The MESA COPD Magnetic Resonance Imaging Field Center Manual of Procedures *for MESA Participants*

(Johns Hopkins University, Northwestern University, University of California-Los Angeles, Columbia University)

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Please name the sequences according to the guide-line below:

Please name the sequences on the scanner according to the left column, the right column is for your information.

Name	Definition
3_PLANE_SCOUT	(three plane scout)
ASSET_Cal	(asset/sense calibration)
PVLA_SCOUT	(vertical or pseudovertical long axis scout)
SA_SCOUT	(short axis scout)
HLA_CINE	(Horizontal long axis cine)
T1_MAP_PRE	(pre-contrast T1 map)
SA_FGRET_LOC*	(short axis fast gre-et multi phase localizer (5))
SA_FGRET_MP*	(short axis fast gre-et multi phase (40))
TRICKS	(time resovled imaging)
3D_CHEST_INSPIR_AT_1MIN	(hi-resolution 3d spgr)
3D_CHEST_EXPIR_AT_1MIN	(hi-resolution 3d spgr)
SA_CINE	(short axis cine)
VLA_CINE	(two chamber cine)
T1_MAP_POST	(post-contrast T1 map at 12 minutes post Gd)
TI_SCOUT	(TI scout on Siemens and Look Locker on Phillips)
SA_GRE_DE	(delayed enhancement → short axis gradient echo)
HLA_GRE_DE	(delayed enhancement → horizontal long axis gradient echo)
VLA_GRE_DE	(delayed enhancement → two chamber gradient echo)
PA_LOC	(pulmonary artery localizer)
PA_CINE	(pulmonary artery cine)
PC_MPA	(phase contrast → main pulmonary artery)
PC_RPA	(phase contrast → right pulmonary artery)
PC_LPA	(phase contrast → left pulmonary artery)
PC_TR_PG	(Phase Contrast -> Tricuspid valve plane pressure gradient)
RT_INF_PULM_VEIN_FLOW*	(phase contrast → right inferior pulmonary vein)
RT_SUP_PULM_VEIN_FLOW*	(phase contrast → right superior pulmonary vein)
LT_INF_PULM_VEIN_FLOW*	(phase contrast → left inferior pulmonary vein)
LT_SUP_PULM_VEIN_FLOW*	(phase contrast → left superior pulmonary vein)

* Perform if time allows.

General Overview

Different sections of this Protocol:

- **Localizer** images (scout images)
- **Gadolinium injection**: In the current protocol gadolinium-based contrast agent (0.15 mmol/kg body weight, total dose) is administered prior to short axis cine imaging.
- **Cine** images acquired in the short-axis plane from the base (atria) to the apex, using the Steady State Free Precession (SSFP) technique. Long-axis SSFP cine series will also be acquired in the four-chamber view and two chamber view.

- **TI time determination** → A TI (inversion time) scout (Siemens) or Look-locker (Philips) should be performed (where available) to help select the optimal TI for viability imaging.
- **Multiple-shot delayed enhancement** images must be acquired no earlier than 15 minutes after the contrast agent injection, in the same short-axis and long-axis planes as the cine series. A segmented inversion recovery (IR) spoiled gradient recalled echo (GRE) sequence is recommended. If available, a phase sensitive reconstruction technique should be used (Philips, Siemens MRI if available).
- **Single-shot delayed enhancement** (Philips, Siemens MRI scanners if available). The same slice position as multiple shot, however whole slices will be acquired in one breath-hold with SSFP sequence.

Sites are requested to complete an 'MESA COPD MRI Submission Form' for each patient. Steps for Image Acquisition and the MR sequence parameters for the protocol are given below. Typical examples of vendor-specific implementations of the protocol are also provided.

Patient Preparation

1. Make sure that the participant is eligible for complete or parts of the MRI study, by checking the MRI eligibility and exclusion form.
2. Complete the MRI safety screening form of your MRI center. MESA COPD participants are pre-screened for MRI safety/ compatibility but this should be confirmed with your own form.
3. Request patient to use the rest room before the study.
4. Breath-holding is done at resting lung volume (Functional Residual Capacity [FRC]) for the entire MESA COPD protocol. Inform and train participant on breath-holding, example: "Breath in … Let your air out until you are comfortable, and stop breathing."
5. Make sure that the connectors for cardiac coils, ECG and chest/abdomen belts are in place.
6. Thoroughly clean the ECG contact area with alcohol and/or acetone. With patient supine on the scanner table, attach ECG electrodes to his/her chest according to your MRI manufacturer suggestions.
7. **Place a 20 ga. cannula in the right antecubital vein**. Use left arm if necessary. A butterfly needle in a vein in the hand will not suffice.
8. Prepare a dose of gadolinium-based contrast agent (0.15 mmol/kg or 0.3ml/kg) with adequate saline flush.

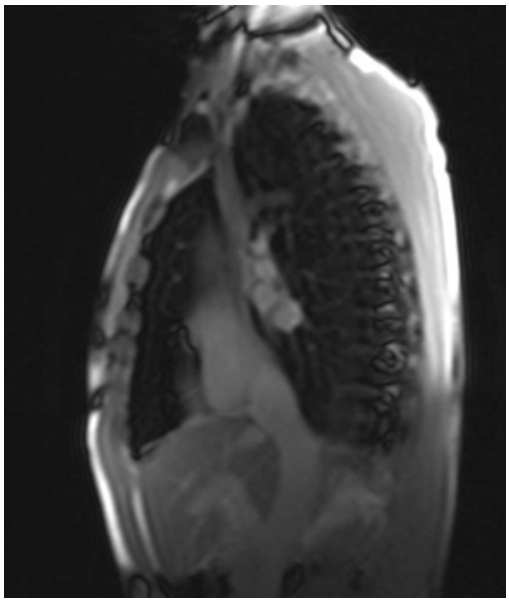
Image Acquisition

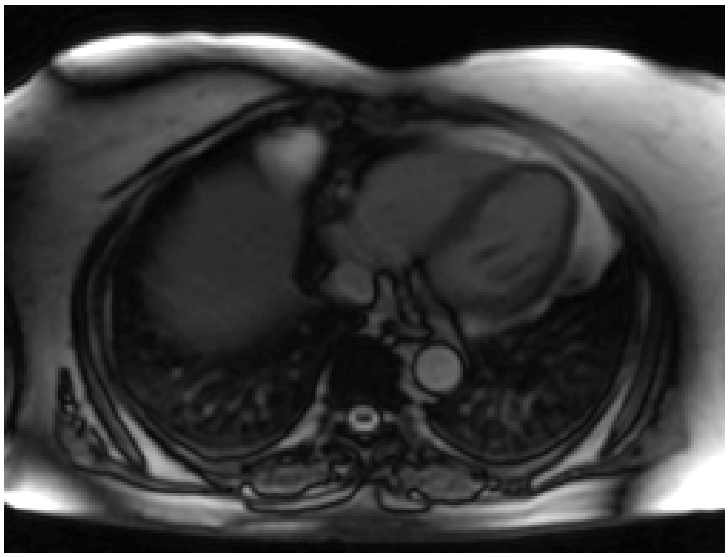
A. Complete the MESA COPD MRI submission form

Please check the exclusion and eligibility form, complete the MRI safety screening form of your center. And complete the MESA COPD MRI submission form.

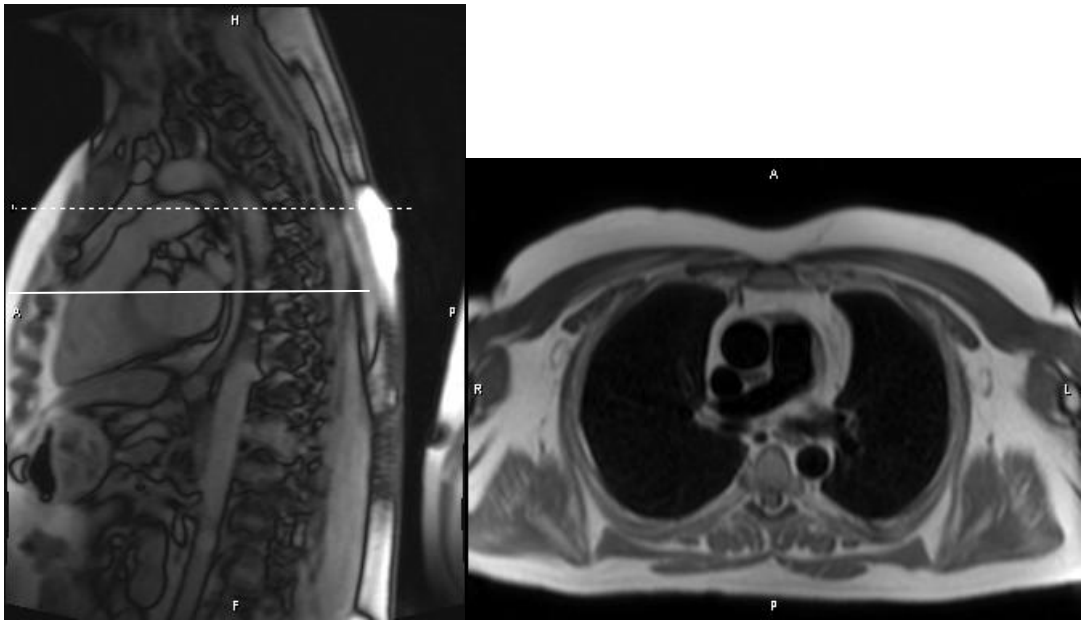
B. Multi-planar Scouts/Localizers:

