Cardiac MR:
A Practical Imaging Guide

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Gay has presented at various meetings, most recently at the SCMR GE User’s meeting. She has poster presentations for “SWIFT” Switch on the fly Technique: A Method for Enabling High-Channel RF Coils with a Lower Number of System Receivers at SCMR and NASCI, and is also cited on “Utility of Fast Cine Magnetic Resonance Imaging and Display for the Detection of Myocardial Ischemia in Patients Not Well Suited for Second Harmonic Stress Echocardiography”.

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Chapter 1

Vector Gating
Vector Gating

The majority of cardiac MRI pulse sequences must be synchronized with the cardiac cycle. Robust ECG gating is a critical factor in the acquisition of diagnostic images of the heart. Due to the magnetohydrodynamic effect, elevated T-waves may lead to false triggering when using a standard amplitude based ECG detection algorithm. With the vector gating (VCG) approach two leads are monitored simultaneously and by using pattern recognition results in higher accuracy of the detection of the R wave. VCG patient set-up is simple and easy to reproduce. From reported user clinical experience VCG virtually eliminates the need for multiple electrode placement trials thus reducing patient set-up time.

Quick Steps for VCG Set-up

- Use new MRI compatible electrodes.
- Shave chest hair if necessary.
- Use an abrasive gel to prep the patient’s chest to help improve the detection of the electrical activity of the heart.
- Anterior placement of the electrodes for VCG is shown.
- Connect the leads in a paired order (RA, LL and RL, LA). They can be connected in either order as long as the pairs are orthogonal.
- Initialize VCG by performing a Gating Reset.

VCG Tips

- VCG I or VCG II can be selected independently.
- Visually inspect the accuracy of the triggers on both vectors while scanning.
- Manually select the vector that is triggering correctly if needed.
- In recording A the VCG-I QRS complex is more robust yielding accurate triggering.
- In recording B VCG-II demonstrates an elevated T wave, however VCG-I is not effected and is triggering accurately.
Chapter 2

Standard Cardiac Imaging Views
Standard Cardiac Imaging Views

1. Method #1 Initial Localizer Plane

**Method 1: Standard Cardiac Imaging Views:**

- Sagittal or 3-Plane Localizer or MR-Echo
- Long Axis Localizer: FIESTA
- Short Axis Stack: FIESTA
- 3-Chamber View: FIESTA
- 2-Chamber View: FIESTA
- 4-Chamber View: FIESTA
- Optional: RVOT View FIESTA

**Sequence:** Acquire either a sagittal plane using non-gated FIESTA or a 3-plane localizer. With the sagittal localizer the coil positioning can be checked. MR Echo can be used for localization of all cardiac scan planes.

From a dedicated orthogonal plane a long axis localizer of the heart is obtained. The long axis localizer can be obtained by using the following scan planes methods as pictured below.

**Short Axis Sequence:**

**Key Points:** The short axis stack covers from base to apex. Each slice location is usually acquired during a breath-hold. It is best to instruct the patient to hold their breath during end-expiration. Use the volume shim feature for optimal image quality.

**Example short axis prescription is shown using the MR Echo application. Further optimization for a shorter breath hold times in patients with irregular heart rates can be achieved by setting the parameters to acquire within 1 heartbeat.**

**Complete short axis stack. The left ventricle has a donut shape appearance.**

**Key Applications:**

- Assessment of global and regional ventricular function.
- Quantification of LV and RV volumes, ejection fraction and LV mass.
Long Axis Views: 3-Chamber, 2-Chamber, 4-Chamber

3-Chamber, Left ventricular outflow tract (LVOT)
Sequence: FIESTA
Key Point: Select a short axis slice location at the level of the base of the heart. Bisect the aortic outflow tract as shown.

Key Applications:
• Assessing the anteroseptal and inferolateral walls of the left ventricle
• Assessment of mitral and aortic valve
• Assessment of left atrial size

2-Chamber
Sequence FIESTA
Key Point: Use a mid-ventricular short axis slice as a guide. The 2-chamber view is prescribed by placing a slice parallel to the septum bisecting the anterior and inferior walls of the left ventricle.

Key Applications:
• Evaluation of anterior and inferior wall motion
• Assessment of the left atrial appendage and mitral valve

4-Chamber
Sequence FIESTA
Key Point: Use a mid-ventricular short axis slice as a guide. The 4-chamber view is prescribed by placing a slice bisecting the highest curvature of the right ventricle (outlined in white). Avoid the left ventricular outflow tract.

Key Applications:
• Evaluation of the septal and lateral wall motion of the left ventricle
• Assessment of mitral and tricuspid valve function
• Assessment of the size and function of the right ventricle

AV = aortic valve
LA = left atrium
LV = left ventricle
RA = right atrium
RV = right ventricle
2. Method #2 Initial Localizer Plane

Method 2: Standard Cardiac Imaging Views:
- 3-Plane Localizer or Axial Localizer or MR-Echo
- Vertical Long Axis Localizer: FIESTA
- Horizontal Long Axis Localizer: FIESTA
- Short Axis Stack: FIESTA
- 3-Chamber View: FIESTA
- 2-Chamber View: FIESTA
- 4-Chamber View: FIESTA
- Optional: RVOT View FIESTA

Sequence: Acquire either an axial localizer using non-gated FIESTA or a 3-plane localizer. With a mid ventricular axial image a vertical long axis can be obtained. MR Echo can be used for localization of all cardiac scan planes.

From a dedicated transverse plane a vertical long axis (VLA) of the heart is obtained. The VLA localizer can be obtained by using the following scan plane method as pictured below.

Prescribe the slice along the long axis of the left ventricle bisecting the apex (outlined in white) and mitral valve plane.

Sequence: FIESTA.
Using the VLA view a Horizontal Long Axis (HLA) can be obtained. Prescribe the HLA view by bisecting the apex (outlined in white) and mitral valve.

Right Ventricular Outflow Tract View

Sequence: FIESTA
Key Point: Use a short axis slice at the level of the mitral valve plane. Prescribe a slice through the RV and outflow tract as shown.

Ao = aorta
Pa = pulmonary artery
RA = right atrium
RV = right ventricle
SVC = superior vena cava

Key Applications:
- Assessment of right ventricular outflow tract stenosis
- Assessment of pulmonary valve insufficiency
- Assessment of tricuspid valve

Short Axis from HLA

Sequence: FIESTA
Key Point: The short axis stack covers from base to apex. Each slice location is usually acquired during a breath-hold. It is best to instruct the patient to hold their breath during end-expiration. Use the volume shim feature to improve image quality.

From the HLA view the short axis is prescribed perpendicular to the left ventricular wall and septum (outlined in white). Start above the mitral valve plane and prescribe a couple a slices beyond the apex.
Chapter 3

Adult - Clinically Optimized Protocols
Adult - Clinically Optimized Protocols:

3a Anomalous Coronary Artery
3b Aortic Valve Evaluation
3c Arrhythmogenic Right Ventricular Dysplasia (ARVD)
3d Cardiac Mass Evaluation
3e Hypertrophic Cardiomyopathy (HCM)
3f Ischemic Heart Disease
3g Mitral Valve
3h Myocardial Delayed Enhancement (MDE)
3i Patent Foramen Ovale (PFO)
3j Pericardial Diseases
3k Pulmonary Vein Stenosis/Atrial Ablation
3l Shunt Quantification
Anomalous Coronary Artery Imaging

Clinical Background:
Anomalous coronary arteries have been described as an important cause of sudden cardiac death in young athletes. Although they occur in 1% of the general population, congenital coronary anomalies are the second most common cause of sudden cardiac death in young athletes’ population after hypertrophic obstructive cardiomyopathy.

Identification of unfavorable anomaly is clinically important to counsel the patient regarding competitive physical activity. Cardiac MR is uniquely suited for this clinical scenario because of its ability to examine the origins and course of coronary arteries as well as to evaluate other differential diagnoses. The imaging goal for the technologists is to identify the course of the right and left coronary origins.

This protocol outlines scan planes that can be used to rule out anomalous or aberrant coronary arteries or coronary artery aneurysms that are commonly seen with Kawasaki Disease.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence.

2. Long Axis Localizer can be obtained from either the Sagittal or Axial plane.

3. Left Coronary Artery (LCA) and Right Coronary Artery (RCA) Origins
A: From a coronal localizer, prescribe a slice through the aortic root using gated FIESTA
B: Resulting aortic root localizer image,
C: From the aortic root image B prescribe a stack of slices perpendicular to the aortic wall at the root using Double-IR FSE or a 3D slab using gated 3D FIESTA
D: If the 3D sequence was used images can be reformatted to show the right and left coronary origins.

4. Right Coronary Artery (RCA) Localization
A: The RCA lies in the aterioventricular (AV) groove (white arrows).
B: From a long axis localizer or a 4-chamber view use a diastolic phase and prescribe a stack of slices using Double-IR FSE or a 3D slab using gated 3D FIESTA just parallel with the mitral valve plane and angled with the notches of the AV groove.
C: If the 3D sequence was used images can be reformatted to show the right coronary artery.

