Aortic Dissection

Aortic dissection can be diagnosed using magnetic resonance imaging (MRI), computed tomography (CT), or transesophageal echo (TEE) with similar sensitivity and specificity (Sommer et al., 1996). CT requires iodinated contrast agent but examination is quick; while TEE is the most invasive imaging modality. With MRI, it is difficult to monitor the patient closely and motion artifacts can be problematic in uncooperative patients. The patient should be screened as to which modality is best suited for the patient by the given clinical situation. MRI is most suitable as a problem solving tool in relatively stable patients or patients with contraindication to iodinated contrast agent.

The core components of the imaging protocol are ECG (electrocardiograph)-gated black blood HASTE (half Fourier single shot turbo spin echo), and contrast-enhanced MR angiography (MRA). When no abnormal findings are seen in black blood HASTE or cine sequences, it is somewhat controversial whether contrast-enhanced MRA is necessary. In this instance, a time of flight (TOF) sequence may be used instead of contrast-enhanced MRA (see Alternate Protocol). At the authors' institution, a contrast-enhanced MRA sequence is routinely performed in all patients with suspected aortic dissection. The authors use contrast-enhanced MRA to exclude other diagnosis such as penetrating atherosclerotic ulcer or vasculitis, which could explain symptoms such as chest pain or differences in blood pressure of upper extremities.

The ECG-gated cine gradient echo sequence provides a view of a single level in multiple phases of the cardiac cycle, which can be used to evaluate the aortic valve.

A typical MRI examination takes 30 to 45 min. In unstable patients or patients who require emergent surgery, the examination should be tailored to save time. In some instances, black blood HASTE sequences may be all that is needed when the extent of aortic dissection is well delineated. Alternatively, one could choose contrast-enhanced MR angiography to answer the question at hand.

The parameters are based on the authors' experience using a Siemens 1.5 T Vision or Symphony and should be altered accordingly for different field strengths and manufacturers.

IMAGING OF THORACIC AORTA TO RULE OUT AORTIC DISSECTION

BASIC PROTOCOL

Table A12.1.1 lists the hardware necessary to perform the procedure, along with appropriate parameters. The available gradient strength will depend on the scanner, and the echo times given below may need to be varied accordingly (the smaller the gradient strength, the longer the echo time for a particular scan). Higher gradient strengths with imaging sequences that allow gated turbo spin-echo and cine gradient echo imaging are preferable.

Table A12.1.1 Equipment Parameters for Aortic Dissection

Coil type	Torso phased array coil and body coil (see 3-D contrast-enhanced MRA)
Gradient coil strength	25 mT/m (or whatever the system permits)
Cardiac gating	Yes
Peripheral gating	No
Oxygen	Yes, 2 liters via nasal cannula for most patients (to ensure breath-holding >15 sec)
Power injector	Yes
Use of contrast agents	Yes

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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 a crash cart or oxygen.

Materials

Normal saline (0.9% NaCl), sterile
Gadolinium-based MR contrast agent (e.g., Magnevist, Omniscan, or Prohance)

Set up patient and equipment

1. Interview (screen) the patient to ensure that he or she has no contraindications such as cardiac pacemakers or defibrillators or other implants containing ferromagnetic materials. Also be sure to find out if the patient has any health conditions that may require the presence of special emergency equipment during the scanning procedure, or necessitate any other precautions.

   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 a discussion of what implants may be safely scanned using magnetic resonance.

   Patients may be accompanied into the magnet room by a friend or family member, who can sit in the room during the scan and comfort the patient as needed. This companion must be screened as well to ensure the absence of loose metal objects on the body or clothing.

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

3. Have the patient remove all jewelry and change into a gown to eliminate any metal that might be found in clothing.

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

5. Inform the patient about what will occur during the procedure, what he or she will experience while in the magnet, and how to behave, including the following:

   a. If earphones or headphones are used to protect the ears from the loud sounds produced by the gradients, the patient will be asked to wear these, but will be able to communicate with you at any time during the imaging.
   b. The patient will be given a safety squeeze-bulb or similar equipment to request assistance at any time (demonstrate how this works).
   c. For good results the patient should not talk, and should avoid or minimize other movement, during each scan—i.e., as long as the banging sounds continue. Between scans, talking is allowed in most cases, but should be avoided when comparative positional studies are being performed; the patient will be informed when this is the case.
   d. Nevertheless, the patient may call out at any time if he or she feels it necessary.
   e. The patient will be asked to hold his or her breath for ~15 to 25 sec for most of the sequences. Assess the need for supplementary oxygen to improve breath-holding capacity, and if necessary, administer 2 liters oxygen via nasal cannula. Advise the patient of the importance of not moving during the acquisition periods and of not taking deep breaths during the nonbreath-hold acquisitions.

