NORTHWESTERN UNIVERSITY
FEINBERG SCHOOL OF MEDICINE

MESA

The MESA Exam 6

Echocardiography Manual of Operations

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INTRODUCTION

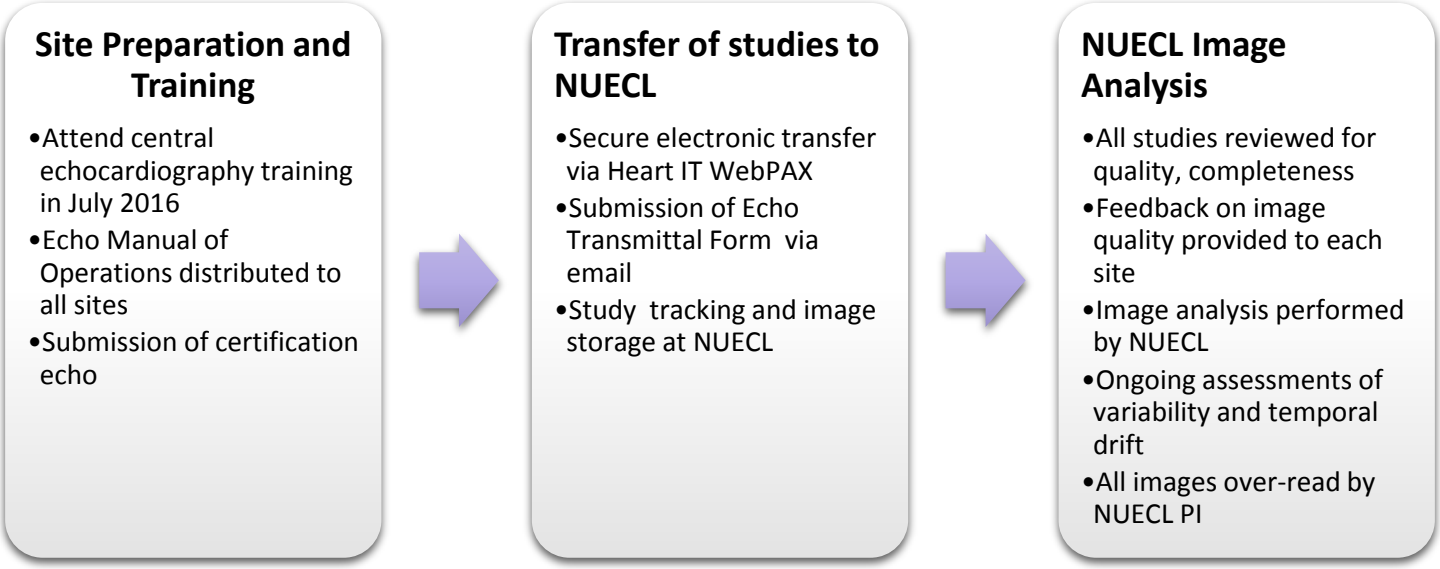
The Northwestern University Echocardiography Core Laboratory (NUECL) in Chicago, Illinois will serve as the echocardiography core laboratory for the Multi-Ethnic Study of Atherosclerosis (MESA) Exam 6. The NUECL was formed to provide accurate and reproducible quantitative analysis of echocardiograms performed during clinical research studies. Echo analysis is performed at the core lab using GE EchoPAC software. All measurements are over-read by the core lab PI, Dr. Sanjiv Shah. This manual contains all key information study sites will need to perform high quality echocardiograms.

ECHOCARDIOGRAPHY OBJECTIVE:

The objective of the MESA Heart Failure study is to determine the prevalence, understand the pathogenesis, and explore the phenomics of early heart failure (HF), particularly early HF with preserved ejection fraction (HFpEF).

Roles and Responsibilities	
Study Sites	• Send representative to attend central training in July 2016 • Ensure that each site sonographer performs a 'certification' echo prior to performing an echo on a study patient • Perform complete, high-quality study echocardiograms per the protocol contained in this document • Submit echos to the NUECL in proper format, in a timely fashion • Keep the NUECL informed of changes in study staff at the site
NUECL	• Train and certify each site sonographer • Receive, review, and analyze study echocardiograms • Provide each site with feedback on echo quality, including suggestions for improvement if needed • Serve as a resource for sites regarding all echo-related questions

STUDY-WIDE PROCESS OVERVIEW



SITE PREPARATION/QUALITY ASSURANCE MEASURES

SELECTION OF SITE SONOGRAPHERS

For the purpose of consistency, one sonographer per site will be chosen as the dedicated sonographer for the MESA study. A back-up sonographer should also be trained at each site in the event that the lead sonographer is unavailable. Certification through the ARDMS (RDCS) or CCI (RCS) is strongly preferred, but not required. Site sonographers should be experienced in echocardiography and able to adhere to the clear, established professional standards for echocardiographic data acquisition that are outlined in this document.