Fifteen slices in three orthogonal plane (axial, coronal and sagittal) SSFP breath hold scout images should be performed. Localize the heart at the isocenter. **Perform the localizer *AT RESTING LUNG VOLUME*.**

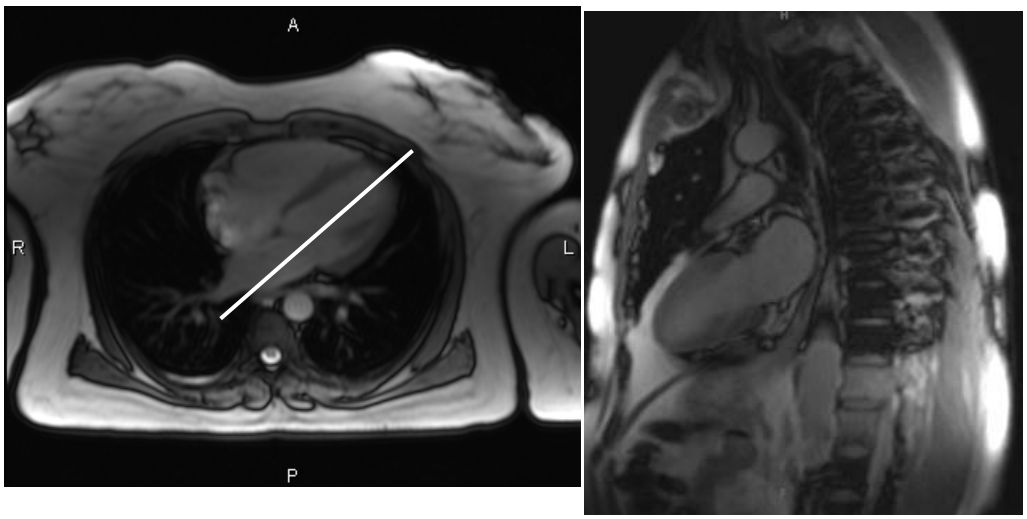




C. Axial Scouts:
Black blood breath hold images (TSE), 10-11 slices starting about 1 cm above the diaphragm, 5 mm slice thickness, covering the half of the upper part of heart. Plan on saggital scouts.
Perform the axial scouts *AT RESTING LUNG VOLUME.*

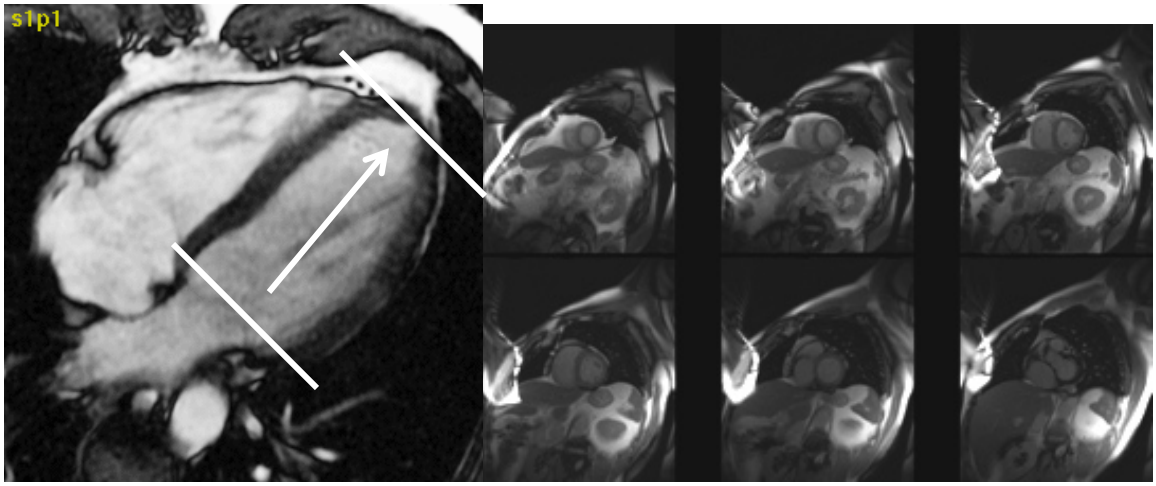


D. Pseudovertical Long Axis Scout:
Bright blood (SSFP), breath-hold, one slice (non-cine) image. Plan this on the axial scout view with the largest volume of heart, form the base (middle of the mitral valve) to apex of the left ventricle, on the axial scouts. Perform the localizer *AT RESTING LUNG VOLUME.*



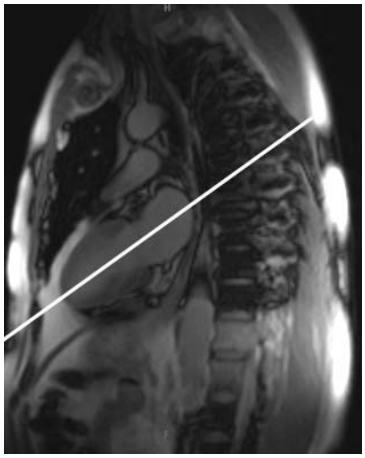
E. Short axis scouts:

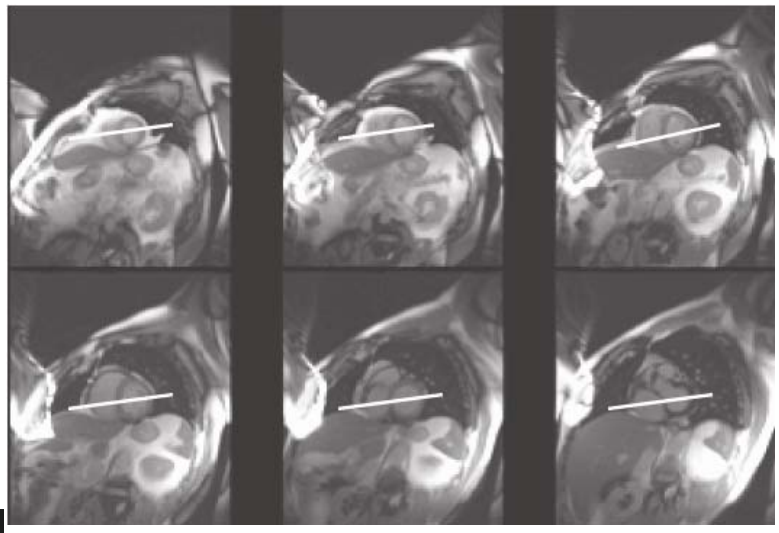
12 bright blood (SSFP) axial images covering the whole heart from great arteries to the apex. These images will be used for planning the short axis cine images. Data acquisition at the diastolic phase.

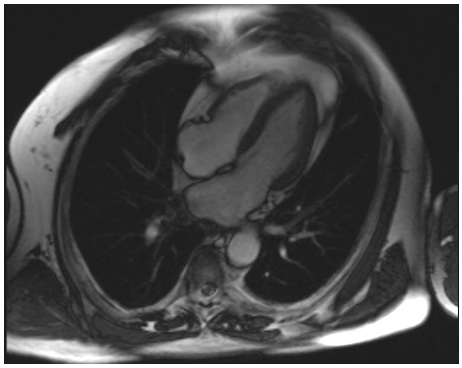


F. Cine Four Chamber (Horizontal long axis, 1 slice):

Bright blood (SSFP), BH method with retrospective gating, 30 phases. This slice should be planned on pseudovertical view. The plane should pass through the middle of the mitral valve to the apex.

