MRI of the Pancreas

MRI provides comprehensive information on the full range of pancreatic diseases. We employ a set protocol incorporating various types of sequences including transverse and coronal data acquisitions, and with the routine use of intravenous gadolinium.

IMAGING THE PANCREAS

BASIC PROTOCOL

The high signal-to-noise ratio (SNR) obtained at high field strength makes it possible to image the pancreas 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 A18.1.1 lists the hardware necessary to perform the procedure, along with appropriate parameters.

The following ten sequences comprise the pancreatic imaging protocol. Most sequences require the patient to be able to suspend respiration for ~20 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 pancreatic 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 prescribed by patient weight

Set up equipment and patient

1. Interview (screen) the patient to assess for contraindications such as cardiac pacemaker, implanted mechanical devices, and/or ferromagnetic materials. Also, determine if the patient has any health conditions that may require the presence of special

Table A18.1.1 Equipment Specifications: Imaging of the Pancreas

Coil type	Circularly 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 mg/m for sequences 3 and 4)
Knee cushion	Yes
Use of contrast agents	Yes
Pulse oximeter	If patient requires sedation
Power injector	Yes
Normal saline	Yes
35-in. extension tubing	Yes

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emergency equipment during the scanning procedure, or if he or she will need sedation medication necessitating the use of appropriate monitoring equipment.

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. 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.

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. Request that the patient change into a gown to eliminate any metal that might be found in clothing. Ask the patient to remove all personal effects such as, jewelry, hearing aids, glasses, etc., 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 and ask them if they have any questions; answer appropriately. If the procedure is a research protocol, have the patient sign any necessary consent form.

4. Fill a 20-ml syringe with normal saline and attach to saline filled extension tubing (35-in.). Obtain intravenous (i.v.) access utilizing a 22-G angiocatheter and attach saline-prepared extension tubing and syringe. This will allow you to flush the extension tubing while the patient waits to be imaged, and, in cases in which a power injector is not available, this will allow preparation for bolus injection (see Note below). Secure the position of the 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 you do not have access to a power injector, you will still be able to perform dynamic imaging 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, you will need to draw up the contrast agent in another syringe. When you are ready to bolus inject the contrast agent, simply disconnect the saline syringe and connect the syringe filled with contrast agent; once you have injected the bolus of contrast agent, 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 agent packet insert and draw up the amount indicated per kg of patient weight. There is no need to double dose.

7. Escort the patient to the MR examination room and ask the patient to lie down accordingly with respect to the exam to be performed. 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.

8. Connect the extension tubing secured to the syringe to the power injector extension tubing.
9. 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. Explain to the patient that one should not reposition one's body between imaging sequences.

      Additionally, review breath-holding instructions with the patient, and provide the patient with an approximate time that the examination will take.

   d. Nevertheless, the patient may call out at any time if he or she feels it necessary.
   e. Position a support under the patient's knees to enhance patient comfort.
10. Secure the top portion of the CP-body array coil to prevent it from moving side-to-side during breath-holding imaging sequences.

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

11. Use the laser light to position the patient, and to center the coil (see Table A18.1.2). Then advance the patient table to isocenter.
12. If the patient is unable to hold still, provide an appropriate sedative.
13. 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 at this time!

Sequence 1: Three-plane positioning scout

14. To validate the patient's position and to have a reference to prescribe successive imaging sequences, acquire a three-plane orthogonal scout sequence. See Table A18.1.2 for specific parameters.

    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: Breath-hold three—plane positioning scout

15. To have a reference to prescribe successive breath-hold imaging sequences, acquire a second three-plane orthogonal scout sequence. See Table A18.1.2 for specific parameters.

Table A18.1.2 Imaging Parameters for Scout Sequence (Sequences 1 and 2)

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 (Δ_x, Δ_y)	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 pulse	Not applicable
Scan time	16 sec

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

Sequence 3: Half-acquisition (partial Fourier) turbo spin echo coronal

18. Display both the coronal and transverse scout images (use *non*-breath-hold images) in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A18.1.3. Position slices to center of the transverse scout, ensuring that the pancreas and liver are covered.
19. Instruct the patient to remain motionless and to breathe normally as the scan will begin and last for ~40 sec.

Sequence 4: Half-acquisition turbo spin echo transverse (Fig. A18.1.1)

20. Display both the coronal and transverse scout images (use *non*-breath-hold images) in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A18.1.4. Position slices to center of the coronal scout, ensuring that the pancreas and liver are entirely covered.
21. 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 (fat suppression) (Fig. A18.1.2)

22. Display both the coronal and transverse scout images (use breath-hold images) in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A18.1.5. Position slices to center of the coronal scout, ensuring that the pancreas is entirely covered.