CENTRAL TRAINING

The chosen sonographer(s) from each field center will attend an orientation and training session at Northwestern University in July 2016. At this training session, the echocardiography protocol will be reviewed in detail, and information about machine settings, transmission of studies to the NUECL, quality control measures, the graded alert system, and sonographer certification will also be covered. Each field center sonographer will have the opportunity to perform the echocardiographic imaging protocol under the supervision of NUECL staff. The practice sessions will provide an opportunity for the field center sonographers to discuss technical issues related to image acquisition and ask questions about the echo protocol, and will also allow the NUECL staff to observe the technical competence of each sonographer. In addition to the central training session, local, on-site training may also be provided if deemed necessary by the NUECL.

REFERENCE MATERIALS

Prior to the beginning of study enrollment, the echo manual of operations (MOP) will be distributed to each site. The MOP will contain detailed information about the echocardiographic protocol (with sample images) as well as information about image optimization, instructions for electronic transfer of echocardiograms, the graded alert system, and NUECL contact information. The manual will also contain sample echo transmittal and feedback forms, as well as a quick reference guide to the echo protocol. The MOP should be carefully reviewed by each field center sonographer and used as a reference for the duration of the study.

SONOGRAPHER CERTIFICATION

All sites must be certified by the NUECL to ensure the performance of the highest quality echocardiograms and to maintain consistency in how echocardiograms are performed study-wide. Any sonographer who will be performing study echocardiograms must submit one certification study performed using the protocol contained in this manual and transferred electronically to the NUECL for review and certification. Studies will be evaluated for adherence to protocol and image quality. Feedback and suggestions from the NUECL technical director will be provided for each study submitted. If the certification study is deemed inadequate, sonographers will have the opportunity to re-submit a new study. Upon submission of an adequate sample study, the sonographer will be officially certified.

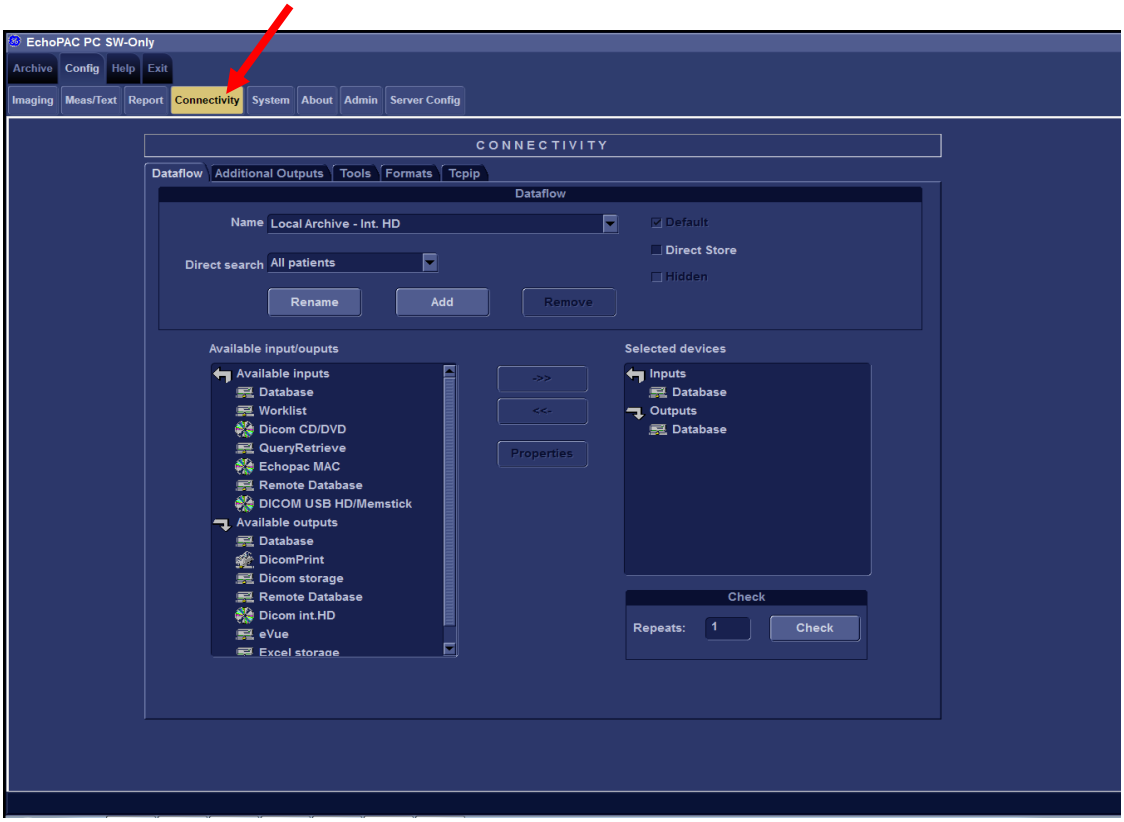
A general outline of the certification process is outlined below:

1. Participate in central echocardiography training
2. Read and review the Echo Manual of Operations, and contact the NUECL with any questions before performing the certification echo
3. Perform the certification echo on a non-study patient, making sure to include all required protocol views
4. Copy the study directly from the echo machine to CD in modified DICOM format, then use WebPAX to transmit to the NUECL
5. Wait for confirmation of certification from the NUECL before submitting any echocardiograms performed on study patients.