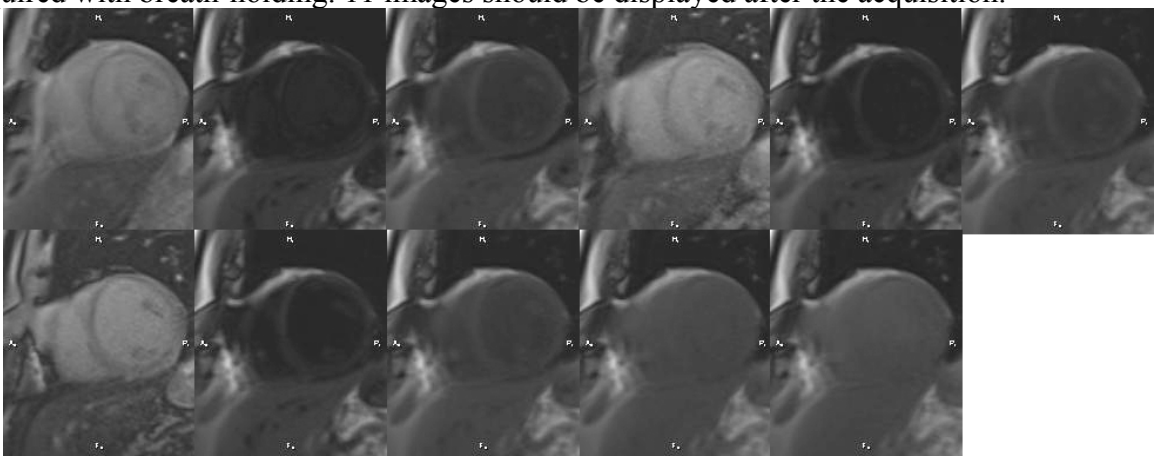






G. T1 mapping: Pre-Contrast (MOLLI, for Siemens scanners ONLY)

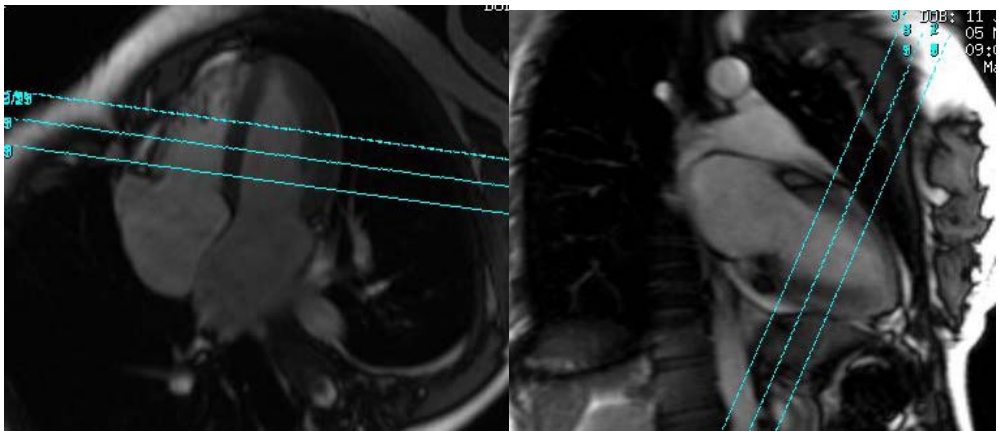
Acquire this sequence in the short axis plane, mid-ventricular level of the LV. MOLLI sequence is used with the following parameters: FOV = 360x360 mm^2, flip angle = 35 degrees, matrix: 256x192, slice thickness = 8 mm. All other parameters should be the default settings. The image sequence is acquired with breath-holding. 11 images should be displayed after the acquisition.



H. **Myocardial First Pass Perfusion (For GE site in Columbia only)**

First, run localizer with the following settings: Use a Gradient Echo Fast GRE-ET, IR prepared multi-phase (5 phases), TE min full, FA 25º, echo train 4, BW 125kHz, FOV≈38cm, slice thickness 8mm skip 5mm, 192x128 (reconstruct to 256x256), zoom mode. Set up 3 SA slices perpendicular to the HLA. Avoid LV outflow tract and apex (check on systolic HLA cine images). Acquisition order should be apex – mid – base. On this scan, check for artifacts (wrapping, motion), myocardial suppression (TI time), phase in the cardiac cycle (trigger delay). Assure that wrapping artifact does not come close to the myocardium; if necessary, increase / rotate FOV or switch phase encoding direction.

For the perfusion sequence, use the same settings as for the localizer scan. Image 40 phases per slice. For the multiphase acquisition, use a contrast agent concentration of 0.05mmol/kg. Start the scan first and collect 2 dynamic images before the start of the CA injection.



I. **Gadolinium Injection and Time Resolved MRA:**

0.1mmol/kg of contrast agent for the lung perfusion MRA (Magnevist, Omniscan or Prohance) is to be used. **Please do not use Multihance without contacting the MRI reading center because of the higher relaxivity of this agent**.

Time resolved methods per each scanner manufacturer are allowed. The desired temporal resolution is approximately 1.5 sec per acquisition.

Gadolinium contrast is infused at 5 ml/sec, followed by saline flush of 20 ml using a 20 g IV minimum. If the I.V. gauge is small, the infusion rate may be decreased. Record **volume** and **time** of each injection on the MRI submission and completion form.

Goals for the time resolved MRA:

- simultaneous injection of the MRA sequence and start the power injection of gadolinium contrast.
- Field of view 48 cm
- slice thickness interpolated to 5 mm
- flip angle/ bandwidth per manufacturer suggestion
- parallel imaging: yes (acceleration factor per manufacturer)
- scan time: 60 seconds

J. **3D_Chest_Inspect_inspire**

This is a 3D Vascular Fast TOF-SPGR. TE min, FA 20º, BW 62.5Khz, FOV 48cm, slice thickness 5mm interpolated to 2.5, 512x160 (freq/phase, for Siemens scanner, 384x269). Cover the entire volume of the lung in the coronal plane. **The subject is asked to take a full breath in and hold it.**

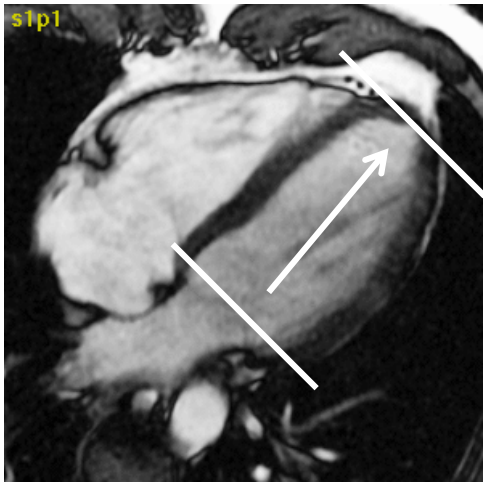
K. **3D_Chest_Inspect_expire**

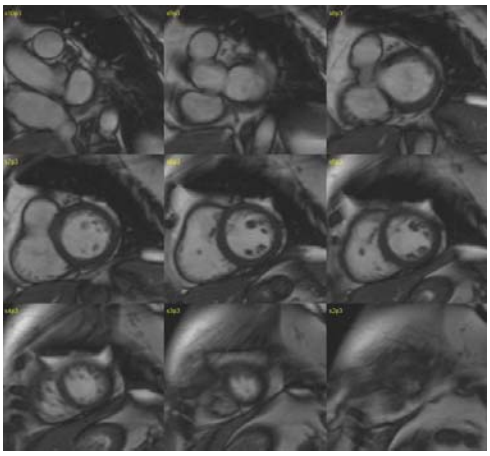
Repeat the same scan as above and ask the subject to breath out to FRC.

J. Cine Short Axis:

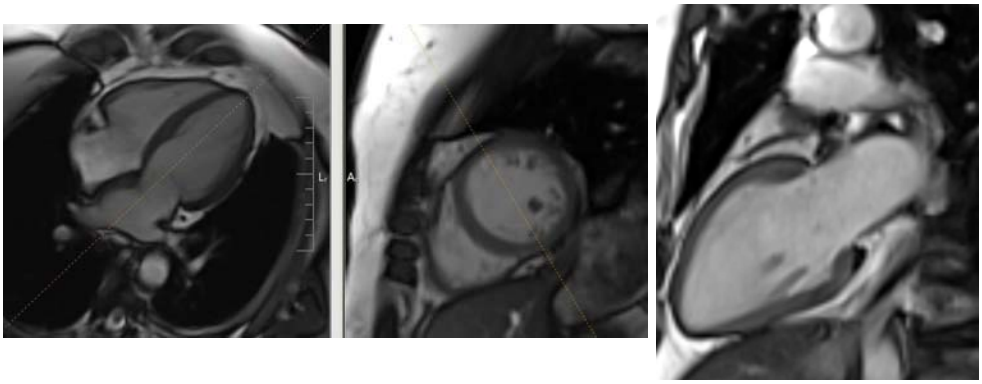
Cine short axis images should be obtained while waiting for gadolinium to wash-out from the myocardium. Bright blood (SSFP) sequence, breath-hold (resting lung volume), **minimum** of 12 slices, 30 phases, covering the whole heart from the atria to apex. Parallel imaging (e.g. ASSET, SENSE, or GRAPPA) with an acceleration factor of 2 to reduce acquisition time (optional). **Begin scanning 1 cm above the mitral valve plane.** Slices should be set in descending order from **base** to **apex**. The position of the slices can be copied from short axis scouts. **Flip angle should be set at the largest possible (90º).**