Example Clinical Case: Double-IR FSE image showing normal right and left coronary origins. No vessels identified coursing between the aorta (Ao) and pulmonary artery (PA).
Example Clinical Cases: Anomalous RCA origin and aberrant coronary artery.

A: Reformatted gated 3D FIESTA images showing an anomalous RCA (arrow) passing between the aorta (Ao) and main pulmonary artery (MPA). This is considered unfavorable geometry.

B: Reformatted gated 3D Fiesta images showing an aberrant coronary (arrow) arising from its own origin at the right coronary cusp.

5. Method 1: Left Main (LM) and Left Anterior Descending (LAD) Coronary Artery Localization

A: LCA can be localized from a coronal plane. Prescribe a stack of slices using Double-IR FSE or a 3D slab, using gated 3D FIESTA. Position just below the main pulmonary artery angled with the left ventricle. If the left main segment of the LCA is not seen, change the angle as needed.

B: Reformatted gated 3D FIESTA image showing the left main and LAD.

Method 2: Left Main (LM) and Left Anterior Descending (LAD) Coronary Artery Localization

A: From the view of the root which the origins can be seen, locate the left main origin. Prescribe a stack of slices using Double-IR FSE or gated 3D FIESTA. Position slab parallel to the LM origins.

B: From the resulting image B, prescribe a stack of slices using Double-IR FSE or gated 3D FIESTA along the course of the vessel.

C: Reformatted gated 3D FIESTA image showing the left main and LAD.

Example Case: Anomalous Left Main coronary artery

A: Double-IR FSE breath-hold images (6 mm slice thickness) parallel to AV show the left main vessel (arrows) coursing between the aorta and pulmonary artery. Normal origin of the left main was not seen.

B: To confirm the course of the left main a slice was prescribed perpendicular to the vessel.

C: Resulting image shows the left main coronary artery positioned between the aorta and pulmonary artery. Clinically this is considered unfavorable geometry.

Key Scanning Points:

- Optimize imaging planes by using the multi-plane viewers in graphic RX.
- Robust ECG gating is essential for good image quality.
- Breath-holding should be done at end expiration.
- Practice the breath-hold instructions with the patient before beginning the scan.
- Scan during diastole by altering the trigger delay.
- Gated 3D FIESTA acquisitions can be reformatted to better visualize the arteries.
Aortic Valve Evaluation

Clinical Background: Aortic regurgitation or aortic insufficiency (AI) is the leakage of blood, back through the aortic valve, into the left ventricle. This condition can be either congenital or acquired, and may be due to abnormalities of either the valvular apparatus or the aortic root.

Aortic Stenosis is a narrowing of the aortic valve opening causing obstruction of blood flow from the LV to the aorta. The imaging goal of the technologists is to acquire functional images of the valve and quantitative information which includes phase contrast. Clinical staging of patients with valvular disease is important as related to treatment decisions.

1. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views. The 3-chamber view is the best scan plane to evaluate the aortic valve. The true 3-chamber view should be prescribed from a short axis location at the mitral valve plane level.

2. Using the 3-chamber view, direct views of the aortic valve can be prescribed. Prescribe a stack of slices perpendicular to the aortic outflow tract covering the aortic valve.

3. Phase contrast scan plane prescription to quantify AI.

A: Using a sagittal localizer, prescribe an oblique coronal plane thru the ascending aorta.
B: Using resulting image B, prescribe another slice parallel to the aortic root.
C: Using resulting image C prescribe one phase contrast slice perpendicular to the wall of the ascending aorta just above the aortic root.
D: Flow curves can be generated by tracing a region around the aorta with ReportCARD flow analysis.

Case Example: Direct quantification of aortic insufficiency using ReportCARD flow analysis.

A: Coronal FastCINE image demonstrating a regurgitant diastolic jet from the aortic valve. The aortic insufficiency jet is very eccentric.
B: Bicuspid aortic valve acquired with FastCINE.
C: Background corrected aortic flow curve shows severe aortic insufficiency. By adjusting the start phase and end phase the amount of blood leaking back into the ventricle (retrograde flow in red) can be obtained. This patient had a regurgitant volume of 48 ml.
4. Phase contrast scan plane prescription for aortic stenosis evaluation.

A: If the aortic valve is determined to be tight, Phase contrast can be acquired to determine peak velocity. From a long axis image prescribe parallel to the jet in the outflow tract.

B: By using a gradient echo sequence such as FastCINE, jets are visualized more easily. Prescribe a stack of phase contrast slices perpendicular to the jet. Velocity information is quantified with ReportCARD flow analysis.

Key Considerations:
- A complete function exam should be performed for patients with valvular disease. The secondary affects of valvular disease compromise left ventricular performance, which is important information for clinicians.
- Cine temporal resolution of 50 ms or less should be achieved to accurately assess valvular abnormalities.
- Using a gradient echo technique such as FastCINE allows for better visualization of valvular abnormalities because longer echo times are utilized.
- When evaluating for stenotic lesions, set the VENC to the maximum value of 550 cm/sec.
- Irregular heart rates or missed triggers during a phase contrast acquisition will compromise the quantitative results.
- To perform aortic background correction for phase contrast, please refer to the ReportCARD 3.0 operator documentation for exact instructions.
- Manual planimetry of the aortic valve can be performed on the FIESTA images.

Notes

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3b
Arrhythmogenic Right Ventricular Dysplasia (ARVD)

Clinical Background: ARVD is a heart muscle disorder of unknown cause that is characterized pathologically by fibrofatty replacement of the right ventricular (RV) myocardium. These patients often present with irregular heart rates. The imaging goal of the technologists is to obtain detailed views of RV wall motion and RV free wall.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence

2. Right ventricular wall motion evaluation using FIESTA.

Right ventricular wall motion can be assessed using an axial view. Note: In this patient the round shaped RV. A normal RV has a triangular shape.

Using the FIESTA cine sequence prescribe a straight axial plane from the bottom of the heart to the level of the pulmonary artery. These are 6-8 mm thick slices prescribed with no gap.

3. Acquire routine functional views of the heart including short axis, 3-chamber, 2-chamber and 4 chamber views using the FIESTA sequence.

Complete stack of short axis images covering the entire heart from base to apex. This view is used to also assess right ventricular wall motion. Note: Right ventricular enlargement as the right ventricle is visualized down at the level of the LV apex.


A: Axial Double-IR FSE image, each slice location is a breath-hold. Due to length of exam this set of images can be abbreviated, acquire 6mm skip 5mm. Use anterior coil elements and small field of view.
B: Axial Triple-IR FSE acquired with the same slice location. Note the increased signal in the RV wall, this is due to slow moving blood trapped in the trabeculations which is a typical appearance with this sequence.


Sagittal Double-IR FSE image, each slice location is a breath-hold. Due to length of exam this set of images can be abbreviated, acquire 6mm skip 5mm. Use anterior coil elements and small field of view.
6. Short Axis, axial and long axis views using Myocardial Delayed Enhancement (MDE) sequence to assess for RV fibrosis component. The acquisition of the short axis and axials can be abbreviated to 6-8 slices.

Key Considerations:
- Consider acquiring MDE images before enhancement with Ti time of 300 msec to visualize fat signal. Repeat same images with Ti time of 150 msec to suppress fat signal.
- To decrease breath-hold time for Double-IR FSE imaging consider using 1xRR interval or Asset with 2xRR interval.

Notes
Cardiac Mass Evaluation

Clinical Background: Signal characterization evaluation of a potential cardiac mass can only be performed by MRI. Patients referred for the evaluation of a cardiac mass usually have had a previous imaging exam such as a transthoracic echocardiogram which has identified an intracardiac tumor. The imaging goal for the technologists is to localize the mass and identify its relationship to other relative cardiac structures. This information is important in deciding a course of treatment for the patient.

The most common cardiac masses seen in an adult population are benign cardiac tumors such as a myxoma or lipoma. Thrombus is also well detected by MRI and has been proven more sensitive than echocardiography as reported in the peer review literature.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence

2. Cardiac Mass localization

Real-time imaging with MR Echo can aid in the location of a potential cardiac mass. If Real-time is not available use the FIESTA cine sequence and prescribe a straight axial plane from the bottom of the heart to the level of the pulmonary artery.

Use FIESTA to acquire cine images to best localize the cardiac mass. This example shows a mass in the right atrium (arrow).

3. Cardiac Mass Signal Intensity Characterization

A: Axial Double-IR FSE proton density image which best demonstrates the location of the mass is shown. For T1 weighting set the R to R interval to 1.
B: Axial Triple-IR FSE acquired at the same slice location. Note the mass has intermediate signal intensity on both sequences.

4. Acquire routine functional views of the heart including short axis, 3-chamber, 2-chamber and 4-chamber views using the FIESTA sequence.

5. Cardiac mass evaluation using the myocardial delayed enhancement technique.

Acquire the imaging plane that best demonstrates the cardiac mass.
A: Pre-enhancement image using the myocardial enhancement sequence.
B: Immediate image using myocardial delayed enhancement image sequence using Ti time of 300 msec.
C: Delayed image using the myocardial delayed enhancement sequence using the same Ti time of 300 msec.
Key Considerations

- Thrombus is commonly seen in the left atrial appendage and LV apex. In these areas, thrombi may form and subsequent embolic events may occur, especially in association with dysrhythmias such as fibrillation. Thrombus appears as medium to high signal intensity on Double-IR FSE (Image A), high signal intensity on Triple-IR FSE (Image B). Myxoma’s can exhibit postcontrast enhancement.