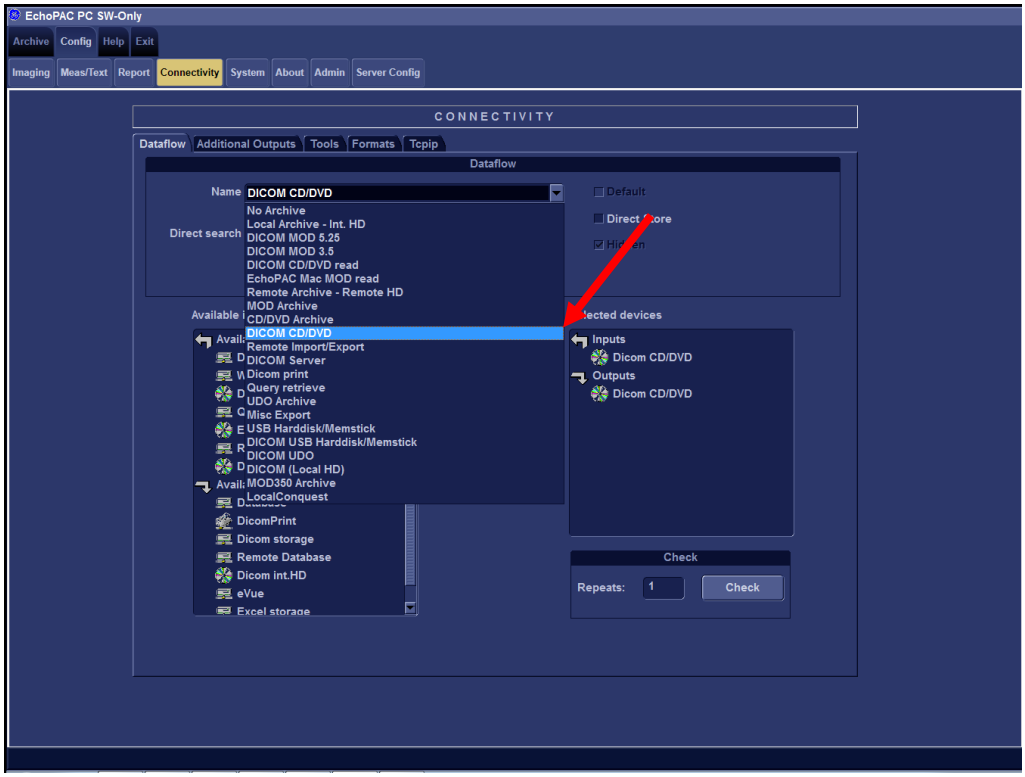
INSTRUCTIONS FOR ELECTRONIC TRANSFER OF ECHO STUDIES TO THE NUECL

All echos performed for the MESA study should be transferred to the NUECL in DICOM format. In order to perform strain analysis on studies transferred to the NUECL, a slight modification must be made to the DICOM CD/DVD settings on the T8 machine. A step-by-step explanation of this process is listed below:

