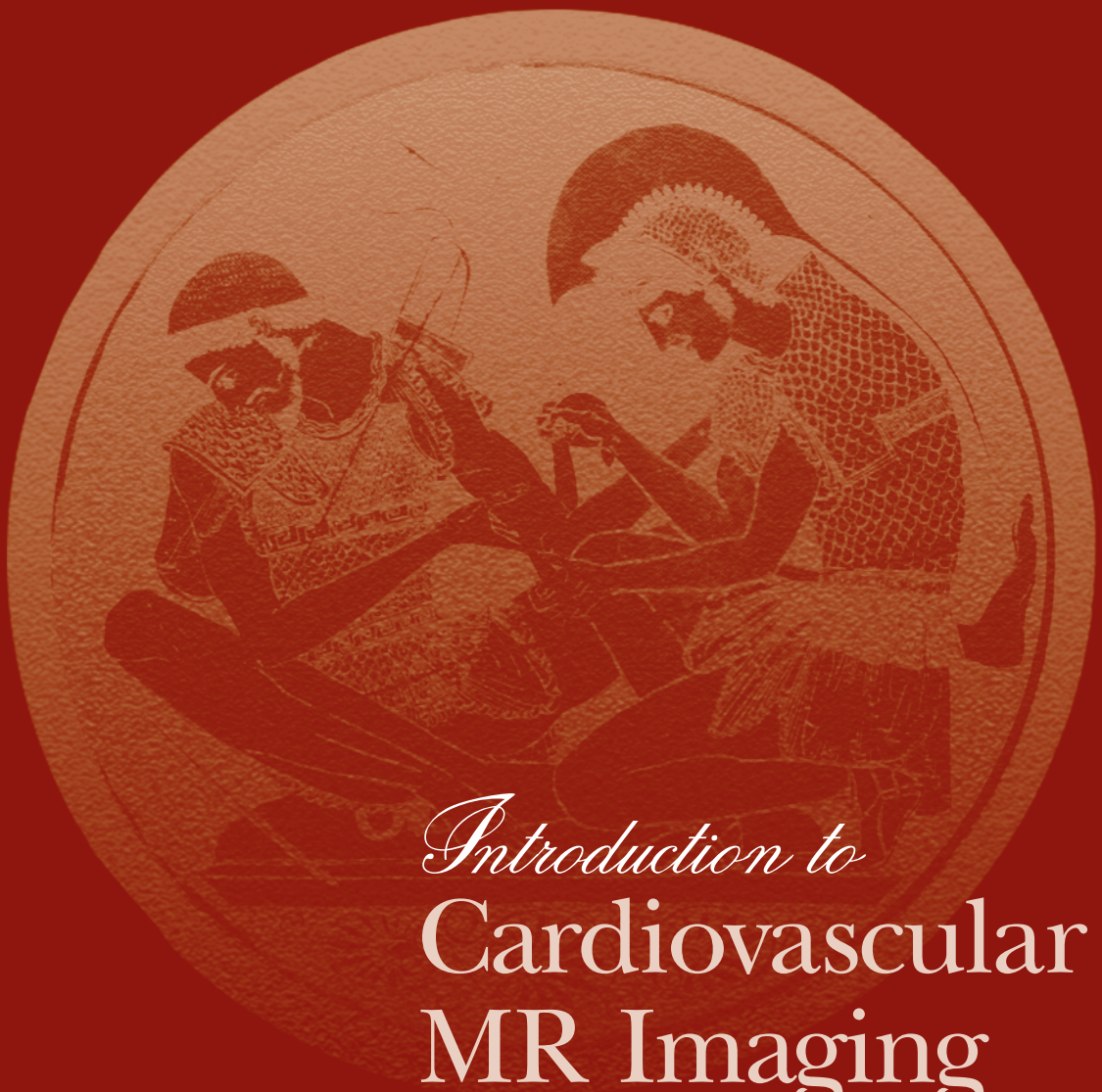
A Practical Guide to Cardiovascular MRI



Introduction to Cardiovascular MR Imaging

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A Practical Guide to Cardiovascular MRI

By Cindy R. Comeau, B.S., RT (N)(MR)

Cardiovascular MRI Senior
Advanced Applications Specialist

GE Medical Systems
Milwaukee, Wisconsin

Preface

This work is a practical guide to understanding and using cardiovascular MRI as an imaging modality. Use it to familiarize yourself with the system's capabilities, flexibility and diagnostic quality. You'll be impressed.

What's Inside

Signa® CV/*i*™ Introduction

Noninvasive Diagnostic Cardiovascular Imaging

The GE Signa CV/i system is a high-resolution, whole body imaging system operating at 1.5 Tesla. The Signa CV/i is the industry's first magnetic resonance system optimized for a full range of cardiovascular applications. With impressive image quality and resolution, cardiac MRI captures movement of the heart as it contracts and relaxes, then reconstructs and displays the images accurately as a real-time cine.

Performing an accurate assessment of cardiovascular disease is now a reality in clinical practice. Advances in cardiovascular imaging have produced faster imaging times when compared to conventional MRI scanning.

GE's Signa CV/*i* scanner introduces hardware and software that expands cardiac applications into the clinical arena for wall motion, function, perfusion studies, coronary anatomy, myocardial viability and quantitative measurement for noninvasive assessment of cardiac performance.

The purpose of this Application Guide is to give Signa CV/*i* users, especially those just starting to use CVMR imaging in everyday clinical practice, a practical introduction to cardiovascular MR imaging.

GE Medical Systems has made a strong commitment to the cardiovascular MR community, and the rapid clinical acceptance of cardiovascular MR applications will clearly place the Signa CV/*i* system as the "gold standard" for cardiovascular noninvasive imaging.

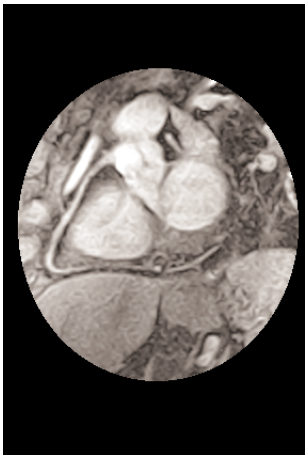
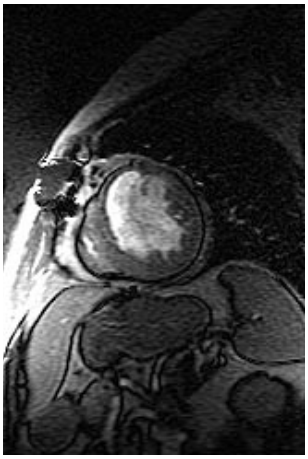
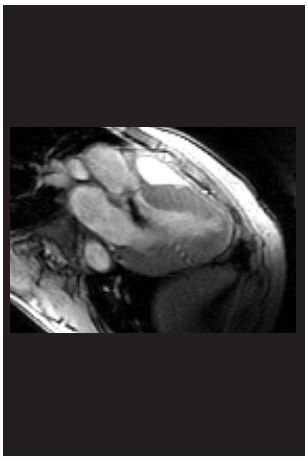


Image of right coronary artery using a 2D vessel tracking technique (WIP).

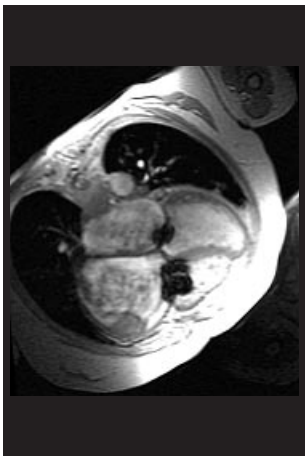


Region of anterior left ventricular wall thinning. FASTCINE technique.

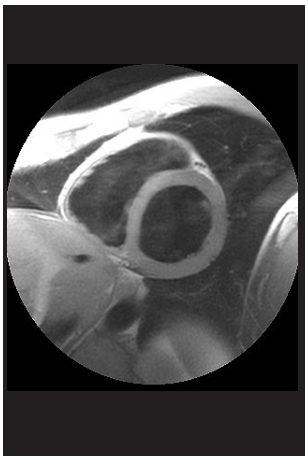
MRA demonstrating partial anomalous pulmonary venous return.



Aortic regurgitation. FASTCINE technique.



Mitral and tricuspid valve replacement with a clot in the right atrium. FASTCINE technique.



Short Axis plane Double-IR FSE technique.

Cardiovascular MR Imaging Techniques

The Signa CV/*i* supports a broad array of pulse sequences to address a full range of cardiac clinical applications. These pulse sequences include black blood techniques and white blood techniques.

Black Blood Techniques

- ECG-Gated Spin Echo.
- Double-IR Fast Spin Echo (FSE).
- Triple-IR Fast Spin Echo (FSE).

Black blood techniques traditionally include Spin Echo and Fast Spin Echo (FSE) sequences. Although these techniques can be used to evaluate cardiac anatomy, they may suffer from blood signal and motion artifacts. The Signa CV/*i* software includes the Double-IR FSE (figure 1) and Triple-IR FSE (figure 2) sequences that can be used to better reduce blood signal and related artifacts.

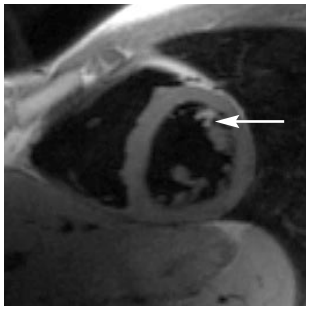


Figure 1:

Figure 1 is a Double-IR FSE short-axis image demonstrating a bright bi-lobed mass (arrow) attached to the anterior wall of the left ventricle. The fact that it has the same signal intensity of subcutaneous fat suggests that the mass is predominantly composed of fat as demonstrated in Figure 2, a Triple-IR FSE image.

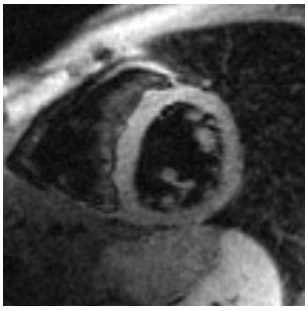


Figure 2:

White Blood Techniques

- Retrospectively gated Cine.
- FastCard (FASTCINE, Phase Contrast, Interleaved).
- EPI/Spiral/FastCard-ET.

The primary white blood technique is a segmented k-space Gradient Recalled Echo (GRE) technique, commonly known as FastCard. The Signa CV/*i* software includes the FASTCINE sequence which enables data acquisition throughout the entire cardiac cycle (figure 3). FastCard-ET, which is a Fast Gradient Echo/Echo Planar Imaging hybrid technique, is the preferred sequence for the assessment of myocardial perfusion by performing a first-pass contrast enhanced scan.

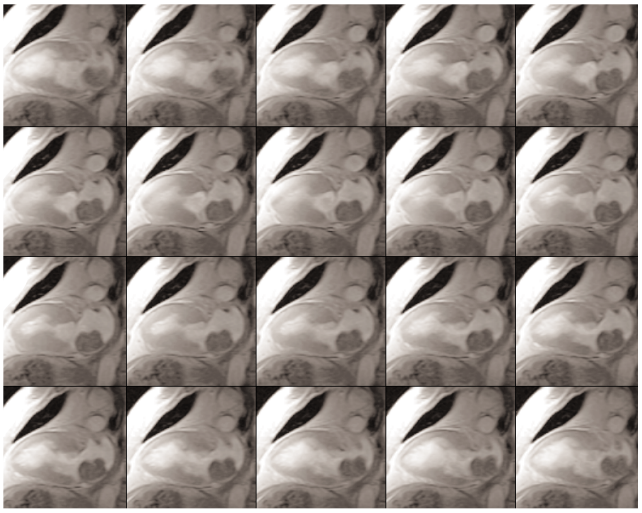
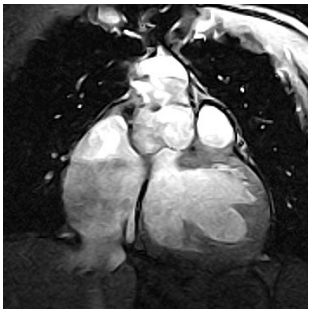


Figure 3:

FASTCINE two chamber image demonstrating an atrial myxoma. 20 phases acquired throughout entire R-R interval with a heart rate of 87 bpm.



FASTCINE image demonstrating cardiomyopathy.

Black Blood Techniques

ECG-gated Fast Spin Echo (FSE) can be used to acquire images of the heart in a breathhold, eliminating motion artifacts from respiration. However, even though FSE is generally thought of as a "black blood" pulse sequence (due to the "wash-out" effect for flowing blood), in practice, signal from the blood may not be thoroughly suppressed and related artifacts can occur. A double Inversion Recovery (IR) preparation pulse applied before the FSE acquisition can be used to better reduce the blood signal and related artifacts. This technique uses signal nulling in combination with a long "wash-in"/"wash-out" period. Resulting images display very dark blood and substantially reduced image artifacts, enabling improved visualization of cardiac anatomy compared to non-prepared images. Also, a third IR preparation pulse can be used for fat suppression and modified (combined T1- and T2-weighted) image contrast.

How Does Double-IR FSE and Triple-IR FSE Work?

A Double-IR pulse sequence uses a double Inversion Recovery (IR) preparation pulse. After the ECG trigger is detected, a non-slice-selective IR pulse inverts all spins in the body, including blood. A second slice-selective IR pulse is immediately applied, re-inverting only the spins in the image slice. At this point, magnetization within the slice is essentially unchanged, as compared to the state of spins outside the slice. A delay time (TI time) occurs, which allows for inverted blood spins that are outside the slice to reach the null point. This inversion time is approximately 650 ms for a heart rate of 60 bpm and occurs during the systolic portion of the cardiac cycle (figure 4).

During the TI time, the nulled blood flows into the imaging slice (wash-in effect), and the blood in the slice that experienced the re-inversion IR pulse flows out (wash-out effect). Finally, after the inversion time, a standard FSE slice-selective pulse is applied and the image data is acquired. The FSE pulse results in no transverse magnetization from the spins flowing into the slice, and therefore, blood has a dark appearance on the image – hence the term, "black blood." A third IR pulse may be applied before the FSE acquisition to null the signal from fat and, therefore, provide "STIR" (Short-Tau Inversion Recovery) contrast. This technique is known as Triple-IR FSE (figure 5). At 1.5T, the inversion time for this IR pulse is set to 150 ms. Initial studies have shown that STIR contrast may be useful in imaging acute myocardial infarction by detecting edema.