- Myxoma is the most common cardiac tumor. It is commonly located in the left atrium attached to the atrial septum, but can be found in other chambers of the heart. Embolic events are common with smaller myxomas. Ventricular myxomas can cause obstruction of the outflow tract. Myxomas appear as heterogeneous signal intensity on Double-IR FSE (Image A), high signal intensity on Triple-IR FSE (Image B). Myxoma’s can exhibit postcontrast enhancement.

- Primary cardiac lipoma is a benign lesion composed of adipose tissue. Although benign, it can cause cardiac arrhythmias. Lipomas (Image A) appear as low signal intensity with Triple-IR sequence (Image B) and do not enhance on MDE.

- Crista terminalis is a normal anatomic structure of the right atrium. It is a vertical ridge of smooth myocardium located in the posterior right atrial wall. This is routinely seen on echo and is sometimes mistaken for a mass.

- Mitral annular calcification is a pathological finding consisting of degenerative change and calcification of the mitral valve. This mass has low signal intensity on FIESTA (A), Double-IR FSE (B) and MDE (C).

Notes

- Patient referred for right atrial mass seen by echo. The MRI study shows a prominent crista terminalis (arrow). This structure is best evaluated by acquiring a stack of 4-chamber views using the FIESTA sequence.
Hypertrophic Cardiomyopathy (HCM)

Hypertrophic Cardiomyopathy (HCM) refers to abnormal thickening of the left ventricular myocardium without any obvious cause. Myocardial hypertrophy can be focal or diffuse. HCM is the leading cause of sudden cardiac death in young athletes in the US.

The imaging goal of the technologists is to acquire a complete functional cardiac MRI exam plus delayed enhancement images. If a left ventricular outflow tract (LVOT) obstruction is detected with cine images (3-chamber view), then additional imaging with phase contrast should be considered to evaluate the severity of the obstruction.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence.

2. Acquire routine functional views of the heart including short axis, 3-chamber, 2-chamber and 4-chamber views using the FIESTA sequence.


**Clinical Case Example**: Hypertrophic Cardiomyopathy with LVOT obstruction.

- A: 3-chamber view acquired using FIESTA. Due to the thickened ventricular wall, narrowing of the LV outflow tract is seen.
- B: 3-chamber view repeated using FastCINE. A jet in the outflow tract is easily visualized. To better visualize jets, FastCINE should be considered because longer repetition time and echo times are used.
- C: Phase contrast scan plane is prescribed perpendicular to the jet. Resulting images are used to determine the peak velocity.

**Long Axis Views**: 3-chamber, 2-chamber and 4-chamber views.
A: Short Axis MDE showing focal fibrosis. The long axis view was prescribed thru the area of hyperenhancement.
B: Resulting long axis MDE image.

Key Considerations:

- Focal HCM can be present in localized areas of the left ventricle, for example, apical hypertrophy. Acquiring complete long axis views are important to be able to evaluate for localized hypertrophy.
- LVOT obstruction can also be associated with HCM. The presence of a jet can be fully appreciated by using the FastCINE sequence in a 3-chamber view.
- Myocardial wall thickness is accurately assessed by using a short axis FIESTA image. Wall-thickness measurements are made on the end-diastolic phase.

Notes

Ischemic Heart Disease

For the determination of ischemic heart disease stress conditions are induced by the use of a pharmacological vasodilator. Coronary artery disease is caused by deposits of atherosclerotic plaque that narrow the lumen of one or more coronary vessels. Patients with this condition have normal perfusion to the heart muscle at rest. When they experience increased demand on the heart during stress conditions, this causes the diseased vessels to be less able to dilate to meet the heart muscle demands. Ischemia is defined as the state of a tissue that is receiving insufficient blood supply to meet its metabolic needs. The imaging goal of the technologist is to acquire a complete functional cardiac exam along with a Time Course imaging sequence, available within the MR-Echo application.

1. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views using the FEISTA sequence.

2. MR Echo features 2 sequences used for evaluating myocardial time course, a 2D FGRE utilizing ASSET or FIESTA. The FGRE Time Course sequence appears to exhibit a better CNR (highly desirable in time course imaging) and the FIESTA exhibits better SNR and the ability to scan in multiple planes simultaneously. CVMR clinician’s recommendation is a preference for FGRE Time-Course using 0.2mmol/kg of gadolinium.

Example Clinical Case:
A: The Time Course short axis images at peak vasodilation show a hypoenhanced region (arrow) in the anteroseptal wall down to the apex. Because of the higher contrast dose used for the Time Course imaging, a MDE sequence (B) is acquired for comparison. The delayed enhancement images show no areas of abnormality. Therefore this study was positive for ischemia.

Considerations:
- Before acquiring the short axis images during peak vasodilation with the FGRE Time Course sequence, check for image quality and left ventricular coverage by acquiring a test acquisition first.
- When using the FGRE Time Course Sequence consider 1 RR for heart rates lower then 50 bpm for improved temporal resolution.
Mitral Valve Evaluation

Magnetic Resonance Imaging (MRI) provides a comprehensive assessment of mitral regurgitation. It can characterize anatomic abnormalities and quantify their functional significance both in terms of the size of the leak as well as its affect on left ventricular structure and function. Currently, patients routinely undergo transesophageal echocardiography (TEE) to determine whether they are candidates for mitral valve surgery. Mitral regurgitation (MR) is an abnormal leaking of the blood through the mitral valve, from the left ventricle to the left atrium of the heart. The imaging goal of the technologist is to acquire a complete functional exam and a phase contrast series of the aortic outflow to indirectly quantify MR.

1. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views. Localizers can be acquired using FastCINE to better evaluate for valvular abnormalities.

   - FastCINE long axis localizer identifies a posteriorly directed jet in the left atrium from the mitral valve.

   - Long Axis localizer with short axis scan plane prescription. A complete short axis set should be acquired to calculate the stroke volume from the segmentation of the left ventricle.

2. Phase contrast scan plane prescription used to indirectly quantify MR.

   - A: Using a sagittal localizer, prescribe an oblique coronal plane thru the ascending aorta.
   - B: Using resulting image B, prescribe another slice parallel to the aortic root.
   - C: Using resulting image C prescribe one phase contrast slice perpendicular to the wall of the ascending aorta just above the aortic root.
   - D: Flow curves can be generated by tracing a region around the aorta with ReportCARD flow analysis.
Considerations:
- Indirect assessment of MR is the preferred method to calculate mitral regurgitation. The stroke volume from the left ventricular segmentation is compared to the stroke volume result from the aortic phase contrast.
- It is recommended to acquire at least 3 phase contrast measurement in order to confirm phase contrast results.
- Mitral valve prolapse can be evaluated with the 3-chamber FIESTA view.
- To perform background correction for phase contrast, please refer to the ReportCARD 3.0 operator documentation for exact instructions.

Reference:

Notes
Myocardial Delayed Enhancement (MDE) Imaging

Clinical Background: The utility of MRI in the detection of viable myocardium is rapidly gaining widespread clinical acceptance in the management of patients with coronary artery disease (CAD). In a recent consensus report, this application has been classified as the first line imaging technique. The detection of viable myocardium in patients with reversible or irreversible myocardial injury is of critical importance. For patients facing revascularization with coronary angioplasty or coronary artery bypass, the determination of viability is an important clinical factor. However, there is also another category of patients that can also benefit from undergoing a myocardial delayed enhancement (MDE) exam. These patients fall into the category of non-obstructive coronary artery disease. Suspected myocarditis, an inflammation of the myocardium, is a clinical indication for a MDE study. Early detection of the disease can be critical as it can progress to arrhythmias or sudden cardiac death. Other disease states that put patients at risk for sudden death include sarcoidosis, amyloid and hypertrophic cardiomyopathy all of which can be detected by using this technique. The imaging goal of the technologists is to optimize the Inversion Time (TI) of the MDE sequence to properly null the normal myocardium.

1. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views using the FIESTA sequence.

Functional FIESTA cine images are used to compare wall motion abnormalities with areas of hyperenhancement. If the wall motion is abnormal and the MDE images are normal this could clinically represent stunned or hibernating myocardium.

2. TI determination for Myocardial Delayed Enhancement Imaging.

Prescribe a single slice short axis in the mid ventricle. Clinical recommendation of contrast dose is .2mmol/kg. Start acquiring the test TI images at 8-10 minutes post administration.

A: Short axis MDE image showing an anteroseptal infarct. If areas of hyperenhancement are identified, prescribe a long axis plane that bisects the hyperenhanced myocardial wall segment.

B: MDE long axis view of the resulting prescription demonstrating the extent of the hyperenhancement.
Example Clinical Case: MRI has superior spatial resolution to differentiate transmural infarcts (large arrow) versus subendocardial infarcts (small arrow). The hyperenhancement pattern of an infarct is well defined and appears in a coronary artery distribution.