6. Have the patient mount onto the table. Place ECG leads according to manufacturer's guidelines on the chest wall. Placing leads on the back may reduce motion artifacts related to breathing. Make sure that the ECG tracing shows positive *R*-waves.
7. Place the phased array coil on the chest.
8. If needed, place a pillow or other support under the knees to make the patient more comfortable.
9. Place a 22-G i.v. catheter in the antecubital fossa. Use of a power injector is necessary for administration of contrast agent.
10. Use the centering light to position the patient with the center at the patient's mid-chest and put him or her into the center of the magnet.
11. Once the patient has been centered in the magnet, check again to be sure that the ECG tracing demonstrates positive *R*-waves for suitable triggering. If not, then with the patient still positioned within the magnet, toggle the lead polarity until a suitable tracing is obtained.

    If the resulting trace is still not satisfactory, then bring the patient out of the magnet, check the lead connections, and if necessary, reposition the leads until a satisfactory tracing is obtained.
12. Load the injector with a double dose (0.2 mmol/kg) of gadolinium contrast agent.

    This is usually 40 ml or less. The concentration of gadolinium contrast agent is usually 0.5 M.

    Do not inject the contrast agent at this time.

Sequence 1: Rapid three-plane positioning scout

13. For localization of subsequent acquisitions, run the system's three-plane scout scan according to Table A12.1.2.

Table A12.1.2 Primary Clinical Imaging Parameters for Sequence 1 (Pilot Scan)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Three-plane: transverse, coronal, and sagittal
Central slice or volume center	Upper chest
Echo time (T_E)	3.1 msec
Repeat time (T_R)	6.5 msec
Flip angle (FA)	80°
Fields of view (FOV_x, FOV_y)	450 mm, 450 mm
Resolution (Δx, Δy)	1.76 mm, 2.34 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	7
Slice gap	Variable
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Slice locations	Variable
Saturation pulses	No
Scan time	8 sec

Sequence 2: 2-D transverse black blood half Fourier single shot turbo spin echo (black blood HASTE)

The black blood HASTE sequence utilizes a nonselective 180° presaturation pulse and a selective 180° pulse to reduce signal from blood flow. Vessels with flow appear as signal void. Obtain black blood HASTE images in transverse, coronal, and oblique sagittal planes. An oblique sagittal plane is prescribed along the plane of the aortic arch to cover the entire thoracic aorta.

14. Position a series of transverse slices off the scout image from the lung apices to below the diaphragm. Two or three sets are necessary to cover the entire thorax.

15. Run sequence 2 according to Table A12.1.3.

    This is a nonbreath-hold sequence.

Sequence 3: 2-D coronal and sagittal black blood half Fourier single shot turbo spin echo (black blood HASTE)

16. Position a series of coronal slices off the transverse images to ensure coverage of the entire thoracic aorta and run sequence 3 according to Table A12.1.4.

17. Position a series of oblique sagittal slices off the transverse images along the orientation of the aortic arch and run sequence 3 according to Table A12.1.4.

    This is a nonbreath-hold sequence.

Sequence 4: 2-D breath-hold cine gradient echo

Gradient-echo cine images are obtained to assess the aortic valve and hemodynamics of aortic dissection. Multiple phases of the heart cycle are imaged at a single slice position.

Table A12.1.3 Primary Clinical Imaging Parameters for Sequence 2 (Transverse Black Blood HASTE)

Patient position	Supine
Scan type	Single shot fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of heart
Echo time (T_E)	43 msec
Repeat time (T_R)	Infinity
Delay time (T_D)	180 msec[a]
Flip angle (FA)	180°[b]
Fields of view (FOV_x, FOV_y)	350 mm, 350 mm
Resolution (Δx, Δy)	1.37 mm, 2.19 mm
Number of data points collected (N_x, N_y)	256, 160
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	5 mm
Number of slices	20[c]
Slice gap	0
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	Yes
Scan time	>47 sec

[a]The true trigger delay time is one R-to-R interval.

[b]The system displays the flip angle of the refocusing pulse.

[c]Two to three sets of 20 slices are generally necessary to cover the entire chest.

Table A12.1.4 Primary Clinical Imaging Parameters for Sequence 3 (Coronal and Sagittal Black Blood HASTE)

Patient position	Supine
Scan type	Single shot fast spin echo
Imaging plane (orientation)	Coronal or oblique sagittal (see Basic Protocol, step 17)
Central slice or volume center	Center of heart
Echo time (T_E)	43 msec
Repeat time (T_R)	Infinity
Delay time (T_D)	180 msec[a]
Flip angle (FA)	180°[b]
Fields of view (FOV_x, FOV_y)	450 mm, 450 mm
Resolution (Δx, Δy)	1.76 mm, 2.81 mm
Number of data points collected (N_x, N_y)	256, 160
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	6 mm
Number of slices	20
Slice gap	1 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	Yes
Scan time	>47 sec

[a]The true trigger delay time is one R-to-R interval.
[b]The system displays the flip angle of the refocusing pulse.

