplete sensitivity to microadenomas and evaluation of cavernous sinus invasion, remain problematic.

T_1-weighted non-contrast imaging detects most microadenomas, with the actual sensitivity varying in different series between 60% and 80% (Kucharczyk et al., 1986; Nichols et al., 1988; Lundin et al., 1991; Elster, 1993). Post-gadolinium imaging improves sensitivity mildly, detecting ~5% to 10% more lesions (Macpherson et al., 1989; Newton et al., 1989; Steiner et al., 1989; Stadnik et al., 1990). Finally, use of dynamic enhanced techniques provides visualization of 5% to 20% more lesions, increasing the overall sensitivity of the complete MR exam to 80% to 90%. The improvement in sensitivity provides the motivation for the dedicated microadenoma protocol. However, with each additional step, the MRI becomes lengthier, more expensive, and, in the case of the dynamic study, logistically more complex. Hence, some consideration should be given to the need for such an exhaustive search.

Use of microadenoma protocol

Not all microadenomas must be detected. The need for definitive microadenoma detection is determined by many factors relating to results of endocrine tests, patient factors, and institutional habits. For a recent review of the issue, the reader is referred to Elster (1994). In many cases, reliable diagnosis of microadenoma can be made by clinical history and results of serum hormone assays. If an institution treats all such neoplasms medically, then detection of the lesion by imaging is not necessary and the MRI is used only to exclude other pathology and perhaps as a baseline. In this event, an all-out MR search for the lesion is unnecessary. However, in some institutions, surgery is applied as a front-line therapy. Also, medical therapy may be ineffective or not tolerated by the patient. In such situations, detection of the lesion preoperatively becomes important.

As a first step in increasing sensitivity to microadenoma detection, the resolution of the T_1-weighted coronal sequence may be further increased. To the author's knowledge, the utility of this rather straightforward move has not been subjected to a careful, controlled prospective study. However, given the small size of lesions to be detected and the proven value of a T_1-weighted coronal sequence, it makes inherent sense. Of course, several problems may arise. First, the quality of implementation on individual scanners will vary. The sequence pushes the limits of image signal-to-noise and some experimentation with acquisition matrix (number of data points collected), slice thickness, and number of acquisitions will likely be necessary to achieve a visually pleasing and hence useful exam. Second, higher resolution will doubtless uncover an increasing number of

the so-called pituitary incidentalomas (Chong et al., 1994; Teramoto et al., 1994). The existence of fairly frequent incidental abnormalities should be kept in mind in proper interpretation of high-resolution pituitary exams.

Differential temporal enhancement of pituitary neoplasms provides another dimension along which they may be separated from the normally enhancing gland. The general approach is to perform some form of fast T_1-weighted imaging in the coronal plane using just a few slices located in the mid-sella. The sequence is repeated serially just before, at the beginning of, and several times after a bolus injection of contrast agent, up to ~2 min. In this way, microadenomas, which usually enhance in delayed fashion compared to the normal adenohypophysis, may be identified. Fast T_1-weighted imaging may be achieved in a number of ways, and several different approaches have been applied successfully, including FSE/TSE sequences, gradient-recalled sequences, and keyhole imaging (Nagele et al., 1993; Davis et al., 1994; Kucharczyk et al., 1994). In the author's experience, the application of a T_1-weighted TSE/FSE sequence, as indicated in Basic Protocol 2, provides reliable and useful information, and is available on many current scanners. In the past, approaches employing gradient-recalled sequences with fairly long T_E's suffered from skull base and sphenoid sinus related susceptibility artifacts. With shorter T_E's (down to 2 msec) afforded by newer scanners, such artifacts are minimized and gradient-echo sequences in this application now represent a viable option. Keyhole dynamic imaging likely has advantages, but is not commonly available.

