MRI of the Adrenal Glands

MRI is an effective method to evaluate adrenal pathology. The authors employ a set protocol incorporating various types of T_1- and T_2-weighted sequences including the use of in-phase and out-of-phase gradient echo techniques and the routine use of intravenous gadolinium.

ADRENAL IMAGING

BASIC PROTOCOL

The high signal-to-noise ratio (SNR) obtained at high field strength makes it possible to image the adrenal glands during a single breath-hold sequence. The sequences described herein are based on the authors' experience with a Siemens 1.5 T Vision scanner, but are expected to be equally applicable to machines from other manufacturers.

Scanning a patient or volunteer is a joint effort among technologists, nurses, and physicians, with the technologist normally responsible for following proper scanning protocols and techniques. Unless otherwise specified, in what follows, the person to whom directions are given is assumed to be the technologist. Table A17.1.1 lists the hardware necessary to perform the procedure, along with appropriate parameters.

The following ten sequences comprise the adrenal imaging protocol. This protocol employs multiple data acquisitions and serial post-gadolinium imaging. Most sequences require the patient to be able to suspend respiration for ~25 sec. It is imperative that there be clear communication between the technologist and the patient throughout the exam. This protocol results in consistent, reproducible image quality that is effective for evaluating the full spectrum of adrenal diseases.

NOTE: Be sure that technologists and nurses have immediate access to any emergency equipment that may be relevant to a given study, or that may be needed for a particular patient, such as crash carts or oxygen.

Materials

Normal saline (0.9% NaCl), sterile, 40 ml minimum
Extravascular contrast agent (e.g., Magnevist, Omniscan, or Prohance), volume is prescribed by patient weight

Set up patient and equipment

1. Interview the patient to assess for contraindications such as cardiac pacemakers, implanted mechanical devices, and/or ferromagnetic materials. Also, determine if the

Table A17.1.1 Equipment Specifications Needed to Perform the Following Imaging Sequences

Coil type	Circular polarized body phased array coil
Manufacturer and system type	Siemens, Vision
Field strength	1.5 T
Gradient strength	24 mT/m (or whatever the system permits, but minimum of 24 mT/m for sequences 2 and 4)
Knee cushion	Yes
Use of contrast agents	Yes
Pulse oximeter	If patient requires sedation
Power injector	Yes
Normal saline	Yes
35" extension tubing	Yes

Contributed by Kathy Wilber, Richard Semelka, and Laurie Fisher
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patient will need sedation medication necessitating the use of appropriate monitoring equipment.

A screening form is signed by each patient or legal guardian prior to bringing the patient into the exam area.

The presence of ferromagnetic materials may be a health hazard to the patient while in the magnetic field and/or adversely affect image quality. To determine the safety of scanning such ferromagnetic materials see Shellock and Kanal (1996).

The presence of ferromagnetic materials in the globe of the eye is contraindicated for MRI. Patients with prior metal exposure to the eye should have plain X rays of the orbital area to ensure that all metal has been removed prior to placing them in the magnetic field.

2. Request that the patient change into a gown and remove all personal effects such as jewelry, hearing aids, and glasses, prior to entering the MRI scan room. All personal belongings should be secured during the examination.

3. Explain the procedure to the patient and record relevant clinical history. Ensure that the patient understands what is expected, ask if the patient has any questions, and answer appropriately.

4. Fill a 20-ml syringe with normal saline and attach to a 35-in. saline-filled extension tubing. Obtain i.v. access utilizing a 22-G angiocatheter and attach the saline-prepared extension tubing and syringe. This allows flushing of the extension tubing while the patient waits to be imaged. In cases where a power injector is not available, this allows for preparation for bolus injection (see note below). Secure the position of angiocatheter with tegraderm or tape.

   Obtaining i.v. access prior to entering the scan room will promote patient throughput and eliminate "dead" time of starting the i.v. while the patient is on the exam table. Follow power injector manufacturer guidelines with regard to appropriate-gauge needle/angiocatheter to be used; this will depend on chosen injection/flow rates.