18. Choose the optimal line per segment acquisition and adjust the number of cardiac phases.

    The parameters may be adjusted depending on the patient's breath-holding capability and heart rate. Two parameters should be modified. One is the number of phase encoding lines (N_y) collected for each excitation, which determines the minimal number of heart beats required to obtain the single-level cine image. With 128 phase encoding steps, 15 heart beats are required for a 9-line per segment acquisition, 19 heart beats for a 7-line per segment acquisition, and 26 heart beats for a 5-line per segment acquisition. Choose the protocol with the optimal line per segment acquisition (in the Siemens' protocol, this is expressed by the number of heart beats required for imaging). Then adjust the number of cardiac phases. Number of cardiac phases times T_R should be ≥100 msec shorter than minimal R-to-R interval. Finally, the number of phase encoding steps can be modified, but this may change the number of heart beats required to obtain the image.

19. Position a single transverse slice at the level just above the aortic valve.

20. Instruct the patient to hold their breath and run the sequence according to Table A12.1.5.

    If the patient cannot hold their breath for this sequence, use sequence 5 as an alternative.

21. Position a single oblique coronal slice along the aortic root, so that the aortic valve can be evaluated in profile and repeat step 20.

Sequence 5: 2-D nonbreath-hold cine gradient echo (alternative for sequence 4)

This is a nonbreath-hold gradient-echo cine sequence. When the patient is unable to hold their breath for the breath-hold cine sequence, use this sequence to assess the aortic valve.

Table A12.1.5 Primary Clinical Imaging Parameters for Sequence 4 (Cine Gradient Echo)

Patient position	Supine
Scan type	Segmented *k*-space cine gradient echo
Imaging plane (orientation)	Transverse or oblique coronal (see Basic Protocol, step 21)
Central slice or volume center	Center of heart
Echo time (T_E)	6.1 msec
Number of lines per segment	5, 7, or 9[a]
Repeat time (T_R)	60-100 msec[b] (temporal resolution)
Delay time (T_D) after R wave	0 msec
Flip angle (FA)	25°
Fields of view (FOV_x, FOV_y)	300 mm, 300 mm
Resolution (Δx, Δy)	1.17 mm, 2.34 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8 mm
Number of slices	1
Slice gap	Not applicable
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	No
Number of cardiac phases	8-15[c]
ECG gating	Yes
Scan time	~10–20 sec

[a]Choose the number of lines per segment according to the patient's breath-hold capability.
[b]T_R is dependent on the number of lines per segment collected.
[c]Number of cardiac phases multiplied by T_R should be ≥ 100 msec shorter than the minimal R-to-R interval.

The limitation of this sequence is that the acquisition time is ≥2 min to obtain single level cine images.

22. Position a single oblique coronal slice along the aortic root, so that aortic valve can be evaluated in profile and run the sequence according to Table A12.1.6.

Sequence 6: 2-D transverse breath-hold single slice T_1-weighted turbo spin echo (optional)

T_1-weighted turbo spin echo (TSE) is a sensitive sequence to detect intramural hematoma. If there is thickening or irregularity of the aortic wall, obtain T_1-weighted turbo spin echo images through the area. Only one image can be obtained during one breath-hold, and multiple breath-holds are necessary to cover the area of interest. If the patient cannot hold their breath, use a nonbreath-hold T_1-weighted spin echo sequence (sequence 7) as an alternative. A breath-hold technique is the preferred sequence because of reduced motion artifact.

23. Position transverse slices through the selected area of aorta with wall thickening or irregularity, instruct the patient to hold their breath and run the sequence according to Table A12.1.7.

Table A12.1.6 Primary Clinical Imaging Parameters for Sequence 5 (Cine Gradient Echo)

Patient position	Supine
Scan type	Segmented *k*-space cine gradient echo
Imaging plane (orientation)	Oblique coronal (see Basic Protocol, step 22)
Central slice or volume center	Center of heart
Echo time (T_E)	7 msec
Number of lines per segment	7
Repeat time (T_R)	80 msec (temporal resolution)
Delay time (T_D) after R-wave	0 msec[a]
Flip angle (FA)	25°
Fields of view (FOV_x, FOV_y)	300 mm, 300 mm
Resolution (Δx, Δy)	1.17 mm, 2.34 mm
Number of data points collected (N_x, N_y)	256, 128
Display matrix (D_x, D_y)	256, 256
Slice thickness (Δz)	8 mm
Number of slices	1
Slice gap	Not applicable
Number of acquisitions (N_{acq})	3
Swap read and phase encoding	No
Saturation pulses	No
Number of cardiac phases	8–12[b]
ECG gating	Yes
Scan time	>2 min, 5 sec

[a]The true trigger delay time is one R-to-R interval.
[b]Number of cardiac phases multiplied by T_R should be ≥100 msec shorter than the minimal R-to-R interval.