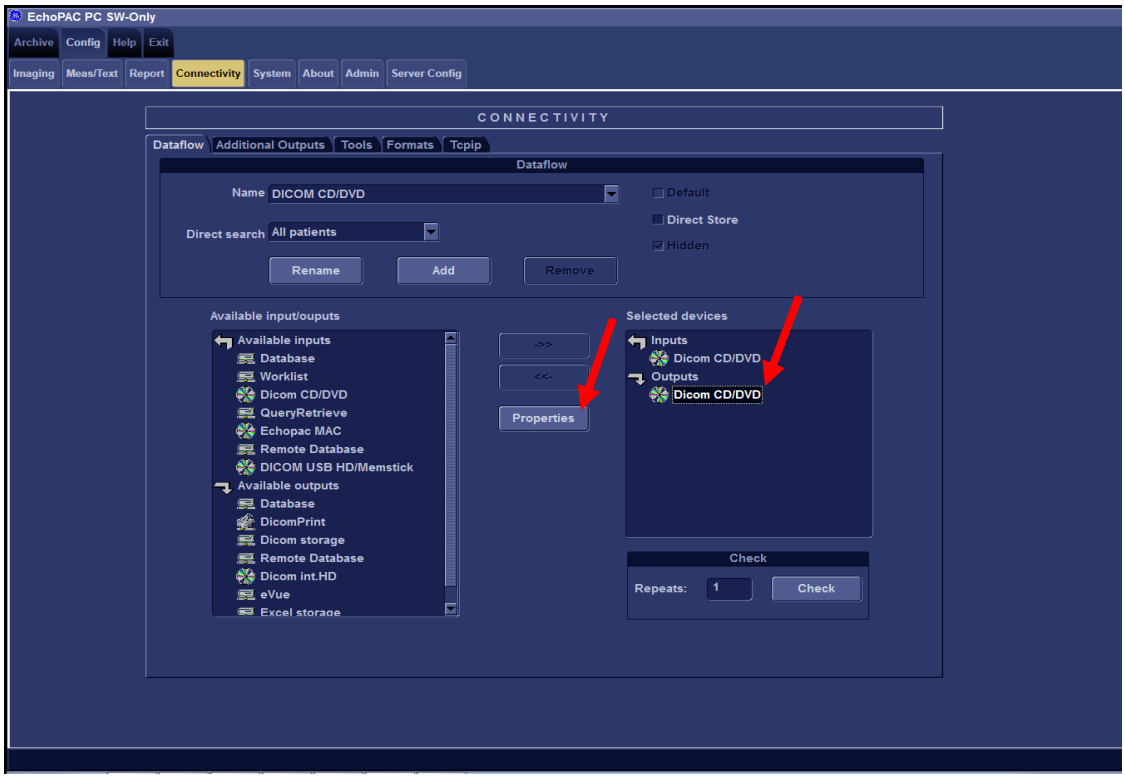
1. First, login as the administrator on your echo machine. Hit the 'config' button on the machine (located on the touch screen under the 'utility' tab). Select the 'connectivity' tab (this tab is located at the bottom of the screen on the T8 machine).



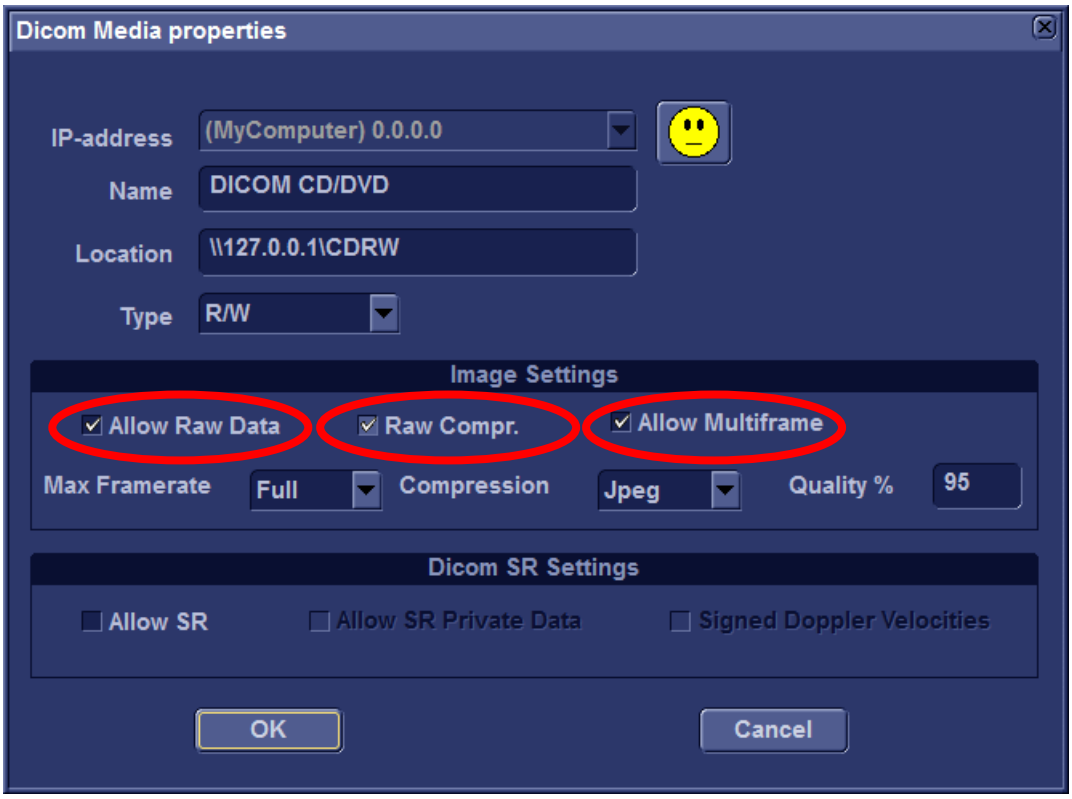
2. The ‘dataflow’ tab should be displayed automatically. Click the arrow next to the ‘name’ field, and select DICOM CD/DVD.