Short axis MDE image A compared with FIESTA short axis function image B shows a very thin inferolateral wall with absent wall thickening (akinetic). This appearance confirms the hyperenhanced transmural inferolateral wall infarct on the MDE image A.

Example Clinical Cases: Non-obstructive coronary artery disease

The pattern of uptake in the myocardium in patients with CAD necrosis is very discrete starting in the subendocardial wall (arrows) which can be seen in Image A. Akinetic wall motion abnormality on the short axis functional CINE images corresponded to the areas of infarction (not shown). Image B shows a patient with heterogeneous enhancement (arrow) in the lateral wall which is subepicardial in appearance. This pattern suggests a nonischemic etiology (wall motion normal) such as myocarditis which was confirmed in this patient. Image C shows hyperenhancement (arrow) again sparing the subendocardial wall as this patient was diagnosed with Lyme myocarditis. Image D is a long axis view of a patient with a history of sarcoidosis which now involves the heart causing arrhythmias. The areas of abnormalities involve the atrial septum and basal ventricular septum (arrows) as this is not the typical pattern for CAD necrosis.

Key Considerations:

- Inversion times can change during the acquisition of the short axis slices. It is recommended to stop the acquisition and adjust the Ti accordingly and restart on the slice last acquired.
- Setting the trigger delay to 300 yields images acquired during end-systole. The selection of the trigger delay can be a clinician preference.
- Accurate ECG gating is critical. Missed triggers (A) can affect the proper appearance of the nullled myocardium. Image (B) is the reacquired image with no missing triggers. The appearance of the myocardium is nullled (dark) versus the grayish appearance on image A.

- The quality of MDE images is very dependant upon the patient cooperation in performing the breath-holds. If a patient cannot hold their breath consider doubling the NEX and let the patient free breath.
- Determining the proper Ti in patients that present with infiltrative diseases can be challenging. Since there is no normal myocardium to null, Ti optimization can be done by checking the appearance of normal skeletal muscle. To ensure the selection of the proper Ti time inspect the nulling of the skeletal chest muscle. Image A shows that the correct Ti has been used as the normal skeletal chest muscle is nulled (dark). The Ti time on image B is not optimal since the normal skeletal chest muscle signal is bright.

References:
Patent Foramen Ovale (PFO)

Blood clots traversing a patent foramen ovale (PFO) are important cardiac sources of cerebral emboli, especially in younger patients. Identifying a PFO is potentially quite difficult because the amount of shunted blood is small (typically < 1ml), the shunt is transient (duration of ~1sec), and the shunt must be evoked by physiologic maneuvers (e.g. Valsalva). By using a real-time contrast-enhanced MRI protocol a PFO can be identified by directly visualizing gadolinium contrast passing from the right atrium to the left atrium. The PFO protocol takes only a few minutes to perform, and multiple contrast injections can be utilized since only a small amount of contrast is used for each injection.

**Realtime procedure with IDrive Pro Plus:**
1. Use the real-time controls to define a 4-chamber view.
2. Rotate the heart so the apex is at the 12:00 position.
3. Click on IR option. (Image should then appear dark.)
4. Pause the scanner and instruct patient to Valsalva.
5. Start the real-time acquisition.
6. When enhancement is seen in the RA, have the patient to release Valsalva.
7. Save the acquisition images before exiting the realtime screen.

Considerations:
- Have someone stand inside the room to instruct patient while scanning. Otherwise, it is difficult to hear the operator’s voice.
- Repeat the procedure two times to ensure the patient followed Valsalva instructions properly.
- Always save the real-time images before exiting the real-time interface, otherwise, the images are lost.
- To identify a PFO signal Intensity curves are generated utilizing ReportCARD.

![PFO (arrow) identified on the real-time frames acquired using IDrive Pro Plus.](image)

**Notes**

- Patients with an atrial septal aneurysm (A) should be evaluated for a possible PFO. Image B is a normal atrial septum.

![Intense images showing PFO](image)
Pericardial Diseases

MRI is considered an ideal tool in the evaluation of pericardial diseases. The pericardium is double-layered fibrous sack that can usually be visualized over the right ventricle on a MR image. Normal pericardial thickness is less then 4mm. Pericarditis, constrictive pericarditis and pericardial effusions can be evaluated by MRI. The imaging goal of the technologists is to acquire a complete functional exam including real-time imaging and myocardial delayed enhancement images.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence.

2. Acquire a Long axis localizer view using FastCINE or FIESTA.

3. Acquire routine functional views of the heart including short axis, 3-chamber, 2-chamber and 4-chamber views using the FIESTA sequence.

4. Patients referred for the evaluation of constrictive pericarditis, MR-Echo realtime images in short axis and 4-chamber views should be acquired while the patient takes deep breaths in and out. Identification of leftward bowing of the interventricular septum can be captured during inspiration. This technique aids in the clinical diagnosis of constrictive pericarditis.

Clinical Case Examples:

5. Patients referred for the evaluation of constrictive pericarditis, black blood axial and coronal views using FSE Double IR should be acquired to assess the thickness of the pericardium.

6. Myocardial Delayed Enhancement short axis and long axis views should be acquired using MDE sequence to assess for other infiltrative diseases such as amyloid or myocarditis.
**Key Considerations:**
- It is important for clinicians to differentiate restrictive cardiomyopathy (RCM) from constrictive pericarditis by assessing the septal wall motion.

Notes
Pulmonary Vein Stenosis/Atrial Ablation

Left Atrial Ablation is a procedure that uses RF energy to destroy extra pathways in the heart that cause tachycardia and arrhythmias. The imaging goal of the technologist is to acquire a complete functional study along with a pulmonary vein magnetic resonance angiography study.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence.

2. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views.

These patients sometimes present with atrial fibrillation, which will affect the cine image quality. MR-Echo parameters can be set to acquire within 1 heartbeat, therefore eliminating the averaging of irregular heartbeats.

Example of scan parameters for MR-Echo to acquire within 1 heart beat. Adjust the temporal resolution accordingly.

3. Acquire a stack of axial gated FIESTA through the left atrium, used to view the pulmonary vein insertion points into left atrium.

Scan plane prescription for axial slices through left atrium.

Key Considerations:
- Reformat the 3D data sets to better visualize the pulmonary veins.
- Consider MDE imaging if fibrosis is a concern.

(www.childrens-heart-fed-org-uk, last accessed August 3, 2006.)

Notes
Shunt Quantification

Noninvasive assessment of cardiac shunts by quantifying the pulmonary-to-systemic blood flow ratio (Qp/Qs) can be done by MRI. This protocol outlines the acquisition of phase contrast data to assess for Qp/Qs. In people without an intra-cardiac shunt the Qp/Qs ratio is 1. In a left-to-right shunt this ratio increases. The Qp/Qs ratio can be determined from measurements of blood flow in the pulmonary trunk and the proximal aorta. The imaging goal of the technologists is to acquire phase contrast of the aorta and pulmonary outflow tracts.

1. Sagittal Localizer or a 3-Plane Localizer using non-gated FIESTA sequence.

2. Perform a complete functional exam with short-axis and 3-chamber, 2-chamber, 4-chamber views using the FIESTA sequence.

3. Phase Contrast scan plane prescription to quantify systemic stroke volume.
   A: Using a sagittal localizer, prescribe an oblique coronal plane thru the ascending aorta.
   B: Using resulting image B, prescribe another slice parallel to the aortic root.
   C: Using resulting image C prescribe one phase contrast slice perpendicular to the wall of the ascending aorta just above the aortic root.
   D: Flow curves can be generated by tracing a region around the aorta with ReportCARD flow analysis.

4. Phase Contrast scan plane prescription to quantify pulmonic stroke volume.
   A: Using a sagittal localizer, prescribe an oblique coronal plane through the right ventricular outflow tract.
   B: Using resulting image B, prescribe another slice parallel to the wall of the pulmonary artery.
   C: Resulting image C: Right ventricular outflow tract view. A phase contrast slice can be prescribed perpendicular to the wall of the pulmonary artery. Set frequency direction to R/L to avoid wrap.
Key Considerations:

- To quantify Qp/Qs, generate flow curves for both the aorta and pulmonary artery.
- To evaluate for a patent ductus arteriosus (PDA) a connection of the proximal descending aorta to the left pulmonary artery oblique candy-cane views of the aorta should be acquired. Cardiac MR is an important modality for the assessment of the PDA because of its ability to both describe the pathology and evaluate its hemodynamic significance. Because we measure the pulmonary flow proximal to the shunt, in the case of PDA (and other extracardiac shunts) the Qp/Qs will be less than one.

Patients referred for the evaluation of atrial septal defects, additional phase contrast acquisitions should be acquire parallel to the atrial septum as shown below.

Scan plane prescription for the phase contrast series parallel to the atrial septum

Resulting view shows an atrial septal defect (arrow) identified using phase contrast.

- Irregular heart rates or missed triggers during a phase contrast acquisition will compromise the quantitative results.
- To perform background correction for phase contrast acquisitions, please refer to the ReportCARD 3.0 operator documentation for exact instructions.
- If right sided heart enlargement is suspected, the Qp/Qs should be calculated to rule out a possible shunt.
- If other congenital anomalies are suspected, a magnetic angiography study of the heart should be performed.