Sequence 7: 2-D transverse nonbreath-hold T_1-weighted spin echo (alternative for sequence 6)

This is a nonbreath-hold T_1-weighted sequence, which can be used in patients with limited breath-hold capacity.

24. Position a series of transverse slices through the selected area of the aorta that has wall thickening or some irregularity, and run the sequence according to Table A12.1.8.

3-D contrast-enhanced MRA

When aortic dissection is evident in the images from any of the previous sequences, the body coil should be used for a contrast-enhanced MRA to cover the entire aorta from aortic arch to aortic bifurcation to delineate the extent of the dissection, site of entry, and origin of the great vessels in relation to each lumen. When the dissection is not evident from previous sequences, phased array coil is still used and only thoracic aorta is imaged.

25. If the entire aorta needs to be imaged, select the body coil from the scanner console. Check the scout image to see if there is enough caudad coverage. If not, recenter the patient over the xyphoid.

26. If the patient is repositioned, repeat the system's three-plane scout scan according to Table A12.1.2.

Table A12.1.7 Primary Clinical Imaging Parameters for Sequence 6 (Single Slice Breath-Hold T_1-Weighted TSE)

Patient position	Supine
Scan type	Fast spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of heart
Echo time (T_E)	30 msec
Echo train length (ETL)	13
Repeat time (T_R)	700 msec[a]
Delay time (T_D) after *R*-wave	150 msec
Flip angle (FA)	160°[b]
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)	5 mm
Number of slices	1
Slice gap	Not applicable
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	Yes
Scan time	>7 sec

[a] T_R should be 50 to 100 msec shorter than minimal R-to-R interval.
[b] The system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

Table A12.1.8 Primary Clinical Imaging Parameters for Sequence 7 (Nonbreath-Hold T_1-Weighted Spin Echo)

Patient position	Supine
Scan type	Spin echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of heart
Echo time (T_E)	30 msec
Repeat time (T_R)	540 msec[a]
Delay time (T_D) after *R*-wave	150 msec
Flip angle (FA)	160°[b]
Fields of view (FOV_x, FOV_y)	300 mm, 263 mm
Resolution (Δx, Δy)	1.17 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)	5 mm
Number of slices	10
Slice gap	1 mm
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	No
Saturation pulses	Superior and inferior
ECG gating	Yes
Scan time	>2 min, 21 sec

[a] T_R should be 50 to 100 msec less than minimal R-to-R interval.
[b] The system displays the flip angle of the refocusing pulse. The flip angle of the first pulse of this sequence is 90°.

Table A12.1.9 Primary Clinical Imaging Parameters for Sequence 8 (Test Bolus)

Patient position	Supine
Scan type	Gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Mid chest
Echo time (T_E)	2.4 msec
Repeat time (T_R)	5.8 msec
Inversion time (T_I)	300 msec
Delay time (T_D)	0 msec
Flip angle (FA)	10°
Fields of view (FOV_x, FOV_y)	400 mm, 300 mm
Resolution (Δx, Δy)	1.56 mm, 2.34 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	1
Slice gap	Not applicable
Number of acquisitions (N_{acq})	1
Number of repetitions	50
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	No
Scan time	52 sec

Sequence 8: Test bolus

Prior to a full injection of the contrast agent, a test bolus is performed to determine the contrast travel time from the peripheral vein to the thoracic aorta.

27. Position a single transverse slice at the level of the mid-thoracic aorta.
28. Set up the injector for a 2-ml gadolinium injection followed by 15 ml normal saline at the rate of 2 ml/sec.
29. As one is starting the injector, run sequence 8 according to Table A12.1.9. The system will then acquire a single slice every second for 50 sec at the same location.
30. By scrolling the images, determine the time to peak signal of the contrast bolus arrival from the start of contrast agent injection.

Sequence 9: 3-D precontrast MRA (mask)

The precontrast sequence is obtained as a mask for subtraction and to ensure the coverage of the aorta and to check the image quality.

31. Position the slab in a sagittal or oblique sagittal plane along the aortic arch. By using an oblique sagittal slab, the slab thickness (thus, number of slices/partitions) can be reduced to shorten the image time.
32. If the thoracic and abdominal aorta need to be imaged, change the coil configuration to body coil.
33. Instruct the patient to hold their breath and run sequence 9 according to Table A12.1.10.

