Ovarian Cancer Diagnosis and Staging

The techniques used for detecting and staging ovarian cancer are similar to those used for general imaging of the liver/abdomen and the pelvis for other applications. However, the importance of imaging both the abdomen and pelvis, and the greater reliance on delayed rather than early post-gadolinium images have led us to include a separate unit for imaging patients with suspected or confirmed ovarian cancer. The authors' experience has been acquired primarily using GE equipment. However, the basic approach should be quite similar, with most details relating to minor vendor-specific differences. Readers are encouraged to read *UNIT A15.2*, the alternate liver unit for GE users, for general comments on breath-holding techniques as well as the other chapters on abdominal and pelvic imaging techniques. These, as well as the authors' other protocols, are available on the web at: *http://www.mri.tju.edu/*.

OVARIAN CANCER

BASIC PROTOCOL

Whenever possible, patients should be triaged to MRI machines that utilize phased-array technology to improve signal-to-noise while maintaining temporal and spatial resolution, and have gradient and radiofrequency (RF) subsystems that are adequate in imaging large portions of the abdomen within a single breathhold. For initial diagnosis of ovarian cancer, T_1-weighted and T_2-weighted thin-slice images should be acquired with small pixel size. In the lower pelvis, breathholding is not essential, especially on unenhanced images, but the breathhold technique will greatly improve image sharpness above the true pelvis, especially on gadolinium-enhanced images. The dynamic technique is less essential for many other applications, but should generally be included for the liver portion of the examination to maximize diagnostic yield and to reduce the likelihood of ambiguous findings.

The most comprehensive method for detecting and staging ovarian carcinoma begins with high resolution T_1-weighted and T_2-weighted imaging of the pelvis using the torso phased array coil. Then, the coil is moved to the abdomen for imaging the liver, including examination with dynamic gadolinium-enhanced technique. Finally, the coil is repositioned inferiorly to obtain post-contrast imaging of the pelvis. In post-operative patients who cannot tolerate a long examination, thicker image slices can be used for the pre-contrast portion of the pelvic examination. This examination should require ≤1 hr.

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. Table A20.2.1 lists the hardware necessary to perform the procedure, along with appropriate parameters.

Table A20.2.1 Equipment Specifications Needed to Perform the Imaging Sequences

Coil type	Torso phased array coil
Manufacturer and system type	GE Signa
Field strength	1.5 T
Gradient strength	25 mT/m (or whatever the system permits)
Knee cushion	Yes
Pulse oximeter	If patient requires sedation
Power injector	Yes, if available
35-in. extension tubing	Yes
Use of contrast agents	Yes

Contributed by Donald G. Mitchell, Peter Natale, and George Holland
Current Protocols in Magnetic Resonance Imaging (2002) A20.2.1-A20.2.18

Materials

Normal saline (0.9% NaCl), sterile, 100 ml minimum
Extravascular contrast agent (e.g., Magnevist, Omniscan, or Prohance), 20 ml for most patients
1 mg glucagon for intramuscular injection

22-G angiocatheter
Extension tubing (110-in.)
Power injector

Set up patient and equipment

1. Interview the patient to assess for contraindications such as a cardiac pacemaker, implanted mechanical devices, and/or ferromagnetic materials. Also, determine if the patient will need sedation medication necessitating the need for appropriate monitoring equipment.

   Generally, standard screening forms are used for all patients scanned in a magnetic resonance system (see APPENDIX 1).

   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. See Shellock and Kanal (1996) for discussion of what implants may be scanned safely using magnetic resonance.

   In patients with prior surgery, metallic clips may produce artifacts that are especially deleterious for fat-suppressed techniques. If metallic clips are present, the shortest possible T_Es should be used, and unenhanced fat-suppressed images should be examined carefully for areas with poor fat suppression, especially when accompanied by water suppression. In areas such as these, a non-fat-suppressed technique should be used for the post-contrast images.

2. If the procedure is a research protocol, have the patient sign any necessary consent forms.

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

4. Have the patient wash off any mascara and other makeup to avoid local tissue heating and image artifacts.

5. 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.

6. Obtain intravenous (i.v.) access utilizing a 22-G angiocatheter and attach to a saline-filled extension tubing (110-in.), with saline set to slow infusion by gravity drip or power injector to keep the line open. Secure position of angiocatheter with sterile clear, occlusive dressing.

   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 needle gauge/angiocatheter to be used; this will depend on chosen injection/flow rates.

If a power injector is not accessible, dynamic imaging is still obtainable. In this case, draw-up the contrast agent in one, 20-ml syringe and saline in two others, and flush the timing and examination boluses. Alternatively, larger syringes can be used, drawing 20 ml of contrast agent into one and 40 ml of saline into the other. To eliminate the need for attaching and detaching syringes when switching from contrast to flush, incorporate the use of a 3-way stopcock or Y-tubing.

7. 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. While there is no need to double dose for hepatic MRI, a higher dose is useful for improving the conspicuity of enhanced tissue throughout the abdomen and pelvis. The dose should be between 20 ml and 40 ml, but we are not aware of any comparative study for this application to determine the improvement of using >20 ml.

8. Escort the patient to the MR examination room and ask her 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 her that she 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 she needs assistance during the exam).
   c. Explain to the patient that you will be talking to her 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 that she remain motionless during the imaging to ensure good results; also explain that she should not reposition her body between imaging sequences.
   e. Nevertheless, the patient may call out at any time if she feels it necessary.
   f. Provide the patient with an approximate time that the examination will take.
   g. Attach the power injector to the i.v., and set it to keep the vein open.
   h. Inject 1 mg glucagon intramuscularly.