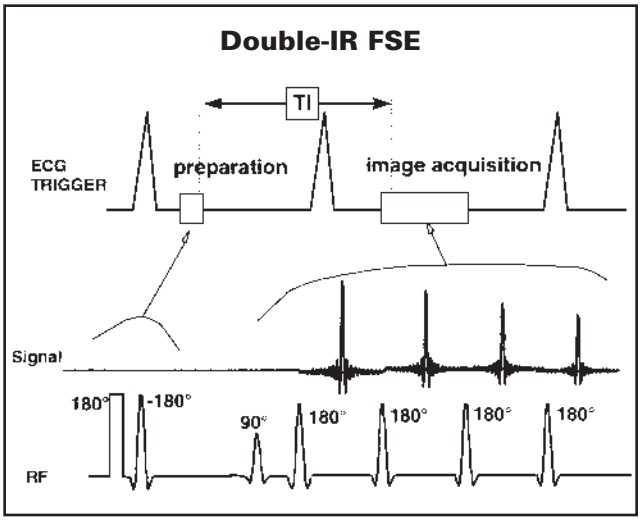


Figure 4:

Gated Double-IR FSE pulse sequence. The inversion time (TI) is calculated to null signal from blood.

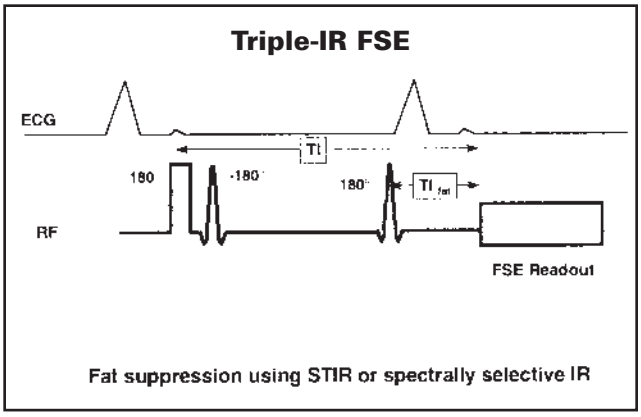


Figure 5:

Triple-IR FSE is the same as Double-IR FSE except for the additional third selective IR pulse.

When Would I Use a Black Blood Sequence?

Breathheld gated Double/Triple-IR images provide excellent delineation of cardiac anatomy with minimal respiratory artifacts. Clinical applications of this technique include:

- Aortic valve assessment (figure 6).
- Insensitivity to susceptibility artifacts. Particularly useful in the evaluation of post-op congenital heart disease.
- Characterization of cardiac masses (achieved by extending the TE to 60 or 80 ms).
- Diagnosis of right ventricular dysplasia.

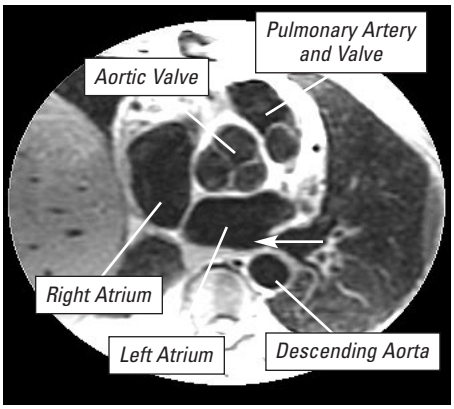


Figure 6: Transaxial image at aortic valve level.

White Blood Techniques

A short TR gated gradient echo pulse sequence is often used to generate Cine images at multiple frames of the cardiac cycle. Due to long scan times, conventional gradient echo Cine imaging suffers from respiratory motion artifacts. With the introduction of FastCard, imaging times have been dramatically reduced, making breathheld acquisitions feasible even in compromised patients.

How does FASTCINE Work?

FastCard uses a k-space segmenting technique that reduces scan times. Views per segment is a programmable parameter in the FastCard sequence. The total scan time can be reduced by increasing the views per segment. However, this is at the expense of reducing image temporal resolution. Minimizing artifacts from cardiac motion by decreasing the number of views per segment would conversely lead to an increase in the total scan time. FastCard, also known as a prospective triggered sequence, can suffer from variations in the heart rate. The temporal phases in a prospectively gated sequence are assigned on the basis of a fixed delay time from the R wave, which can result in missing the end of the cardiac cycle.

FASTCINE, an improved k-space segmenting technique, reconstructs all phase steps regardless of when they are acquired within the cardiac cycle. The FASTCINE method allows for complete imaging of the R-R interval, allowing better visualization of end diastolic events (figure 7). Rather than reconstructing images at fixed delays from the R wave, variable view sharing reconstructs images at different delay times within each cardiac cycle depending on a temporal phase position that varies with the heart rate. The primary advantage of this technique is that it combines the strengths of FastCard and CINE, respectively, by enabling shorter scan times through prospective gating and k-space segmentation and by retrospectively reconstructing images throughout the entire cardiac cycle.

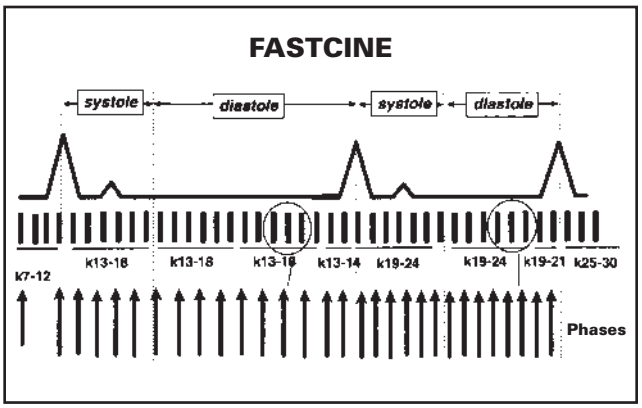


Figure 7: FASTCINE divides each R-R interval evenly upon programming the number of phases. K-space data is resorted according to temporal position in systole and diastole. For example: phase at 60% (circled) into diastole gets k-lines at around 60% diastole for R-R interval.

When Would I Use a White Blood Sequence?

Clinical applications are widespread with this technique for the heart. Depending on the imaging plane selected, global heart function can be assessed. Clinical applications of this technique include:

- Obtaining images of the entire cardiac cycle, including end diastole. This is very important, especially if quantitative analysis is to be performed (figure 8).
- Assessing regional wall motion. Tagging can also be used in conjunction with FASTCINE (figures 9 and 10).
- Assessing valvular function.

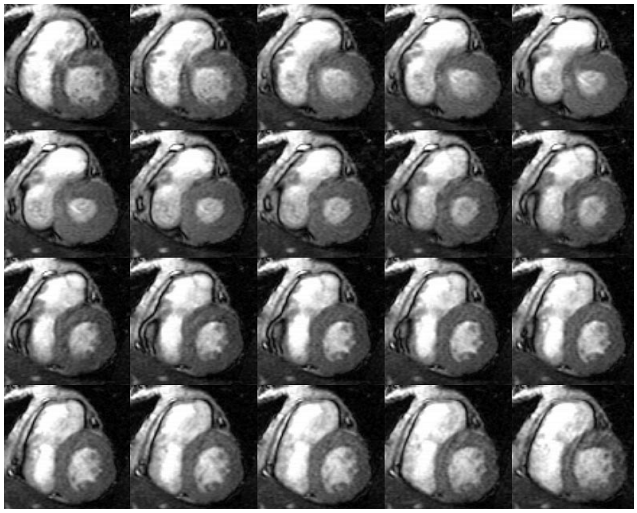


Figure 8: FASTCINE can result in a much smoother cine, even at high heart rates. The number of phases to reconstruct is a programmable parameter. This image represents one slice location with 20 phases. Short-axis image shown.

An important indicator of cardiovascular disease is the ability of the myocardium to maintain normal contractile motion under stress. To achieve this type of evaluation of wall motion, spatial tags can be placed as a series of two dimensional grid lines on the images using saturation pulses and observe the evolution of these MR tags through systole.

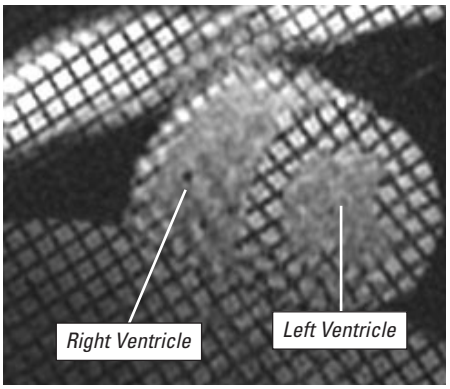


Figure 9: Example of myocardial tagging at end diastole.

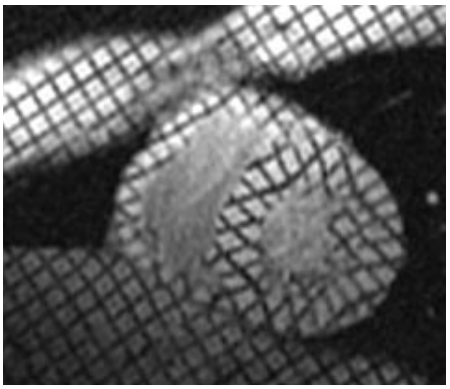


Figure 10: Example of myocardial tagging at end systole.

With spatial tags, wall motion abnormalities resulting from ischemia or left ventricular hypertrophy can be evaluated. Regions of the myocardium not seen as contracting can be assessed as a site of possible infarct.

Perfusion

FastCard EchoTrain, which is a hybrid of FGRE and EPI, uses a short TR gradient-echo sequence with a short Echo Train Length (ETL), echo planar readout. This approach substantially reduces imaging speed and virtually eliminates geometric distortion and flow related artifacts typically associated with long ETL EPI scans. It is optimized for first pass cardiac perfusion imaging with rapid acquisition time on the order of 100ms per image (figure 11).

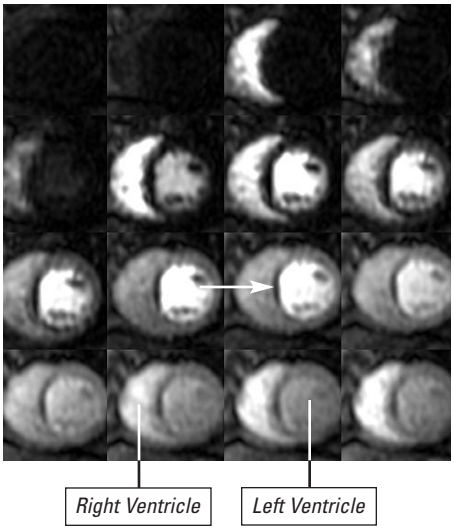
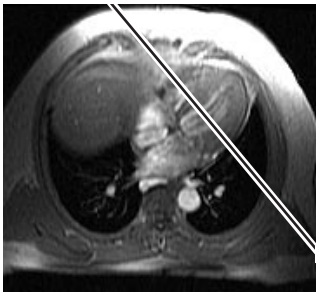


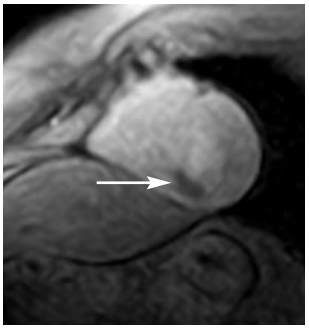
Figure 11:

These images were acquired at one slice location at successive points in time during a dipyridamole stress test. The contrast agent first appears in the right ventricle, then the left ventricle, then finally the myocardium. A slowly enhancing region (arrow) in the septum was detected which corresponds to an 80% stenosis of the LAD.

As a result, temporally resolved images of the entire heart can be acquired every 1-2 RR cycles, making it the ideal tool for assessing cardiac perfusion, even under high heart rate stress conditions (figures 12 and 13).



Long-axis plane demonstrating slice location for image below.



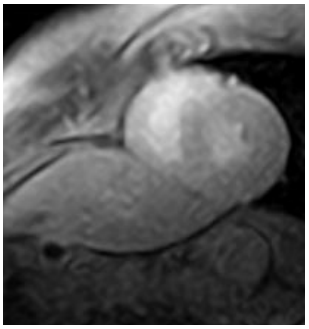


Figure 12:

Figure 13:

First-pass contrast-enhanced cardiac imaging performed with adenosine. The short-axis image in Figure 12 demonstrates a non-enhancing region in the inferior wall (arrow). Upon rest (Figure 13), the region appears to be of normal signal intensity. This patient successfully underwent a coronary balloon angioplasty of the right coronary artery.

Cardiac Structure and Function

To perform cardiovascular MR procedures effectively, it is important to understand the patient's disease process. And, to understand the disease process, a fundamental understanding of cardiac anatomy and physiology is critical.

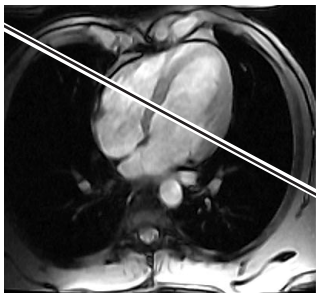
Cardiac Anatomy

The adult heart weighs about 9 ounces (300 g), holds approximately 500 ml of blood and beats about 100,000 times each day to push almost 2,000 gallons of blood through about 65,000 miles of blood vessels. It's a complex, interesting organ to image. It is located in the mediastinum, above the diaphragm and between the lungs.

Cardiac Layers

The heart consists of three layers: outer (epicardium), middle (myocardium) and inner (endocardium) (figure 14).

- Epicardium is the outermost layer of the heart.
- Myocardium (muscle) is the thickest layer of the heart.
- Endocardium is the inner lining of the myocardium. The folds of the endo-cardium form the cardiac valves.



Long-axis plane demonstrating slice location for image below.

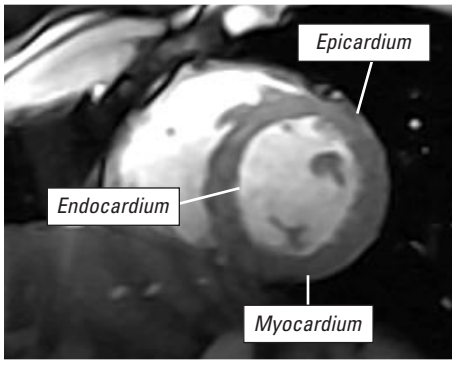


Figure 14: Short-axis image.

Chambers

The normal heart contains four chambers.

Atria: Right and Left (figure 15)

- Small, thin-walled chambers, typically 2mm wall thickness.
- Functions as holding tank of blood.
- Ejects the blood into the ventricles.

Ventricles: Right and Left (figure 15)

- Larger, thick-walled chambers.
- Right ventricle: 3mm thick walls.
- Left ventricle: 10mm thick walls.
- Performs most of the pumping work.