Table A12.1.10 Primary Clinical Imaging Parameters for Sequence 9 (3-D MRA, Mask)

Patient position	Supine
Scan type	3-D gradient echo
Imaging plane (orientation)	Sagittal or oblique sagittal
Central slice or volume center	Mid-chest or xyphoid[a]
Echo time (T_E)	1.8 msec
Repeat time (T_R)	4.6 msec
Flip angle (FA)	30°
Fields of view (FOV_x, FOV_y)	390 mm, 390 mm or 480 mm, 480 mm[b]
Resolution (Δx, Δy)	1.52 mm, 2.29 mm or 0.94 mm, 2.82 mm
Number of data points collected (N_x, N_y)	256, 170 or 512, 170[c]
Display matrix (D_x, D_y)	256, 256 or 512, 512
Slice thickness (Δz)	3 mm (1.5 mm after interpolation)
Number of slices	40 (80 after interpolation)
Slice gap	0 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
ZIP[d] 2	Yes
Saturation pulses	No
ECG gating	No
Scan time	25 sec

[a]Center at mid-chest if phased array coil is used and at xyphoid if body coil is used.
[b]390 mm FOV for phased array coil and 480 mm FOV for body coil.
[c]256, 170 matrix for phased away coil and 512, 170 matrix for body coil.
[d]Zerofill interpolation process. This process produces twice the number of slices by interpolating the data. Also see *UNIT A7.4*.

34. Check the images to ensure the coverage of the entire aorta. Minimal wrapping artifact does not interfere with the diagnostic ability of the study. The degree of respiration artifact should be checked.

    If the patient cannot hold their breath long enough, consider shortening the scan time at the cost of spatial resolution.

Sequence 10: 3-D contrast-enhanced MRA

35. Set up the injector for a 38-ml gadolinium injection followed by 15 ml normal saline at the rate of 2 ml/sec.

    The amount of contrast agent is dependent on patient's body weight.

36. Scan delay from the start of injection can be calculated based on time to peak of contrast arrival determined by the test bolus injection, injection duration, and scan duration using the following formula:

    scan delay = (time to peak) + (injection duration)/2 − (scan duration)/2.

    The scan time is typically 25 sec and injection duration 19 sec (38 ml at 2 ml/sec). If the time to peak at test injection is 15 sec, the scan delay would be 12 sec (= 15 + 19/2 – 25/2).

37. Position the slab exactly the same as in sequence 9.

    The position should be copied from history so that subtraction can be performed later. Two measures (two repetitions) are performed in this sequence, and an ~8-sec interval should be allowed for the patient to breathe between the first and second measures.

Table A12.1.11 Primary Clinical Imaging Parameters for Sequence 10 (3-D Contrast-Enhanced MRA)

Patient position	Supine
Scan type	3-D gradient echo
Imaging plane (orientation)	Sagittal or oblique sagittal
Central slice or volume center	Mid-chest or xyphoid[a]
Echo time (T_E)	1.8 msec
Repeat time (T_R)	4.6 msec
Flip angle (FA)	30°
Fields of view (FOV_x, FOV_y)	390 mm, 390 mm or 480 mm, 480 mm[b]
Resolution (Δx, Δy)	1.52 mm, 2.29 mm or 0.94 mm, 2.82 mm
Number of data points collected (N_x, N_y)	256, 170 or 512, 170[c]
Display matrix (D_x, D_y)	256, 256 or 512, 512
Slice thickness (Δz)	3 mm (1.5 mm after interpolation)
Number of slices	40 (80 after interpolation)
Slice gap	0 mm
Number of acquisitions (N_{acq})	1
Number of repetitions	2, with 8-sec interval between these two measures
Swap read and phase encoding	No
ZIP 2	Yes
Saturation pulses	No
ECG gating	No
Scan time	25 sec (the total sum time including two measurements is 58 sec)

[a]Center at mid chest if phased array coil is used and at xyphoid if body coil is used.
[b]390 mm FOV for phased array coil and 480 mm FOV for body coil.
[c]256, 170 matrix for phased array coil and 512, 170 matrix for body array coil.

38. Change the coil configuration as described in step 32.
39. Start the injector and instruct the patient to hold their breath at the 5-sec mark before the calculated scan delay from step 36. When the scan delay is reached, start sequence 10 according to Table A12.1.11.

Data processing and viewing for sequences 9 and 10

40. Create a subtraction data set from the pre- and post-contrast MRA. Display these data sets using a maximal intensity projection (MIP). For multi-plannar reconstruction (MPR), use the nonsubtracted original data sets.

TIME OF FLIGHT (TOF)

ALTERNATE PROTOCOL

When no abnormal findings are seen in black blood HASTE or cine sequences, it is somewhat controversial whether contrast-enhanced MRA is necessary. In this instance, a time of flight (TOF) sequence may be used instead of a contrast-enhanced MRA.