It is imperative that the slices are prescribed off of the breath-hold scout images 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.
24. Initiate the scan.

Table A18.1.3 Imaging Parameters for Half-Acquisition Turbo Spin Echo (Sequence 3)

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 pancreas
Echo time (T_E)	90 msec
Repeat time (T_R)	4.4 msec (note: The true T_R is infinite; 4.4 msec represents the echo spacing)
Delay time (T_D)	1500 msec
Flip angle (FA)	150°
Fields of view (FOV_x FOV_y)	400 mm, 400 mm
Resolution (Δ_x Δ_y)	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 location	Centered to cover the pancreas and liver
Saturation pulses	No
Slice series	Interleaved
Scan time	40 sec

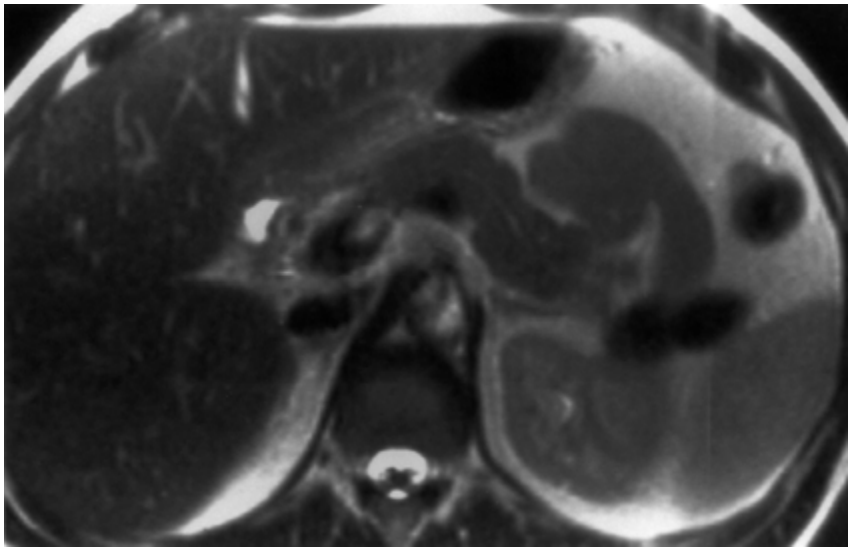

Figure A18.1.1 Unenhanced transverse half-acquisition turbo spin echo image.

Table A18.1.4 Imaging Parameters for Half-Acquisition Turbo Spin Echo (Sequence 4)

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 pancreas
Echo time (T_E)	90 msec
Repeat time (T_R)	4.4 msec (note: The true T_R is infinite; 4.4 msec represents the echo spacing)
Delay time (T_D)	1500 msec
Flip angle (FA)	150°
Fields of view (FOV_x, FOV_y)	350 mm, 263 mm
Resolution (Δx, Δy)	1.37mm, 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 location	Centered to cover the pancreas and liver
Saturation pulses	Yes, superior and inferior to slices
Fat suppression	No
Slice series	Interleaved
Scan time	40 sec

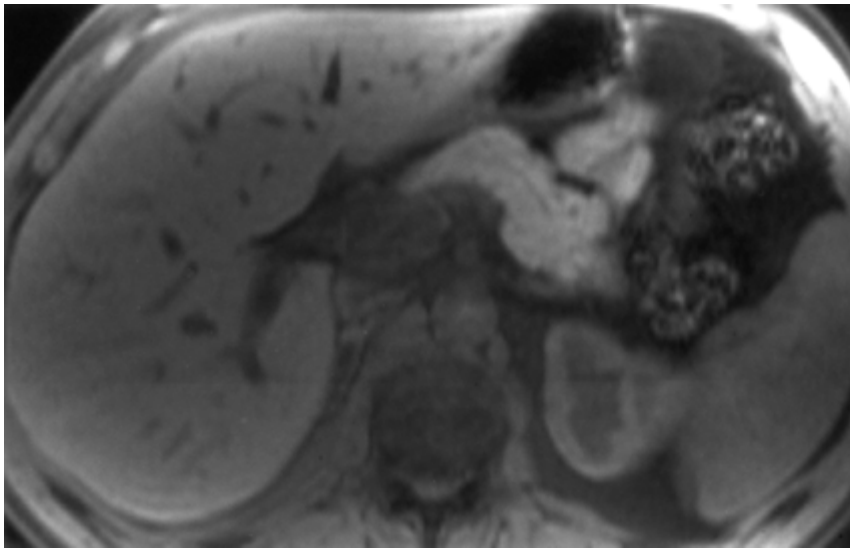

Figure A18.1.2 Unenhanced fat suppressed transverse spoiled gradient echo image.