Septum (figure 15)

The septum is the layer of tissue separating the chambers. The interatrial septum is the thin muscular wall between the two atria and the interventricular septum is the thicker muscular wall between the two ventricles.

Valves

Valves are flaps of the endocardial layer strengthened by a framework of fibrous connective tissue. The heart contains four valves that control the one-way flow of blood.

The two atrioventricular (AV) valves separate the atria from the ventricles.

- The tricuspid valve separates the right atrium and right ventricle and consists of three cusps or flaps.

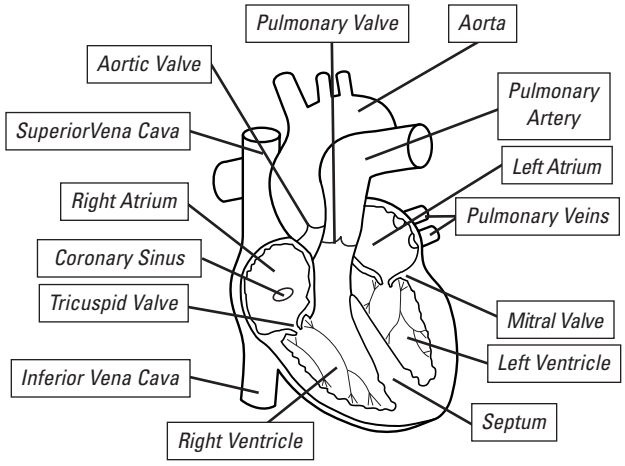


Figure 15: Normal heart.

► The bicuspid (or mitral) valve separates the left atrium and left ventricle and consists of two cusps or flaps.

Cordae tendineae anchor valve cusps to the papillary muscles of the ventricles. They prevent the valves from opening into the atria during ventricular contraction.

There are two semilunar valves which are half-moon shaped.

► The pulmonary valve, located inside the pulmonary artery, controls blood flow between the right ventricle and pulmonary artery.

► The aortic valve regulates blood flow between the left ventricle and aorta.

Each semilunar valve consists of three cusps that look like shallow cups cut in half vertically, with the cut edges attached to the vessel wall. These valves have different functions during contraction and relaxation also known as systole and diastole.

During ventricular contraction or systole, blood forces the cusps against vessel walls, allowing blood to flow through the valve (figure 16).

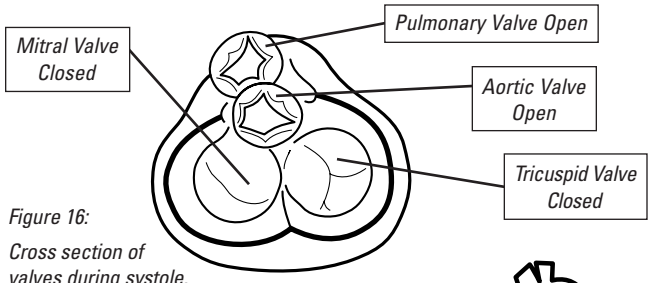
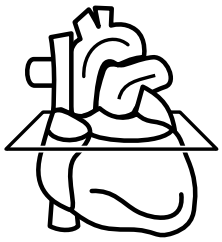


Figure 16:
Cross section of valves during systole.

During relaxation or diastole, blood fills the cusps, making them bulge and causing the free edges to meet in the middle. This prevents backflow of blood (figure 17).



Cross sectional view from the top of the ventricles.

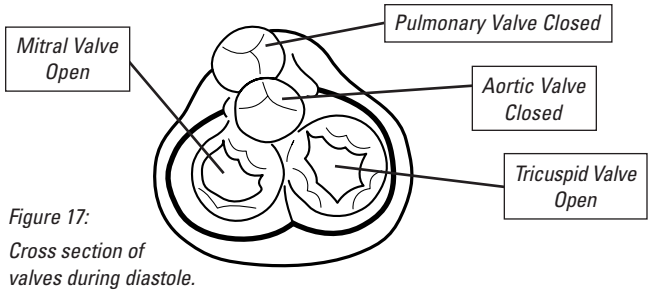


Figure 17:
Cross section of valves during diastole.

Cardiac Circulation

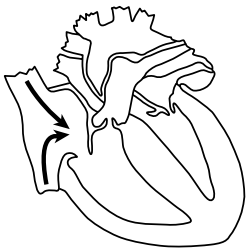
As the heart contracts and relaxes, it mechanically pumps blood through the atria and ventricles. This process is called circulation.

► Pulmonary circulation carries blood from the right side of the heart to the lungs and back to the left side of the heart.

► Systemic circulation carries blood from the left side of the heart to the rest of the body and back to the right side of the heart.

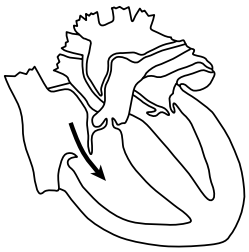
Like any muscle, the heart contracts (thickens) and relaxes. Systole means contract; diastole means relax. In a normal heart, the right and left ventricles contract and relax synchronously. To force blood into the ventricles, the atria contract while the ventricles relax.

Pulmonary Circulation



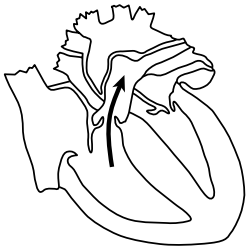
Right Atrium Fills

Dark deoxygenated blood flows into the right atrium from the superior vena cava and inferior vena cava.



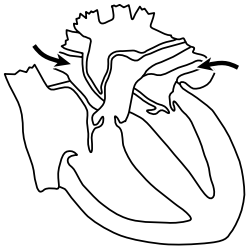
Right Ventricle Fills

The right atrium contracts, forcing blood into a relaxed right ventricle through the tricuspid valve.



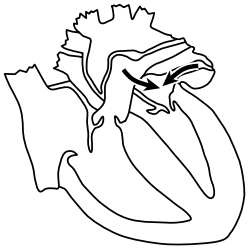
Blood Sent to Lungs

When the right ventricle is filled, it contracts and forces blood into the lungs via the pulmonary arteries to become oxygenated.



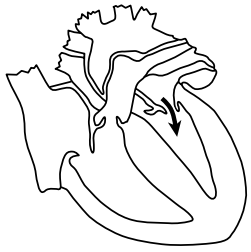
Oxygenated Blood Returns to Heart

Oxygenated blood in the lungs returns to the heart through the pulmonary veins. These are the only veins that carry oxygenated blood in the body. Note that the definition of an artery is a blood vessel that carries blood away from the heart. A vein, by definition, carries blood to the heart.



Left Atrium Fills

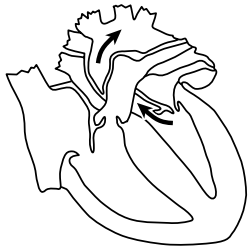
The pulmonary veins deliver oxygenated blood to the left atrium.



Left Ventricle Fills

The left atrium contracts forcing blood through the mitral valve into a relaxed left ventricle.

Systemic Circulation



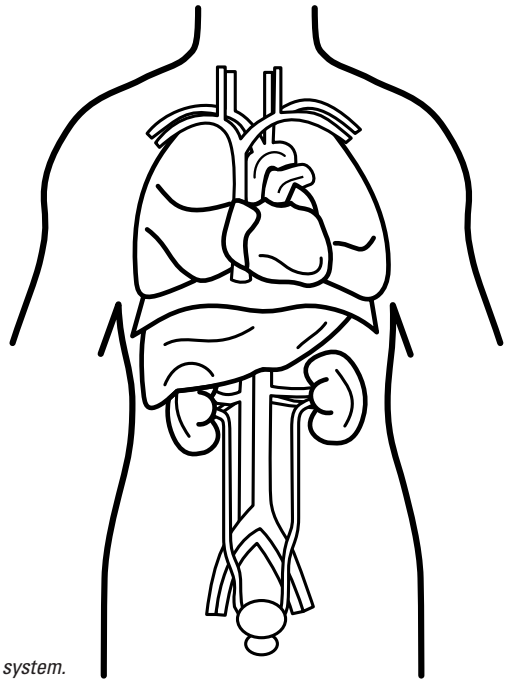
Blood Forced into Aorta

As the left ventricle contracts, it forces oxygenated blood through the aortic valve into the aorta.

Blood Supplies Body

From the aorta, the blood travels through the arterial system, supplying blood to the rest of the organs.

- Arteries empty into smaller vessels called arterioles. Arterioles are arteries with diameters of less than 0.5mm.
- Arterioles regulate blood flow into capillaries. Capillaries are 0.5-1.0mm long and 0.01mm in diameter.
- From the capillary beds, the deoxygenated blood flows into the venous system. Capillaries empty into venules, and venules empty into larger vessels called veins.
- Blood from the body returns to the right atrium by either the superior vena cava or inferior vena cava.



The circulatory system.

Coronary Arterial Blood Supply

How does blood get to the myocardium after it leaves the left ventricle through the aorta? There are two principal vessels – the right and left coronary arteries – that branch off and feed the cardiac tissue (figure 18). All of the arteries branch into smaller vessels called "end arteries" which feed the myocardial tissue. Details regarding several vessels are listed below.

Right Coronary Artery (RCA)

- Runs through the atrioventricular groove which is situated between the right atrium and right ventricle.
- Goes around the lateral wall to the posterior wall of the right ventricle.
- Feeds right atrium and right ventricle.
- Feeds inferior wall of the left ventricle.
- In approximately 50% of people, the RCA also supplies the area of the sinoatrial node. In the other 50%, this area is supplied by the left circumflex. The SA node is the heart's "pacemaker."

► In 90% of people, the RCA also feeds the area of the atrioventricular node.

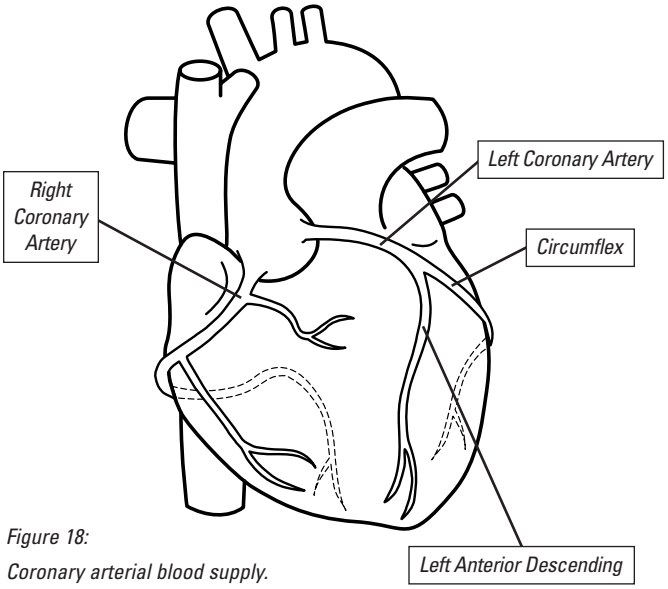


Figure 18:
Coronary arterial blood supply.

Left Coronary Artery (LCA)

► Feeds left ventricle and interventricular septum.

► Splits into two branches: left anterior descending and left circumflex.

Left Anterior Descending (LAD)

► Runs downward between the ventricles toward the apex.

► Feeds anterior walls of right and left ventricles and interventricular septum.

Left Circumflex (LCx)

► Runs between left atrium and ventricle, traveling to the posterior wall.

► Runs downward toward the apex.

► Feeds the posterior and lateral walls of the left ventricle and a portion of the inferior wall (diaphragmatic surface).

What Does a Coronary Artery Look Like in MR?

Current coronary imaging techniques include using Fat Saturation with FASTCINE (figure 19). Imaging coronary vasculature of the heart can be challenging. Limitations include cardiac and respiratory motion, artery's small size, highly tortuous course of the vessels, and their adjacency to fat and cardiac chambers. With the improvements of hardware and software, coronary MRI will have a larger role in diagnostic cardiology. Currently under clinical investigation are methods that include navigator acquisition to monitor and gate respiratory motion. Used in conjunction with 3DFGRE sequence, a volume acquisition can be acquired. Then reformats can be performed that localize the coronary vessels.

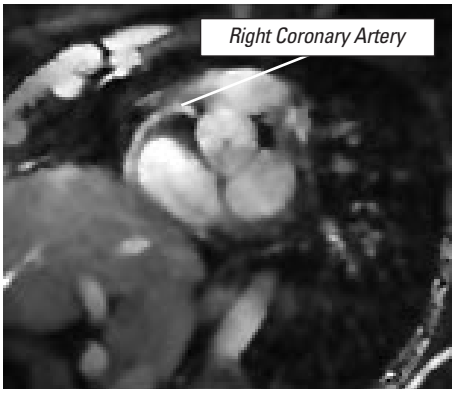
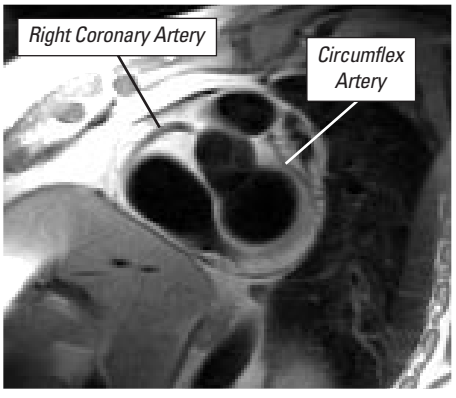


Figure 19:
FASTCINE technique using Fat Sat demonstrating the right coronary artery.



Double-IR FSE technique demonstrating the right coronary artery and circumflex.

Myocardial Blood Supply in Relationship to Cardiac Anatomy

When viewing a short-axis image, the coronary arteries supply certain portions of the heart muscle. The LAD supplies areas G, H, A. The RCA supplies areas E and F. The circumflex supplies areas B, C and D. Recognizing this anatomy becomes important, especially for perfusion imaging and wall motion studies (figure 20).

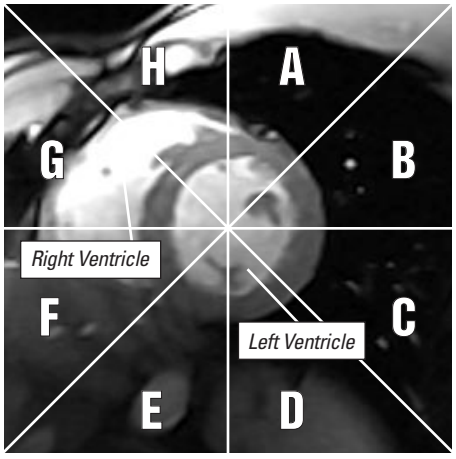
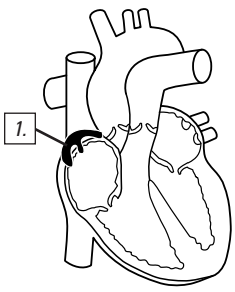


Figure 20:
Short-axis plane.