3. In the ‘selected devices’ under ‘outputs,’ select Dicom CD/DVD and click on the ‘properties’ button.



4. A pop up menu should open up on your screen. Within the image settings box, make sure all three boxes are checked (allow raw data, raw compr., and allow multiframe). Hit 'ok'.



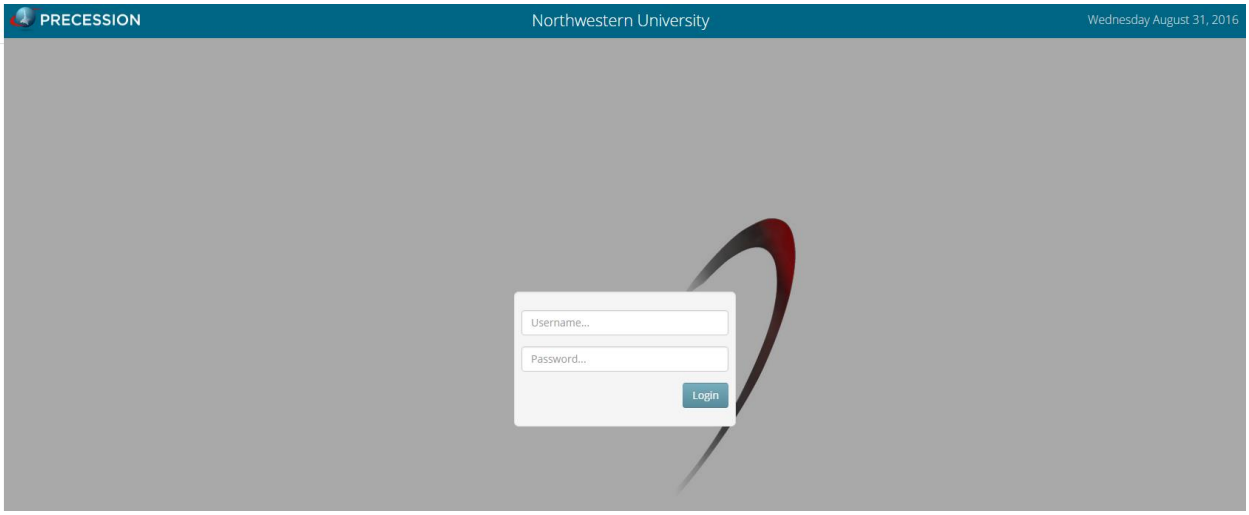
5. The new DICOM settings should now be saved on your machine. Please ensure that these settings are enabled for all study patients.

After the machine has been appropriately configured, study echos can be copied to DVD. Images should be exported directly to the DVD from the echo machine, and not a PACS (Picture Archiving and Communication System) system. To export a study echo, hit 'alt+e' on the T8 keyboard to open the CD/DVD drive. Insert a DVD, then hit the 'Export' tab. Under the 'To' field, select **DICOM CD/DVD** and hit 'ok'. The machine will ask you if you would like the DVD to be formatted – hit 'ok.' Once the DVD is formatted, you will be redirected to the patient list. Select the echo(s) that you would like to export. You may copy all studies performed in one day to the same DVD, but please use a new DVD each day. Hit the 'copy' button. The machine will copy the entire study to the DVD. Once it is finished, hit 'ok,' then hit 'done'. After you hit 'done,' you will be redirected back to the Local Archive. Hit 'alt+e' to eject the DVD.

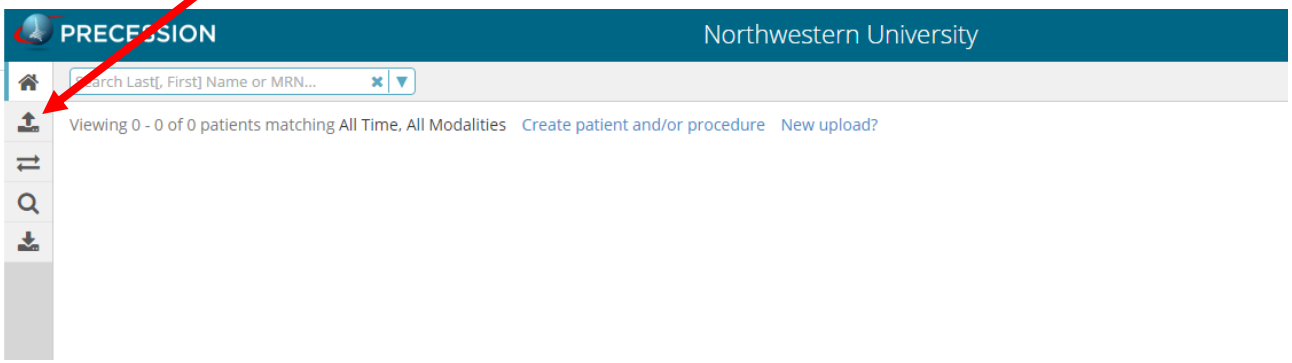
Once the echo has been copied to DVD in the appropriate format, it can then be transmitted to the NUECL electronically. The NUECL utilizes Heart Imaging Technologies (IT) WebPAX for the secure and efficient submission of de-identified echo studies from MESA Field Sites to the NUECL for review. *Please submit all echos to the core lab within 24 hours of performing the study.*