   NOTE: *If access to a power injector is not available, performing dynamic imaging is still possible as the extension tubing will allow the saline syringe to be placed at the foot of the patient table during pre-contrast imaging. In this case, the contrast agent will need to be drawn up by another syringe. When the bolus injection of the contrast agent is prepared, simply disconnect the saline syringe and connect the syringe filled with the contrast agent; once the bolus of contrast agent is injected, reconnect the saline syringe and bolus an appropriate volume of flush, usually ~10 ml. Alternatively, to eliminate the need of switching syringes, incorporate the use of a 3-way stopcock.*

5. Set up the exam room by securing the circularly polarized (CP)-body array coil onto the table and providing a clean exam table.

6. Set up the power injector as specified by the manufacturer. A minimum of 40 ml normal saline should be drawn-up to ensure sufficient saline is available to keep the vein open (KVO) throughout the exam. To determine the amount of contrast agent to be used, reference the contrast packet insert and draw-up the amount indicated per kilogram of patient weight. There is no need to double dose.

7. Escort the patient to the MR examination room and ask them to lie down accordingly with respect to the exam to be performed. Connect the extension tubing secured to the syringe to the power injector extension tubing. Review the following items with the patient:

   a. Provide earplugs or headphones to the patient to minimize the loud knocking noise that will be produced by the gradients, but ensure them that the patient will still be able to hear you.

b. Provide the patient with a safety squeeze-bulb and demonstrate how it works; explain to the patient when to use the squeeze-bulb (i.e., if assistance is needed during the exam).

c. Explain to the patient that you will be talking to them between imaging sequences which will be when the loud knocking noise stops. Additionally, review breath holding instructions with the patient.

d. Explain to the patient that it is imperative to remain motionless during the loud knocking noise to ensure good results; also explain that one should not reposition one's body between imaging sequences.

e. Position a support under the patient's knees to enhance patient comfort.

f. Provide the patient with an approximate time that the examination will take.

8. Secure the top portion of the CP–body array coil to prevent it from moving side-to-side during breath-holding imaging sequences.

   Usually there are straps provided by the manufacturer that are directly attached to the coil.

9. Use the laser light to position the patient and to center the coil (see Table A17.1.2).

10. Advance the patient table to isocenter.

11. Program the power injector for a contrast agent and saline injection rate of 2 ml/sec. Total volume of saline following contrast agent injection should be programmed for 10 ml. Program a scan delay of 18 sec (contrast agent is injected, scan is initiated 18 sec after contrast agent and saline are delivered). Arm the power injector and keep the vein open. *Do not inject the contrast agent.*

Sequence 1: Three-plane positioning scout

12. To validate the patient's position and to have a reference to prescribe successive imaging sequences, acquire a three-plane orthogonal scout sequence using parameters in Table A17.1.2.

    Most MR scanners can be programmed to acquire the scout automatically after coil tuning or after the patient has been placed in isocenter (for systems that do not require tuning).

Sequence 2: Half-acquisition (partial Fourier) turbo spin echo (HASTE) coronal

13. Display both the coronal and transverse scout images in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A17.1.3. Position slices to center of the transverse scout ensuring that the adrenals are covered.

14. Instruct the patient to remain motionless and to breathe normally as the scan will begin and last for ~40 sec.

Sequence 3: Gradient echo coronal

15. Change imaging parameters to those listed in Table A17.1.4. Position slices to center of the transverse scout ensuring that the adrenals are covered.

16. Instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

Sequence 4: Half-acquisition turbo spin echo transverse with fat saturation (fat suppression)

17. Display both the coronal and transverse scout images in two separate quadrants on the scan monitor (see step 13). Change imaging parameters to those listed in Table A17.1.5. Position slices to cover from the diaphragm to the aortic bifurcation.

18. Perform system shim as recommended by manufacturer, as this is a fat saturation sequence.

Table A17.1.2 Imaging Parameters for Sequence 1 (Scout Sequence)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Sagittal, transverse, and coronal
Central slice or volume center	Laser light centered approximately one hand width above the inferior rib margin
Echo time (T_E)	6 msec
Repeat time (T_R)	15 msec
Flip angle (FA)	30°
Field of view (FOV_x, FOV_y)	450 mm, 450 mm
Resolution (Δx, Δy)	1.76 mm, 3.52 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	10 mm
Number of slices	3
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	16 sec

Table A17.1.3 Imaging Parameters for Sequence 2 (Half-Acquisition Turbo Spin Echo)

Patient position	Supine
Scan type	Half-acquisition turbo spin echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Slices posted on transverse scout; center to adrenals
Echo time (T_E)	90 msec
Repeat time (T_R)	4.4 msec[a]
Delay time	1500 msec
Flip angle (FA)	150°
Field of view (FOV_x, FOV_y)	400 mm, 400 mm
Resolution (Δx, Δy)	1.56 mm, 2.08 mm
Number of data points collected (N_x, N_y)	256, 192 (using half Fourier)
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	20
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to adrenals
Saturation pulses	No
Slice series	Interleaved
Scan time	40 sec

[a]The true T_R is infinite; 4.4 msec represents the echo spacing.