A. Anterior
B. Anterolateral
C. Posterorlateral
D. Inferoposterior
E. Inferior
F. Inferior Septum
G. Middle Ventricular Septum
H. Anterior Ventricular Septum

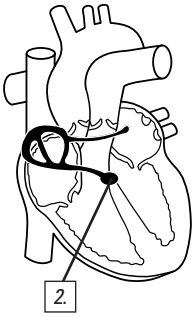
Electrocardiography

Electrical impulses cause the heart to contract and, therefore, blood to flow throughout the body. An electrocardiogram, or ECG, is a map of the electrical activity of the heart. Before we review the ECG components, we will discuss the components and sequence of cardiac excitation.



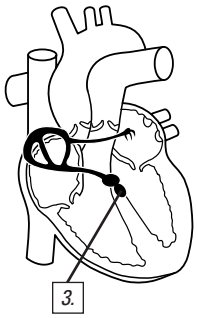
1. SA Node

The sinoatrial (SA) node is the heart's natural pacemaker. It generates an excitation impulse at a regular pace between 60 and 100 per minute. Located near the junction of the superior vena cava and the right atrium, the SA node is sensitive to damage from diseases that affect the heart's surface.



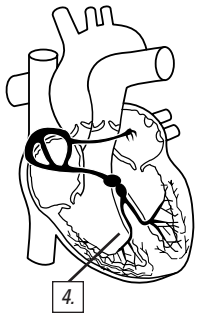
2. AV Node

The atrioventricular (AV) node receives an excitation pulse from the SA node and triggers signals for transmission to the ventricles. It is located between the atria and ventricles. The pulse sent by the AV node travels slowly to reach the bundle of His. During this delay, the atrial contraction completes, so when the impulse reaches the ventricles, they are already full of blood.



3. Bundle of His

The excitation pulse travels from the AV node to the bundle of His.



4. Right and Left Bundle Branches

From the bundle of His, the excitation pulse travels to the right and left bundle branches. These branches subdivide into smaller and smaller branches called Purkinje fibers. The Purkinje fibers spread diffusely throughout the myocardium whose ends terminate at the muscle fibers. This is where the excitation pulse terminates.

ECG Components

Let's look at the components of an ECG signal (figure 21).

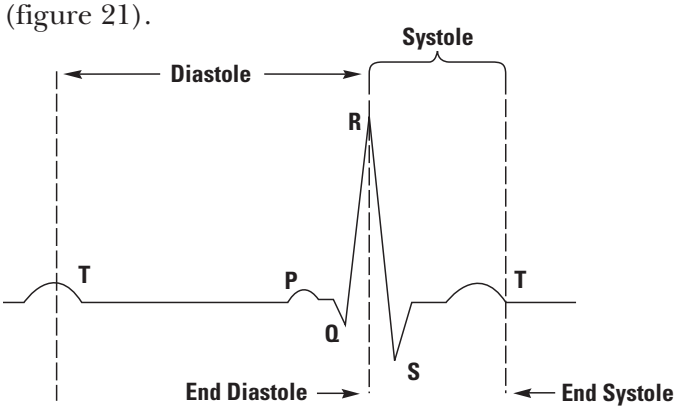
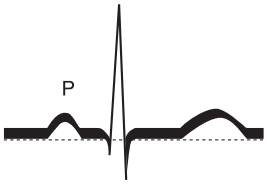
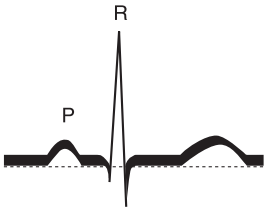


Figure 21:
Normal ECG shows pattern of P, Q, R, S and T waves in the cardiac cycle.



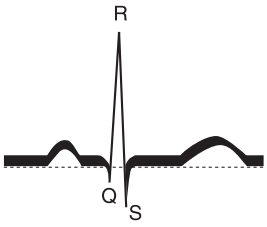
P Wave

The P Wave represents the original pacemaking impulse from the SA node, which spreads through the atria. A normal P wave is no more than 3mm high and .12 seconds in duration. Keep in mind that it is difficult and sometimes impossible to see the P wave from an ECG acquired when the patient is inside the magnet.



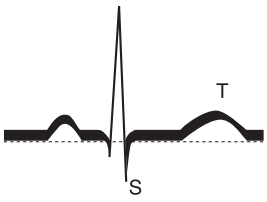
PR Interval

This is the time between the onset of the P wave and the onset of the QRS complex. The normal PR interval is .12 to .20 seconds. Anything greater than .20 seconds is abnormal.



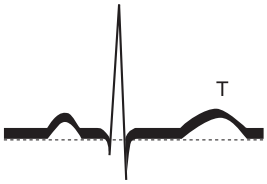
QRS Complex

The QRS complex represents the depolarization of the right and left ventricles. A normal QRS complex is about .08 to .11 seconds in duration. A longer complex may indicate a ventricular conduction defect, such as a left bundle branch block.



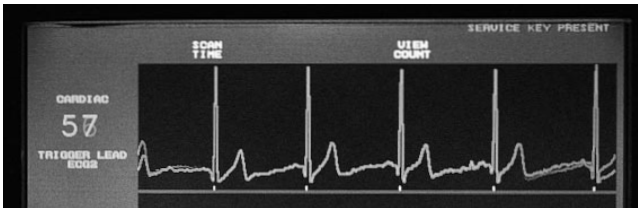
ST Segment

The ST segment represents the time between the completion of a depolarization and the beginning of repolarization of the ventricle. An elevated or depressed ST segment could indicate ischemia or an infarction.

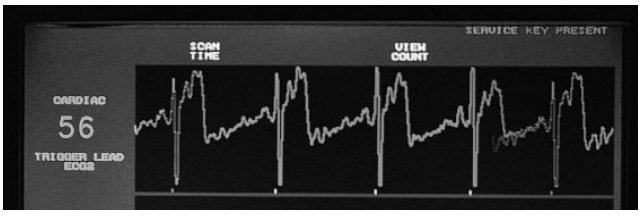


T Wave

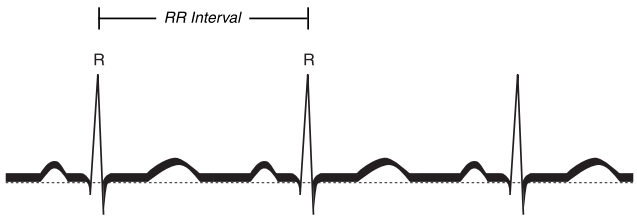
The T wave represents the recovery phase after ventricular contraction. In cases of heart injury, the T wave may be inverted. Flowing blood in the body makes an artifact in the ECG that obscures the normal T wave when the patient is inside the magnet.



Normal ECG.



ECG demonstrating a high T wave.



R to R Interval

The R to R interval represents the time between one heartbeat and the next.

Abnormalities

Like cardiac anatomy, the heart's electrical conduction system can be affected by disease. Abnormalities in the electrical activity are called arrhythmias.

In MR imaging, it's important to keep data acquisition times short to avoid motion-related artifacts. For cardiac imaging, this means acquisition times under 150 ms. If we can't acquire all k-space data to reconstruct an image within a single R-R interval, then acquisition must be partitioned across several cardiac cycles, with each data segment acquired at the same cardiac phase. This synchronization of data acquisition to the cardiac cycle ensures that the heart is in the same spatial position or cardiac state for each k-space-encoding segment. For this reason, it is important that the patient's heartbeat is regular. It is particularly critical for FastCard applications. As the heartbeat becomes more irregular, the image quality decreases.

Scan Setup

Patient Preparation and Lead Placement

To perform a successful MR cardiovascular exam, it is very important to follow the steps, as with any MR exam. ***Patient safety is a primary concern. Be sure to use all patient screening techniques when conducting a cardiac exam. The most widely quoted contraindication to MRI is the presence of a cardiac pacemaker.***

Also, be sure to explain to the patient how important it is to lie still and follow breathing instructions. Breathholding can be done on inspiration or expiration. If performed on expiration, there is a better chance of reproducibility among the views.

Gating Checklist

To ensure reliable gating, use the following checklist:

- Use an abrasive gel when preparing the patient. Apply gel to a cotton swab or gauze and rub lightly on the skin where the electrodes will be placed. Remove excess gel when done cleaning. Shave chest if necessary.
- Use non-metallic, pre-gelled electrodes (they should not be dry). Do not use outdated electrodes or electrodes that have been out of a sealed pouch for a long time since they will dry out.
- Use an anterior lead placement, if possible.
- Place non-metallic, pre-gelled electrodes on the prepared area.
- If available, use an impedance meter to check the contact impedance. It should be less than 20K outside of the magnet.
- Connect the leads.
- On the LX screen, under Gating Control, make sure that the calibrated value is greater than 1.0 mV. If it is not greater than 1.0 mV, repeat the preparation procedure or reposition the electrodes.
- On the Gating Control Screen, check Lead I, Lead II, and Lead III to determine the best signal.
- After the electrodes are in place, position the patient to enter the magnet feet first. (The positioning of the cardiac coil requires a feet-first entry).
- Position the cardiac coil in the proper orientation, making sure the anterior and posterior coils align with each other (figures 22, 23, 24).
- Explain to the patient what will happen during the exam.
- **Provide the patient with ear plugs.**
- Place bellows on the patient to ensure that breath-holding instructions are followed.
- On the Gating Control Screen, check for the proper ECG signal.
- Move the patient into the magnet and landmark in the mid-chest area. Use the anatomical marker on the coil to help in positioning.
- Check that the ECG cable that is outside of the magnet is routed down the center of the table.
- Check for proper ECG signal prior to starting the acquisition.
- Begin the exam with a Sagittal Localizer. A sagittal localizer visualizes the coil placement in the superior/inferior direction.

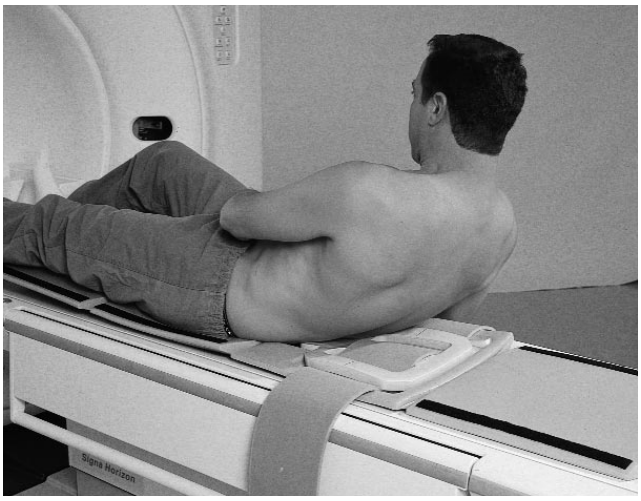


Figure 22: Posterior placement of the cardiac phased array coil.

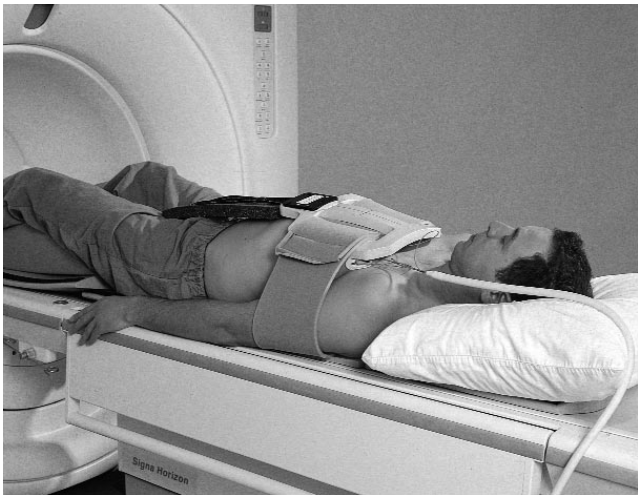


Figure 23: Anterior placement of the cardiac phased array coil with high impedance gating cable. Positioning the straps over the arms, however, may interfere with monitoring devices such as a blood pressure cuff.

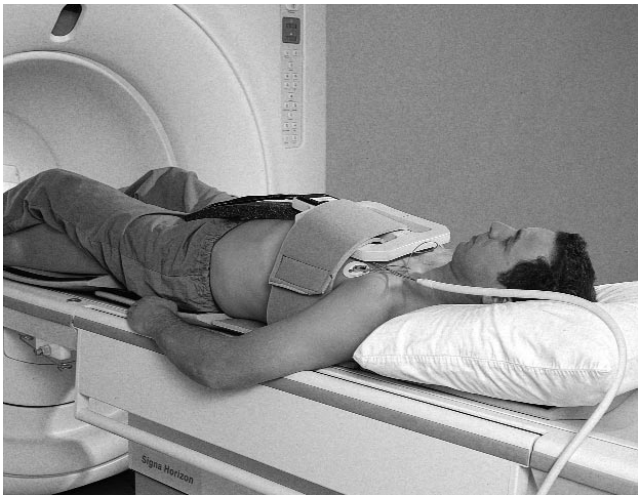


Figure 24: Positioning of the cardiac phased array coil with straps wrapped under the arms.

Positioning the Electrodes

There are two setups for an electrocardiogram. The first setup, called "Lead 2," uses four electrodes on the patient's chest. This is the most commonly used setup for a gated cardiac MRI exam.

The second setup, called "12-Lead ECG," provides a more detailed analysis of the areas or walls of the heart. It is used for routine screening to detect cardiovascular disease. It is not used for gated MR exams.

The goal is to place the electrodes in such a way as to minimize ECG motion artifacts.

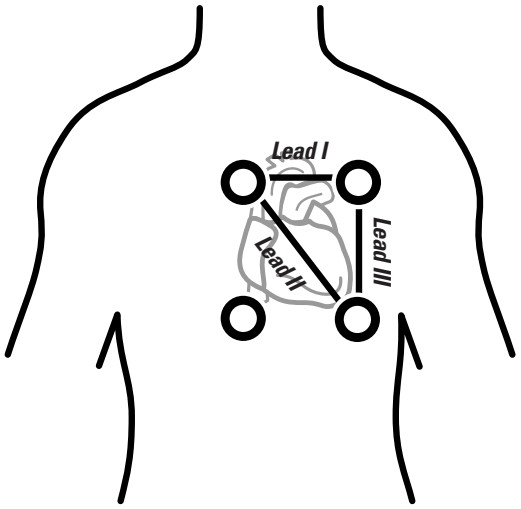


Figure 25:
Anterior electrodes placement.