Notes

Scan plane prescription for oblique candy-cane views of the aorta from an axial localizer.

Jet from the PDA is better appreciated on image A using a FastCINE sequence versus image B acquired using FIESTA.
Chapter 4

Pediatric - Clinically Optimized Protocols
Pediatric Procedures

Listed below are commonly scanned MR cardiac procedures for children. Please note that these protocols are intended to use as guidelines. There are infinite numbers of variations of congenital heart diseases, which make it difficult to establish definitive protocols for all defects. Many patients have been surgically repaired as well. It is imperative that adequate history is provided and reviewed before beginning the exam.

4a  Aortic Stenosis (AS)
4b  Atrial Septal Defect (ASD)
4c  Bicuspid Aortic Valve
4d  Coarctation of the Aorta
4e  Dextrocardia
4f  Hypertrophic Cardiomyopathy (HCM)
4g  Kawasaki Disease
4h  Marfan Syndrome
4i  Mitral Valve Stenosis
4j  Partial Anomalous Pulmonary Venous Return (PAPVR)
4k  Patent Ductus Arteriosus (PDA)
4l  Patent Foramen Ovale (PFO)
4m  Pulmonary Atresia
4n  Single Ventricle
4o  Tetrology of Fallot (TOF)
4p  Transposition of the Great Vessels (TGA)
4q  Vascular Ring
4r  Ventricular Septal Defect (VSD)
Aortic Stenosis (AS)

Aortic Stenosis (AS) is a defect in the outflow tract from the heart into the aorta. The most common type is valvular stenosis, which is a narrowing of the aortic valve. This is caused by valvular leaflets that are too small, too thick, or do not close properly. Occasionally the obstruction does not include the valve leaflets but instead consists of a narrowing of the passage either above (supravalvular) or below (subvalvular). The left ventricle must work harder to pump blood out of the heart into the aorta if the LVOT is narrowed. In severe cases, the LV becomes hypertrophied, which can lead to arrhythmias and sudden death.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FastCINE or FIESTA 4-chamber view
3. Short Axis FIESTA
   • Cover entire LV to evaluate LV function
4. Long Axis FIESTA
   • Acquire 2-3-4 chamber views
5. Long Axis FastCINE
   • Acquire a 3- chamber view
6. High Resolution FIESTA
   • Scan perpendicular to the aortic valve plane
   • Visualization of valve leaflets
   • Visualization of orifice
7. Phase Contrast (optional)
   • Perform perpendicular to the valve plane and at several slice locations, from the LV outflow tract to above the aortic valve plane
8. Double IR-FSE
   • Perform several slices at the level of the aortic valve.
9. 3D CeMRA (optional)
   • Evaluates aortic root and aortic arch.

Considerations:
• DIR imaging of valve plane area may be beneficial to visualize stenotic areas.
• Utilize ReportCARD to quantify PC sequences for flow analysis results.
• Utilize ReportCARD to measure valve area as seen on high resolution FIESTA.
• Consider 3D CeMRA if supravalvar stenosis is suspected to evaluate the supravalvar aorta and aortic arch. Reformat these data sets to visualize vasculature.
• Refer to Adult Protocols in Chapter 2 for more detailed information of high resolution FIESTA imaging through the aortic valve.

Notes
**Atrial Septal Defect (ASD)**

An atrial septal defect (ASD) is an opening in the septal wall that separates the right and left atria. The opening allows blood in the atria to mix. This defect allows oxygenated blood to travel to the right ventricle and back to the lungs instead of the body. ASD's account for 5-10% of congenital heart diseases and vary in size and severity of symptoms.

**Protocol:**
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   - FIESTA or FastCINE 4-chamber view
3. Axial FIESTA
   - Visualizes morphology
4. Short Axis FIESTA
   - Cover both ventricles and atria to evaluate blood shunting and ASD
   - Visualize blood shunting
   - Visualize ASD
5. 4-chamber FIESTA
   - Cover entire heart to visualize morphology
6. Phase Contrast
   - Perform Qp/Qs for shunt quantification.
7. 3D CeMRA (optional)
   - Cover entire cardiac anatomy to visualize heart and pulmonary veins

**Considerations:**
- Utilize realtime MR Echo to localize proper imaging planes.
- FastCINE sequence may be beneficial to visualize blood shunting.
- Consider 3D CeMRA to evaluate for anomalous pulmonary veins if there is sinus venous septal defect.
  - This defect is commonly located slightly above the true atrial septum.
- For more detailed information on Qp/Qs acquisition refer to the Adult Protocol Section in chapter 3.
- Qp/Qs can be quantified using ReportCARD. To perform background correction for phase contrast, please refer to the ReportCARD 3.0 operator documentation for instructions.

**Notes**
Bicuspid Aortic Valve

The aortic valve normally develops with three leaflets. Bicuspid Aortic Valve is a heart defect in which only two aortic leaflets form. A bicuspid aortic valve may occur in isolation or be associated with other heart defects. Isolated bicuspid aortic valve is the most common of all congenital cardiac anomalies and usually has no adverse effects. However, if the bicuspid valve does not open and close normally, this can lead to aortic valve stenosis.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   • Cover entire LV to evaluate LV function
4. Long Axis FIESTA
   • Acquire 3 and 4-chamber views to visualize LVOT
5. FastCINE or FIESTA through aortic valve plane
   • Visualize valve leaflets
   • FIESTA is recommended if there is a tight stenosis seen
6. Phase Contrast (optional)
   • Performed at the level of the aortic valve to assess flow.
7. 3D CeMRA (optional)
   • Visualizes vasculature

Considerations:
• Consider PC sequence to evaluate degree of stenosis. Analyze with ReportCARD to calculate flow velocities.
• Bicuspid aortic valve is often associated with aortic coarctation, so consider performing 3D CeMRA.

Notes
Coarctation of the Aorta

Aortic Coarctation is a blockage of the aorta. This blockage can be a narrowing of the vessel or an obstruction. The coarctation is typically located in the descending aorta and immediately past the takeoff of the subclavian artery. This obstruction causes an increase in pressure of the left ventricle and ascending aorta. Aortic coarctation is often clinically diagnosed when the blood pressure in the upper body presents high and the blood pressure in the lower body is low.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   - FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   - Cover entire LV to evaluate LV function and mass
4. Long Axis FIESTA
   - Acquire 2-3-4-chamber views
5. 3D CeMRA
   - Cover the entire thoracic aorta to the level of the renal arteries.
6. FastCINE
   - “Candy Cane” sagittal oblique view of the aorta to visualize flow jet related to the coarctation
6. Phase Contrast
   - Acquired above, at, and below stenotic area for analysis of flow velocities

Considerations:
- TRICKS may be beneficial to evaluate dynamic blood flow and collateral circulation, specifically of the Internal mammary artery and intercostal arteries.
- The 3D CeMRA data set is used to evaluate for involvement of the left subclavian artery and for associated aneurysms of the ascending aorta and intercostal arteries.
- Generate flow curves utilizing ReportCARD to evaluate velocities near areas of stenosis.
- Left ventricular hypertrophy may be present secondary to hypertension and coarctation. LV mass measurements may be obtained utilizing ReportCARD.
- Aortic coarctation is often associated with bicuspid aortic valve. Consider acquiring FIESTA or FastCINE through the valve plane to visualize leaflets.

Notes
Dextrocardia

Dextrocardia is a rare condition that means the heart is located in the right side of the chest instead of the left. There are various degrees of Dextrocardia. These differ from a normally configured heart that is positioned more right in the chest to a more severe “mirror-image dextracardia”, in which the position of the heart chambers and great vessels reverse the normal arrangement.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Axial and Coronal FIESTA
   - Gated or non-gated
   - Evaluates morphology
3. Long Axis localizer
   - FIESTA or FastCINE 4-chamber view
4. Short Axis FIESTA
   - Evaluates LV and RV function
5. Long Axis FIESTA
   - Acquire 2-3-4-chamber views and RVOT view
6. Phase Contrast
   - Qp/Qs for shunt quantification if needed
7. 3D CeMRA
   - Cover entire cardiac anatomy

Considerations:
- Utilize realtime MR Echo to localize proper imaging planes.
- Consider TRICKS to visualize flow dynamics.
- Reformat 3D CeMRA datasets to visualize vasculature.
- Note that “mirror-image” Dextrocardia is often associated with other defects such as CHD, ASD, VSD, Situs Inversus, RVE, and RAE. Additional imaging may be necessary for further evaluation.
- Consider Qp/Qs PC imaging and analysis with ReportCARD for shunt quantification. For information that is more detailed refer to the Adult Protocol section in Chapter 2.
- May need to place the ECG leads on the right chest instead of the left chest to acquire optimal waveform for gating purposes.