Table A17.1.4 Imaging Parameters for Sequence 3 (Gradient Echo)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Coronal
Central slice or volume center	Slices posted on transverse scout; center to adrenals
Echo time (T_E)	4.1 msec
Repetition time (T_R)	140 msec
Flip angle (FA)	80°
Field of view (FOV_x, FOV_y)	400 mm, 400 mm
Resolution (Δx, Δy)	1.56 mm, 3.13 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	20
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to cover adrenals
Saturation pulses	No
Slice series	Interleaved
Scan time	18 sec

Table A17.1.5 Imaging Parameters for Sequence 4 (Half-Acquisition Turbo Spin Echo with Fat Saturation)

Patient position	Supine
Scan type	Half-acquisition turbo spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to adrenals
Echo time (T_E)	90 msec
Repeat time (T_R)	4.4 msec[a]
Delay time	1500 msec
Flip angle (FA)	150°
Field of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37 mm, 1.37 mm
Number of data points collected (N_x, N_y)	256, 192 (using half Fourier)
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	20
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to cover adrenals
Saturation pulses	Yes, superior and inferior to slices
Fat suppression	Yes
Slice series	Interleaved
Scan time	40 sec

[a]The true T_R is infinite; 4.4 msec represents the echo spacing.

19. Instruct the patient to remain motionless and to breathe normally as the scan will begin and last for ~40 sec.

Sequence 5: Transverse gradient echo with fat saturation (Figure A17.1.1)

20. Display the coronal images (use breath-hold images from sequence 3) on the scan monitor. Change imaging parameters to those listed in Table A17.1.6. Position slices to center of the coronal gradient echo image ensuring that the adrenals are covered.

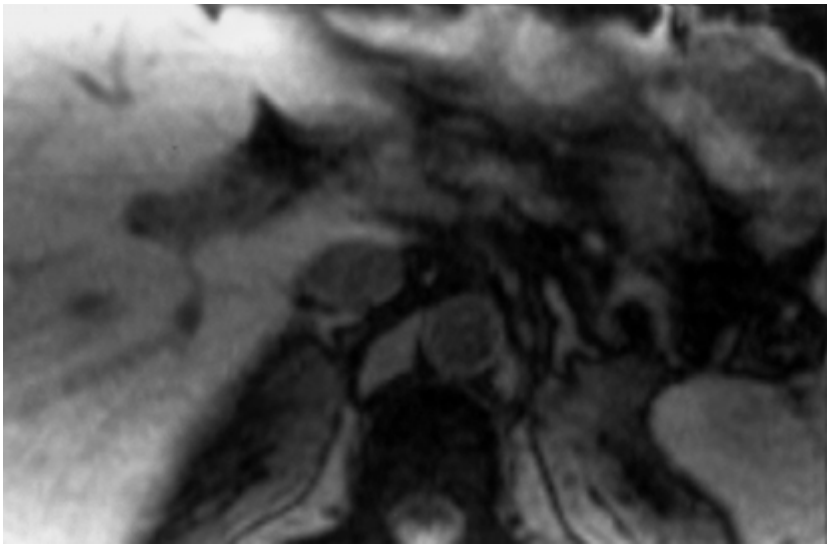

Figure A17.1.1 Unenhanced fat suppressed transverse spoiled gradient echo image.

Table A17.1.6 Imaging Parameters for Sequence 5 (Gradient Echo with Fat Saturation)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to adrenals
Echo time (T_E)	4.1 msec
Repeat time (T_R)	147.2 msec
Flip angle (FA)	80°
Field of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37 mm, 2.05 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	6 mm
Number of slices	20
Slice gap	1.2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to cover adrenals
Saturation pulses	No
Fat suppression	Yes
Slice series	Interleaved
Scan time	19 sec

It is imperative that the slices are prescribed off of the breath-hold gradient echo images from sequence 3 as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a nonbreath-held image is used.

21. Instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

Sequence 6: Transverse gradient echo (out-of-phase) (Figure A17.1.2)

22. Display the midline slice of the gradient echo coronal image (sequence 3) and the previous transverse gradient echo image in two separate quadrants on the scan

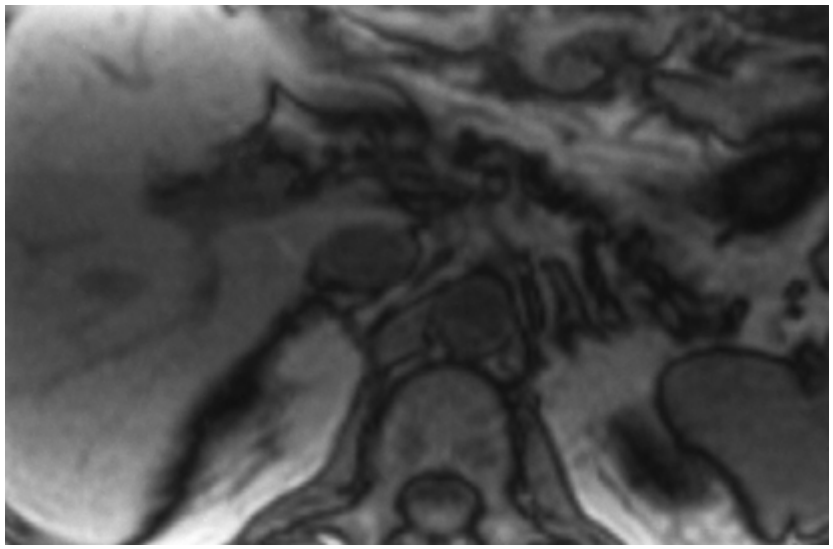

Figure A17.1.2 Out-of-phase transverse spoiled gradient echo image.

Table A17.1.7 Imaging Parameters for Sequence 6 (Gradient Echo–Out-of-Phase)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to adrenals
Echo time (T_E)	2.2 msec
Repeat time (T_R)	140 msec
Flip angle (FA)	80°
Field of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37 mm, 2.05 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	20
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to adrenals
Saturation pulses	No
Slice series	Interleaved
Scan time	19 sec

monitor. Change imaging parameters to those listed in Table A17.1.7. Position slices to cover the adrenals.

It is imperative that the slices are prescribed off of the gradient echo coronal image as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a non-breath-held image is used.

23. Instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

Sequence 7: Transverse gradient echo

24. Display the midline slice of the gradient echo coronal image (sequence 3) and the previous transverse gradient echo image in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A17.1.8. Position slices to cover the adrenals.

It is imperative that the slices are prescribed off of the gradient echo coronal image as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a non-breath-held image is used.

25. Instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

Sequence 8: Transverse gradient echo—immediate post contrast (Figure A17.1.3)

See patient set up section for specific instructions on preparation for contrast agent injection. This preparation must be done prior to placing the patient in the scanner.

26. Repeat step 24.

It is imperative that the slices be prescribed off of the gradient echo coronal image as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a non-breath-held image is used.

27. Explain to the patient that you will now be injecting the contrast agent and he/she may feel a cool sensation in his/her arm. Initiate the injection. Do not begin scanning

Table A17.1.8 Imaging Parameters for Sequence 7 (Gradient Echo)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to adrenals
Echo time (T_E)	4.5 msec
Repeat time (T_R)	140 msec
Flip angle (FA)	80°
Field of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37 mm, 2.05mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	18
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to cover adrenals
Saturation pulses	No
Slice series	Interleaved
Scan time	18 sec

until the 18 sec scan delay has expired. However, breathing instructions should be delivered when 10 sec of delay are remaining (see step 28).

If you do not have access to a power injector and are "hand" injecting, you can still use step 27. However, after you have completed the bolus contrast agent injection, reattach the saline-filled syringe and flush with 10 ml of saline. Begin breathing instructions after 5 ml of the saline has been injected then proceed to initiate the scan. The process of switching syringes must be completed as quickly as possible and thus, the suggestion of incorporating the use of a 3-way stopcock.