9. Secure the torso phased array coil to the patient, centering approximately four fingers below the iliac crest in most patients.

   While the pelvic phased array coil, if available, provides a slightly better signal-to-noise ratio (SNR) of the pelvis than does the torso coil, the latter should be used since it can be used for both the pelvic and abdominal portions.

   Usually, straps are provided by the manufacturer that are directly attached to the coil. A foam pad can be placed between the patient's abdomen and the coil to reduce near-field artifacts.

10. Place a support under the patient's knees to enhance patient comfort.

11. Insert nasal canula for oxygen and set the flow rate to 2 liter/min, if available, to aid in suspended respiration. A total of 2 liter of oxygen should be administered.

    Hyperventilation before breath-holding is helpful. The administration of oxygen is most helpful during the examination.

12. Use the laser light to center the patient, at about three fingers below the iliac crests. Advance the patient table to isocenter.

    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.

13. Program the power injector for a contrast agent and saline injection rate of 2 ml/sec. Program the volume of saline following contrast agent injection for 20 ml. The scan delay in healthy young patients averages 18 sec (when contrast agent is injected, initiate scan 18 sec after contrast agent and saline are delivered), but this is highly variable in the elderly or those with cardiovascular disease.

    As indicated in the authors' unit on liver MRI (UNIT A15.2), they strongly recommend determination of the optimum delay in each patient. This can be done either with the automated bolus detection (SMARTPREP) feature, or by use of a 2-ml timing bolus sequence, as per Earls et al. (1997) and described later in this unit. Both of these methods can be adapted to either hand or power injection.

14. Arm the power injector and keep the vein open. Do not inject the contrast agent.

Sequence 1: Coronal single-shot fast-spin echo (SSFSE)

Although some technologists precede this with a three-plane orthogonal scout sequence, the authors find that this can be omitted safely by most experienced technologists. The coronal single shot fast-spin echo (FSE) sequence of the pelvis is nearly always of high quality and high information content (Fig. A20.2.1). These can be acquired using a 320 mm to 360 mm square field of view (FOV) and 5-mm image slices. The image should be centered at or slightly below the iliac crests.

The average patient's pelvis or abdomen can be covered in two breath-holdings, while larger patients may require three. Adjust the number of acquisitions before pause to limit times of suspended respiration to 20 to 25 sec. For example, if 28 slices are needed, this can be accomplished by acquiring two sets of 14 images, with suspended respirations of ~20 sec each. The pause between image sets should be ~10 sec, to allow the patient to rest between suspended respirations.

15. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Run the sequence according to the parameters listed in Table A20.2.2. Let the patient breathe for 10 sec, ask patient to hold her breath, and finish running this sequence.

    If a torso phased array coil is used, the kidneys are outside its optimal range. The pelvis should be included at the bottom of the image, while at least the lower portion of the kidneys is included at the top part of the image. Even though the kidneys are outside the optimal range of the torso phased array coil, the images will be sufficient to verify their presence and positions, and to detect or exclude urinary obstruction. If benign disease is diagnosed on the pelvic examination, scanning of the abdomen may not be necessary.

16. Confirm positioning of the torso phased array coil by making certain that all parts of the pelvis are included within the sensitive volume of the coil. Reposition and repeat the sequence, if necessary.

Sequence 2: Transverse T_2-weighted FSE for pelvis

17. Using the coronal images, position slices to ensure that the entire pelvis is covered on transverse images, from bottom of symphysis pubis to iliac crests (Fig. A20.2.2). Run the sequence according to the parameters listed in Table A20.2.3.

    The patient should be instructed to breath quietly, with minimal body movement.

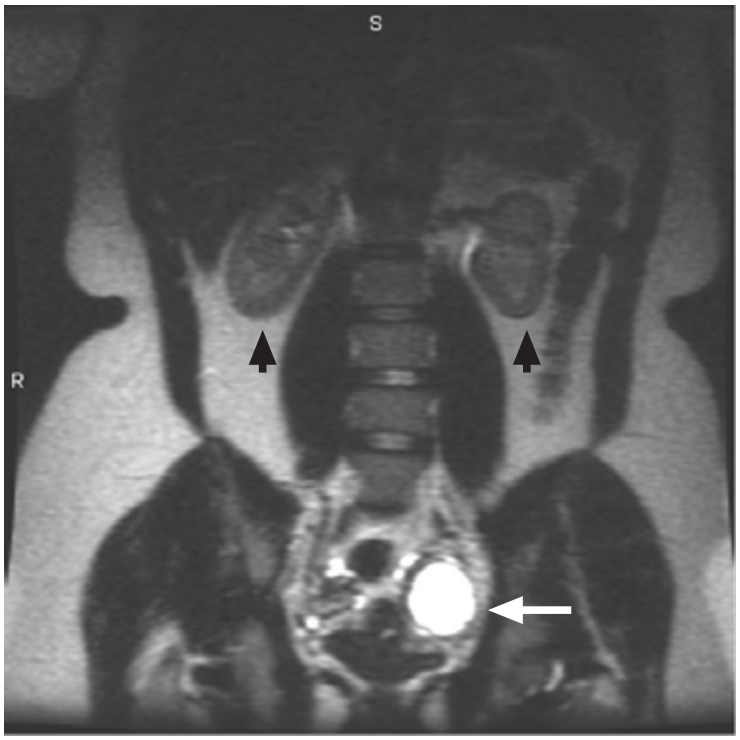

Figure A20.2.1 Coronal T_2-weighted single-shot FSE sequence used as a localizer, with field of view of 36 cm. White arrow indicates a cystic mass in the left adnexa. Black arrows indicate the lower poles of the kidneys; although they are out of ideal range of the torso phased array coil, image quality is sufficient to verify their locations and lack of collecting system dilatation.