Sequence 6: Transverse gradient echo (out-of-phase) (Fig. A18.1.3)

25. Display the coronal and transverse breath-hold scout images (sequence 2) in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A18.1.6. Position slices to cover the pancreas and liver.

It is imperative that the slices bee prescribed off of the breath-hold coronal scout 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.

Table A18.1.5 Imaging Parameters for Gradient Echo with Fat Saturation (Sequence 5)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to pancreas
Echo time (T_E)	4.1 msec
Repeat time (T_R)	147.2 msec
Flip angle (FA)	80°
Fields 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 location	Centered to cover the pancreas
Saturation pulses	No
Fat suppression	Yes
Slice series	Interleaved
Scan time	19 sec

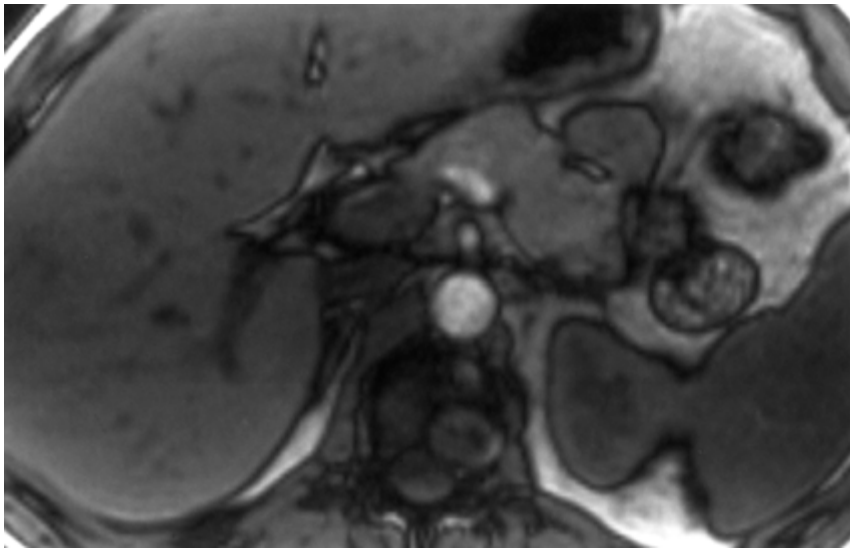

Figure A18.1.3 Out-of-phase transverse spoiled gradient echo image.

26. Instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it.
27. Initiate the scan.

Sequence 7: Transverse gradient echo (Fig. A18.1.4)

28. Display the breath-hold coronal and transverse scout images (sequence 2) in two separate quadrants on the scan monitor. Change imaging parameters to those listed in Table A18.1.7. Position slices to cover the pancreas and liver.

Table A18.1.6 Imaging Parameters for Gradient Echo—Out-of-Phase (Sequence 6)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to the pancreas
Echo time (T_E)	2.2 msec
Repeat Time (T_R)	140 msec
Flip angle (FA)	80°
Fields 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 location	Centered to cover the pancreas and liver
Saturation pulses	No
Slice series	Interleaved
Scan time	19 sec

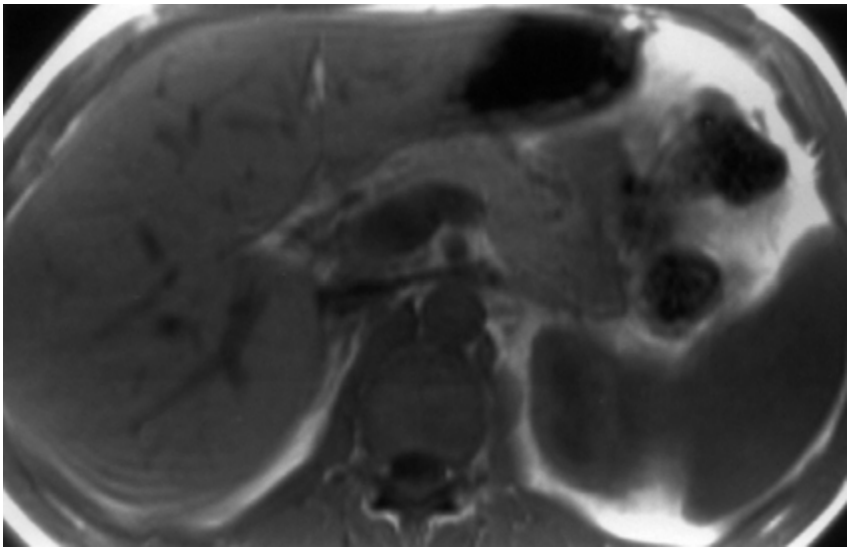

Figure A18.1.4 Unenhanced transverse spoiled gradient echo image.