Heart IT WebPAX can be accessed at: https://webpax.fsm.northwestern.edu/. Google Chrome is the recommended browser for WebPAX; the data transfer application may not run as efficiently on other browsers. To transfer a study using WebPAX, perform the following steps:

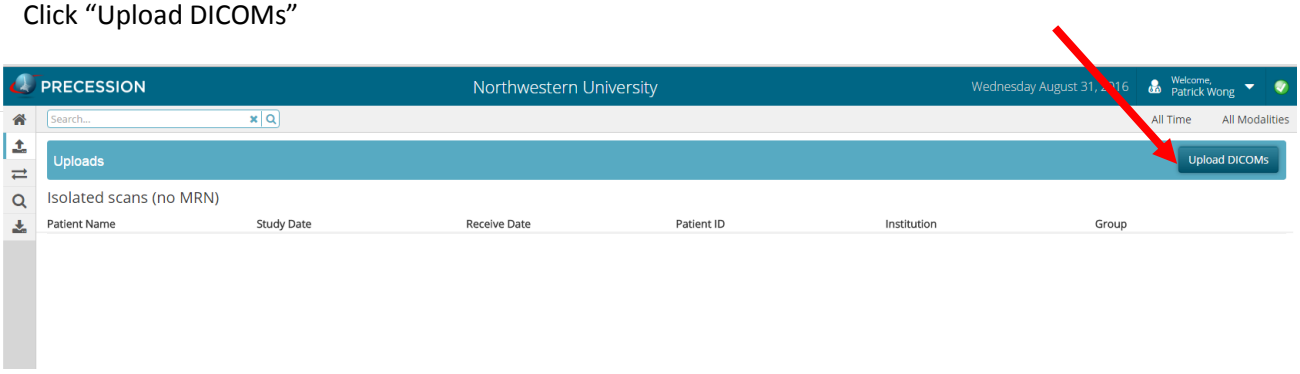
1. Enter Username and Password provided by NUECL.



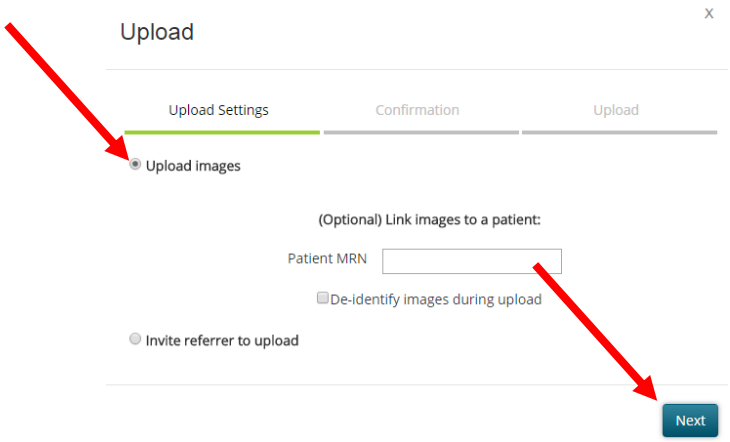
2. Click on the "Upload" button.



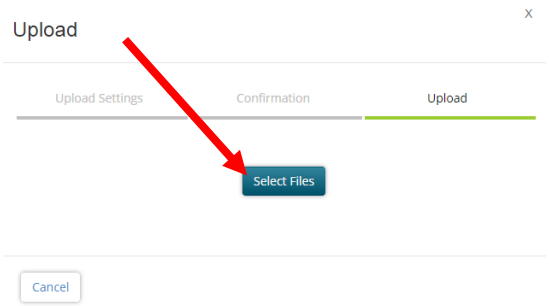
3. Click "Upload DICOMs"



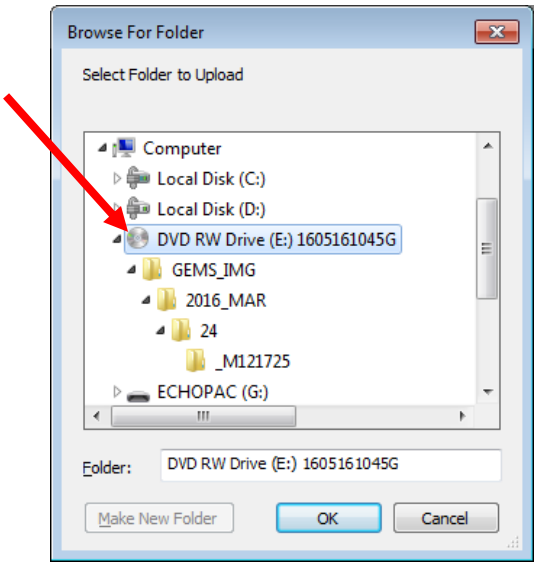
4. Click “Upload images,” then the “Next” button. *Do not enter anything into the Patient MRN field*.