Table A20.2.2 Imaging Parameters for Sequence 1 (Single-Shot Fast-Spin Echo)

Patient position	Supine
Scan type	Single-shot fast-spin echo
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Pulse sequence database (PSD)	ssfse
Central slice or volume center	Center 3 fingers below iliac crests
Echo time (T_E)	100 msec (effective)
Receiver bandwidth (RBW)	±31 kHz
Repeat time (T_R)	Infinite
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	360 mm, 360 mm
Resolution (Δx, Δy)	1.41 mm, 2.77 mm
Number of data points collected (N_x, N_y)	256, ~130
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	14 for one set (28 in total)[a]
Slice gap	0
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice locations	A40–P40 to cover the entire pelvis
Saturation pulses	None
Scan time	20 sec for one set (40 sec total)[a]

[a]See text under sequence 1.

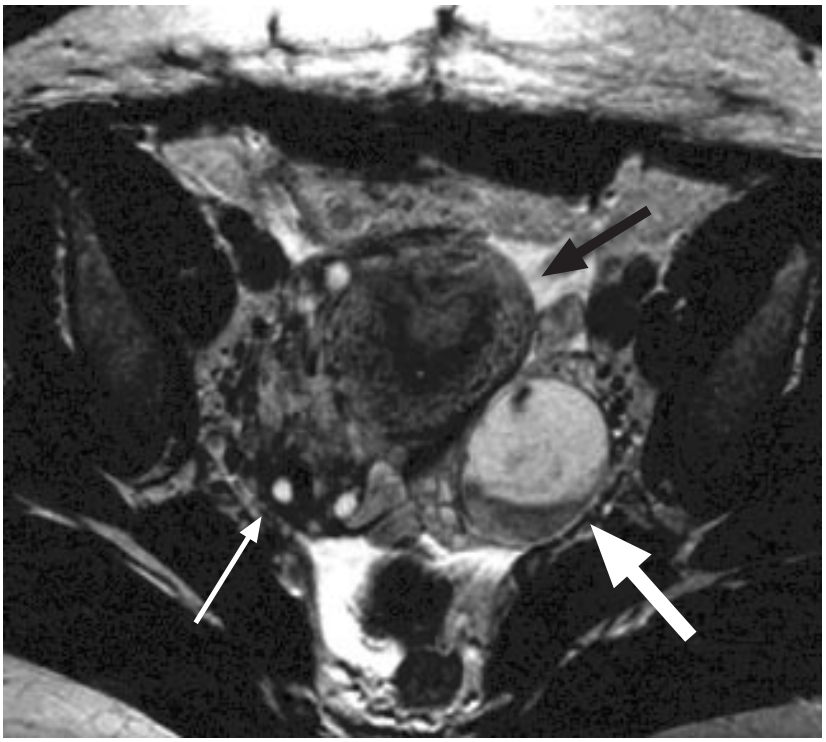

Figure A20.2.2 Transverse T_2-weighted FSE image. Large white arrow indicates left adnexal cystic mass, which has dependent low signal. Thin white arrow indicates the right ovary, black arrow indicates the uterus. There is a small amount of free pelvic fluid.

Table A20.2.3 Imaging Parameters for Sequence 2 (Fast-Spin Echo)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	fse
Central slice or volume center	Center to pelvis
Echo time (T_E)	100 msec (effective)
Receiver bandwidth (RBW)	±31 kHz
Echo train length (ETL)	12
Repeat time (T_R)	4000 msec
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	200 mm, 200 mm
Resolution (Δx, Δy)	0.78 mm, 0.78 mm
Number of data points collected (N_x, N_y)	256, 256
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	4 mm
Number of slices	32
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	Yes
Read direction	Anterior–posterior
Slice location	Pelvis
Saturation pulses	Superior, inferior
Scan time	4 min

Sequence 3: T_1-weighted transverse spin echo

18. Obtain images as for sequence 3 according to the parameters listed in Table A20.2.4 (Fig. A20.2.3).

    The patient should be instructed to breathe quietly, with minimal body movement.

19. Pull the patient out of the magnet. Reposition the torso phased array coil for imaging the upper abdomen, centering it three fingers below the xyphoid (or switch to abdominal portion of abdominal/pelvic coil). Send the patient into the magnet.

    If abdomen is to be included, which is necessary for staging ovarian cancer, proceed to sequence 4. If a full abdominal exam is not needed, as for a patient with a benign adnexal mass, skip to sequence 11.

Sequence 4: Coronal single-shot FSE of abdomen

20. Run sequence 4 using a 360-mm square FOV and 5-mm slice thickness, according to the parameters listed in Table A20.2.5.

    Adjust the number of slices before running the sequence to limit times of suspended respiration to 20 to 25 sec. For example, if 28 slices are needed, this can be accomplished by acquiring two sets of 14 images, with suspended respirations of ~20 sec each. The pause between image sets should be ~10 sec, to allow the patient to rest between suspended respirations.

21. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Begin acquisition. Let the patient breathe for 10 sec, ask the patient to hold her breath, and finish running the sequence.

22. Confirm positioning of the torso phased array coil by making certain that all parts of the liver are included within the sensitive volume of the coil. Reposition and repeat the sequence, if necessary.