Table A18.1.7 Imaging Parameters for Gradient Echo (Sequence 7)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to the pancreas
Echo time (T_E)	4.1 msec
Repeat time (T_R)	140 msec
Flip angle (FA)	80°
Fields 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 location	Centered to cover the pancreas and liver
Saturation pulses	No
Slice series	Interleaved
Scan time	18 sec

It is imperative that the slices are prescribed off of the breath-hold coronal scout 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.

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

30. Initiate the scan.

Sequence 8: Transverse gradient echo—Immediate postcontrast (Fig. A18.1.5)

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

31. Repeat step 28.

It is imperative that the slices be prescribed off of the breath-hold coronal scout 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. 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 until the 18 sec scan delay has expired. However, deliver breathing instructions when 10 sec of delay are remaining (see step 33).

If you do not have access to a power injector and are "hand" injecting, you can still use step 32. However, after you have completed the bolus contrast 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 it is suggested that a 3-way stopcock be incorporated.

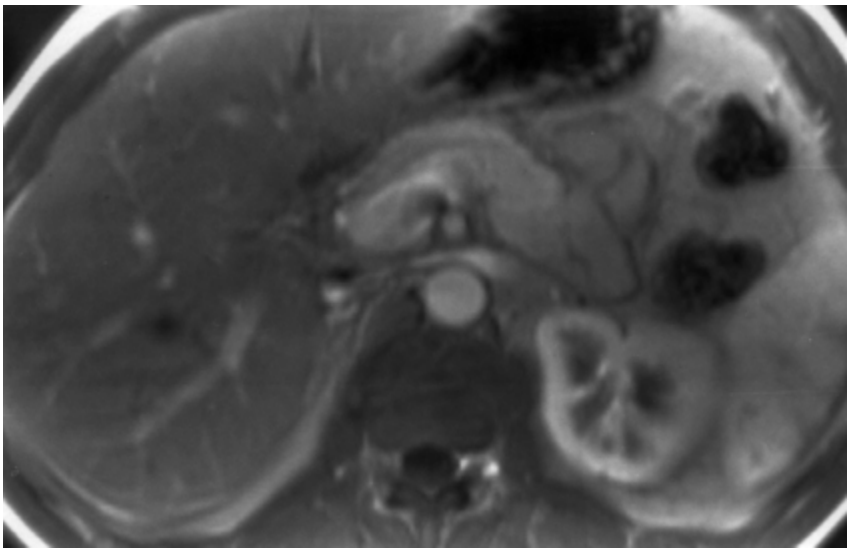

Figure A18.1.5 Immediate post contrast transverse spoiled gradient echo image.

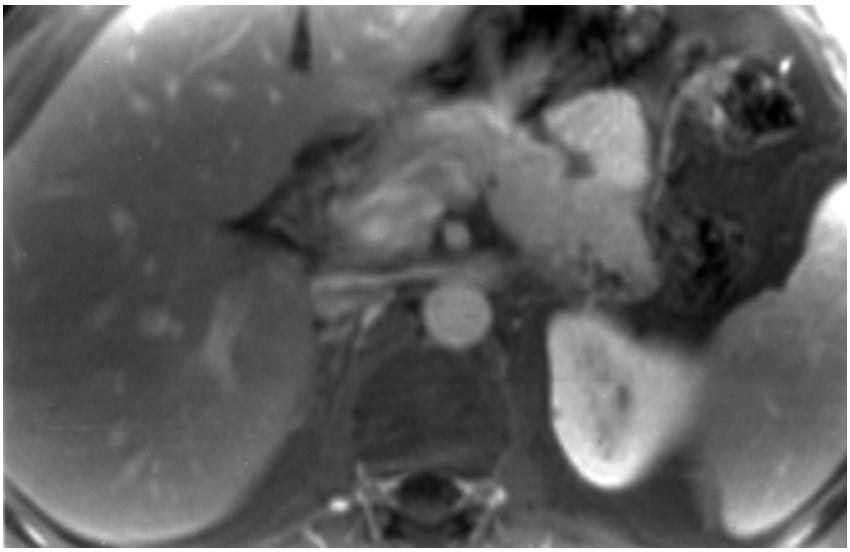

Figure A18.1.6 Post contrast fat suppressed transverse spoiled gradient echo image.