Lead I represents the voltage between the left arm lead and the right arm lead. Lead II represents the voltage between the right arm lead and the left leg lead. Lead III represents the voltage between the left arm lead and the left leg lead. Positioning of the electrodes may be different from patient to patient. The recommended starting placement for the electrodes is shown in figure 25. Lead II usually achieves the biggest voltage possible or best signal. Placement of the left leg electrode is critical in order to obtain the best signal since this is where the apex of the heart is positioned. The position of the heart can vary from patient to patient which can make ECG gating challenging.

It is recommended that cardiac acquisition be acquired during a breathhold. This will eliminate artifacts due to the patient's breathing. However, there may be clinical patients who cannot hold their breath. In those cases, selecting Respiratory Gating/Triggering from the Imaging Option page is recommended. Respiratory Gating/Triggering is compatible with Cardiac Gating/Triggering for Fast Gradient Echo sequences such as FastCard and FASTCINE (figures 26 and 27).

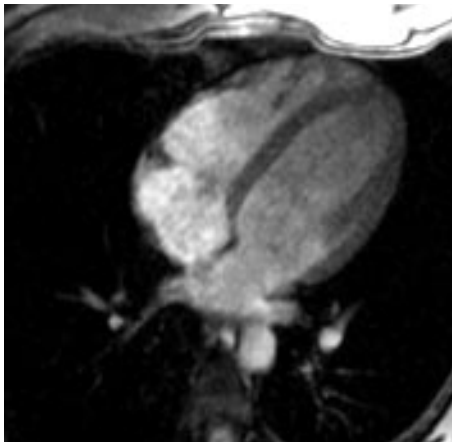
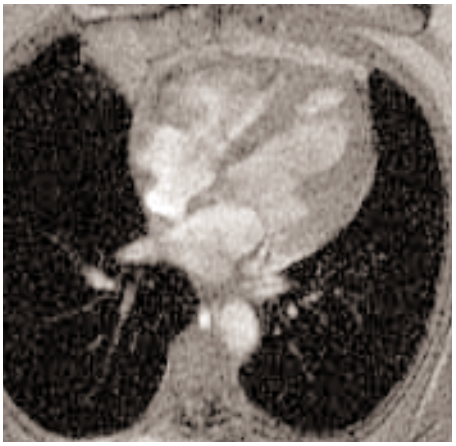


Figure 26:

Long-axis image acquired during a 14-sec breathhold. Notice the absence of any motion or related artifacts.



Long-axis view acquired using the body coil.

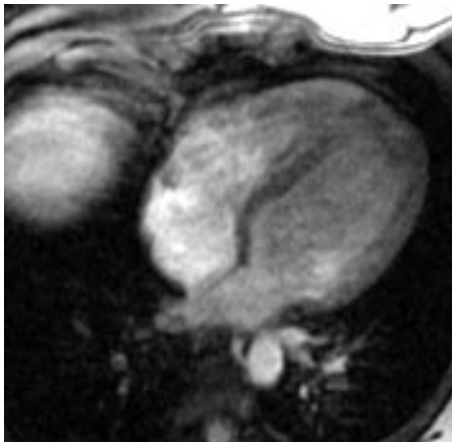
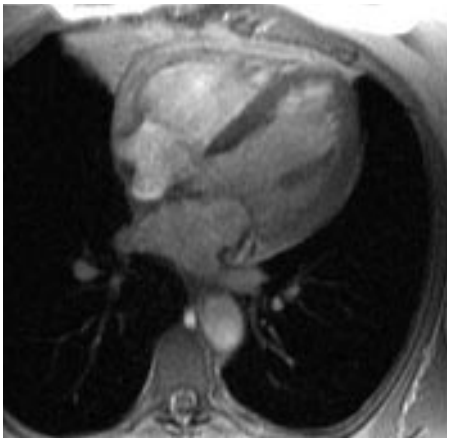


Figure 27:

Long-axis image acquired during free breathing with the Respiratory Gating/Triggering option with FASTCINE. Notice however, the motion artifacts, although overall cardiac anatomy can be seen.



Same long-axis view as above acquired using the cardiac phased array coil. Notice the improved signal-to-noise.

Imaging Plane Selection

Optimal Imaging Planes

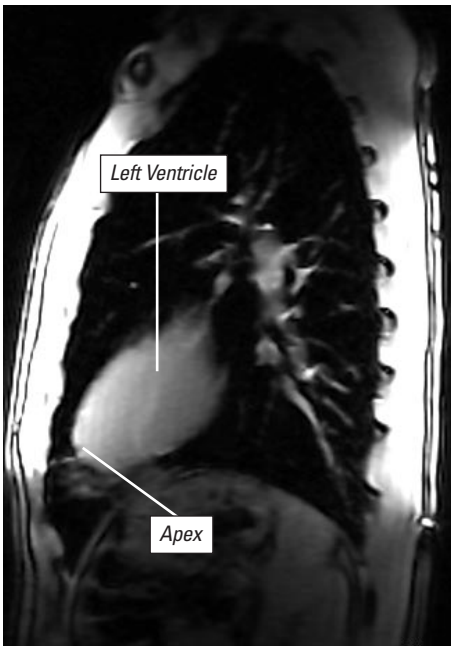
Cardiovascular MR images can be acquired in three planes perpendicular to the magnetic field: coronal, axial and sagittal. Although these planes are common to other imaging modalities, they are not the planes most commonly used for cardiovascular MR applications. Therefore,it is imperative to familiarize yourself with cardiac anatomy and imaging planes as they apply to cardiac magnetic resonance imaging.

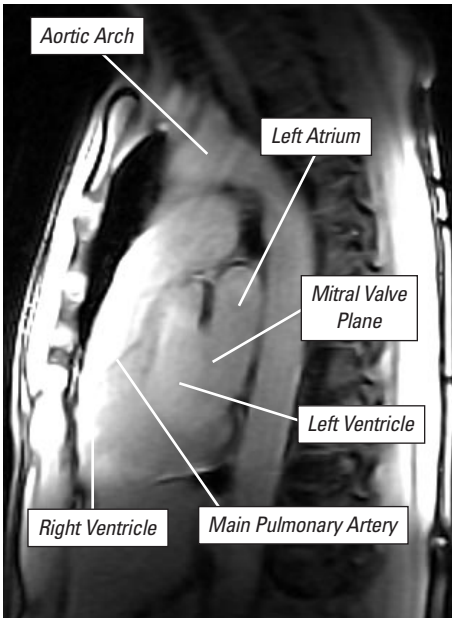
Sagittal Localizer

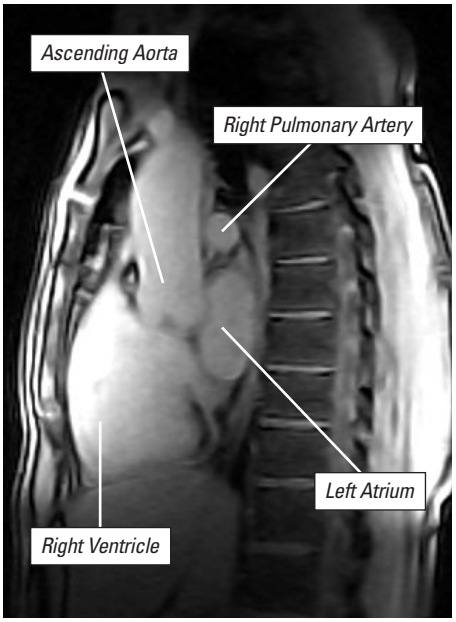
Description

The cardiac MRI exam typically begins with a sagittal localizer to get coverage over the chest area, in two to five breathholds, and to verify coil positioning.

Typically we use a FastCard, single-phase, multi-slice acquisition (non-sequential). This means you will obtain four or five image locations per breathhold. All the images will be ECG-gated, but you will obtain them at different phases of the cardiac cycle.







Application

- From the sagittal plane, you can prescribe a true, single, long-axis image of the heart with only a single oblique acquisition.
- Rapid screen of the chest can detect a wide range of pathologies. It is important to have some standard imaging planes in the exam so that unexpected findings on the double oblique images can be correlated with these standard planes.
- Verify cardiac phased array coil positioning.

How To

PARAMETER	SCAN VALUE	PARAMETER	SCAN VALUE	IMAGING OPTIONS	GAT/RESP OPTIONS	
Plane	Sagittal	Slice Thk	8mm	Gat, FC	Trig Type: Select Best Lead	
Mode	2D	Slice Space	0.0		Trig Win:	20
PSD	FastCard SPGR	Frequency	256		Trig Delay:	Min
TE	Minimum	Phase/PFOV	128/0.75		Cardiac Phases:	1
TR	N/A	NEX	1		VPS:	8 to 12
Flip	20 degrees	Freq. Direction	S/I			
RBW	31.25	Ctr. Frequency	Water			
FOV	40cm	Auto Shim	On			

Comments

- Use Resp Gate/Trig for non-breathhold scans.
- Typically, scan from L120 to R50.
- After the patient has been moved into the magnet, use the Gating Control Screen to check which lead has the best gating signal. This can be done realtime by clicking on the lead selection on the Gating Control Screen.
- While scanning the first set of locations, if you are finding that the gating algorithm is missing triggers, the following options can be tried without having to re-prescribe the scan:
  - Reduce the trigger level and see if the performance is better.
  - If the above fails, select the ECG Noise Filter. This changes the algorithm to the delayed mode which is more reliable.
- If the heart rate varies upon the patient holding his/her breath, increase the Trigger Window.

Long-Axis Localizer

Description

The long axis is typically prescribed from the sagittal localizer. Depending on variants in the patient's anatomy and pathology, the long-axis image is a four-chamber view. The long-axis acquisition is a single-slice, multi-phase, FASTCINE scan.

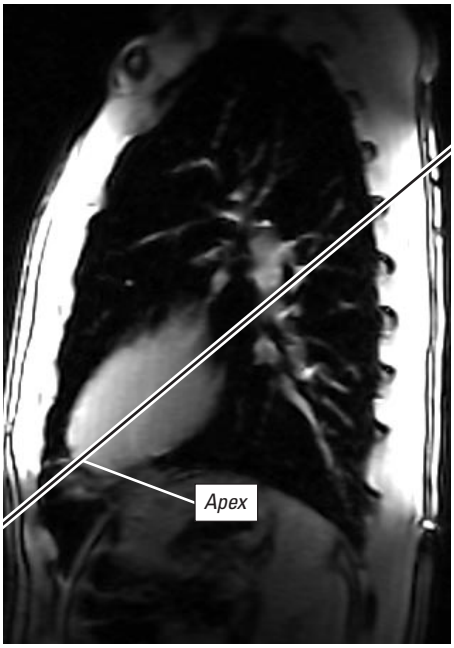


Figure 28: Graphic Rx placement of long-axis slice going thru the apex.

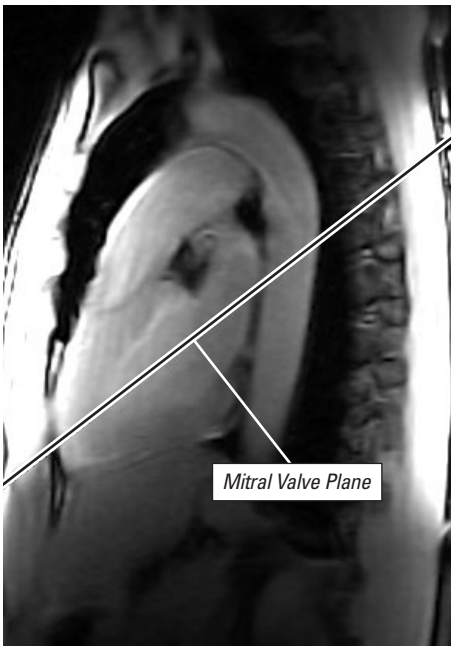
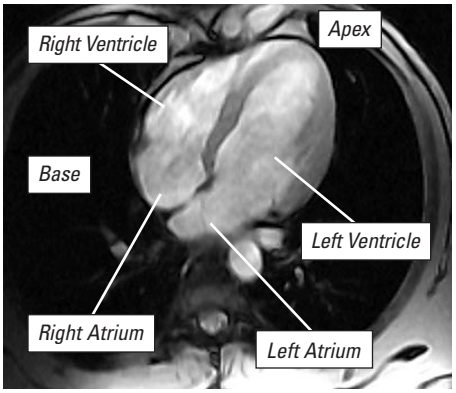


Figure 29: Localizer graphic Rx placement thru the mitral valve plane.



Long-axis plane of the heart. Depending on the angle of the graphic prescription, the apex in some patients may point down.

Long-axis plane demonstrating all 20 phases acquired during one cardiac cycle.

Application

- Assess regional myocardial function of both LV and RV.
- Detection of mitral and tricuspid regurgitation.
- Detection of possible septal defects. These lesions are usually detected on the cine image by the corresponding flow disturbance rather than visualization of the defect itself.
- Essential plane for prescribing the short axis.

How To

PARAMETER	SCAN VALUE	PARAMETER	SCAN VALUE	IMAGING OPTIONS	GAT/RESP OPTIONS	
Plane	Sagittal	Slice Thk	8mm	Gat, FC, Seq	Trig Type: Select Best Lead	
Mode	2D	Slice Space	0.0		Trig Win:	20%
PSD	FastCard SPGR	Frequency	256		Trig Delay:	Min
TE	Minimum Full	Phase/PFOV	128/0.75		Cardiac Phases:	20
TR	N/A	NEX	1		VPS:	4 to 8
Flip	15 degrees	Freq. Direction	Unswap			
RBW	31.25	Ctr. Frequency	Water			
FOV	36-40cm	Auto Shim	On			

Comments

- Adjust the VPS and number of locs before Pause for a breathhold scan.
- Number of Cardiac Phases to Recon: use Auto for FastCard and enter 20 for FASTCINE.
- Use Resp Gate/Trig for non-breathhold scans.
- Prescribe the slices parallel to the long axis of the left ventricle cavity. The graphic Rx line cursor should pass thru the mitral valve and the left ventricle apex. Hint: Once the apex is found: (1) save the series then copy paste the series; (2) open Graphic Rx, erase location; (3) locate the image that best depicts the mitral valve plane (figure 28); and (4) copy Rx to check for positioning thru mitral valve plane (figure 29). (In some cases the apex and mitral valve may not line up; a compromise may be needed.)
- Give the breathhold instructions. Press [Scan] once the ECG signal has stabilized. Typically the stabilization takes about 2 seconds. For consistency, have patients hold their breath on expiration.