Table A20.2.4 Imaging Parameters for Sequence 3 (T_1-Weighted Spin Echo)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	No
Pulse sequence database (PSD)	se
Central slice or volume center	Center to pelvis
Echo time (T_E)	8 msec
Receiver bandwidth (RBW)	±16 kHz
Repeat time (T_R)	500 msec
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	200 mm, 200 mm
Resolution (Δx, Δy)	0.78 mm, 1.04 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	32
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	Yes
Read direction	Anterior–posterior
Slice location	Pelvis
Saturation pulses	Superior, inferior
Fat suppression	No
Scan time	4 min

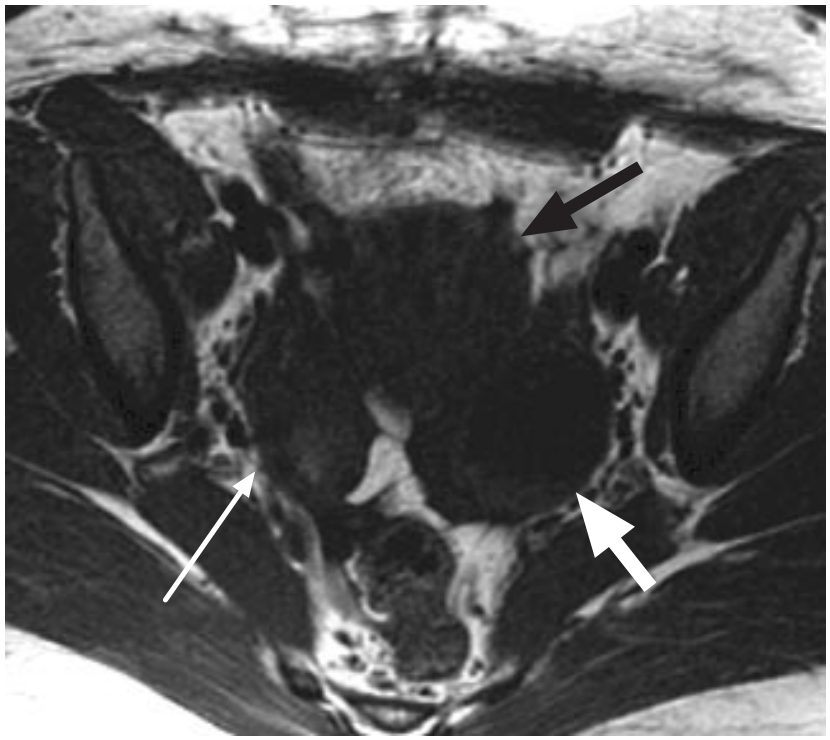

Figure A20.2.3 Transverse T_1-weighted spin echo image at the same level as the image in Figure A20.2.2.

Table A20.2.5 Imaging Parameters for Sequence 4 (Single-Shot Fast-Spin Echo)

Patient position	Supine
Scan type	Single-shot fast-spin echo
Imaging plane (orientation)	Coronal
Variable bandwidth	Yes
Pulse sequence database (PSD)	ssfse
Central slice or volume center	Center to xyphoid
Echo time (T_E)	100 msec (effective)
Receiver bandwidth (RBW)	±31 kHz
Repeat time (T_R)	Infinite
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	360 mm, 360 mm
Resolution (Δx, Δy)	1.41 mm, 1.88 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	14 for one set (28 in total)[a]
Slice gap	0
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice locations	Abdomen
Saturation pulses	None
Scan time	20 sec for one set (40 sec total)[a]

[a]See annotation under step 20.

Table A20.2.6 Imaging Parameters for Sequence 5 (Single-Shot Fast-Spin Echo)

Patient position	Supine
Scan type	Single-shot fast-spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	ssfse
Central slice or volume center	Center to liver
Echo time (T_E)	180 msec (effective)
Receiver bandwidth (RBW)	±31 kHz
Repeat time (T_R)	Infinite
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 2.00 mm
Number of data points collected (N_x, N_y)	256, ~120
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	0
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice location	Abdomen
Saturation pulses	None
Scan time	24 sec

For examples of abdominal imaging using sequences 4 through 9, please refer to UNIT A15.2, for liver imaging.

Sequence 5: Heavily T_2-weighted (T_E = 180 msec) transverse single-shot FSE

23. Using the coronal images, position slices to ensure that the entire liver is covered on transverse images. Run sequence 5 according to the parameters listed in Table A20.2.6, during one or two suspended respirations to cover the entire abdomen.

Sequence 6: Moderately T_2-weighted FSE with fat suppression

24. Prescribe the volume to cover the liver. Usually, this will require two separate, overlapping breath-holdings. Do not obtain these as interleaved images. "Pause before scan" must be set as "None". Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Run the sequence according to the parameters listed in Table A20.2.7 with 13 slices. Allow the patient to breathe for 10 sec. Instruct the patient to hold her breath and run the sequence with the remaining 13 slices.

25. Evaluate for image quality. This is the first motion-sensitive scan in the abdomen, and will therefore be the first to be degraded if breath holding is not successful.

If there is substantial motion artifact, remind the patient about the importance of breath holding, and repeat the acquisition. Consider reducing coverage or matrix, or increasing image thickness, to reduce acquisition time if necessary.

Sequence 7: In-phase and out-of-phase transverse gradient echo

If possible, these should be obtained as a dual-echo sequence, with T_Es of ~2.3 and 4.6 msec. If this is not available, separating in-phase and opposed-phase acquisitions will be necessary. Although the T_Es mentioned are ideal, software may be configured to yield slightly different T_Es, with acceptable results.