33. 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.
34. Initiate the scan.

Sequence 9: Transverse gradient echo—45 sec delay after sequence 8

35. Repeat step 28.
36. Once 45 sec has expired, instruct the patient to take in a deep breath and exhale, take in another deep breath and hold it.
37. Initiate the scan.

Sequence 10: Transverse gradient echo with fat saturation (90 sec delay after injection; Fig. A18.1.6)

38. Display the midline slice of the breath-hold coronal and transverse scout images (sequence 2) in two separate quadrants on the scan monitor. Change imaging

Table A18.1.8 Imaging Parameters for Gradient Echo with Fat Saturation—90 Sec Delay (Sequence 10)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to the pancreas
Echo time (T_E)	4.1 msec
Repeat time (T_R)	147.2 msec
Flip angle (FA)	80°
Fields 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)	6 mm
Number of slices	20
Slice gap	1.2 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice location	Centered to cover entire pancreas and liver
Saturation pulses	No
Fat suppression	Yes
Slice series	Interleaved
Scan time	19 sec

parameters to those listed in Table A18.1.8. Position slices to cover the pancreas and liver.

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.

39. Once 90 sec has expired, instruct the patient to take in a deep breath and exhale, then take in another deep breath and hold it.
40. Initiate the scan.

COMMENTARY

Background Information

MRI using a combination of non-contrast T_1-weighted fat suppressed imaging and immediate post-gadolinium spoiled gradient echo has been shown to be effective at exhibiting the full range of pancreatic disease (Gabata et al., 1994; Kelekis et al., 1995; Mitchell et al., 1995; Semelka et al., 1991; Semelka and Ascher, 1993; Semelka et al., 1993a,b; Semelka et al., 1996; Winston et al., 1995). Normal pancreas enhances in a moderately intense, uniform fashion on immediate post-gadolinium images, reflecting a uniform network of capillary vessels (Semelka et al., 1991; Semelka and Ascher, 1993). The normal pancreas is also moderately intense on non-contrast T_1-weighted fat suppressed images due to the presence of aqueous protein in the ascini of the glandular pancreas (Mitchell et al., 1995; Semelka et al., 1991; Semelka et al., 1993a; Winston et al., 1995). Particular strengths of MRI include the detection of small ductal adenocarcinomas and islet cell tumors (Gabata et al., 1994; Kelekis et al., 1995; Semelka et al., 1991; Semelka et al., 1993a,b; Semelka et al., 1996).

Critical Parameters and Troubleshooting

The most important data acquisition is the immediate post gadolinium spoiled gradient

Table A18.1.9 Imaging Parameters for Breathing Averaged Fat Suppressed Spin Echo (Use if Fat Suppressed Spoiled Gradient Echo Sequence Is Unavailable)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Slices posted on coronal; center to pancreas
Echo time (T_E)	15 msec
Repeat time (T_R)	500 msec
Flip angle (FA)	90°
Fields 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	10
Slice gap	1.6–2 mm
Number of acquisitions (N_{acq})	4
Swap read and phase encoding	No
Slice location	Centered to cover pancreas
Saturation pulses	No
Fat suppression	Yes
Slice series	Interleaved
Scan time	4 min, 19 sec

echo sequence. The critical aspect of this sequence is that the timing of gadolinium must be during the hepatic arterial dominant phase (or capillary phase) of enhancement (Semelka et al., 1993a). To ensure appropriate timing, contrast should be present in the hepatic arteries and portal veins and not yet present in the hepatic veins (Semelka et al., 1993a). The patient must be able to breath-hold for 20 sec to achieve optimal results for studying the pancreas, as required for the T_1-weighted gradient echo sequence.

Fat-suppressed spin echo (see Table A18.1.9) can be substituted for the fat suppressed spoiled gradient echo, if this latter sequence is not available on the scanner. Patients who are unable to breathhold or breathe in a regular fashion are better examined by CT (computed tomography).

Anticipated Results

In a patient who can suspend respiration and using an MR protocol that includes non-contrast T_1-weighted fat suppressed spoiled gradient echo and immediate post contrast spoiled gradient echo imaging, one can successfully evaluate a full range of pancreatic diseases. Particular strengths of this approach are in the detection of small pancreatic ductal adenocarcinomas, ampullary tumors and islet cell tumors, and staging of pancreatic neoplasms in general.

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Key References

Shellock, F.G. 1996.

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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