The following guidelines can be used to adjust the VPS depending upon the heart rate:

- BPM ≤60: use an 8 VPS.
- BPM 61-95: use a 6 VPS.
- BPM 96-125: use a 4 VPS.
- BPM 126-155: use a 2 VPS.
- BPM >156: use a 1 VPS.

Short-Axis Plane

Description

The short axis is typically prescribed from the long-axis images. The short-axis acquisition is a multi-slice, multi-phase, FASTCINE scan.

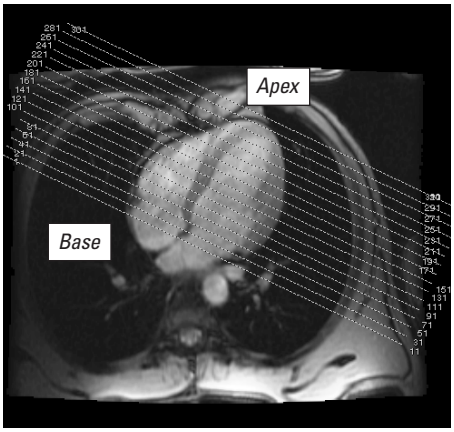


Figure 30:

Graphic Rx lines placed on long-axis plane. Prescribe from base to apex.

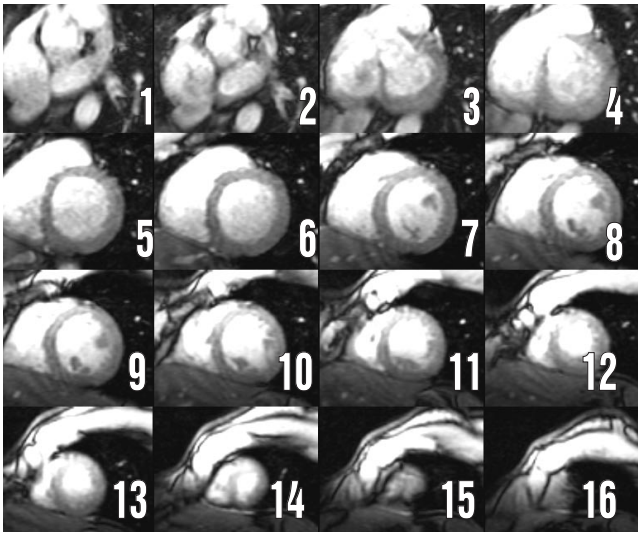
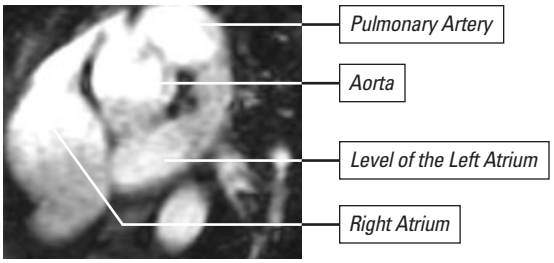
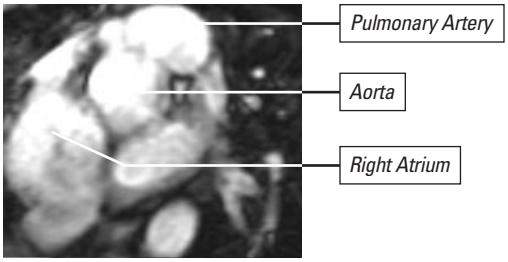


Figure 31:

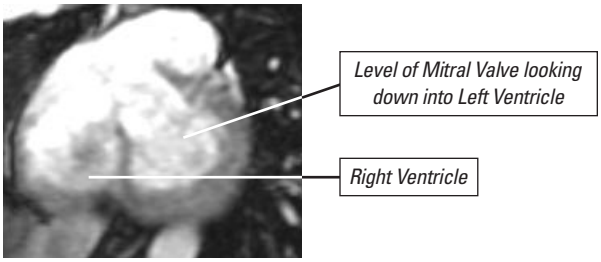
Short-axis images demonstrating 16 slice locations from base to apex. Each slice location has 20 phases acquired during a single breathhold.



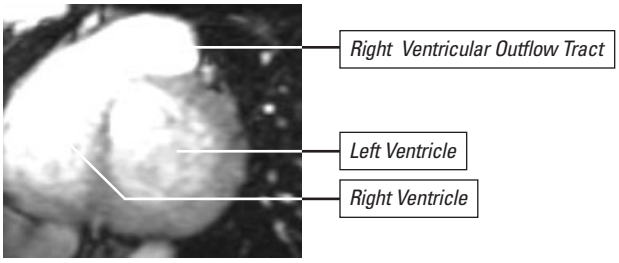
Slice location 1.



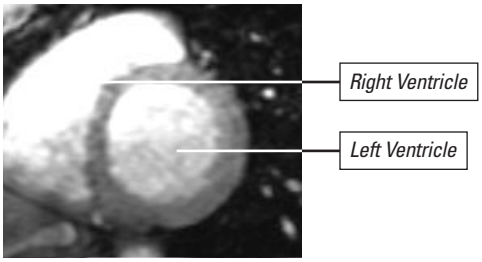
Slice location 2.



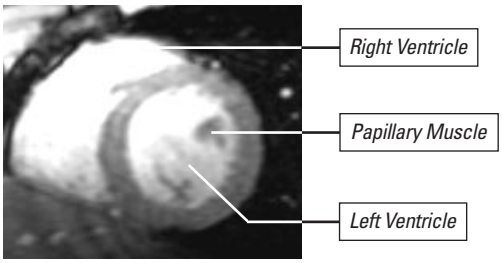
Slice location 3.



Slice location 4.



Slice location 5.



Slice location 7.

Application

- Use a short-axis plane for regional LV wall motion assessment.
- Quantification of LV and RV volumes, ejection fraction and mass.

How To

PARAMETER	SCAN VALUE	PARAMETER	SCAN VALUE	IMAGING OPTIONS	GAT/RESP OPTIONS	
Plane	Oblique	Slice Thk	8mm	Gat, FC, Seq	Trig Type: Select Best Lead	
Mode	2D	Slice Space	0.0		Trig Win:	20%
PSD	FastCard SPGR	Frequency	256		Trig Delay:	Min
TE	Minimum Full	Phase/PFOV	128/0.75		Cardiac Phases:	20
TR	N/A	NEX	1		VPS:	4 to 8
Flip	20 degrees	Freq. Direction	Unswap			
RBW	31.25	Ctr. Frequency	Water			
FOV	36-40cm	Auto Shim	On			

Comments

- Prescribe the short-axis images perpendicular to the septum. To check for image wrap-around, prescribe from the base to the apex (figure 30).
- Adjust the VPS and number of locs before pause for a breathhold scan.
- Number of cardiac phases to Recon: use Auto for FastCard or enter 20 for FASTCINE.
- Use Resp Gate/Trig for non-breathhold scans.
- Acquire each location as a breathhold, 10-15 seconds per location (figure 31).
- Consider .5 NEX for patients having difficulty with the breathhold time.
- If the acquisition is aborting due to triggers outside of the Arrhythmia Rejection Window, open the User CV Screen and enter “1” to turn Automatic Arrhythmia Monitoring off. (Arrhythmia Rejection is still on. Therefore, if triggers are detected outside the rejection window, the data obtained during that cycle will be discarded and must be obtained again. This will increase the scan time.)

Radial Views

Description

Once the short axis has been obtained, radial views of the heart can be prescribed. These views can be acquired as multi-slice, multi-phase FASTCINE acquisition.

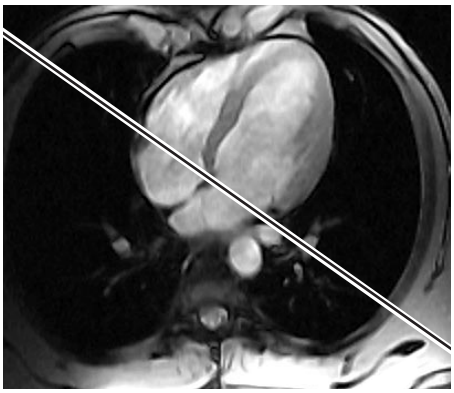


Figure 32:
Axis plane showing the slice level in which the radial views are graphically prescribed from slice pictured below.

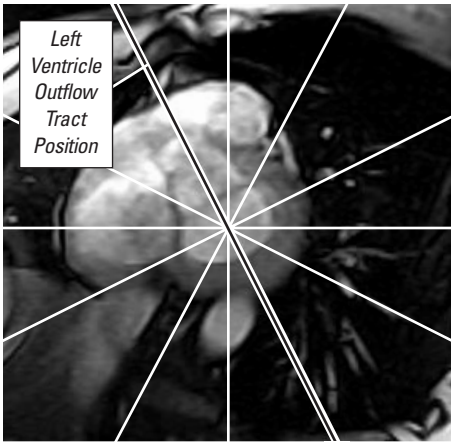


Figure 33:
Start with the first slice location, prescribe thru the left ventricle bisecting the left ventricular outflow tract.

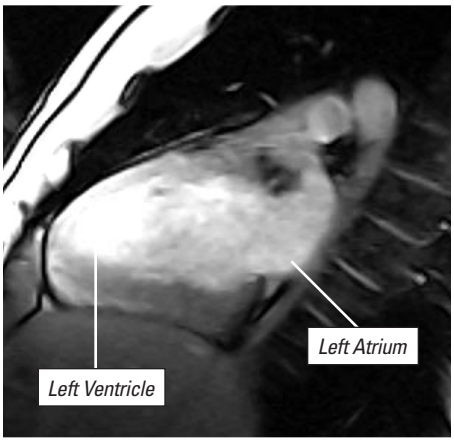


Figure 34:
Two chamber view (also referred to as a long-axis plane).

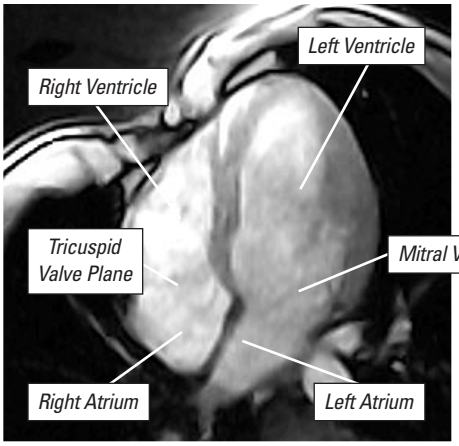


Figure 35:
Four chamber view (also referred to as a long-axis plane).

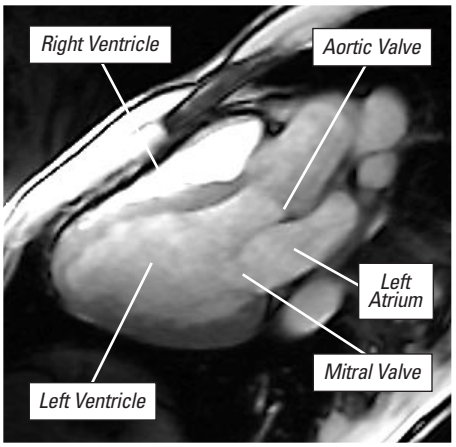


Figure 36:
Left ventricular outflow track or parasternal view (also referred to as a long-axis plane).

Application

Radial views are considered left ventricular long-axis images. Prescribing long-axis images radially oriented around the center of the ventricle every 30 degrees yields a set of six long-axis images. These images provide uniformity of coverage of the left ventricle and give an overview of the cardiac chambers.

The left ventricular outflow track image (figure 36) can be very sensitive for the detection of aortic regurgitation. In contrast to mitral regurgitation, most of the aortic regurgitant is usually visualized because the left ventricular outflow track is smaller than the left atrium, and the regurgitation is less likely to be eccentric. Two-chamber (figure 34) and four-chamber (figure 35) views, similar to standard echocardiography views, are also obtained from this prescription.

How To

PARAMETER	SCAN VALUE	PARAMETER	SCAN VALUE	IMAGING OPTIONS	GAT/RESP OPTIONS	
Plane	Oblique	Slice Thk	8mm	Gat, FC, Seq	Trig Type: Select Best Lead	
Mode	2D	Slice Space	0.0		Trig Win:	20%
PSD	FastCard SPGR	Frequency	256		Trig Delay:	Min
TE	Minimum Full	Phase/PFOV	128/0.75		Cardiac Phases:	20
TR	N/A	NEX	1		VPS:	4 to 8
Flip	15 degrees	Freq. Direction	Unswap			
RBW	31.25	Ctr. Frequency	Water			
FOV	36-40cm	Auto Shim	On			

Comments

- Start with an imaging plane, perpendicular to the short axis (figure 32), that includes the left ventricular outflow track and is centered on the LV apex (figure 33). Then prescribe long-axis images radially oriented around the center of the ventricle every 30 degrees (figure 33). This will produce an image equivalent to the echocardiograph three-chamber view, also called the left ventricular outflow track or parasternal view.
- Adjust the VPS and number of locs before pause for a breathhold scan.
- Number of cardiac phases to Recon: use Auto for FastCard or enter 20 for FASTCINE.
- Use Resp Gate/Trig for non-breathhold scans.
- Acquire each location as a breathhold, 10-15 seconds per location.

Coronal Ascending Aorta Plane

Description

From a sagittal image, a coronal plane prescribed through the aorta yields a coronal orientation. This view can be prescribed as a single-slice, multi-phase FASTCINE acquisition.

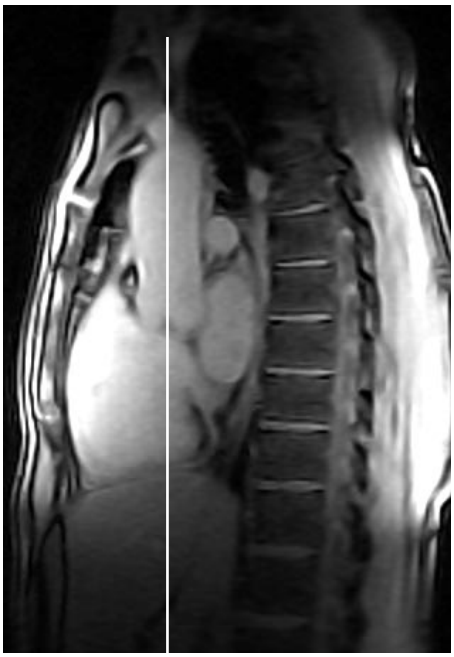


Figure 37: Graphic Rx prescription.