Table A20.2.7 Imaging Parameters for Sequence 6 (Fast-Spin Echo)

Patient position	Supine
Scan type	Fast-spin echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	frfse-opt
Central slice or volume center	Center to liver
Echo time (T_E)	80 msec (effective)
Receiver bandwidth (RBW)	±62 kHz
Echo train length (ETL)	19
Repeat time (T_R)	2850 msec
Flip angle (FA)	Default (90°)
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 1.67 mm
Number of data points collected (N_x, N_y)	256, ~144
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	7 mm
Number of slices	26
Slice gap	0.5 mm
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice location	Cover the liver
Saturation pulses	Superior, inferior
Fat suppression	Yes
Scan time	46 sec

Table A20.2.8 Imaging Parameters for Sequence 7 (Gradient Echo)

Patient position	Supine
Scan type	2-D double-gradient echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	fgre-dual
Central slice or volume center	Center to liver
Echo time (T_E)	2.3 msec and 4.6 msec
Receiver bandwidth (RBW)	±62 kHz
Repeat time (T_R)	200 msec
Flip angle (FA)	90°
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 3.00 mm
Number of data points collected (N_x, N_y)	256, ~80
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	24
Slice gap	0
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice location	Cover the liver
Saturation pulses	Superior, inferior
Scan time	24 sec

26. Position slices to cover entire liver and adjust levels if necessary. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Run sequence 7 according to the parameters listed in Table A20.2.8.

Sequence 8: Timing bolus sequence (if SMARTPREP is not used)

If SMARTPREP is used, skip steps 27 and 28; a timing bolus sequence is not needed.

27. Inject 2 ml of gadolinium chelate of 2 ml/sec, followed immediately by a 20-ml flush of saline (Earls et al., 1997).

    The size of the syringe used should be the same as that used for injecting the bolus of gadolinium chelate, and the speed of injection should be as identical as possible.

28. Begin image acquisition at the beginning of the flush, according to the parameters listed in Table A20.2.9. Breath-holding is not necessary.

    The aorta will have low signal intensity on all of these images, until the 2-ml bolus of gadolinium arrives, at which point there will be a noticeable increase in aortic signal intensity. The time after the beginning of the acquisition is annotated in the upper left hand corner of the image as the delay time (DT), and can also be determined by noting the image number and multiplying by 1 sec.

    If the acquisition of the sequence begins when the flush begins, when signal intensity peaks in the mid aorta, the delay time is the time it takes an injection of the contrast agent to travel from the i.v. tubing port to the abdominal aorta. This should correspond to the delay time between beginning the major gadolinium bolus and beginning the acquisition. For example, if it takes 25 sec for the gadolinium to travel from the i.v. tubing port to the mid-abdominal aorta, breathholding instructions should be given so that the actual pulse sequence begins 25 sec following the beginning of the gadolinium injection.

29. Set up SMARTPREP region of interest, if SMARTPREP is used. This should cover the upper abdominal aorta on the coronal scout image obtained from sequence 1, at the level of the upper poles of the kidneys. It should be 50 mm long by 20 mm wide. The trigger should be set for a 20% increase in intensity, with a 7-sec delay to allow breathholding instructions.

Sequence 9: Dynamic multi-phasic pre/post 3-D short T_R gradient echo (liver)

30. Prescribe the volume to cover the liver. T_R and T_E should be as short as possible, and flip angle should be 12° to 15°. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Run the sequence according to the parameters listed in Table A20.2.10 but with a certain number of slices such that the scan time is ~20 sec. Allow the patient to breathe and move the region of interest to the next slab. Instruct the patient to hold her breath again and continue to run the sequence. Repeat this procedure until the entire region of interest is covered.

    There will be visible contrast in the kidneys and collecting systems if a timing bolus was used, but there will be no significant effect on any other tissues.

31. Explain to the patient that the contrast agent will be injected and that she may feel a cool sensation in her arm. Initiate the injection. Do not begin scanning until the scan delay has expired. However, breathing instructions should be initiated when ~5 sec of delay remain.

    If access to a power injector is not available and are manual injecting, reattach the saline-filled syringe and flush with 20 ml of saline. 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.

Table A20.2.9 Imaging Parameters for Sequence 8 (Timing Bolus)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Sagittal
Variable bandwidth	No
Pulse sequence database (PSD)	fspgr
Central slice or volume center	Upper abdominal aorta
Echo time (T_E)	Minimum (~2 msec)
Receiver bandwidth (RBW)	±16 kHz
Repeat time (T_R)	7 msec
Flip angle (FA)	70°
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 2.50 mm
Number of data points collected (N_x, N_y)	256, 96
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	20 mm
Number of slices	1
Slice gap	N/A
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice location	Upper abdominal aorta
Saturation pulses	None
Multi-phase	60
Scan time	50 sec

Table A20.2.10 Imaging Parameters for Sequence 9 (Dynamic 3-D Gradient Echo)

Patient position	Supine
Scan type	3-D gradient echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	lufgre3d
Central slice or volume center	Center to liver
Echo time (T_E)	Minimum (~1.5 msec)
Receiver bandwidth (RBW)	±62 kHz
Repeat time (T_R)	4 msec
Flip angle (FA)	12°to 15°
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 3.00 mm
Number of data points collected (N_x, N_y)	256, ~80
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	192
Slice gap	−2.5 mm (overlap)
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice location	Cover the liver
ZIP2	Yes
Saturation pulses	None
Fat suppression	Yes, spectral inversion at lipids (SPECIAL)
Scan time	72 sec