Cavernous sinus invasion by pituitary adenoma

Identification of cavernous sinus invasion by pituitary adenomas carries important clinical implications. For the neurosurgeon, an adenoma invading the cavernous sinus cannot usually be successfully removed, so once invasion is diagnosed, the goal of transphenoidal surgery shifts from tumor removal to tumor debulking. MRI does not often allow for definitive evaluation of invasion as the medial wall of the cavernous sinus is generally not visualized even with high-resolution imaging. As with most pituitary pathology, the T_1-weighted spin echo coronal sequence provides the most useful information. Clear signs of invasion include encasement of the intracavernous carotid artery by tumor, cavernous sinus expansion, and invasion beyond the lateral wall of the cavernous sinus. For less obvious cases, several classification schemes have been devised for predicting the likelihood of invasion, generally using the intracavernous carotid artery as a landmark (Scotti et al., 1988; Knosp et al., 1993).

Pathology primary to the cavernous sinus

The cavernous sinus protocol, Basic Protocol 3, focuses on pathology primary to the cavernous sinus. Reflecting the wide variety of potential pathology, the protocol is somewhat longer and uses several types of scan weighting along with enhancement. The protocol may not be ideal for each patient and appropriate modifications will be necessary from time to time. Symptoms related to the cavernous sinus derive from dysfunction of its cranial nerve and venous contents. If the symptomatology is limited to just one or a few of the cranial nerves present, then one of several other similar protocols may be more appropriate. Symptoms related to cranial nerves III, IV and VI may be better evaluated by an orbit protocol (see *UNIT A7.5*). If only cranial nerve V symptoms are present, then a dedicated protocol for imaging the full extent of this important nerve is likely more suitable (see *UNIT A7.2*).

Symptoms and signs of a cavernous-carotid fistula are often dramatic and the diagnosis clinically apparent. If MRI evaluation of the condition is desired, then 3-D TOF MRA should be used (sequence 21 of Basic Protocol 3). Inspection of source images for flow related enhancement in the cavernous sinus has been shown to be more sensitive to the presence of a CCF (Hirai et al., 1998). It should be noted that not all CCFs will be positive on an MRA and catheter angiography may be necessary. In this fairly specific clinical context, not all of the sequences in Basic Protocol 3 will be necessary.

Critical Parameters and Troubleshooting

Fat saturation techniques will exaggerate susceptibility artifacts related to dental hardware. Such artifacts are not as common in the sella as in the orbits and paranasal sinuses but nonetheless can occasionally be problematic. As a first step to deal with such a problem, simply repeat the sequence without the fat saturation pulse. In the case of post-contrast imaging, if a pre-contrast scan in the same plane exists, then interpretation is still certainly possible, albeit perhaps a bit more demanding. If T_2-weighted FS imaging is desired, as in the cavernous sinus protocol, then a T_2-weighted

STIR (short tau inversion recovery) scan provides a comparable substitute.

Anticipated Results

The pituitary protocols will provide excellent visualization of the sella and its key neighboring relationships. The pituitary gland, infundibulum, and sella itself will be demonstrated. Pathology in the adjacent sphenoid sinus and clivus will be apparent. The optic chiasm, as well as adjacent optic nerves and tracts, will be well identified and their displacement by pituitary pathology characterized. All macroadenomas will be detected along with most microadenomas. Some information regarding the possibility of cavernous sinus invasion will be present.

The cavernous sinus protocol will identify and characterize contents of the cavernous sinus. Multiple sequences are employed in two advantageous planes in an effort to detail the intricate anatomy of this region. Reflecting the variety of pathology which may be present, T_1 weighting, T_2 weighting, and contrast agent enhancement sequences are all utilized. Using this approach, small tumors and inflammatory processes of the nerves of the sinus will be demonstrated. The morphology of the cavernous carotids will be demonstrated, although not quite as well as by catheter angiography. The presence of abnormalities of cavernous sinus venous flow will be visualized.

Literature Cited

Chong, B.W., Kucharczyk, W., Singer, W., and George, S. 1994. Pituitary gland MR: a comparative study of healthy volunteers and patients with microadenomas. *Am. J. Neuroradiol.* 15:675-679.

Davis, W.L., Lee, J.N., King, B.D., and Harnsberger, H.R. 1994. Dynamic contrast-enhanced MR imaging of the pituitary gland with fast spin-echo technique. *J. Magn. Reson. Imaging* 4:509-511.

Elster, A.D. 1993. Modern imaging of the pituitary. *Radiology* 187:1-14.