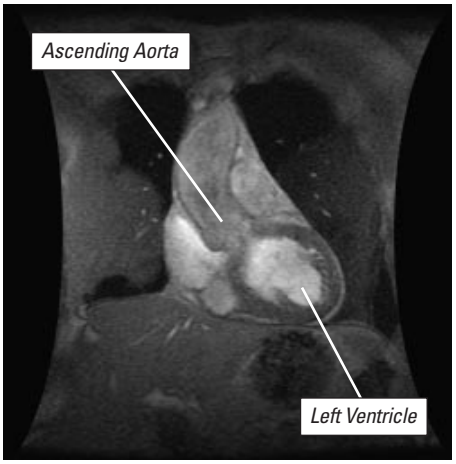


Figure 38: Ascending aorta plane.

Application

The coronal ascending aorta plane is used for assessment of:

- Ascending aorta pathology.
- Aortic regurgitation.

How To

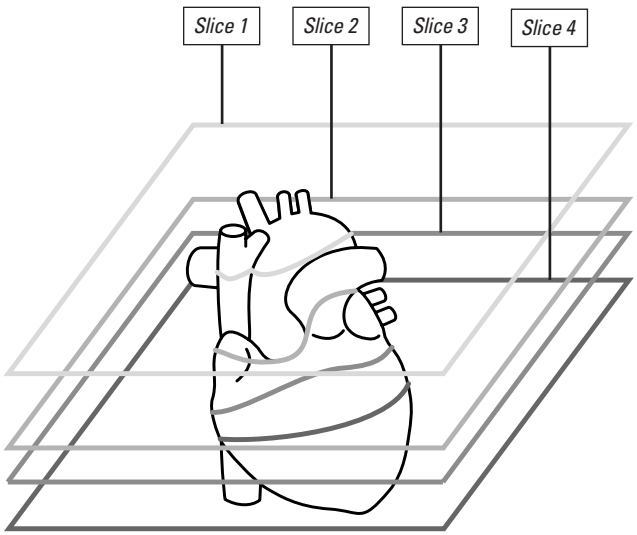
PARAMETER	SCAN VALUE	PARAMETER	SCAN VALUE	IMAGING OPTIONS	GAT/RESP OPTIONS	
Plane	Oblique	Slice Thk	8mm	Gat, FC, Seq	Trig Type: Select Best Lead	
Mode	2D	Slice Space	0.0		Trig Win:	20%
PSD	FastCard SPGR	Frequency	256		Trig Delay:	Min
TE	Minimum Full	Phase/PFOV	128/0.75		Cardiac Phases:	20
TR	N/A	NEX	1		VPS:	4 to 8
Flip	15 degrees	Freq. Direction	Unswap			
RBW	31.25	Ctr. Frequency	Water			
FOV	36-40cm	Auto Shim	On			

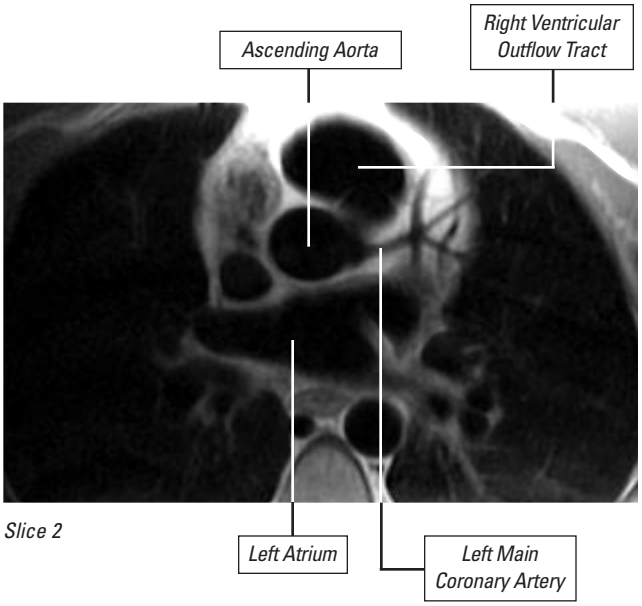
Comments

- From the sagittal localizer, prescribe a coronal plane through the aorta (figure 37).
- Acquire as a breathhold, 10-15 seconds.

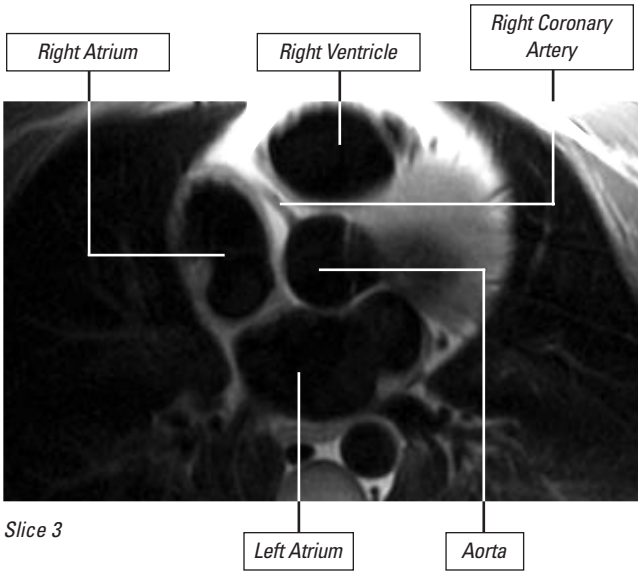
Orthogonal Imaging Planes –Transverse (Axial)

These images were acquired using the Double-IR sequence. The Double-IR sequence can be used in oblique planes as well. Protocol on page 30.

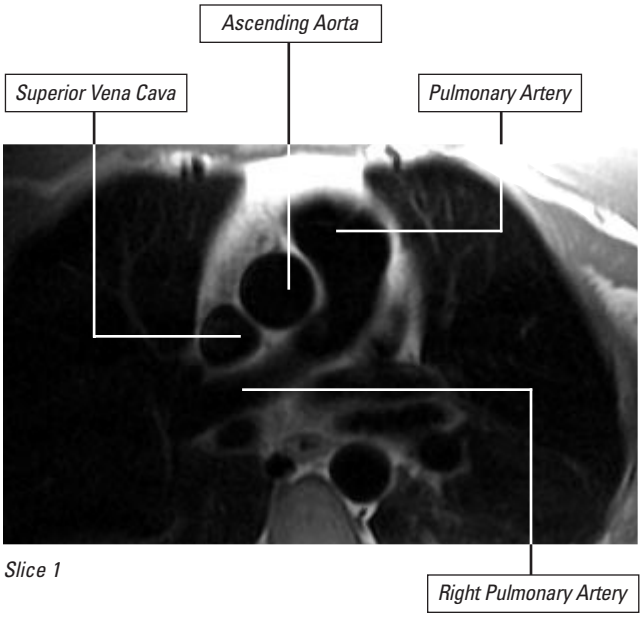




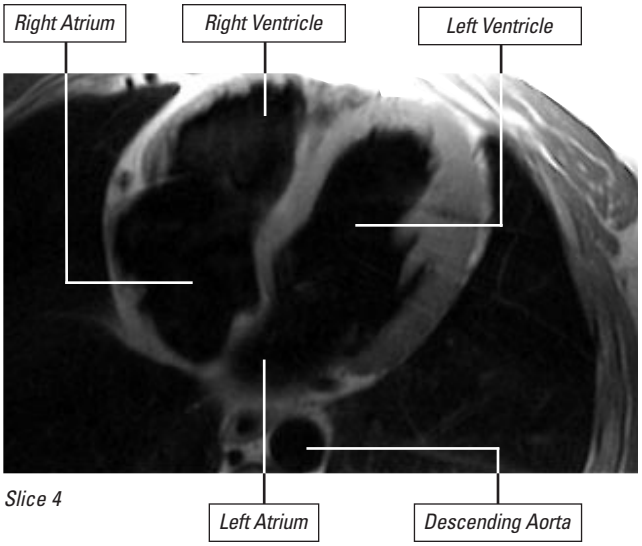
Slice 2



Slice 3

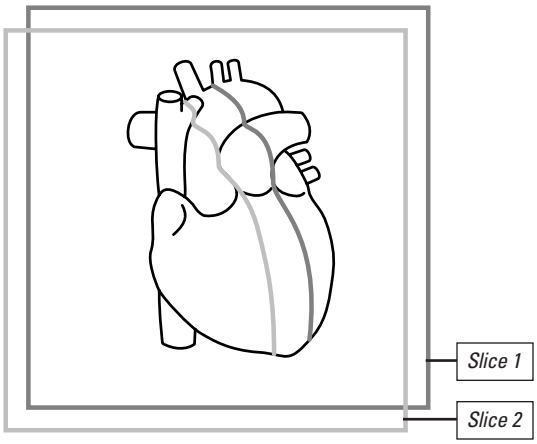


Slice 1

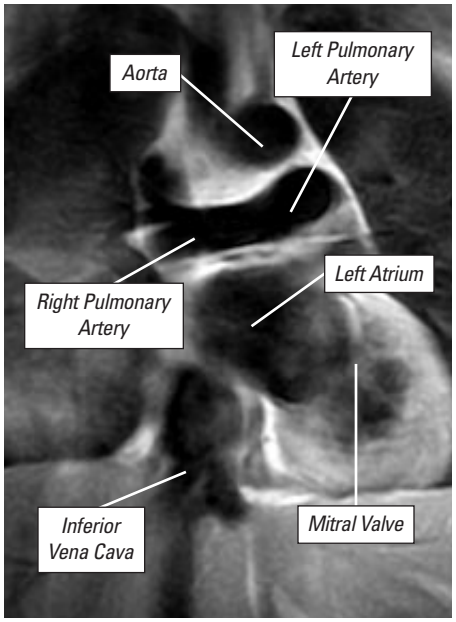


Slice 4

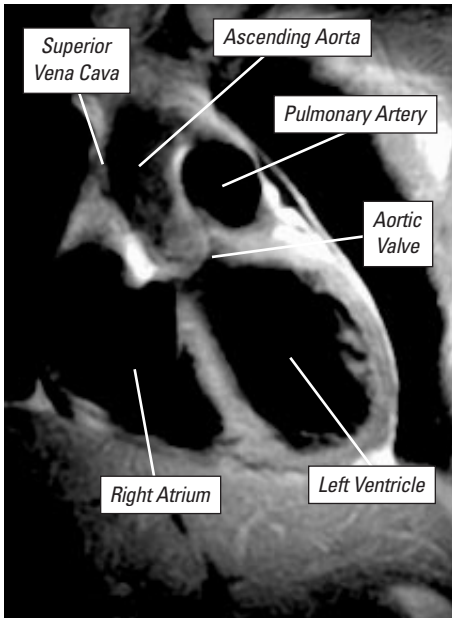
Coronal Plane



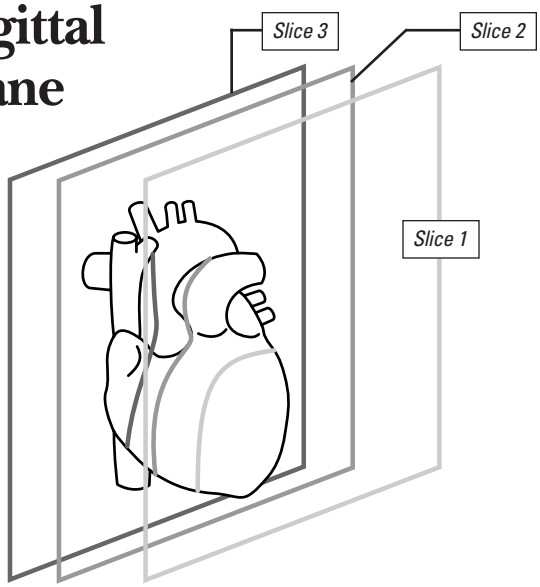
Slice 1



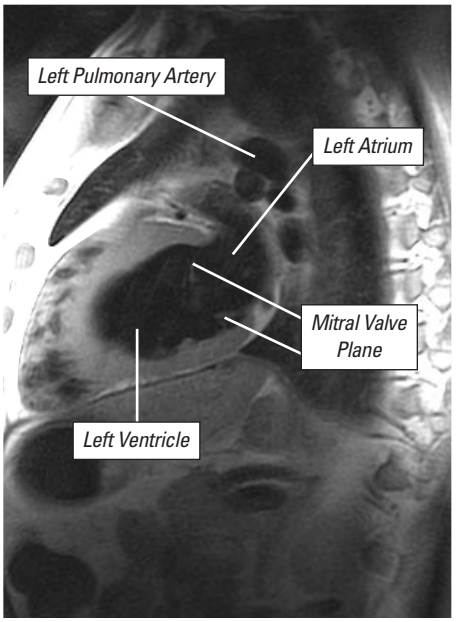
Slice 2



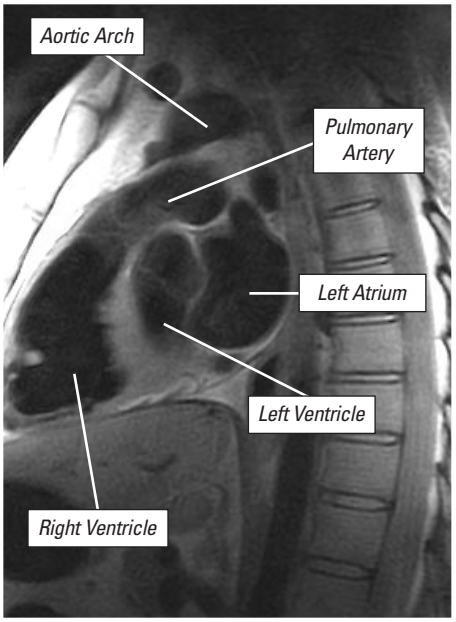
Sagittal Plane

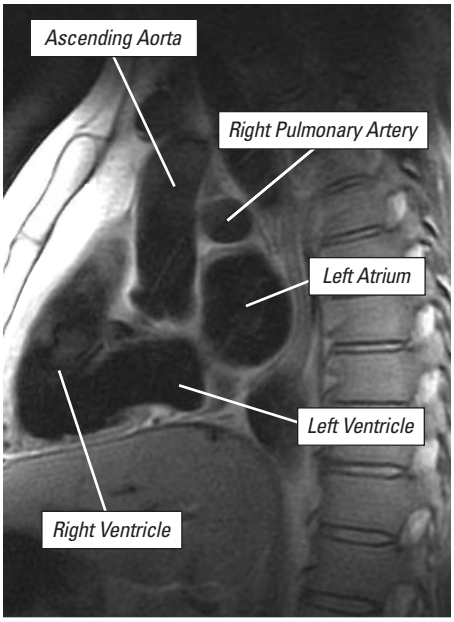


Slice 1



Slice 2





Slice 3

How To

PARAMETER	SCAN VALUE
Plane	Any
Mode	2D
PSD	FSE Type in: FSE-XL
TE	20-40
TR	N/A
ETL	32
RBW	62
FOV	32-40cm

PARAMETER	SCAN VALUE
Slice Thk	3-8mm
Slice Space	Dependent on Coverage Needed
Frequency	256
Phase/PFOV	256/0.75
NEX	1
Freq. Direction	Default
Ctr. Frequency	Water
Auto Shim	On
Phase Correction	Off

IMAGING OPTIONS
Gat, FC, Seq
ZIP 512 Blood Suppression

GAT/RESP OPTIONS	
Trig Type: Select Best Lead	
Trig Win:	20%
Trig Delay:	Min
2XRR is on automatically	

Comments

- Acquire as a breathhold, 10-20 seconds per slice location.
- Can also be used as a localizer. Increase the NEX and acquire as a non-breathhold.
- For Triple-IR, select FSE-IR from the pulse sequence screen.