CINE Imaging	Recommended GENERAL Protocol	Vendor Specific Protocol	
		Siemens	GE
Sequence	SSFP	True FISP	FIESTA
Repetition Time (TR; ms)	minimize δ 3.8	δ 3.8	Min
Echo Time (TE; ms)	minimize	minimized	Min Full
Flip Angle (degrees)	maximize	Up to 90°	Maximum, 45°
Field of View (mm)	360-400 frequency * 270-400 phase (depending on patient size)	360 * 360	360 * 360
Spatial Resolution (mm)	Better than 2.5 * 2.0 * 10.0	1.4*1.7*8	1.4 * 1.8 * 8
Image Matrix	256*128	256*205	256 * 192
Slice Thickness (mm)	8 mm	8	8
Slice Gap (Short Axis) (mm)	2 mm	2	2
Number of phase	30	30	30
Number of slices	Minimum of 12 short axis 1 vertical long axis 1 horizontal long axis	Minimum of 12 SA, 1 four-chamber, 1 VLA	Minimum of 12 SA, 1 four-chamber, 1 VLA
Bandwidth (Hz/pixel)	ε 900	1221	125kHz, 977 Hz/pixel
Parallel Imaging	*(Optional)* Acceleration factor: 2	GRAPPA: 2	ASSET
Partial Fourier (if any)	No	off	No
Gating	Retrospective	ECG/Retro	ECG/Retrospective
Number of segments	δ 20	18	16
Temporal Resolution (ms)	30-50 msec	49	48
Breath-hold time (s)	δ 15	δ 15	δ 15



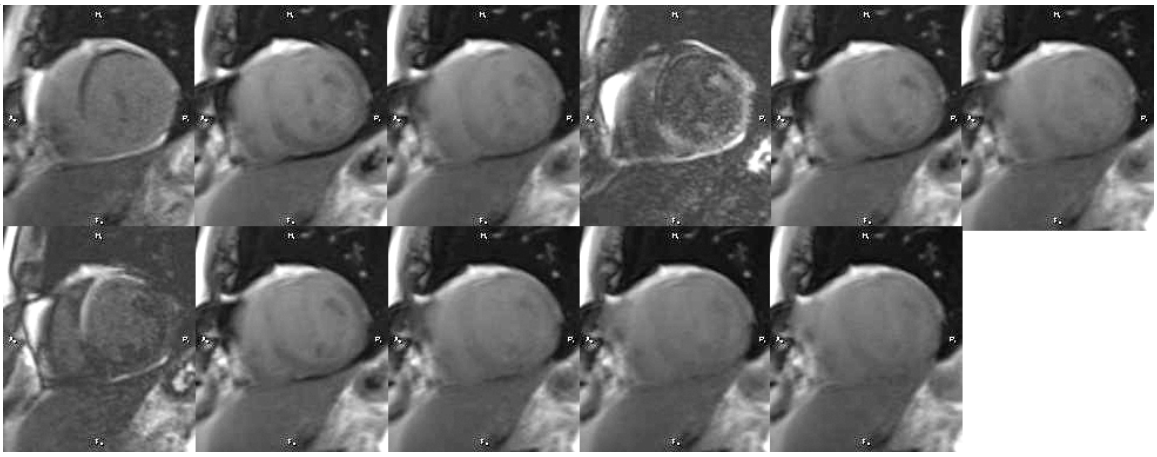


K. Cine Two Chamber (Vertical long axis):
One slice, BH, bright blood (SSFP) sequence. 30 phases in one slice. The slice position be prescribed from a short axis view, and cross-referenced on the 4 chamber view and short axis slices to insure correct positioning.

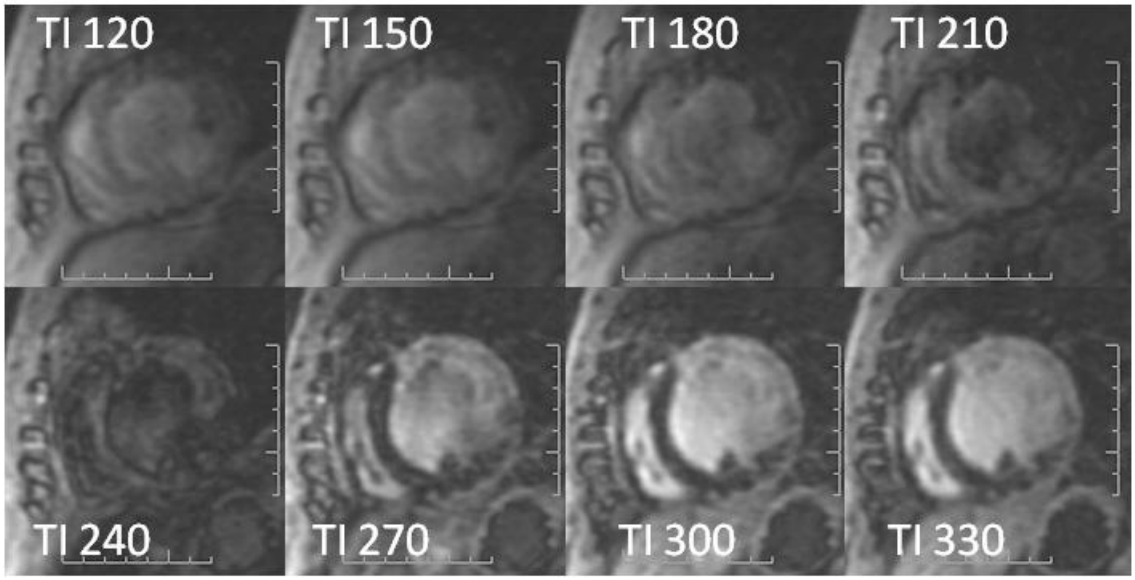


L. T1 mapping: Post-Contrast (MOLLI, for Siemens) at 12 minutes post Gd

Copy and paste the same protocol as in T1 mapping Pre-Contrast. The remaining parameters are based on default setting. Image is acquired with breath-holding. 11 images should be displayed after acquisition.

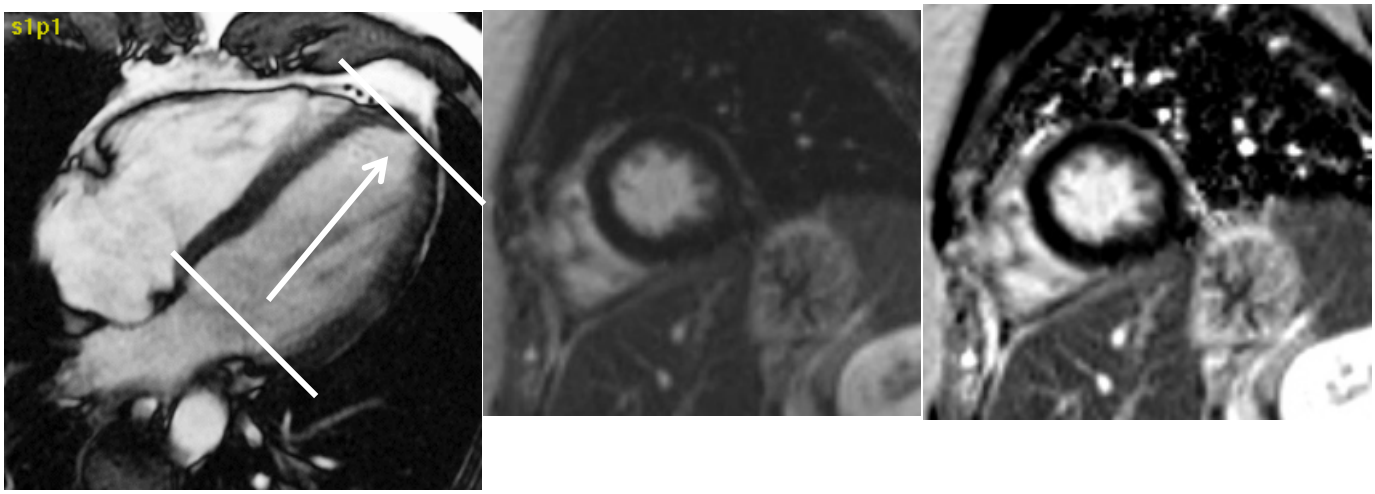


M. TI Scout (Siemens, GE) The purpose of these sets of images is to find the best inversion time that the myocardium appears dark (arrow). This is a bright blood (SSFP), BH sequence, which the slice position can be copied from the cine four chamber view. If TI scout or Look-Locker is unavailable, the following TI may be used: 250ms (Siemens) or 200ms (GE). If myocardium is not nulled, increase TI by 25 ms increments and check resulting images. <u>Perform the TI scout in a mid-ventricular short axis view:</u>



N. Short Axis Gradient Echo Delayed Enhancement:

Segmented inversion recovery (IR) spoiled gradient recalled echo (GRE), if available use PSIR, BH, Stack of short axis slices to cover the LV (use same geometry as short axis cine images). Slice thickness 8 mm; Gap for short-axis slices: δ 2 mm. Use Phase Sensitive IR sequence if available. Check for artifact associated with arrhythmia. If present, proceed directly to single-shot viability (where available).