Elster, A.D. 1994. High-resolution, dynamic pituitary MR imaging: Standard of care or academic pastime? *[comment]. Am. J. Roentgenol.* 163:680-682.

Hirai, T., Korogi, Y., Hamatake, S., Ikushima, I., Sugahara, T., Sigematsu, Y., Higashida, Y., and Takahashi, M. 1998. Three-dimensional FISP imaging in the evaluation of carotid cavernous fistula: comparison with contrast-enhanced CT and spin-echo MR. *Am. J. Neuroradiol.* 19:253-259.

Knosp, E., Steiner, E., Kitz, K., and Matula, C. 1993. Pituitary adenomas with invasion of the cavernous sinus space: A magnetic resonance imaging classification compared with surgical findings *[see comments]. Neurosurgery* 33:610-617; discussion 617-618.

Kovacs, K., and Horvath, E. 1986. Tumors of the Pituitary Gland. Armed Forces Institute of Pathology, Washington, D.C.

Kucharczyk, W., Davis, D.O., Kelly, W.M., Sze, G., Norman, D., and Newton, T.H. 1986. Pituitary adenomas: high-resolution MR imaging at 1.5 T. *Radiology* 161:761-765.

Kucharczyk, W., Bishop, J.E., Plewes, D.B., Keller, M.A., and George, S. 1994. Detection of pituitary microadenomas: comparison of dynamic keyhole fast spin-echo, unenhanced, and conventional contrast-enhanced MR imaging *[see comments]. Am. J. Roentgenol.* 163:671-679.

Lundin, P., Bergstrom, K., Thuomas, K.A., Lundberg, P.O., and Muhr, C. 1991. Comparison of MR imaging and CT in pituitary macroadenomas. *Acta Radiol.* 32:189-196.

Macpherson, P., Hadley, D.M., Teasdale, E., and Teasdale, G. 1989. Pituitary microadenomas. Does Gadolinium enhance their demonstration? *Neuroradiology* 31:293-298.

Nagele, T., Petersen, D., Klose, U., Grodd, W., Opitz, H., Gut, E., Martos, J., and Voigt, K. 1993. Dynamic contrast enhancement of intracranial tumors with snapshot-FLASH MR imaging. *Am. J. Neuroradiol.* 14:89-98.

Newton, D.R., Dillon, W.P., Norman, D., Newton, T.H., and Wilson, C.B. 1989. Gd-DTPA-enhanced MR imaging of pituitary adenomas. *Am. J. Neuroradiol.* 10:949-954.

Nichols, D.A., Laws, E.R., Jr., Houser, O.W., and Abboud, C.F. 1988. Comparison of magnetic resonance imaging and computed tomography in the preoperative evaluation of pituitary adenomas. *Neurosurgery* 22:380-385.

Peck, W.W., Dillon, W.P., Norman, D., Newton, T.H., and Wilson, C.B. 1989. High-resolution MR imaging of pituitary microadenomas at 1.5 T: experience with Cushing disease. *Am. J. Roentgenol.* 152:145-151.

Scotti, G., Yu, C.Y., Dillon, W.P., Norman, D., Colombo, N., Newton, T.H., De Groot, J., and Wilson, C.B. 1988. MR imaging of cavernous sinus involvement by pituitary adenomas. *Am. J. Roentgenol.* 151:799-806.

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

Stadnik, T., Stevenaert, A., Beckers, A., Luypaert, R., Buisseret, T., and Osteaux, M. 1990. Pituitary microadenomas: Diagnosis with two-and three-dimensional MR imaging at 1.5 T before and after injection of gadolinium. *Radiology* 176:419-428.

Steiner, E., Imhof, H., and Knosp, E. 1989. Gd-DTPA enhanced high resolution MR imaging of pituitary adenomas. *Radiographics* 9:587-598.

Teramoto, A., Hirakawa, K., Sanno, N., and Osamura, Y. 1994. Incidental pituitary lesions in 1,000 unselected autopsy specimens. *Radiology* 193:161-164.

Key References

Shellock, 1996. See above.

Covers a number of important patient management issues related to MR imaging, including recommended safety procedures, a list of metallic implants that have been tested for MR compatibility, and a list of other sources on MR safety.

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