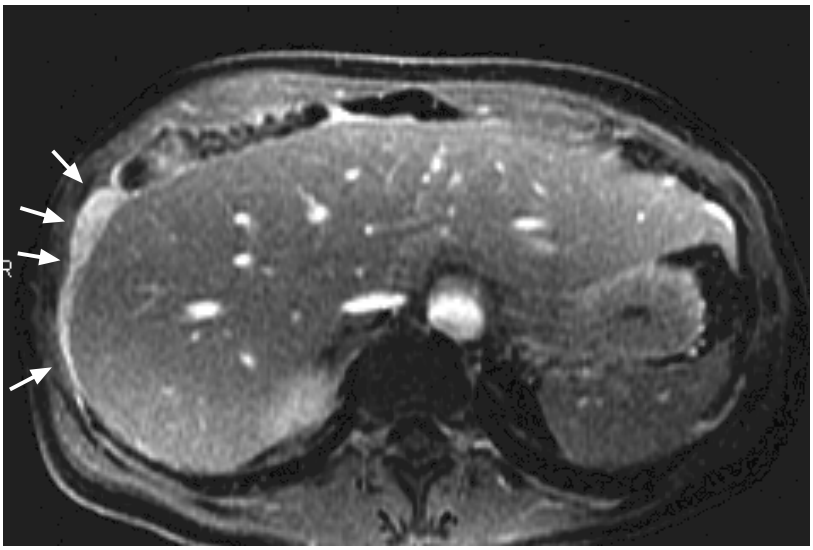

Figure A20.2.4 In a different patient, with history of ovarian cancer, 2-D fat-suppressed short T_R gradient echo images with T_R/T_E = 19/2 msec, and 30° flip angle, ~5 min after gadolinium chelate injection. Arrows indicate solid enhancing perihepatic tissue consistent with peritoneal metastases.

Table A20.2.11 Imaging Parameters for Sequence 10 (Fat-Suppressed Gradient Echo)

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Transverse
Variable bandwidth	No
Pulse sequence database (PSD)	fspgr
Central slice or volume center	Center to liver
Echo time (T_E)	Minimum (~2 msec)
Receiver bandwidth (RBW)	±16 kHz
Repeat time (T_R)	19 msec
Flip angle (FA)	30°
Fields of view (FOV_x, FOV_y)	320 mm, 240 mm
Resolution (Δx, Δy)	1.25 mm, 2.0 mm
Number of data points collected (N_x, N_y)	256, 120
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	~30
Slice gap	0
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice location	Entire liver
Fat suppression	Yes
Scan time	~60 sec