DELAYED ENHANCEMENT	Recommended GENERAL Protocol	Vendor Specific Protocol	
Multi-Shot		Siemens	GE
Sequence	Inversion Recovery segmented, spoiled GRE	Turbo FLASH PSIR segmented	Fast GRE
Repetition Time (TR; ms)	δ 10	δ 10	Min
Echo Time (TE; ms)	δ 5.0	3.34	Min Full
Flip Angle (degrees)	20-30	25	20
Field of View (mm)	360-400 frequency * 270-400 phase (depending on patient size)	360 * 360	360*360
Spatial Resolution (mm)	Better than 2.5 * 2.0 * 10.0	1.4 * 1.8 * 8	1.4 *2.25*8
Image Matrix	At least 128 * 256	256 * 192	256 * 160
Slice Thickness (mm)	δ 10	8	8
Slice Gap (Short Axis) (mm)	δ 2	2	2
Number of slices	(same as for Cines: short-axis slices to cover heart from valve plane to apex + 1 four-chamber, 1 VLA)	minimum 12 SA	minimum 12 SA
		1 HLA; 1VLA	1HLA; 1VLA
Magnetization Preparation	Inversion Recovery (IR)	non-sel. IR	IR
Inversion time (TI; ms)	Optimize, using TI scout or Look-Locker if available	Start at 300 if uncertain	225 if uncertain
Bandwidth (Hz/pixel)	100-150	130	31.25
Parallel Imaging	None	Off	No
Partial Fourier (if any)	No	Off	No
Trigger	every heart beat	1 trigger pulses	300 ms
Number of segments	δ 30	15	10
Breath-hold time (s)	δ 15	δ 15	12-14

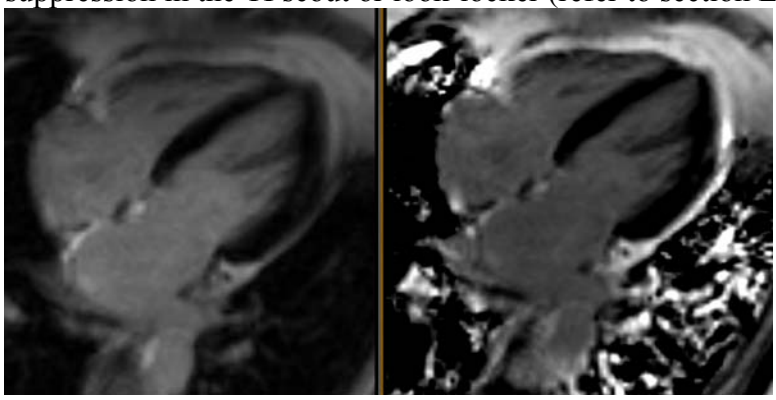
O. Short Axis SSFP Delayed Enhancement

Single-shot inversion recovery (IR) steady state free precession (SSFP) sequence, if available use PSIR. Use parallel imaging (e.g. ASSET, SENSE, or GRAPPA) with an acceleration factor of 2. Select optimal TI and check for nulling of normal myocardium (as described above). Acquire in same short axis and long axis planes as cine images.
Slice thickness: δ 10 mm; Gap: none (contiguous slices).

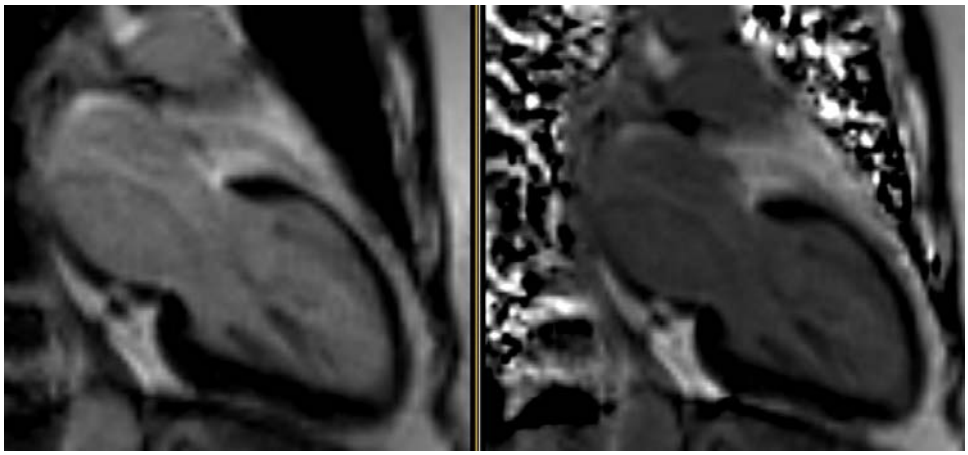
DELAYED ENHANCEMENT		**Vendor Specific Protocol**
Single-shot	**Recommended GENERAL Protocol**	Siemens
Sequence	Single-shot Inversion Recovery SSFP	True FISP IR Single-Shot
Repetition Time (TR; ms)	minimize	δ 3.0
Echo Time (TE; ms)	minimize	minimized
Flip Angle (degrees)	maximize	45
Field of View (mm)	360-400 frequency * 270-400 phase (depending on patient size)	400 * 300
Spatial Resolution (mm)	Better than 3.0 * 3.0 * 10.0	Better than 3.0 * 3.0 * 10.0
Image Matrix	At least 108 * 192	192*130
Slice Thickness (mm)	10	10
Slice Gap (Short Axis) (mm)	none (contiguous slices)	0
Number of slices	(same as for Cines: short-axis slices to cover heart from valve plane to apex + 1 four-chamber, 1 VLA and 1 LVOT)	~10 SA
		1 four-chamber; 1VLA
Magnetization Preparation	Inversion Recovery (IR)	non-sel. IR
Inversion time (TI; ms)	Optimize, using TI scout	Start with 300 if uncertain
Bandwidth (Hz/pixel)	ε 900	1532
Parallel Imaging	Acceleration factor: 2	GRAPPA: 2
Partial Fourier (if any)	None	Off
Trigger	every other heart beat	2 trigger pulses
Number of segments	1	1
Breath-hold time (s)	10-15	13 (BH optional)

P. Four Chamber Gradient Echo Delayed Enhancement

Bright blood (FGRE) if available use PSIR, BH, four chamber view. The position of the slice can be copied form the cine four chamber view. TI should be set based on the optimum myocardial suppression in the TI scout or look-locker (refer to section L).

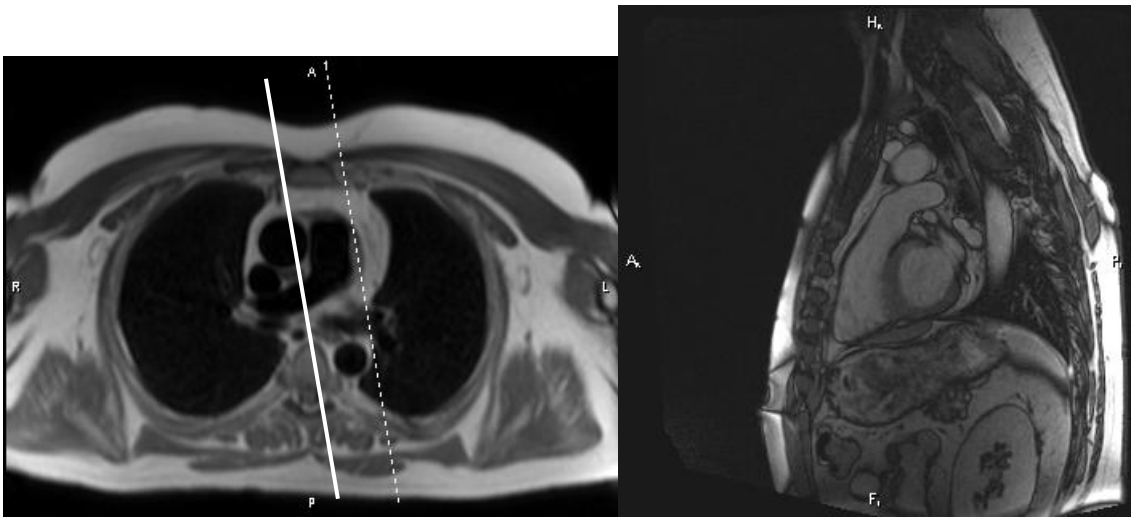


Q. Two Chamber Gradient Echo Delayed Enhancement



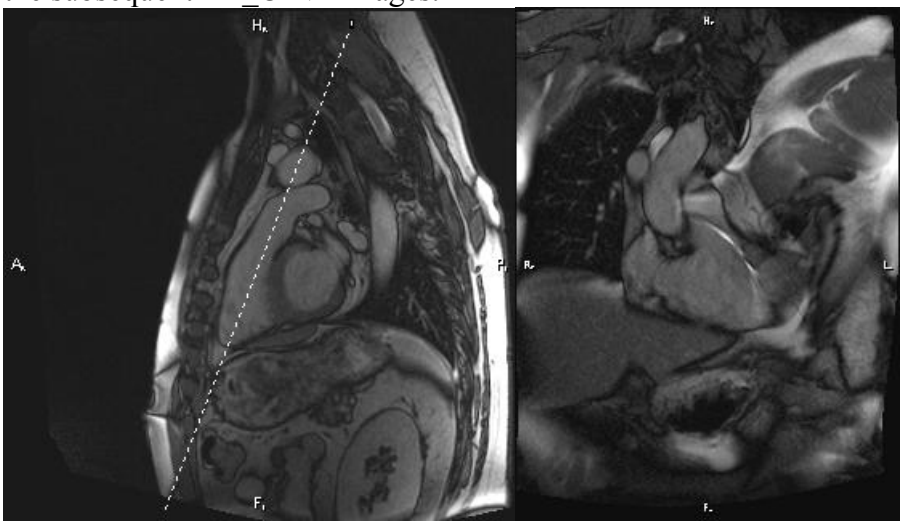
R. Pulmonary Artery Loc (PA_LOC)