Set up patient and equipment

1. Use the same equipment and the same patient setup as for the previous method except for venous access or contrast agent (see Basic Protocol, steps 1 to 11, excluding step 9). No venous access or contrast agent is necessary.
2. Run sequences 1 to 7 as in Basic Protocol, steps 13 to 24.

Sequence 11: 2-D transverse breath-hold gradient echo time of flight (TOF)
This is a breath-hold bright blood TOF sequence. Vessels with flowing blood appear bright because of the time-of-flight effect.

3. Position transverse slices from lung apex to diaphragm. Instruct the patient to hold their breath and run sequence 11 according to Table A12.1.12.

   Only 1 to 3 slices can be obtained in a single breath-hold.

   Multiple breath-holds are required to cover the entire aorta.

Sequence 12: 2-D transverse nonbreath-hold gradient echo time of flight (TOF) (alternative for sequence 11)
This is a nonbreath-hold TOF sequence as an alternative for sequence 11 for patients who cannot hold their breath.

4. Position a series of transverse slices from the lung apex to diaphragm and run sequence 12 according to Table A12.1.13.

Sequence 13: 2-D transverse breath-hold cine gradient echo (same as Basic Protocol, sequence 4)
Cardiac pulsation artifact may be severe with the TOF technique (sequence 12) in some slices near the heart. In those instances, use the cine gradient echo sequence to clear the cardiac pulsation artifact.

5. Repeat Basic Protocol, step 18 and position a single transverse slice over the area of interest where pulsation artifact was severe by the TOF technique (sequence 12).
6. Instruct the patient to hold their breath and run sequence 13 according to Table A12.1.5.

Table A12.1.12 Primary Clinical Imaging Parameters for Sequence 11 (Transverse Gradient Echo TOF)

Patient position	Supine
Scan type	Segmented *k*-space gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of heart
Echo time (T_E)	10 msec
Number of lines per segment	13
Repeat time (T_R)	333 msec (temporal resolution)
Delay time (T_D) after R-wave	200 msec
Flip angle (FA)	50°
Fields of view (FOV_x, FOV_y)	300 mm, 263 mm
Resolution (Δx, Δy)	1.17 mm, 2.02 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	1–3
Slice gap	0 mm
Number of acquisitions (N_{acq})	1
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	Yes
Scan time	~6–18 sec

Table A12.1.13 Primary Clinical Imaging Parameters for Sequence 12 (Transverse Gradient Echo TOF)

Patient position	Supine
Scan type	Segmented *k*-space gradient echo
Imaging plane (orientation)	Transverse
Central slice or volume center	Center of heart
Echo time (T_E)	10 msec
Number of lines per segment	13
Repeat time (T_R)	333 msec (temporal resolution)
Delay time (T_D) after *R*-wave	200 msec
Flip angle (FA)	50°
Fields of view (FOV_x, FOV_y)	300 mm, 263 mm
Resolution (Δx, Δy)	1.17 mm, 2.02 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	30
Slice gap	0
Number of acquisitions (N_{acq})	2
Swap read and phase encoding	No
Saturation pulses	No
ECG gating	Yes
Scan time	>5 min, 43 sec

COMMENTARY

Background Information

Aortic dissection is the most common acute emergency affecting the aorta. Untreated aortic dissection is often fatal, and immediate diagnosis is necessary.

Aortic dissection can be diagnosed using MRI, CT, or transesophageal echo (TEE) with similar accuracy. MRI is most suitable in relatively stable patients or patients with a contraindication to iodinated contrast agent.

The classification of aortic dissection is important in treatment decision making. Type A aortic dissections (dissections involving ascending aorta) usually require emergency surgery because of the risk of complication, including rupture into pericardial space and resultant tamponade, coronary artery occlusion, and aortic valvular regurgitation. Type B aortic dissections (dissection not involving ascending aorta) are usually treated medically.

Intramural hematoma and penetrating atherosclerotic ulcer are other conditions that affect the aorta and require immediate medical attention.

Critical Parameters and Troubleshooting

Customization of gated MR imaging parameters

MR imaging of the aorta requires optimization of imaging parameters according to a patient's heart rate and breath-hold capability. For a turbo spin echo sequence, the T_R should be shorter than the patient's minimal R-to-R interval (also see the discussion under the same subsection in *UNIT A11.1*).