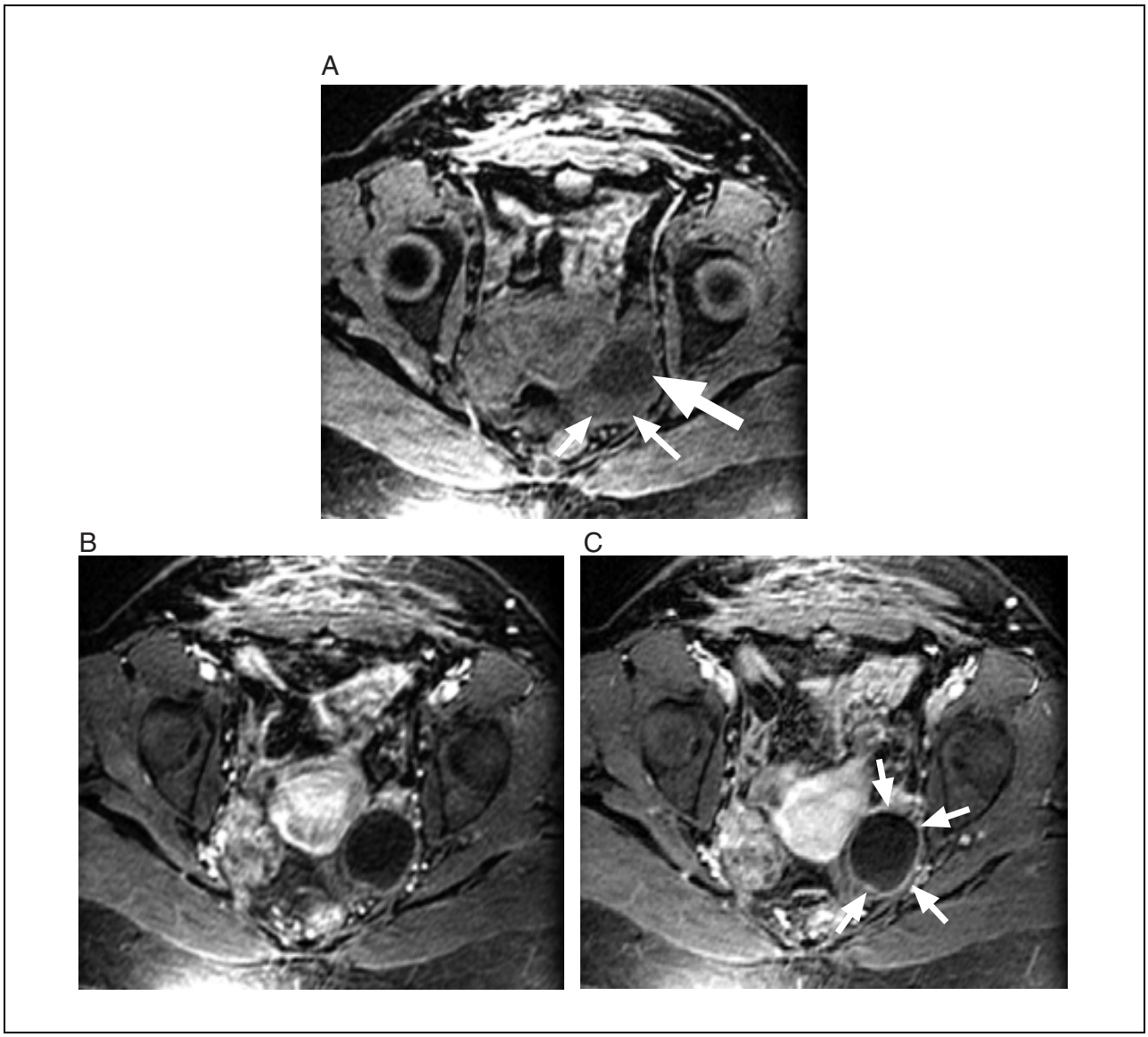

Figure A20.2.5 3-D fat-suppressed short T_R gradient echo images before (**A**), immediately after (**B**), and 45 sec after (**C**) gadolinium chelate injection. Through Fourier interpolation, images are reconstructed every 2.5 mm. Large arrow in **A** indicates the left adnexal cyst, small arrows indicate dependent increased signal intensity. Arrows in **C** indicate uniform thickness of the enhancing wall of the cyst, without solid or nodular enhancement to suggest tumor. Findings are most compatible with a benign hemorrhagic cyst.

32. Obtain the first set of post-contrast images as soon as possible according to Table A20.2.10. Repeat step 30. Allow the patient ~5 sec rest between the first and second post-contrast acquisitions. Repeat step 30 again and obtain a second set of post-contrast acquisitions. It is best to observe the patient's respirations on the screen to verify that she is suspending respirations successfully when directed.

Sequence 10: 2-D transverse gradient echo with fat suppression (Fig. A20.2.4)

33. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Run sequence 10 according to the parameters listed in Table A20.2.11 but with a certain number of slices such that the scan time is ~20 sec. Allow the patient to breathe and move the region of interest to the next slab. Instruct the patient to hold her breath again and continue to run the sequence. Repeat this procedure until the entire region of interest is covered.

Table A20.2.12 Imaging Parameters for Sequence 11 (Dynamic 3-D Gradient Echo)

Patient position	Supine
Scan type	3-D gradient echo
Imaging plane (orientation)	Transverse
Variable bandwidth	Yes
Pulse sequence database (PSD)	lufgre3d
Central slice or volume center	Center to pelvis
Echo time (T_E)	Minimum (~1.5 msec)
Receiver bandwidth (RBW)	±62 kHz
Repeat time (T_R)	4 msec
Flip angle (FA)	12°to 15°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 2.82 mm
Number of data points collected (N_x, N_y)	256, ~85
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	256
Slice gap	–2.5 mm
Number of acquisitions (N_{acq})	0.5 (half Fourier)
Swap read and phase encoding	No
Slice location	Pelvis
ZIP 2	Yes
Saturation pulses	None
Fat suppression	Yes, spectral inversion at lipids (SPECIAL)
Scan time	96 sec

T_R should be ~20 msec. These images show delayed extracellular space contrast, and all vessels are white because of the combined effects of gadolinium and time-of-flight. Motion artifact is minimal because the short T_R allows completion of each image in <2 sec. These should be obtained as several stacks of overlapping slices, to ensure that the fat suppression is adjusted properly for the volume of interest. The upper- and mid-abdomen should be imaged without significant gaps between image stacks.

Sequence 11: Dynamic 3-D short T_R gradient echo (pelvis)

If an abdominal examination is not included, such as if the pelvic images are not suggestive of ovarian cancer, the dynamic multi-phasic examination should be modified for imaging of the pelvis (Fig. A20.2.5).

34. Pull the patient out of the magnet. Reposition torso phased array coil for pelvis (or switch to pelvic portion of abdominal/pelvic coil). Center the patient and advance the patient into the magnet.

35. Repeat step 30 (with the coverage of pelvis) but run sequence 11 according to the parameters in Table A20.2.12. This involves the use of smaller field of view. If desired, slice thickness can be reduced. A timing bolus is generally not used for pelvic imaging. Obtain three sets of post-contrast images. The procedures are similar to those in steps 31 and 32.

Although dynamic scanning is less important for imaging the adnexa than for imaging the abdomen, vessels and some tissues may be defined better. Next, sequence 12 should be obtained.