Subclavian Artery

Notes
Hypertrophic Cardiomyopathy (HCM)

Hypertrophic Cardiomyopathy (HCM) is a condition in which the ventricular septum is thickened. This thickened septal wall can potentially obstruct the aortic or pulmonary outflow tracts. HCM can be hereditary. Symptoms in these patients range from chest pain and shortness of breath on exertion to fainting, arrhythmias, and heart failure.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   - FastCINE or FIESTA 4-chamber views
3. Short Axis FIESTA
   - Cover entire LV and RV
   - Evaluates LV and RV function
4. Long Axis FIESTA
   - Acquire 2-3-4-chamber views and RVOT view
5. Post Enhancement Short Axis MDE
   - Evaluates for fibrosis
   - Be sure to cover RV insertion points, as this is a common site for fibrosis
6. Post Enhancement Long Axis MDE
   - Acquire in optimal plane
   - Evaluates for fibrosis

Considerations:
- The most common type of HCM is ASH. This can best be evaluated on the short axis or 3-chamber long axis view.
- Focal HCM can be present in localized areas of the LV. This can normally be evaluated on the short axis, 2- and 4-chamber long axis view.
- LVOT obstruction can also be associated with HCM. This can best be evaluated on the 3-chamber long axis view.
- Look for systolic anterior motion (SAM) of the mitral valve which can be seen best on the 3-chamber FIESTA images.

There are four types of HCM.
- Asymmetric Septal Hypertrophy (ASH) - muscle thickening occurs mainly in the upper portion of the ventricular septum.
- Concentric-diffuse ventricular muscle thickening occurs.
- Apical- myocardial thickening occurs at the apex of the left ventricle.
- Mid Cavity Obstruction

Notes
Kawasaki Disease

Kawasaki Disease is an acquired heart disease that affects children between the ages of 6 months and 4 years of age. The cardiac affects of this disease consist of myocarditis and development of coronary artery aneurysms. These aneurysms most commonly arise in the coronary origins. Note that coronary artery stenosis may develop as well.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   - FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   - Evaluates LV function
4. Post enhancement Short Axis MDE
   - Evaluates for myocarditis or myocardial infarction.
5. Post enhancement Long Axis MDE
   - Acquire 2-3-4 chamber views
   - Evaluates for myocarditis or myocardial infarction.
6. 3D Fatsat FIESTA thru the coronary arteries
   - Attention to the coronary origins

Considerations:
- Utilize realtime MR Echo to localize proper imaging planes.
- Consider using the navigator option with 3D Fatsat FIESTA coronary artery sequence for non-breath hold imaging.
- Although contrast is not necessary for the coronary artery sequence, if contrast has been used, perform this 3D fatsat FIESTA afterwards to take advantage of the increased SNR benefits.

Notes
Marfan Syndrome

Marfan Syndrome is a heart disease that affects the body’s connective tissue. An enlarged aorta marks this disease. The aortic enlargement occurs near the aortic valve or in the ascending aorta. Abnormalities may also be found in the aortic and mitral valves.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   • Evaluates LV function
4. Long Axis FIESTA
   • Acquire 2-3-4-chamber views to visualize mitral and aortic valves
5. Phase Contrast
   • Acquire at the level of the ascending aorta for flow quantification
   • Acquire at the level of the aortic valve for valvular flow quantification
6. 3D CeMRA
   • Evaluates the vasculature
   • Used for the evaluation of a possible dissection

Considerations:
• Note that Marfan Syndrome is often associated with mitral valve prolapse. Additional imaging of the MV may be necessary.
• Perform PC in ascending aorta and compare to LV stroke volume results calculated in ReportCARD to evaluate for mitral regurgitation.
• Perform PC at the aortic valve and generate flow curves utilizing ReportCARD to quantify regurgitate blood volume.
• Reformat the 3D CeMRA data sets to visualize vasculature. Measure the aortic root and ascending aorta on the these images.
• Measure sinotubular junction. This is located at the junction of the aortic root and ascending aorta. An enlarged sinotubular junction can be an indication of Marfan Syndrome.

Notes
Mitral Valve Stenosis

The mitral valve is located in the left side of the heart. It controls blood flow between the left atrium and left ventricle. Mitral stenosis occurs when there is a narrowed area of the valve. The malformed valve can be a congenital defect or as a result from rheumatic fever.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   • Evaluates LV function
4. Long Axis FIESTA
   • Acquire 2-3-4 chamber views
5. Long Axis FastCINE
   • Acquire parallel and perpendicular to valve leaflets to assess for anatomic abnormality
6. Phase Contrast
   • Perform at the level of the mitral valve plane

Considerations:
• Analyze PC utilizing ReportCARD to generate flow curves and assess degree of stenosis or insufficiency.
• Refer to Adult Protocol section in Chapter 2 for more detailed information on mitral valve imaging.

Notes
**Partial Anomalous Pulmonary Venous Return (PAPVR)**

Partial Anomalous Pulmonary Venous Return (PAPVR) is a congenital heart disease in which the pulmonary veins carry blood from the right lung to the right side of the heart instead of the left atrium. These abnormal veins may carry blood directly to the right atrium or connect to another right side vein. This condition often causes right heart enlargement.

**Protocol:**
1. Sagittal localizer or 3-plane localizer
2. Axial FIESTA  
   • Cover entire chest to evaluate for anomalous pulmonary venous return
3. Long Axis localizer  
   • FIESTA or FastCINE 4-chamber view
4. Short Axis FIESTA  
   • Evaluates right and left heart function
5. Axial and Coronal FIESTA  
   • Acquire thin slices thru the atria to visualize the pulmonary veins connecting to the left atrium
6. Phase Contrast  
   • Qp/Qs imaging to assess the hemodynamic significance of the shunt
7. 3D CeMRA  
   • Cover entire chest to visualize pulmonary vasculature

**Considerations:**
- Consider TRICKS 3D CeMRA if dynamic flow information is necessary.
- Reformat 3D CeMRA data sets to visualize the pulmonary veins.
- Analyze the PC series utilizing ReportCARD to generate flow curves and compare flow values in the right and left heart.

**Notes**
Patent Ductus Arteriosus (PDA)

The Patent Ductus Arteriosus (PDA) is a connection between the aorta and pulmonary artery that is present in the fetus. This structure typically closes soon after birth. If the opening does not close, shunting across the PDA occurs. This may eventually lead to heart failure.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FIESTA or FastCINE 4-chamber view
3. Short Axis FIESTA
   • Evaluates right and left heart function
4. Long Axis FIESTA
   • Acquire 2-3-4 chamber views
5. Phase Contrast
   • Perform Qp/Qs in the main pulmonary artery and aorta to determine hemodynamic significance of the shunt
6. 3D CeMRA
   • Evaluates vasculature
   • Evaluates luminal diameter and length of PDA for coil placement

Considerations:
• Reformats of the 3D CeMRA data sets may be beneficial to visualize vasculature and to establish dimensions of the PDA.
• Analyze the PC series utilizing ReportCARD to determine and compare flow values in the right and left heart. Refer to Adult Protocols in Chapter 3 for more detailed information.
• Qp/Qs ratio is important to evaluate. Measurement results depend on the direction of flow in the PDA. If the flow is toward the pulmonary artery and shunts blood from left to right, an increase in pulmonary blood flow is present. If the PDA is present long term, the pulmonary vascular resistance increases and if this reaches suprasystemic levels, blood will begin to shunt from right to left. Qp/Qs results will vary depending on this physiology.
• Consider additional phase contrast series across the ductus to evaluate ductal flow and direction of ductal flow.

Notes
**Patent Foramen Ovale (PFO)**

A Patent Foramen Ovale (PFO) is an opening in the atrial septum that allows shunting of blood between the right and left atria in fetal circulation. This opening typically closes at birth. If the shunt does not close it is a PFO. Although small, the PFO may increase in size as the heart grows.

**Realtime procedure with iDrive Pro Plus:**
1. Use the real-time controls to define a 4-chamber view.
2. Rotate the heart so the apex is at the 12:00 position.
3. Click on IR option. (Image should then appear dark.)
4. Pause the scanner and instruct patient to Valsalva.
5. Start the real-time acquisition and administer contrast.
6. When enhancement is seen in the RA, have the patient to release Valsalva.
7. Save the acquisition images before exiting the realtime screen.

**Considerations:**
- Refer to the Adult Protocol Section in Chapter 2 for more detailed scanning instructions.
- If the valsalva maneuver is not performed correctly, then results may not be accurate.
- If the first injection is negative, then it may be necessary to repeat the procedure as needed up to three times.
- Use ReportCARD to generate signal intensity flow curves to support results.

**Notes**

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Pulmonary Atresia

Pulmonary Atresia is a congenital heart disease in which there is no pulmonary valve. Hypoplastic right ventricle, ventricular septal defects, and small pulmonary arteries are often associated with this anomaly.

Protocol:
1. Sagittal localizer or 3-plane localizer

2. Axial and Coronal FIESTA
   • Visualize anatomy, specifically of the pulmonary arteries

3. Short Axis FIESTA
   • Evaluates right and left ventricular function

4. RVOT FIESTA
   • Visualize pulmonary valve plane

5. 3D CeMRA
   • Evaluates vasculature
   • Visualize possible associated PDA

6. Phase Contrast (optional)
   • Obtained perpendicular to LPA and RPA to evaluate flow

Considerations:
• TRICKS 3D CeMRA may be beneficial to visualize vasculature.
• Reformat 3D CeMRA datasets to visualize vasculature.
• Consider PC to quantify right vs. left lung pulmonary artery flow. Analyze these PC series utilizing ReportCARD to generate flow curves and compare the results.