For cine gradient echo images, multiple phases of the cardiac cycle are imaged at a single slice position. The parameters may be adjusted depending on the patient's breath-holding capability and heart rate. Two parameters should be modified. One is the number of phase encoding lines collected for each excitation, which determines the minimal number of heart beats required to obtain the single-level cine image. With 128 phase encoding steps, 15 heart beats are required for a 9-line per segment acquisition, 19 heart beats for a 7-line per segment acquisition, and 26 heart beats for a 5-line per segment acquisition. Choose the protocol

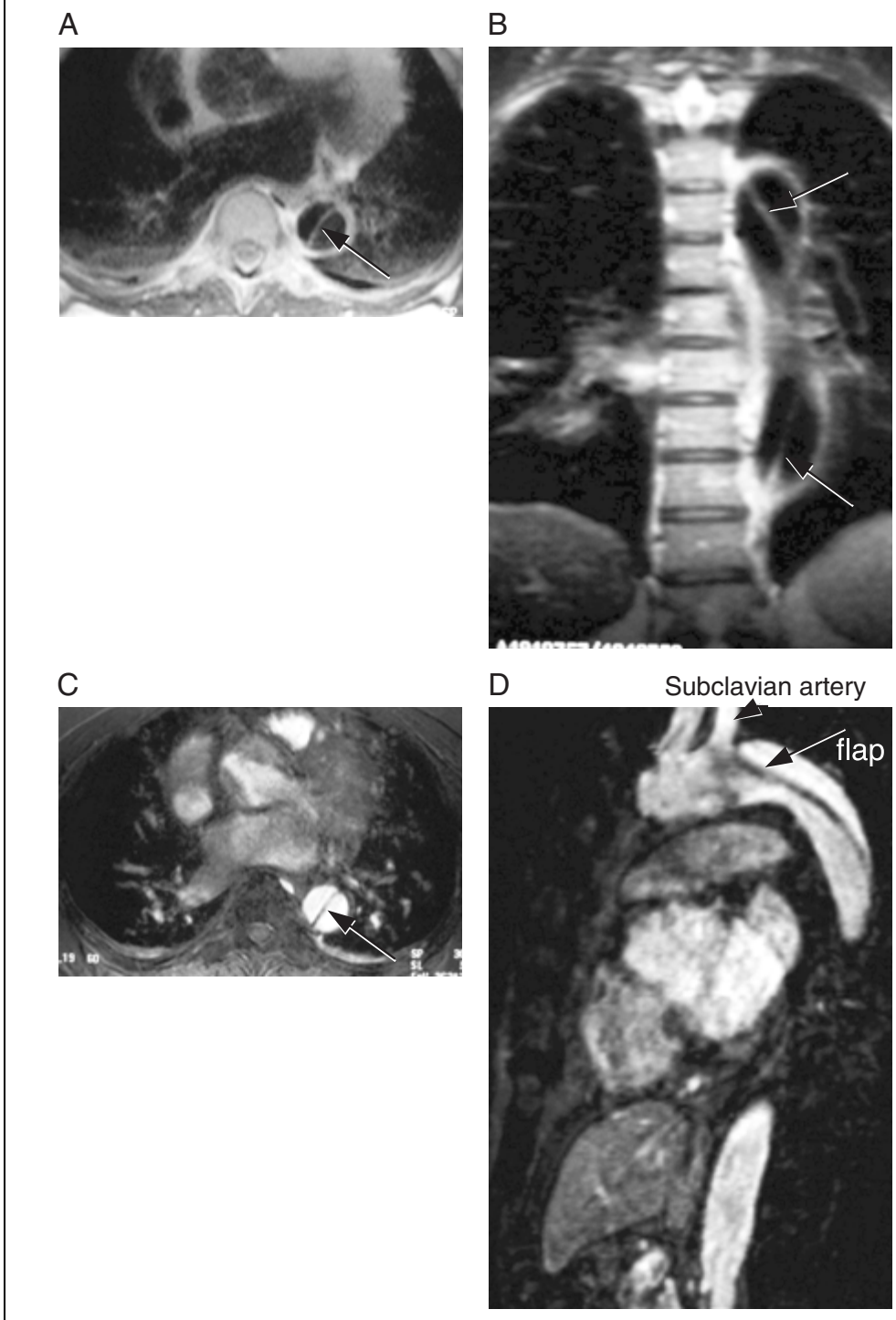

Figure A12.1.1 Aortic dissection. Transverse (**A**) and coronal (**B**) ECG-gated black blood images demonstrate an intimal flap (arrows) in the descending aorta. (**C**) Transverse ECG-gated TOF image demonstrates an intimal flap (arrow) in the descending aorta. (**D**) Multi-planar reconstruction image from the Gadolinium-enhanced MRA shows an intimal flap (arrow) in the descending aorta. The relation between the origin of left subclavian artery (arrowhead) and the flap is well depicted.

with optimal line per segment acquisition (using the Siemens' system, these protocols are expressed by the number of heart beats required for imaging). Then adjust the number of cardiac phases. The number of cardiac phases multiplied by T_R should be at least 100 to 150 msec shorter than the minimal R-to-R interval. Finally, the number of phase encoding steps can be modified, but this may change the number of heart beats required to obtain the image.