To prescribe PA_LOC, from the axial scout images, find the pulmonary trunk (main). Prescribe a stack of PA_LOC position (6-7 slices, 6mm slice thickness). Angle the slice (line) along the length of the main pulmonary artery on the axial images Scroll through the reference images while plotting the slice to ensure that the angle at which you are positioning the blue line follows the MPA from the base of the right ventricle up until it branches into the right and left pulmonary arteries. The resulting 6-7 slice, one phase image at end-diastole. One of the 6 (or 7) images that with the full view of pulmonary artery (as following image) served as a localizer for the subsequent image.



S. Pulmonary Truck Localizer

From the resulting image in previous section, prescribe the position in parallel to the main pulmonary trunk as following. The resulting one slice, one phase image at end-diastole served as a localizer for the subsequent PA_CINE images.

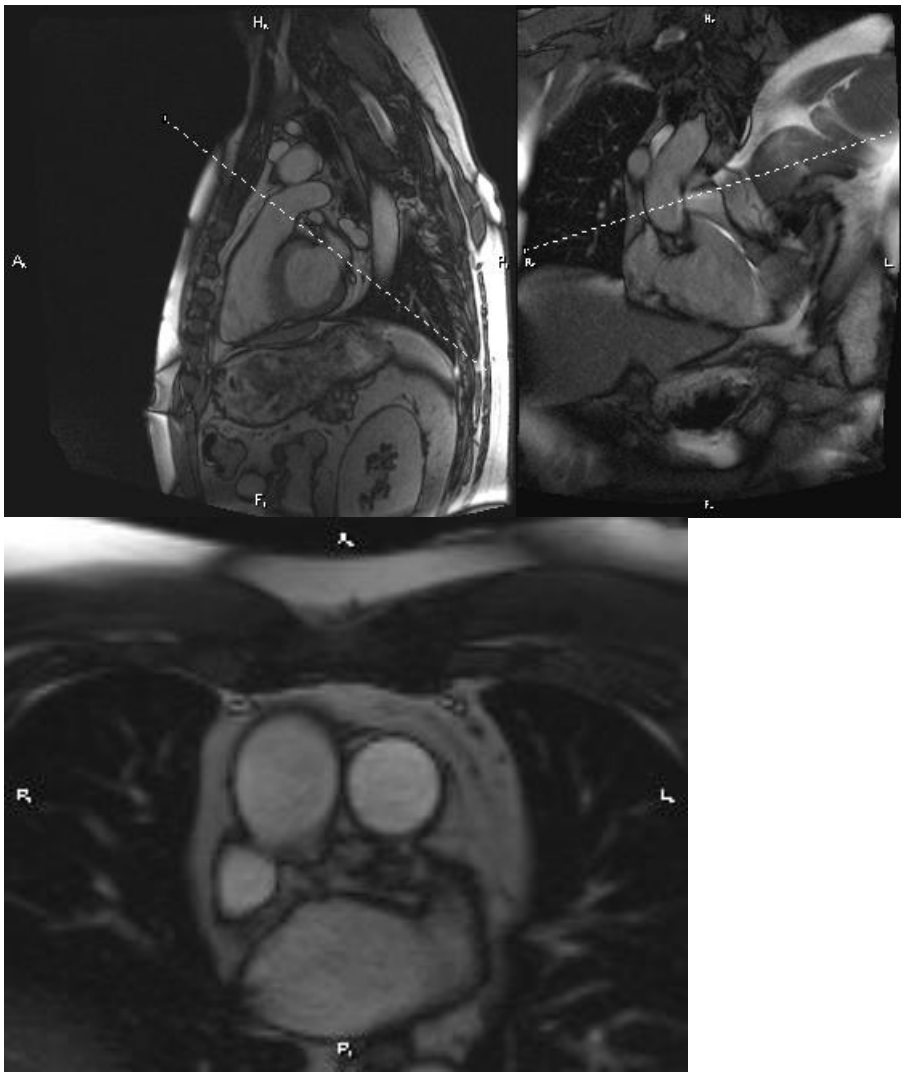


T. Pulmonary Cine

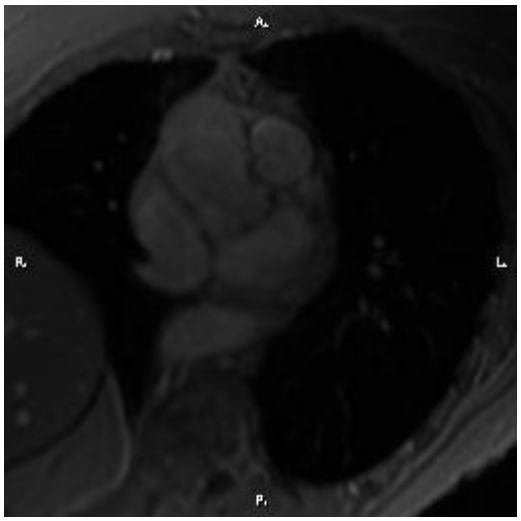
For the following pulmonary artery and vein imaging, adjust the FOV as small as possible without wrapping into the region of interesting.

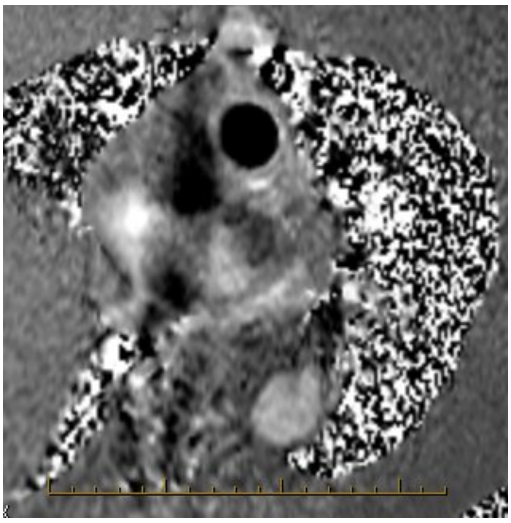
Prescribe PA_CINE images as following:

Use the PA_LOC from previous two sections to angle the slice through the pulmonary trunk. Use the same protocol as SA CINE for PA CINE (30 phases, 8 mm, 256x205), except FOV could be as small as possible with wrapping into the region of interest.



U. Phase contrast main pulmonary artery
Copy and paste the same scan position as the pulmonary CINE in the previous section. One slice phase contrast cine bright blood, breath-hold sequence, 30 phases.