28. When there are 10 sec of delay remaining, instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

Sequence 9: Transverse gradient echo—45 sec delay after injection (Figure A17.1.4)

29. Repeat step 24.

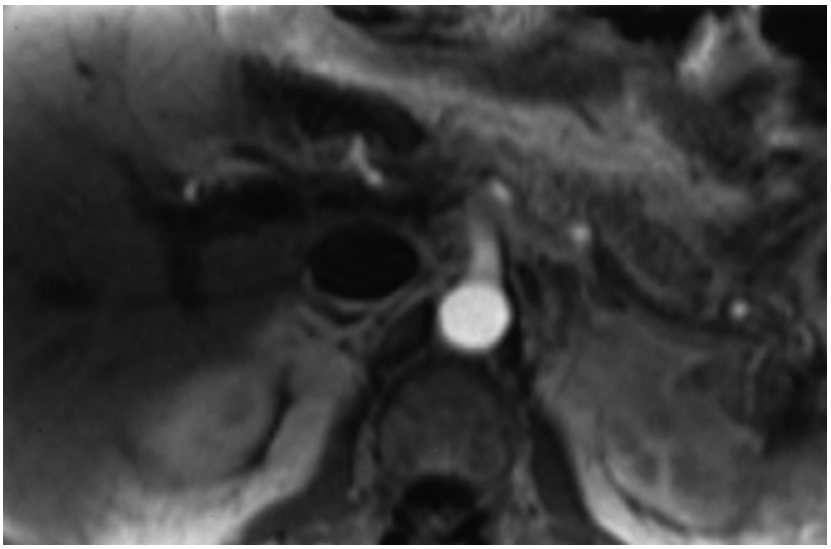

Figure A17.1.3 Immediate post contrast transverse spoiled gradient echo image.

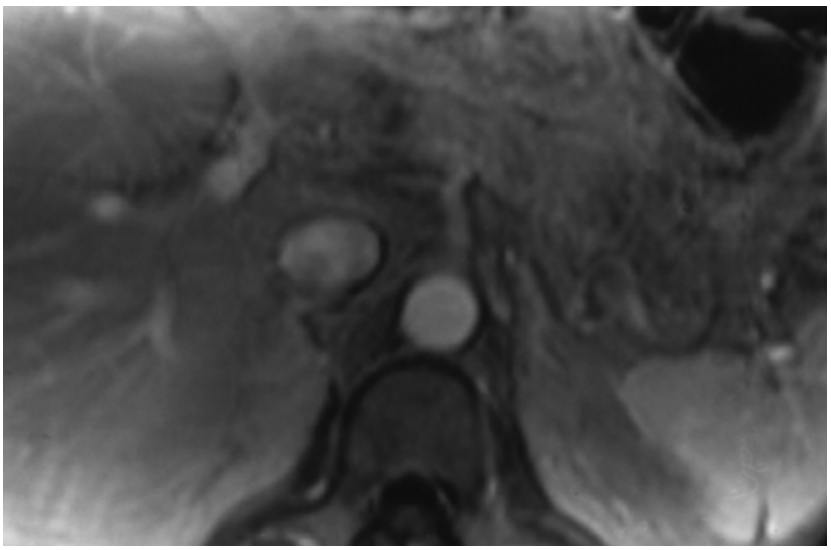

Figure A17.1.4 One-minute post gadolinium spoiled gradient echo transverse image.

It is imperative that the slices are prescribed off of the gradient echo coronal image as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a non-breath-held image is used.