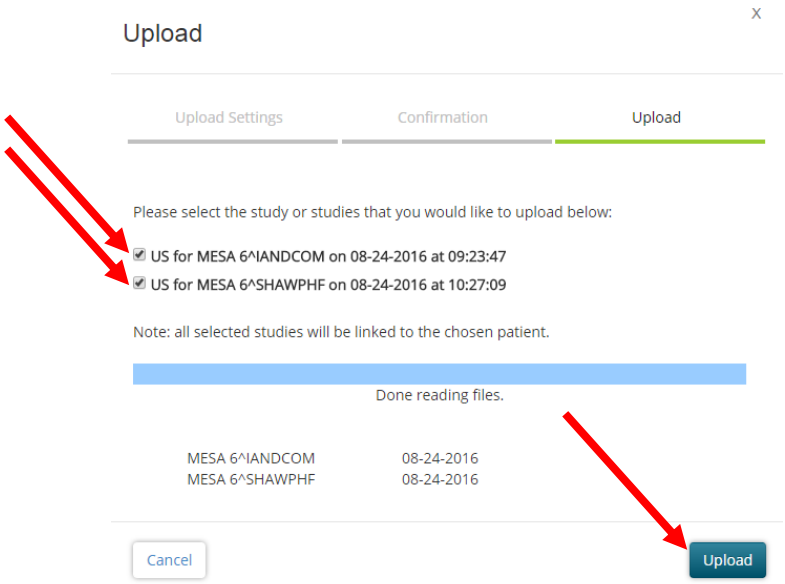
5. Click the “Select Files” button.



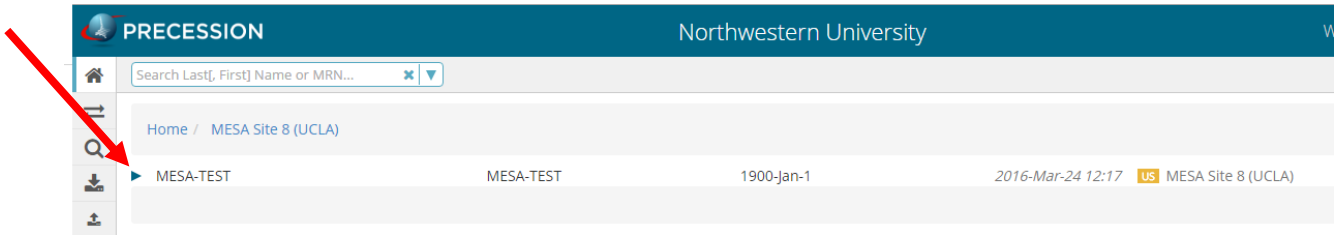
6. A new window will pop up prompting you to select the folder to upload. Click on the small arrow next to “Computer,” then select your DVD drive. *Do not select any of the subfolders or files on the DVD itself*. Hit the “OK” button.



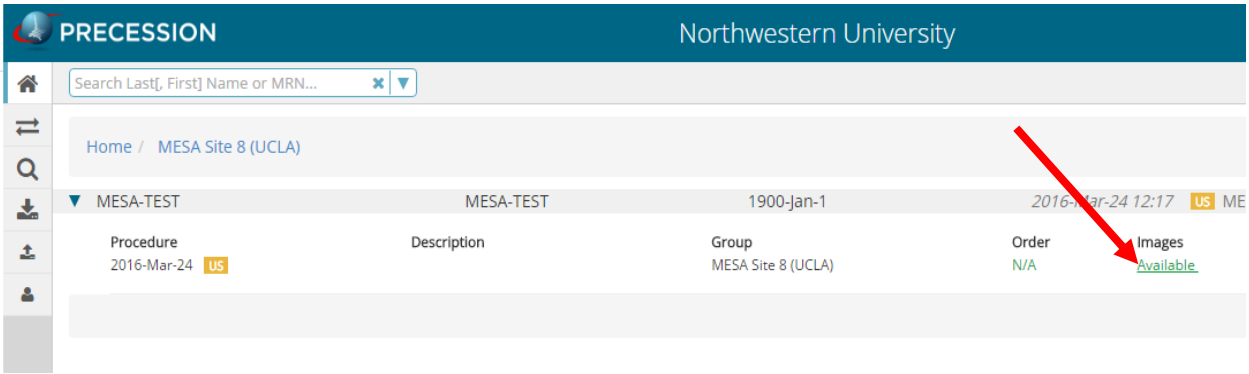
7. If multiple studies are present on the disk, click the check box next to each study that you would like to upload, then hit the “Upload” button.