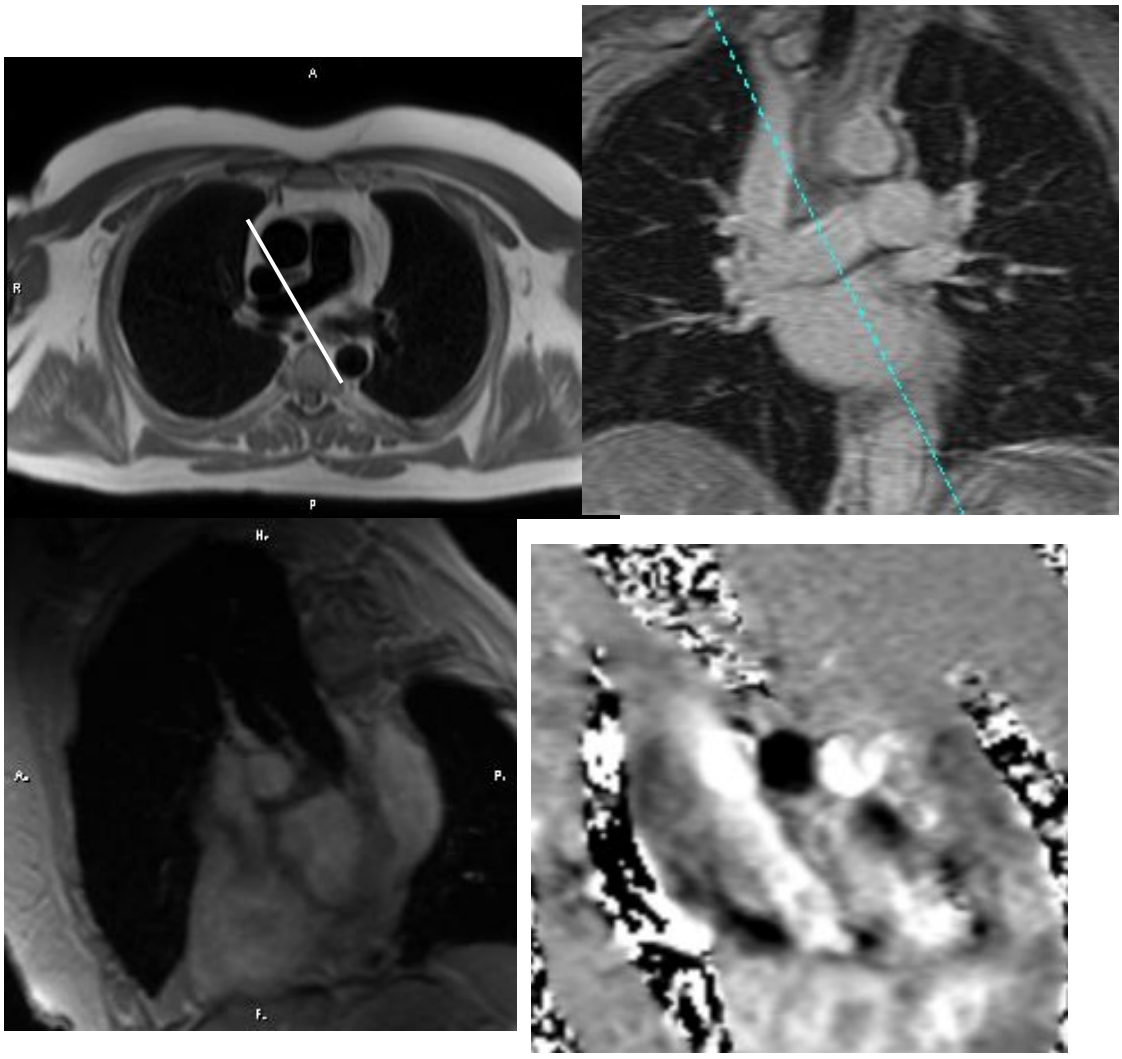




Phase Contrast	Recommended GENERAL Protocol	Vendor Specific Protocol	
		Siemens	GE
Sequence	Phase contrast	FLASH	Fast 2D PC
Repetition Time (TR; ms)	minimize	32	6.2
Echo Time (TE; ms)	minimize	3.1	Minimum
Flip Angle (degrees)	<20	20	20
Field of View (mm)	300*300	300*300	350*350
Spatial Resolution (mm)	1.3*1.3*8	1.3*1.3*8	1.3*1.3*8
Image Matrix	256*128	256*128	256*128
Slice Thickness (mm)	8	8	5
Number of slices	1	1	1
Bandwidth (Hz/pixel)		244	15.63
Parallel Imaging	No	No	No
Partial Fourier (if any)	No	No	No
Gating	Retrospective	Retrospective	Retrospective
Temporal Resolution (ms)	30	30	30
Number of Averaging	2	2	1
VENC	100 cm/sec, through-plane	100 cm/sec	100 cm/sec
Number of phases	30	30	30

V. Phase contrast right pulmonary artery

Use the same protocol as the main pulmonary artery phase contrast imaging. Load the 3D Fast TOF-SPGR (coronal) and one of the axial scout images (that shows the main and right pulmonary arteries) to get a good view of the RPA. On the coronal images, follow the RPA as it branches from the MPA out toward the right lung. Plot your single slice perpendicularly through the RPA approximately 2cm from the bifurcation of the MPA. On the axial images, adjust the angle of the slice to ensure that it is running perpendicularly through the RPA. The best plane is between the trachea and the ascending aorta as indicated in the following axial image.

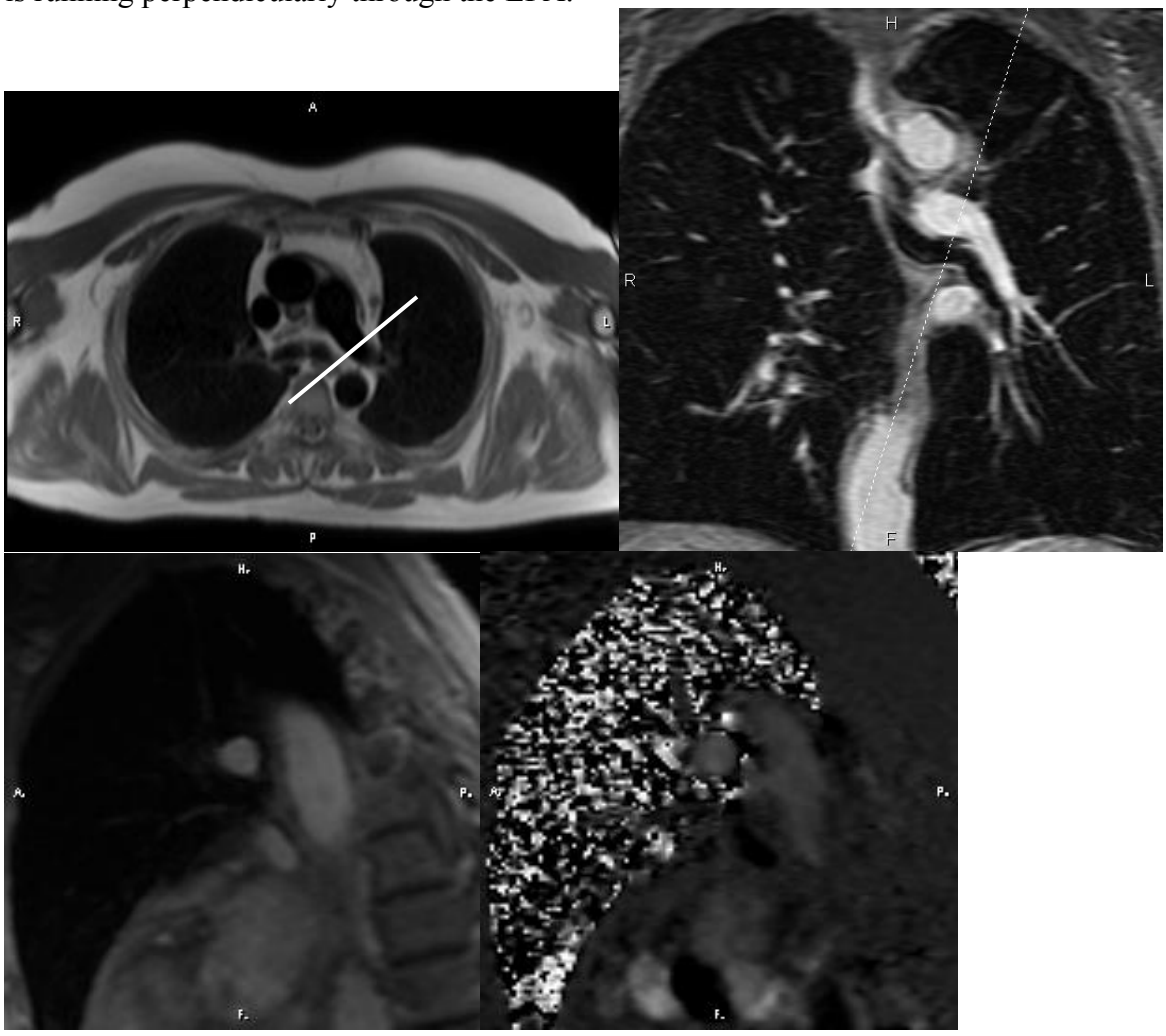


W. Phase contrast left pulmonary artery

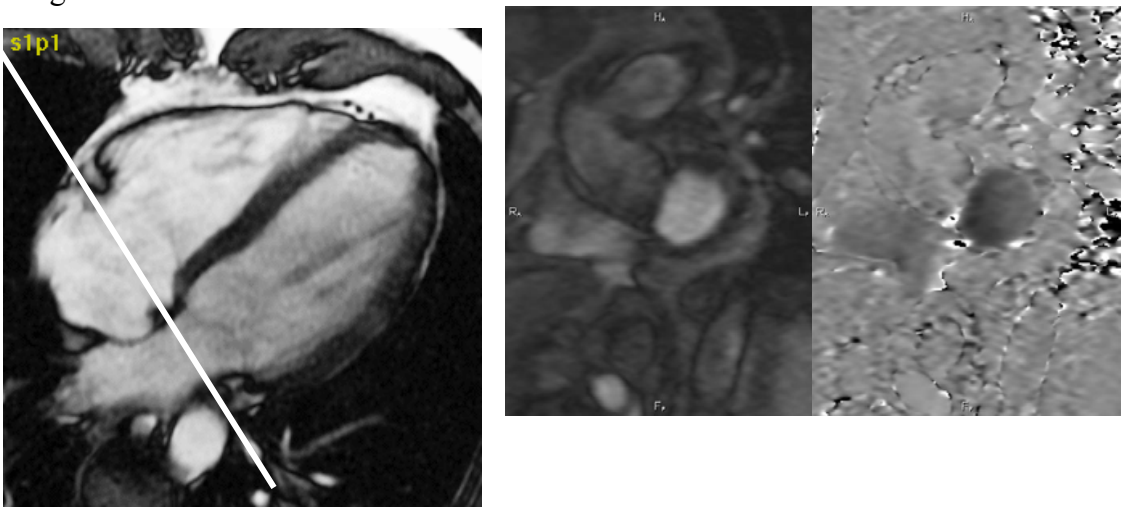
Use the same protocol as the main pulmonary artery phase contrast imaging.