30. Once 45 sec has expired, instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

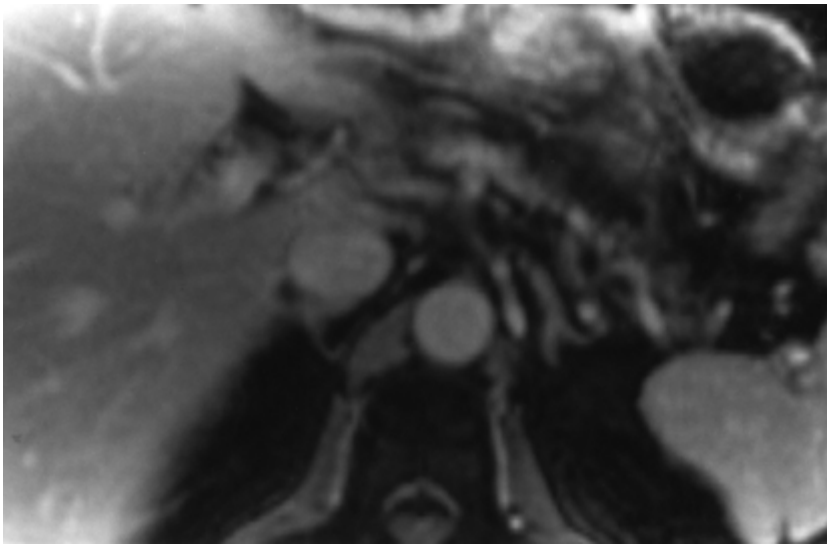

Figure A17.1.5 Post-contrast fat suppressed transverse spoiled gradient echo image.

Table A17.1.9 Imaging Parameters for Sequence 10 (Gradient Echo with Fat Saturation, 90 Sec Delay)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to adrenals
Echo time (T_E)	4.1 msec
Repeat time (T_R)	147.2 msec
Flip angle (FA)	80°
Field of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37 mm, 2.05mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8–10 mm
Number of slices	20
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Centered to cover adrenals
Saturation pulses	No
Fat suppression	Yes
Slice series	Interleaved
Scan time	19 sec

Sequence 10: Transverse gradient echo with fat saturation (90 sec delay after injection) (Figure A17.1.5)

31. Display the midline slice of the gradient echo coronal image (sequence 3) and the previous transverse gradient echo image in two separate quadrants on the scan monitor using parameters in Table A17.1.9. Position slices to cover the adrenals.

    It is imperative that the slices are prescribed off of the gradient echo coronal image as this is a breath-held imaging sequence. Otherwise, the slice location will not be accurate relative to the reference image if a non-breath-held image is used.

32. Once 90 sec has expired, instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it. Run the scan.

COMMENTARY

Background Information

The most common indication for MR of the adrenals is to distinguish adenoma from metastases (Mitchell et al., 1992; Tsushima et al., 1993; Lee et al., 1994; Reinig et al., 1994; Bilbey et al., 1995; Korobkin et al., 1995, 1996; Mayo-Smith et al., 1995; McNicholas et al., 1995; Outwater et al., 1995, 1996). The above described protocol employs gadolinium contrast in order that the full range of adrenal diseases may be evaluated. The use of gadolinium is not, however, essential if the clinical question is just the characterization of a known adrenal mass such as adenoma or metastasis. The next most common indication is the detection of pheochromocytoma (Lee et al., 1994). Rather than having separate protocols for adenoma versus metastases and pheochromocytoma search, we combine both indications into a single protocol to maintain study simplicity.

Critical Parameters and Troubleshooting

The most critical sequences are in-phase and out-of-phase spoiled gradient echo (Mitchell et al., 1992; Tsushima et al., 1993; Lee et al., 1994; Reinig et al., 1994; Bilbey et al., 1995; Korobkin et al., 1995; Mayo-Smith et al., 1995; McNicholas et al., 1995; Outwater et al., 1995). It is essential that patients be able to hold their breath in order to achieve optimal results. In the event that patients are unable to breath-hold, contrast computed tomography (CT) should be performed. Results with Hounsfield unit measurements on non-contrast CT and observed loss of signal from in-phase to out-of-phase MRI are comparable for the characterization of adrenal masses as adenomas (Korobkin et al., 1996; Outwater et al., 1996).

In looking for pheochromocytomas, the fat suppressed T_2-weighted HASTE sequence is the sequence (sequence 4) in the protocol that is employed for this detection. Pheochromocytomas are moderately high in signal on the fat suppressed T_2-weighted HASTE and are generally higher in signal than other adrenal masses and higher in signal than the majority of retroperitoneal structures. As fat suppressed T_2-weighted HASTE is breathing independent, there is no requirement that the patient be able to suspend respiration in order to search for pheochromocytomas.

Anticipated Results

In patients who are able to suspend respiration for 20 sec, successful imaging of the full range of adrenal abnormalities is achieved. This single protocol is designed to image the various types of disease processes that affect the adrenal glands. The combination of in-phase and out-of-phase images distinguish between benign adenomas and metastases.

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Key References

Shellock and Kanal, 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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