Notes

...............................................................................................................................
Single Ventricle

Complex heart defects that result in underdevelopment of the cardiac ventricle are often called Single Ventricle defects. Although rare, these defects allow for mixing of oxygenated and deoxygenated blood. Single Ventricle requires surgical intervention to repair heart function.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Axial and Coronal FIESTA
   • Evaluates morphology
3. Short Axis FIESTA
   • Evaluates ventricular function
4. Long Axis FIESTA
   • Acquire 2-3-4 chamber views and RVOT
5. Phase Contrast
   • Perform Qp/Qs in the aorta and main pulmonary artery to evaluate flow in the right and left heart
6. 3D CeMRA
   • Evaluates vasculature and PDA

Considerations:
• Utilize realtime MR Echo to localize proper imaging planes.
• Reformat 3D CeMRA datasets to visualize vasculature.
• Analyze PC utilizing ReportCARD to determine and compare flow values in the right and left heart.
• Refer to Qp/Qs protocol in Adult Protocol in Chapter 3 for more detailed information.
• Single Ventricle defects are often corrected by the Fontan Procedure which redirects oxygen poor blood to the lungs. The ventricle is reserved for collecting and distributing oxygen rich blood to the body.
Tetralogy of Fallot (TOF)

Tetralogy of Fallot (TOF) is a congenital heart disease that has four characteristics:
- Large ventricular septal defect
- Narrowed right ventricular outflow tract and/or pulmonary valve stenosis
- Enlarged and overriding aorta
- Right ventricular hypertrophy

A right-sided arch is commonly seen with this defect as well. In the most severe cases, blood flow to the lungs is extremely compromised.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Axial and coronal FIESTA
   • Evaluates morphology
3. Short Axis FIESTA
   • Evaluates LV and RV function
   • Visualizes VSD
4. Long Axis FIESTA
   • Acquire 2-3-4 chamber views and RVOT view
5. Phase Contrast
   • Perform Qp/Qs in the aorta and main pulmonary artery to evaluate flow in the right and left heart and to evaluate for pulmonary regurgitation following repair
   • Obtain optional PC series perpendicular to RPA and LPA for comparison of flow
6. 3D CeMRA
   • Visualizes vasculature
   • Evaluates for peripheral pulmonic stenosis

Considerations:
- Utilize realtime MR Echo to localize proper imaging planes.
- Reformat 3D CeMRA data sets to evaluate the vasculature.
- Analyze the Qp/Qs PC series utilizing ReportCARD to evaluate and compare flow results in the right and left heart and to determine pulmonary regurgitate fractions.
- Consider additional PC series to evaluate differential pulmonary blood flow in the right and left pulmonary arteries. Analyze these series utilizing ReportCARD to generate flow curves for comparison.
Transposition of the Great Arteries (TGA)

Transposition of the Great Arteries (TGA) is a congenital heart disease in which the aorta and pulmonary artery arise from the wrong cardiac chamber. The aorta connects to the right heart and the pulmonary artery attaches to the left heart. This condition is very often associated with other defects such as VSD, LVOT obstruction, and abnormal coronary arteries. TGA often presents with the pulmonary artery positioned anterior to the aorta.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Axial and Coronal FIESTA
   - Evaluates morphology
3. Long Axis FIESTA
   - Acquire 2-3-4 chamber views and RVOT to evaluate left and right outflow tracts
4. Short Axis FIESTA
   - Evaluates LV and RV function
5. 3D Fatsat FIESTA
   - Evaluates coronary origins and their courses
6. Phase Contrast
   - Perform Qp/Qs in the aorta and pulmonary artery to evaluate flow in the right and left heart
7. 3D CeMRA
   - Evaluates vasculature

Considerations:
- Commonly, TGA has been surgically repaired via the Senning, Mustard, or Jatene Atrial Switch procedures. Conduits may also be in place. Adequate surgical history is essential to thoroughly evaluate this disease after repair.
- Utilize MR Echo to localize proper imaging planes.
- Reformat the 3D CeMRA data sets to evaluate vasculature.
- Analyze the PC series utilizing ReportCARD to determine and compare flow values in the right and left heart.

Notes
Vascular Ring

Vascular Ring is a congenital disease in which the aorta has formed abnormally and some portion of the aorta completely encircles the esophagus and trachea. There are two common types of vascular rings: Double Aortic Arch and Right Aortic Arch with left ligamentum arteriosum. These malformations entrap the trachea and esophagus and may cause compromised breathing and swallowing.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Axial and Coronal FIESTA
   - Cover entire area of great vessels and trachea to evaluates morphology
3. Double-IR FSE
   - Acquire thin slices thru the trachea
4. 3D CeMRA
   - Evaluate vasculature

Considerations:
- Utilize real-time MR Echo to locate the trachea, esophagus, and vasculature.
- Measurements are made on the DIR FSE sequence to evaluate the tracheal lumen.
- Reformat the 3D CeMRA data sets to visualize the vasculature.

Notes
Ventricular Septal Defect (VSD)

Ventricular Septal Defect (VSD) is the most common congenital heart disease. A VSD is an opening in the septal wall that separates the left and right ventricles. This hole allows shunting of blood in the ventricles.

Protocol:
1. Sagittal localizer or 3-plane localizer
2. Long Axis localizer
   • FIESTA or FastCINE 4-chamber view
3. Axial FIESTA
   • Cover entire heart anatomy
   • Evaluates morphology
4. Short Axis FIESTA
   • Visualizes VSD and blood shunting
   • Evaluates LV and RV function
5. 4-chamber FIESTA
   • Cover entire ventricle
6. Phase Contrast
   • Perform Qp/Qs in the main pulmonary artery and in the aorta to evaluate flow in right and left heart

Considerations:
• FastCINE sequence in the plane of the VSD may be beneficial to visualize blood shunting.
• Analyze the PC series utilizing ReportCARD to generate flow curves and compare flow values in the right and left heart.
• Refer to Adult Protocols in Chapter 3 for more detailed scanning information.
Chapter 5

Cardiac Pulse Sequences
Parameter Guide

- 3-Plane Non-Gated FIESTA
- Gated CINE FIESTA Standard Resolution
- Gated CINE FIESTA (1 heart beat mode)
- FastCINE
- FastCINE Phase Contrast
- FGRE Time Course MR-Echo (HDx 14.0)
- FIESTA Time Course MR-Echo (HDx 14.0)
- Fast GRE-ET Time Course
- 2D Myocardial Delayed Enhancement
- 3D Myocardial Delayed Enhancement
- Double IR FSE
- Triple IR-FSE
- 3D Gated FIESTA with FatSat
- Continuous IR for Real-time Imaging (PFO Sequence I-DrivePro)
### 3-Plane Non-Gated FIESTA

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>2D FIESTA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>3-plane</td>
</tr>
<tr>
<td>TE</td>
<td>Min full</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>40/1.0</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>60°</td>
</tr>
<tr>
<td>NEX</td>
<td>1</td>
</tr>
<tr>
<td>BW</td>
<td>125</td>
</tr>
<tr>
<td>Slice Thickness</td>
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</tr>
<tr>
<td>Gap</td>
<td>2 mm</td>
</tr>
<tr>
<td>Matrix</td>
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</tr>
<tr>
<td>Imaging Options</td>
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### Gated CINE FIESTA Standard Resolution

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</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min full</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>35-40/1.0</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>45°</td>
</tr>
<tr>
<td>NEX</td>
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<tr>
<td>BW</td>
<td>125 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Trigger Delay</td>
<td>Min</td>
</tr>
<tr>
<td>Arrhythmia Rejection Window</td>
<td>20</td>
</tr>
<tr>
<td># card phases recon</td>
<td>20</td>
</tr>
<tr>
<td>VPS</td>
<td>24 (Temporal resolution 50-80 msec)</td>
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<tr>
<td>Slice Thickness</td>
<td>8 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>0</td>
</tr>
<tr>
<td>Matrix</td>
<td>192 x 160</td>
</tr>
<tr>
<td>Imaging Options</td>
<td>Gating, seq, fast</td>
</tr>
</tbody>
</table>
### Gated CINE FIESTA (1 heart beat mode)

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>FIESTA (MR Echo)</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>Plane</td>
<td>oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min full</td>
</tr>
<tr>
<td>FOV</td>
<td>35-38</td>
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<tr>
<td>BW</td>
<td>125 KHz</td>
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<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Temp Res:</td>
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<tr>
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<tr>
<td>Gap</td>
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<tr>
<td>Matrix</td>
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<tr>
<td>Imaging Options</td>
<td>Gating, Seq, Fast, ASSET</td>
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### FastCINE