Once again, load the 3D Fast TOF-SPGR (coronal) and axial scout images, this time to get a good view of the LPA. On the coronal images, follow the LPA as it branches from the MPA out toward the left lung. Plot your single slice perpendicularly through the LPA approximately 3cm from the bifurcation of the MPA. This may prove to be more challenging than the RPA, as the LPA curves more than the RPA, so try to position the slice within the straightest portion of the LPA before it

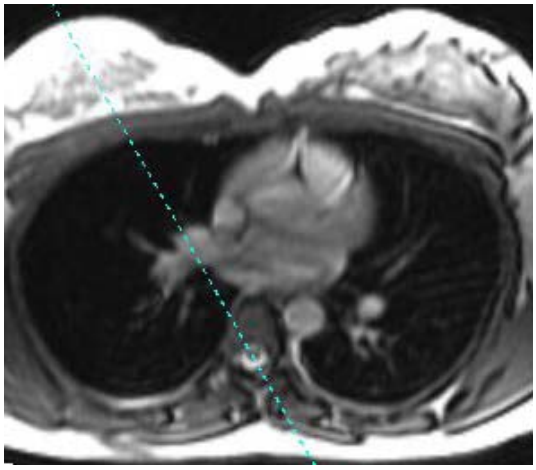
breaks off into second order vessels. On the axial images, adjust the angle of the slice to ensure that it is running perpendicularly through the LPA.



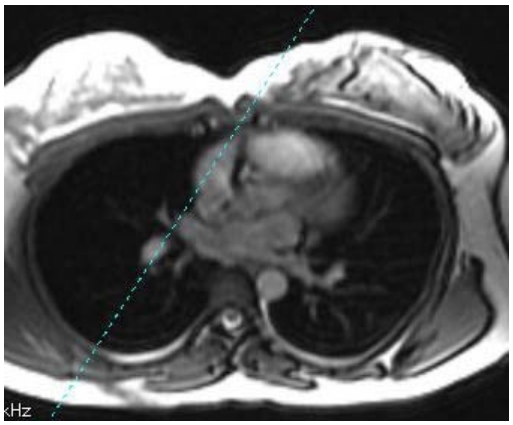
X. Phase Contrast Tricuspid valve plane pressure gradient (PC_TR_PG)
Use the same protocol as the main pulmonary artery phase contrast imaging. For pressure estimation, image is performed in the perpendicular section to the regurgitant jet, and 1 cm proximal to the tricuspid valve. Use diastole CINE HLA view for positioning. Crossed check on systolic CINE images. Set VENC = 150cm/sec.

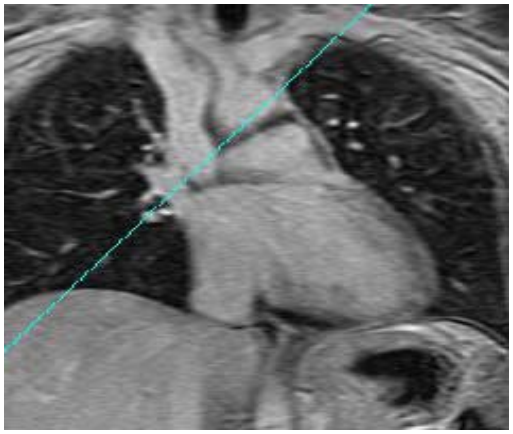


Y1. Phase contrast RT_INF_PULM VEIN FLOW
Use the same protocol as the main pulmonary artery phase contrast imaging. Set the VENC=40cm/sec, and adjust FOV as small as possible without wrapping.

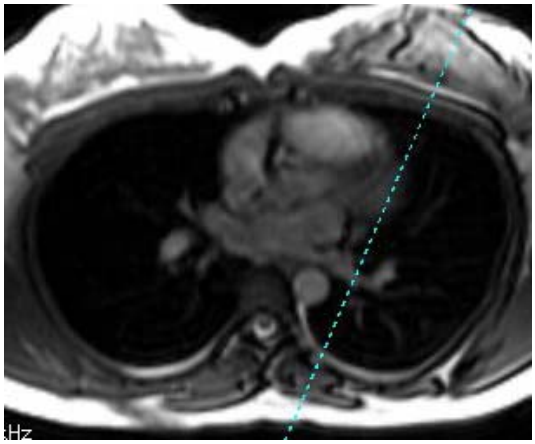


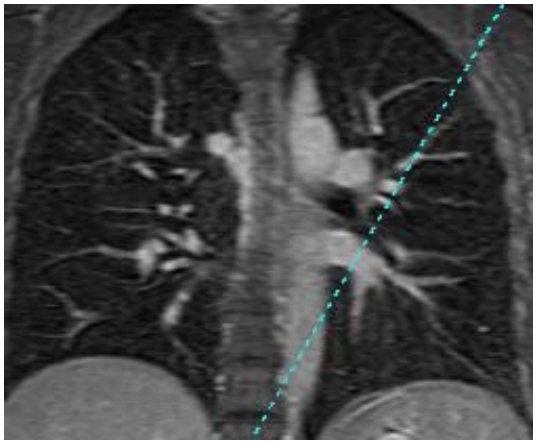
Y2. Phase contrast RT_SUP_PULM VEIN FLOW
Use the same protocol as the main pulmonary artery phase contrast imaging. Set the VENC=40cm/sec, and adjust FOV as small as possible without wrapping.



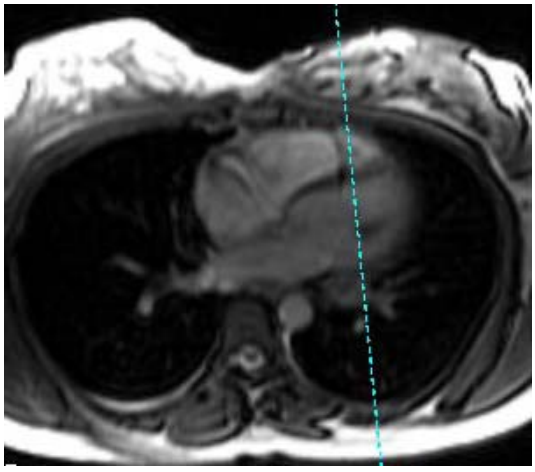


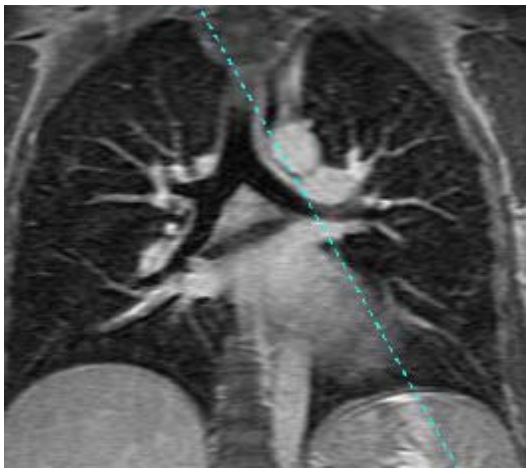
Z1. Phase contrast LT_INF_PULM VEIN FLOW
Use the same protocol as the main pulmonary artery phase contrast imaging. Set the VENC=40cm/sec, and adjust FOV as small as possible without wrapping.





Z2. Phase contrast LT_SUP_PULM VEIN FLOW
Use the same protocol as the main pulmonary artery phase contrast imaging. Set the VENC=40cm/sec, and adjust FOV as small as possible without wrapping.





Submit image-set to MRI Core Lab as per Data Transfer Instructions**.** Burn 2 CD's: one for the MESA COPD coordinator; the other will be sent to Johns Hopkins Hospital by the MESA COPD staff. Back up the data to your PACS system, and fill out the MRI completion form.