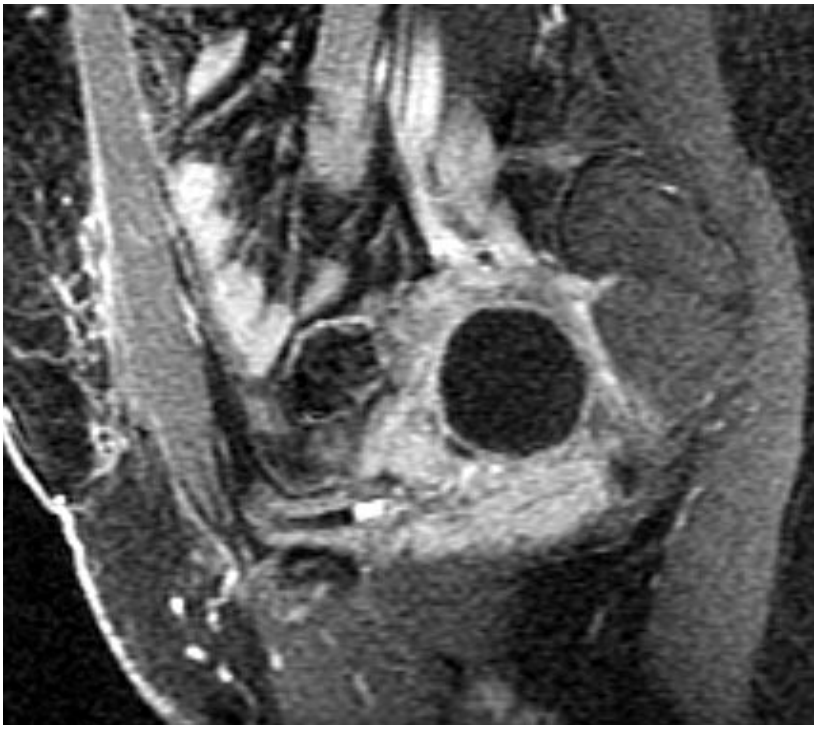

Figure A20.2.6 In the same patient as in Figures A20.2.1 to A20.2.4, 2-D sagittal fat suppressed short T_R gradient echo images with T_R and T_E = 19/2 msec, and 30° flip angle, about five minutes after gadolinium chelate injection. The cyst wall and surrounding tissues enhance, but there is no internal enhancement.

Table A20.2.13 Imaging Parameters for Sequence 12 (Fat-Suppressed Gradient Echo)

Patient position	Supine
Scan type	2-D gradient echo
Imaging plane (orientation)	Transverse or sagittal
Variable bandwidth	No
Pulse sequence database (PSD)	fspgr
Central slice or volume center	Center to pelvis
Echo time (T_E)	Minimal (~2 msec)
Receiver bandwidth (RBW)	±16 kHz
Repeat time (T_R)	19 msec
Flip angle (FA)	30°
Fields of view (FOV_x, FOV_y)	240 mm, 240 mm
Resolution (Δx, Δy)	0.94 mm, 1.88 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	~30
Slice gap	0
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice location	Pelvis
Fat suppression	Yes
Scan time	~60 sec

Sequence 12: 2-D transverse or sagittal gradient echo with fat suppression (Fig. A20.2.6)

36. Instruct the patient to remain motionless, and to take a deep breath in, blow it out, deep breath in, blow it out, and hold it. Cover the pelvis, and run sequence 12 according to the parameters in Table A20.2.13 but with a certain number of slices such that the scan time is ~20 sec. Allow the patient to breathe and move the region of interest to the next slab. Instruct the patient to hold her breath again and continue to run the sequence. Repeat this procedure until the entire region of interest is covered.

COMMENTARY

Background Information

A comprehensive protocol for imaging the abdomen and pelvis in women with ovarian cancer that includes in-phase and out-of-phase T_1-weighted images, moderately and heavily T_2-weighted, and early and late post-gadolinium images is described in this unit. Each abdominal sequence is acquired in one or two breath-holds, while un-enhanced T_1-weighted and T_2-weighted images are non-breath-hold and are used in the pelvis. It is possible that comparable or better image quality can be obtained using an entirely breath-hold protocol, but the authors have retained the longer sequences in the pelvis to ensure high spatial resolution and SNR. If the initial pelvic images and/or patient history are not strongly suggestive of ovarian cancer, staging is unnecessary, and the abdominal portion of the examination may be omitted, as described above.

The most important pulse sequence for diagnosing and staging ovarian carcinoma is the delayed fat-suppressed post-gadolinium sequence. In cooperative patients, thinner overlapping slices with higher SNR can be obtained by using the fast 3-D short T_R gradient echo sequence (efgre3d or lufgre3d in the GE machine). However, these images are more motion-sensitive, and do not depict blood vessels as well, compared to the single-slice 2-D sequences described here.

Critical Parameters and Troubleshooting

The two major potential problems with this protocol are that, for the abdominal portion, patients may not be able to suspend respiration or timing of gadolinium administration may be incorrect. The first problem can be addressed by substituting short T_R (≤10 msec) single-slice 2-D gradient echo T_1-weighted sequences with a flip angle of ~30°. The second problem is prevented in most cases by using a test dose of gadolinium to determine timing (Earls et al., 1997), or by using an automated detection method such as SMARTPREP. If abdominal images are not acquired, the timing of gadolinium injection is not critical; the delayed post-gadolinium images are most important.

Another problem occurs in patients with implanted metal, such as from surgical clips. Artifacts from metal on gradient echo images can be minimized by using the shortest possible T_E, avoiding fat suppression, and increasing the number of acquisitions (N_{acq}) or number of excitations (NEX) from 0.5 to 1.0. T_E on the 3-D-short T_R gradient echo sequence is minimized by increasing the sampling bandwidth from ±31 to ±62 KHz. The acquisition time will be slightly longer, so adjustments in number of image slices and/or acquisition matrix may be necessary.

Anticipated Results

Most reports comparing MRI and computed tomography (CT) indicate that MRI is superior for depicting normal and abnormal gynecologic anatomy, and for distinguishing between benign and malignant adnexal and hepatic masses. Importantly, proper use of gadolinium and fat suppression leads to a higher sensitivity of MRI for detecting small peritoneal implants from ovarian carcinoma.

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Comparison between MRI and CT

Shellock and Kanal, 1996. See above.

Discussion of safety issues

Yamashita, Y., Torashima, M., Hatanaka, Y., Harada, M., Higashida, Y., Takahashi, M., Mizutani, H., Tashiro, H., Iwamasa, J., Miyazaki, K., et al. 1995. Adnexal masses: Accuracy of characterization with transvaginal US and precontrast and postcontrast MR imaging. *Radiology* 194:557-565.

Comparison of MRI to ultrasound

Internet Resources

http://www.mri.tju.edu/

A non-commercial site that lists all body MRI protocols, continually updated, used by updated GE Signa scanners by the Thomas Jefferson University Department of Radiology. Additionally, there are descriptions and explanations of the various pulse sequences, tips for problems solving, examples of clinical applications.

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