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>2D FastCard SPGR</th>
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</thead>
<tbody>
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</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min full</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>40/.75</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>10°</td>
</tr>
<tr>
<td>NEX</td>
<td>.5-1</td>
</tr>
<tr>
<td>BW</td>
<td>20 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Arrhythmia Rejection Window</td>
<td>20</td>
</tr>
<tr>
<td>Trigger Delay</td>
<td>Min</td>
</tr>
<tr>
<td># phases to reconstruct</td>
<td>20</td>
</tr>
<tr>
<td>VPS</td>
<td>6-8 (heartrate dependent)</td>
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<tr>
<td>Slice Thickness</td>
<td>8 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>0</td>
</tr>
<tr>
<td>Matrix</td>
<td>256 x 128</td>
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<tr>
<td>Imaging Options</td>
<td>FC, Gating, Fast, Sequential</td>
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### FastCINE Phase Contrast

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</tr>
</thead>
<tbody>
<tr>
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<td>Body or 8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min full</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>36-48/1.0</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>20°</td>
</tr>
<tr>
<td>NEX</td>
<td>1</td>
</tr>
<tr>
<td>BW</td>
<td>31 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Arrhythmia Rejection Window</td>
<td>20</td>
</tr>
<tr>
<td>Trigger Delay</td>
<td>min</td>
</tr>
<tr>
<td>Number of cardiac phases</td>
<td>30</td>
</tr>
<tr>
<td>VPS</td>
<td>4-8</td>
</tr>
<tr>
<td>Slice Thickness</td>
<td>8 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>0</td>
</tr>
<tr>
<td>Matrix</td>
<td>256 x 128</td>
</tr>
<tr>
<td>Imaging Options</td>
<td>Gating, Sequential, Fast</td>
</tr>
<tr>
<td>CV's</td>
<td>CV0 = 1, CV2 = 0</td>
</tr>
<tr>
<td>Vascular Screen</td>
<td>Collapse off, flow analysis on, VENC = Aorta 200-250 cm/sec, PA 150-200 cm/sec, Flow recon=phase diff, flow direction=slice</td>
</tr>
</tbody>
</table>

### FGRE Time Course MR-Echo (HDx 14.0)

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>FGRE MR-Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min Full</td>
</tr>
<tr>
<td>Frequency FOV</td>
<td>36 - 40 cm</td>
</tr>
<tr>
<td>Phase FOV</td>
<td>36 - 40 cm</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>15°</td>
</tr>
<tr>
<td>NEX</td>
<td>1</td>
</tr>
<tr>
<td>BW</td>
<td>83.3 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Number of phases</td>
<td>30</td>
</tr>
<tr>
<td>Slice Thickness</td>
<td>10 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>Adjust for LV coverage</td>
</tr>
<tr>
<td>Matrix</td>
<td>128 x 128</td>
</tr>
<tr>
<td>Options</td>
<td>Gating, MultiPhase, Asset, IR prep</td>
</tr>
<tr>
<td>R-R interval</td>
<td>1 for up to 50 bpm, 2 for 50-90 bpm</td>
</tr>
</tbody>
</table>
## FIESTA Time Course MR-Echo (HDx 14.0)

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>FIESTA MR-Echo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min Full</td>
</tr>
<tr>
<td>Freq</td>
<td>36 - 40</td>
</tr>
<tr>
<td>Phase</td>
<td>27 - 40</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>20°</td>
</tr>
<tr>
<td>NEX</td>
<td>.5</td>
</tr>
<tr>
<td>BW</td>
<td>125 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>Number of phases</td>
<td>30</td>
</tr>
<tr>
<td>Slice Thickness</td>
<td>8 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>Adjust for LV coverage</td>
</tr>
<tr>
<td>Matrix</td>
<td>224 x 160</td>
</tr>
<tr>
<td>R-R interval</td>
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## Fast GRE-ET Time Course

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>Fast GRE-ET</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil</td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>Min Full</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>35-38/.75</td>
</tr>
<tr>
<td>Flip Angle</td>
<td>20°</td>
</tr>
<tr>
<td>ETL</td>
<td>4</td>
</tr>
<tr>
<td>BW</td>
<td>125 KHz</td>
</tr>
<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td>3 RR interval</td>
<td>2</td>
</tr>
<tr>
<td>Trigger Delay</td>
<td>MIN</td>
</tr>
<tr>
<td>Arrhythmia Rejection Window</td>
<td>5</td>
</tr>
<tr>
<td>Multiphase</td>
<td>30</td>
</tr>
<tr>
<td>Slice Thickness</td>
<td>10 mm</td>
</tr>
<tr>
<td>Gap</td>
<td>Adjust for LV coverage</td>
</tr>
<tr>
<td>Matrix</td>
<td>128 x 128</td>
</tr>
<tr>
<td>Imaging Options</td>
<td>Gat, Fast, MultiPhase, IR Prep, ET</td>
</tr>
</tbody>
</table>
# 2D Myocardial Delayed Enhancement

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>2D Gradient Echo IrP</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coil</strong></td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td><strong>Plane</strong></td>
<td>oblique</td>
</tr>
<tr>
<td><strong>TE</strong></td>
<td>Min</td>
</tr>
<tr>
<td><strong>Flip</strong></td>
<td>20</td>
</tr>
<tr>
<td><strong>FOV/Phase FOV</strong></td>
<td>35-38/1.0</td>
</tr>
<tr>
<td><strong>TI Prep time</strong></td>
<td>Adjust as needed optimized for contrast dose and nulling of the normal myocardium</td>
</tr>
<tr>
<td><strong>NEX</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>BW</strong></td>
<td>25 KHz</td>
</tr>
<tr>
<td><strong>Gated</strong></td>
<td>ECG</td>
</tr>
<tr>
<td><strong># of RR Interval</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Trigger Window</strong></td>
<td>20</td>
</tr>
<tr>
<td><strong>Trigger Delay</strong></td>
<td>300 (onset of systole)</td>
</tr>
<tr>
<td><strong>Slice Thickness</strong></td>
<td>8 mm</td>
</tr>
<tr>
<td><strong>Gap</strong></td>
<td>0</td>
</tr>
<tr>
<td><strong>View per Segment (VPS)</strong></td>
<td>16-24 (10-15 second breath hold)</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td>224 x 160</td>
</tr>
<tr>
<td><strong>Imaging Options</strong></td>
<td>Gat, Fast, IrP</td>
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</table>

# 3D Myocardial Delayed Enhancement

<table>
<thead>
<tr>
<th>Pulse Sequence</th>
<th>3D FGRE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coil</strong></td>
<td>8-Channel cardiac</td>
</tr>
<tr>
<td><strong>Plane</strong></td>
<td>short axis</td>
</tr>
<tr>
<td><strong>TE</strong></td>
<td>Min Full</td>
</tr>
<tr>
<td><strong>Flip</strong></td>
<td>15</td>
</tr>
<tr>
<td><strong>FOV/Phase FOV</strong></td>
<td>3-38/1.0</td>
</tr>
<tr>
<td><strong>TI Prep time</strong></td>
<td>Adjust as needed optimized for contrast dose and nulling of the normal myocardium</td>
</tr>
<tr>
<td><strong>NEX</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>BW</strong></td>
<td>25 KHz</td>
</tr>
<tr>
<td><strong>Gated</strong></td>
<td>ECG</td>
</tr>
<tr>
<td><strong># of RR Interval</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Trigger Window</strong></td>
<td>20</td>
</tr>
<tr>
<td><strong>Trigger Delay</strong></td>
<td>300 (onset of systole)</td>
</tr>
<tr>
<td><strong>Slice Thickness/#locs</strong></td>
<td>8 mm/8</td>
</tr>
<tr>
<td><strong>CV</strong></td>
<td>CV3=0, CV6=1</td>
</tr>
<tr>
<td><strong>Matrix</strong></td>
<td>224 x 160</td>
</tr>
<tr>
<td><strong>Imaging Options</strong></td>
<td>Gat, Fast, IrP ZIP2</td>
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### Double IR-FSE

<table>
<thead>
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<th>Pulse Sequence</th>
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<tbody>
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<td>Coil</td>
<td>8-Channel cardiac</td>
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<tr>
<td>Plane</td>
<td>Oblique</td>
</tr>
<tr>
<td>TE</td>
<td>42</td>
</tr>
<tr>
<td>FOV/Phase FOV</td>
<td>24-40/.75</td>
</tr>
<tr>
<td>ETL</td>
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<tr>
<td>BSP TI</td>
<td>Auto</td>
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<td>NEX</td>
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<tr>
<td>BW</td>
<td>62 KHz</td>
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<tr>
<td>Gated</td>
<td>ECG</td>
</tr>
<tr>
<td># of RR Interval</td>
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</tr>
<tr>
<td>Trigger Delay</td>
<td>Min</td>
</tr>
<tr>
<td>Slice Thickness</td>
<td>6-8 mm</td>
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<td>Gap</td>
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### Triple IR-FSE

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### 3D Gated FIESTA with FatSat

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### Continuous IR for Real-time Imaging (PFO Sequence I-DrivePro)

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Acknowledgements:

1. Online reference for congenital images: http://pted.org/htms/list.php#1

2. Cynthia Rigsby, MD  
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   Childrens Memorial Hospital, Chicago, ILL

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6. Joanna Jobson  
   MR Global Marketing Program Manager  
   GE Healthcare, Waukesha, WI
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