Breath-hold versus nonbreath-hold technique

Occasionally, despite a patient's effort to hold their breath, substantial motion artifacts are seen on MR images. These artifacts can also be seen when the patient is not able to hold their breath long enough to complete the sequence. In these instances, use nonbreath-hold sequences as an alternative. Breath-hold sequences usually give better images, and should initially be tried, if the patient can hold their breath long enough.

Customizing 3-D contrast-enhanced MRA for patients who are not able to hold their breath

Typically, an MRA sequence is ~25 sec long, but the patient may not be able to sustain their breath for the entire sequence. In this situation, shorten the scan time to 15 to 20 sec by reducing the FOV along the phase encoding directions or slab thickness and/or by reducing the phase encoding steps or number of partitions. If the patients can hold their breath for only ~10 sec, instruct the patient to hold their breath during the middle third of the scan, granted noncentric *k*-space filling is used. If the patient cannot hold their breath at all, have the patient breathe shallowly through the scan, and obtain the scan at a routine or high resolution setting.

Anticipated Results

Identification of an intimal flap in the aortic lumen is key to the diagnosis of aortic dissection. With the spin-echo technique, the intimal flap appears as an intermediate signal curvilinear structure in the background of low signal from blood (Fig. A12.1.1A and A12.1.1B; Simonetti et al., 1996; Krinsky et al., 1997). With a contrast-enhanced MRA or TOF technique, the intimal flap appears as an intermediate to low signal curvilinear structure in the background of high signal blood (Fig. A12.1.1C and A12.1.1D; Prince et al., 1996). When the false lumen is thrombosed, the intimal flap is not visible. However, the thrombosed lumen appears as a crescent area of high signal intensity on the spin echo technique, which is indistinguishable from intramural hematoma. Very slow flow in the lumen can mimic a thrombosed lumen on noncontrast techniques. In this instance, contrast-enhanced MRA is useful in differentiating thrombosed lumen versus slow flow.

One should be careful not to mistake pulsation or motion artifact for an intimal flap. These artifacts tend to extend outside the lumen of the aorta. This artifact occurs only in the phase encoding direction (*UNIT B7.3*), and usually, the source of artifact can be identified. On the 3-D

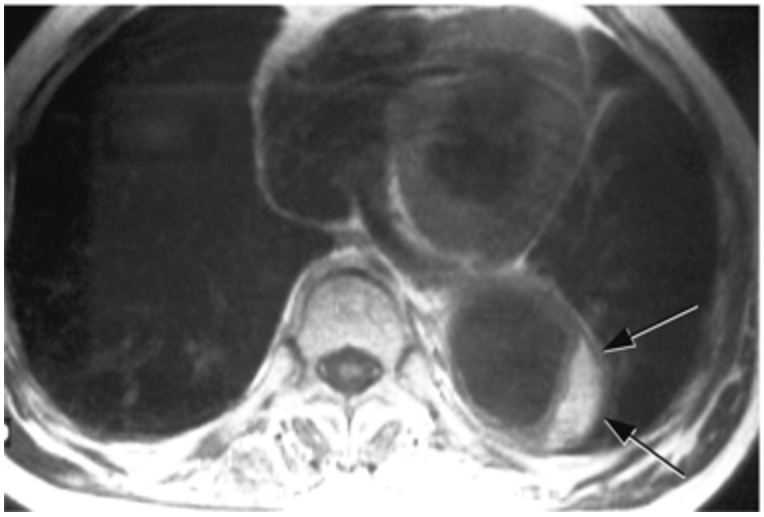

Figure A12.1.2 Intramural hematoma. Transverse breath-hold ECG-gated T_1-weighted turbo spin echo image shows a crescent area of hyperintensity (arrows) in the wall of the descending aorta.

contrast-enhanced MRA sequence, these artifacts could arise from out-of-plane structures such as the main pulmonary artery, since there is a second phase encoding gradient along the *z*-axis (slab direction). In instances where a linear structure is seen in the aortic lumen and one is not certain if this is a flap, use the cine sequence at the same level to differentiate it from an artifact.

The extent of aortic dissection should be carefully evaluated. Contrast-enhanced MRA is the best sequence for this purpose since it is a 3-D technique and has the highest spatial and contrast resolution in the shortest possible time. Use of multi-planar reconstruction is important in the evaluation of the extent of aortic dissection and also to access the origin of the vessel in relation to true and false lumens (Fig. A12.1.1D).

Intramural hematoma appears as a crescent of high signal intensity on the spin echo technique. T_1-weighted spin echo (sequence 6 or 7) is a sensitive sequence to identify the intramural hematoma (Fig. A12.1.2; Murray et al., 1997). With contrast-enhanced MRA or TOF, intramural hematomas can be overlooked (Krinsky et al., 1997). Penetrating atherosclerotic ulcer appears as a focal outpouching of aortic lumen into the aortic wall.

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