Glossary of Terms

Akinesis

Wall motion abnormality characterized by absent systolic motion. Akinesia is generally associated with severe infarction or cardiomyopathy.

Aneurysm

A circumscribed sac caused by dilation of the wall of an artery, a vein or the heart wall.

Angina Pectoris

Severe constricting pain in the chest, often radiating to the left shoulder and arm and/or to the jaw, due to myocardial infarct and ischemia.

Angiography

The roentgenographic visualization of blood vessels following the introduction of contrast material; used as a diagnostic aid in conditions such as myocardial infarct and ischemia.

Apex of the Heart

The blunt rounded tip of the heart forming the left ventricle. The apical portion of the ventricular myocardium is thinner than other portions.

Arrhythmia

Any variation from the normal rhythm of the heartbeat.

Artifact

An error in the reconstructed image that does not correspond to the patient. Three major forms of artifacts that can occur in MR imaging and cause poor image quality: geometric distortion, inhomogeneous signal intensity, and spurious signal.

Base of the Heart

The region formed by the atrium and roots of the great vessels; thus, the "top" of the heart, located opposite the apex of the heart.

Beats per Minute (BPM)

The average heart rate as shown by the cardiac waveform display.

Bundle Branch Block

A defect in the heart's electrical conduction system in which there is a failure to conduct electricity down either the left or the right bundle of His.

Bundle Branches

The right and left conduction pathways continuing from the bundle of His and proceeding along both sides of the interventricular septum to the tips of the ventricles.

Cardiac Catheterization

The introduction of the catheter from outside the body, into the heart, through blood vessels. The catheter may be introduced into one of the heart's chambers, or it may be guided into one of the coronary arteries, or both.

Cardiac Output

Liters of blood pumped by each of the ventricles per minute. Stroke Volume x Heart Rate.

Cardiomegaly

Enlargement of the heart.

Cardiomyopathy

Disease of the muscular wall of the heart which impedes filling and/or emptying of the cardiac chamber.

Cine

Software that lets you generate images for dynamic views of such anatomy as the heart. This option employs retrospective gating techniques and a Gradient Echo pulse sequence.

Congestive Heart Failure (CHF)

The syndrome of tissue congestion and edema that develops with failure of the heart to maintain adequate circulation of blood. The congestion may occur in the lungs (pulmonary edema), in the peripheral circulation, or in both, depending on whether the failure is of the left ventricle, right ventricle, or both.

Coronal

The horizontal plane along the longitudinal axis of the body dividing it into anterior (front) and posterior (back) halves.

Coronary Arteries

The right and left coronary arteries, which branch off the aorta to supply the heart muscle with oxygen and nutrients.

Coronary Artery Disease (CAD)

A disease state that affects the coronary arteries, such as arteriosclerosis, usually resulting in reduced blood flow capability.

Depolarization

The electrical process by which the resting potential of a polarized, resting cell is reduced to a less negative value or reversed state.

Diastole

The period between the end of the T wave and the beginning of the R wave in the cardiac cycle. Also called ventricular filling.

Dyskinesis

Wall motion abnormality characterized by systolic outward motion, generally in the apex. May be associated with ventricular aneurysm.

Effective R-R Interval (RR)

The inverse of BPM (Beats per Minute) measured in msec: RR = 60,000 divided by BPM.

Effective TR

The "average" repetition time, or TR, in cardiac gating. Measured as the number of RR intervals between successive excitations of a particular slice location.

Ejection Fraction

Measurement of the percentage of blood pumped out of the ventricle in each cardiac cycle.

Electrocardiogram (ECG or EKG)

Graphic representation of the electrical activity generated as a result of the depolarization and repolarization of the atria and ventricles.

Embolus

A dislodged blood clot (thrombus) or other material brought by the blood from one vessel that may lodge in a smaller one and thus obstruct blood flow.

Fast Cardiac Gating (FastCard)

A 2D Time-of-Flight, Fast, Gradient Recalled, single-breath PSD for acquiring multiple phases of the cardiac cycle at a single slice location.

Fat/Water Suppression (F/W)

An imaging enhancement that suppresses signal within the imaging volume from either fat or water by applying a frequency-selective saturation pulse.

FGRE 3D

A 3D Fast GR/SPGR sequence with a vascular option. This PSD creates collapsed and projection images and provides the shortest TE and TR times possible.

Fibrillation

Rapid, incomplete, uncontrollable quivering of the atria or ventricles.

Flow

A measure of the volume of displacement per unit of time, expressed as cm3/sec.

Flow Compensation (Flow Comp)

An imaging enhancement using the system's gradients to put flowing protons into phase with stationary protons, thereby reducing flow artifacts. Applied in the slice and frequency directions.

Fractional NEX

A feature instructing the system to use about half or exactly three-quarters of the phase encodings acquired in conventional imaging. Cuts scan time significantly.

Frequency

The scanning direction associated with the frequency gradient. Usually corresponds to the image's long axis.

Gating

An MR technique for imaging rapidly moving anatomy such as the heart. Uses equipment such as a standard electrocardiograph to trigger data acquisition.

Gradient Echo

A basic Fast Scan pulse sequence that uses pulses of 1 to 180 degrees to excite the protons of interest and rephase them. Gradient Echo uses gradients rather than conventional RF pulses. Permits short TRs and flip angles of less than 90 degrees to excite only a portion of the longitudinal magnetization.

Gradients

1. The magnetic fields that are added to, or subtracted from, the main field to make it stronger in some locations than others.
2. Waveforms, generated by the Pulse Control Module, which instruct the gradient amplifiers and coils inside the magnet to modify the static magnetic field by adding or subtracting field strength, and by how much.

Graphic Prescription (Graphic Rx)

The prescription of an image by placing a cursor on a localizer image to "draw" slice locations.

Heart Block

An interruption of the normal physiological function of the AV node resulting in the dissociation of the atrial and ventricular rhythms.

Hypertrophy

Enlargement or overgrowth of an organ due to an increase in size of its constituents' cells.

Hypokinesis

Wall motion abnormality characterized by decreased systolic wall motion. Associated with infarction, ischemia and cardiomyopathy.

Image Acquisition Time

Scanning time, the product of TR, NEX, and the number of encoding steps. The number of encoding steps is a product of the number of phase encoding views, the number of slices in a 3D volume scan, and the number of flow encodings in a Phase Contrast scan.

Infarction

An area of coagulation necrosis in a tissue due to partial or total obstruction of circulation to the area, most commonly by thrombus or embolus.

Inversion Recovery (IR)

A pulse sequence that inverts the magnetization and then measures the recovery rate as the nuclei return to equilibrium. This rate of recovery depends on T1.

Inversion Time (TI)

The time between the center of the first (180-degree) inverting pulse and the beginning of the second (90-degree) refocusing pulse in an IR pulse sequence.

Ischemia

The state of a tissue that is receiving insufficient blood to meet its metabolic needs. Ischemia may be reversible or irreversible, depending upon the cause of the insufficiency.

Number of Excitations (NEX)

The number of times a pulse sequence is repeated in a given acquisition.

Oblique Imaging

An acquisition method that allows you to obtain images in a variety of different planes. This can result in an image taken in a tilted or rotated plane through a localizer image.

Orthogonal Planes

Planes that are perpendicular to one another, for example, axial, sagittal, and coronal planes.

Papillary Muscles

Rounded or conical muscular projections from the walls of the ventricles that connect via delicate fibrous cords to the cusps of the atrioventricular valves. Their insertions are sometimes seen as "blips" on perfusion images.

Partial Volume Effect

Result which occurs when image voxels contain both fat and water, causing an almost complete signal void in the affected voxels. In Cardiovascular MR, this can occur when the short-axis slices are too thick and the ventricular volume is overestimated due to the curvature of the ventricular edge, especially near the apex.

Pericardial Effusion

Accumulation of serous fluid, pus or blood between the two layers of pericardium. This effusion may prevent adequate filling of the chambers and reduce cardiac output.

Peripheral Gating

A gating technique useful in studies of the central nervous system, particularly in the head and cervical spine. Peripheral gating minimizes the artifacts caused by pulsatile cerebrospinal fluid flow. It gates from the mechanical action of blood pulsing through the body.

Phase

1. A distinguishable period of time within a cardiac cycle – systole, for example.
2. The scanning direction associated with the phase gradient, usually corresponding to the image's short axis.
3. The position of a spinning proton.

Physiological Acquisition Controller (PAC)

The device that collects triggering information from a bellows, ECG lead or photopulse sensor and sends it on to the system to trigger acquisitions.

Presaturation (SAT)

An imaging option that minimizes artifacts that may result from scanning anatomy subject to motion. SAT saturates spins outside the FOV with extra RF pulses to flip flowing protons into the transverse plane. Protons dephased by gradient pulses can't create a signal that results in artifacts.

Region of Interest (ROI)

A user-defined area on an acquired image used to perform and display statistical analysis.

Regurgitation

Backward flow of blood into the ventricles of the heart from the aorta or pulmonary artery, or into the atria from the ventricles, due to valvular incompetency.

Repolarization

The electrical process by which a depolarized cell returns to its polarized, resting state.

R-R Interval

That part of an ECG waveform representing the heart's electrical activity showing the time between the peak of one R wave and the peak of the next one. Each R-R interval represents the length of one cardiac cycle.

Sagittal Plane

A plane dividing the right side of the body from the left.

SAT

See Presaturation.

Signal-to-Noise Ratio (SNR)

The ratio of signal amplitude to noise – i.e., the amplitude of signal emitted by the patient's protons, divided by the amount of patient noise and electronic noise inherent in any electronic instrument. Also called S/N.

Spatial Resolution

That distance between two points at which the points can be distinguished as being separate and distinct – partly a function of voxel size. Defines how small an object can be distinguished in an image and therefore, contributes to the overall clarity of the image.

Stroke Volume

The amount of blood ejected from the ventricular during a single beat. Left ventricular end – diastolic volume; ventricular end – systolic volume.

Subendocardial Infarction

Infarction that involves only the layer of muscle beneath the endocardium, and thus not the entire thickness of the myocardial wall.

Supine Position

Describes the position of a patient lying face up on the cradle.

Surface Coil

An RF coil that is placed on or near the surface of the region of interest to be imaged, for a higher signal-to-noise ratio.

Systole

The period between the R wave and the end of the T wave. Also known as ventricular contraction.

Temporal Resolution

The shortest time that can be used to distinguish events in, for example, the cardiac cycle.

Transmural Infarction

Infarction that involves the entire thickness of the myocardium.

Trigger

In cardiac gating, the signal sent by the cardiac monitor to activate data acquisition.

Trigger Delay

In Signa gating, the time between the occurrence of the triggering pulse and the actual onset of imaging.

Trigger Window (TW)

In cardiac gating, a period during which no further data can be acquired. During this period, the system waits for the next R wave trigger, which initiates a new sequence of data acquisition.

Unstable Angina

A more severe and ominous type of angina characterized by severe pain lasting several minutes. The pain may occur at periods of rest and relaxation. Myocardial infarct and arrhythmia may occur due to tissue damage from decreased myocardial blood flow.

Vascular Occlusive Disease

The narrowing of the vessel lumen due to a pathologic process such as atherosclerotic disease.

Ventricular Aneurysm

Dilation or outpocketing of the ventricular wall during systole, caused by healing with fibrosis and scar formation of infarcted myocardium.

Viable Myocardium

The term applied to myocardium that is alive, even if ischemic, in tissue zones with reduced perfusion. Cell function may improve after revascularization/reperfusion.

Views Per Segment (VPS)

Number of k-space lines acquired per cardiac phase during an R-R period.

Volume Imaging

An acquisition technique in which signal is collected from an entire volume rather than individual slices. Permits reconstruction of extremely thin slices, and usually enhances SNR.

Measurements of Ventricular Function

CO: Cardiac Output
CI: Cardiac Index
SV: Stroke Volume
SVI: Stroke Volume Index
EF: Ejection Fraction
EDV: End Diastolic Volume (LVEDV)
ESV: End Systolic Volume (LVESV)

CO = SV x beats per minute

$$CI = \frac{CO}{BSA}$$

SV = LVEDV - LVESV (left ventricle)

$$SVI = \frac{SV}{BSA}$$

$$EF\ [\%] = \frac{SV}{EDV}\ \text{(left ventricle)} \times 100$$

BSA = Body Surface Area [m^2]

Acronyms

AV: Atrioventricular
BPM: Beats Per Minute
CVMR: Cardiovascular Magnetic Resonance
ECG: Electrocardiogram
EPI: Echo Planar Imaging
ET: Echo Train
ETL: Echo Train Length
FC: Flow Comp
FOV: Field Of View
FSE: Fast Spin Echo
GAT: Gating
GRE: Gradient Recalled Echo
IR: Inversion Recovery
LAD: Left Anterior Descending (Coronary Artery)
LCX: Left Circumflex (Coronary Artery)
LV: Left Ventricle
MRA: Magnetic Resonance Angiography
MRI: Magnetic Resonance Imaging
NEX: Number of Excitations
PFOV: Phase Field Of View
PSD: Pulse Sequence Description
RBW: Received Band Width
RCA: Right Coronary Artery
RV: Right Ventricle
SA: Sinoatrial
SPGR: Spoiled Gradient Echo
STIR: Short-Tau Inversion Recovery
TE: Echo Time
TI: Inversion Recovery Time, Prep Time
TR: Repetition Time

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GE Medical Systems – Americas: Fax 414-544-3384
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GE Medical Systems – Europe: Fax 33-1-30-70-94-35
Paris, France

GE Medical Systems – Asia:
Tokyo, Japan – Fax: +81-425-85-5490
Hong Kong – Fax: +852-2559-3588