8. A status window will pop up displaying the progress of your upload. After the upload is complete, the echo(s) submitted will appear in the list of studies for your site. To view the images and verify that the upload was successful, click on the arrow next to the patient name.



9. Under the “Images” column, click on “Available.” A DICOM viewer should pop up in another tab. Verify that all images are present and that the video clips play successfully. You will receive a confirmation email once the study has been successfully submitted.



ECHO TRANSMITTAL FORM AND GRADED ALERT SYSTEM

In addition to the electronic transmission of echo images using WebPAX, the site sonographer is responsible for filling out an Echo Transmittal Form to accompany each study echocardiogram sent to the NUECL (Appendix A). This form is used to record basic physiologic information about each patient and also gives the site sonographer the opportunity to comment on any echo findings or problems with image acquisition. A copy of this form should be filled out, signed, and emailed to the technical director of the NUECL (lauren.nelson@northwestern.edu) each time an echo is submitted.

For routine studies, a qualitative echo report will be provided within 6-8 weeks of study receipt. The report will be emailed to the site PI and site study coordinator, who are responsible for supplying it to the participant. The echocardiographic protocol for MESA is a limited research protocol and is not intended to provide a comprehensive evaluation of cardiac structure and function. In addition, these studies are not clinically indicated and will be reviewed in the absence of any clinical information. Qualitative reporting of the echocardiographic findings is provided as a courtesy to MESA participants, and is not intended as a substitute for a full echocardiographic assessment.

Because routine studies may not be fully analyzed for 6-8 weeks, it is important that the site sonographer note any abnormalities at the time of the echo, report them to the site PI and/or cardiologist, and generate a medical alert for the study as outlined below. The NUECL has created a list of abnormalities that will qualify as medical alerts for this study. The purpose of defining these alerts is to make sure that the participant and his/her physician are aware of any significant medical findings that arise as a result of the MESA clinic exam. If any of the qualifying abnormalities are noted, the sonographer should **acquire additional echo images as needed** and notify the site PI or cardiologist at the time of the echocardiogram. Each site is responsible for coordinating local echo review and follow up for any patient with a clinical alert or other abnormal finding noted on the echo. *The NUECL is not responsible for detecting or reporting abnormal echo findings.*

IMMEDIATE REFERRALS

Immediate referrals are medical emergencies which require immediate notification of both the participant and his or her primary physician. Participants receiving immediate referrals are those who would go directly from the Field Center clinic to their physician's office or hospital. If a potentially serious or life-threatening abnormality is detected that may require urgent medical evaluation, the sonographer is expected to **immediately** notify both the site principal investigator (PI) or cardiologist and the NUECL (by phone or email). The site PI will then review the images, verify the study findings, and determine whether emergent medical care is required. The site PI is also responsible for communicating the results to the participant and his/her personal physician **at the time of the clinic visit**. An immediate referral is indicated by the sonographer on the Echo Transmittal Form, accompanied by a description of the findings. The study is then transmitted to the NUECL for rapid review and verification by the NUECL readers and physicians. A detailed echocardiographic report will be generated and e-mailed to the site within 24-48 hours.

For sites that do not have a designated cardiologist to serve as the echo co-investigator, a safety read will be performed by the cardiologists at the NUECL within one business day to ensure that no serious abnormalities have been overlooked. If any immediate referral abnormalities are detected by the NUECL cardiologists, the site will be contacted immediately and a detailed echocardiographic report will be generated and e-mailed within 24-48 hours.

Abnormalities that should be classified as immediate referrals include:

- Suspected tamponade
- Aortic aneurysm (measuring ≥5.0 cm) or dissection
- Intracardiac abscess or obvious vegetation
- Intracardiac thrombus or mass
- Pseudoaneurysm
- Significant arrhythmia (eg atrial fibrillation with heart rate > 110 bpm, sustained ventricular arrhythmias, or NSVT > 10 beats)

URGENT REFERRALS

Urgent referrals are made when abnormalities are detected which may require medical attention, but not on an emergency basis. The site sonographer is expected to notify the site PI at the time of the echocardiogram. The site PI will review the images and verify the study findings, then communicate the results to the participant at the time of the clinic visit**.** The site PI is also responsible for providing notification of the participant's physician within one week of the clinic visit. An urgent referral is indicated by the sonographer on the Echo Transmittal Form, accompanied by a description of the findings. The study is then transmitted to the NUECL and a detailed echocardiographic report will be generated and e-mailed to the site within 48-96 hours.

Abnormalities that should be classified as urgent referrals include:

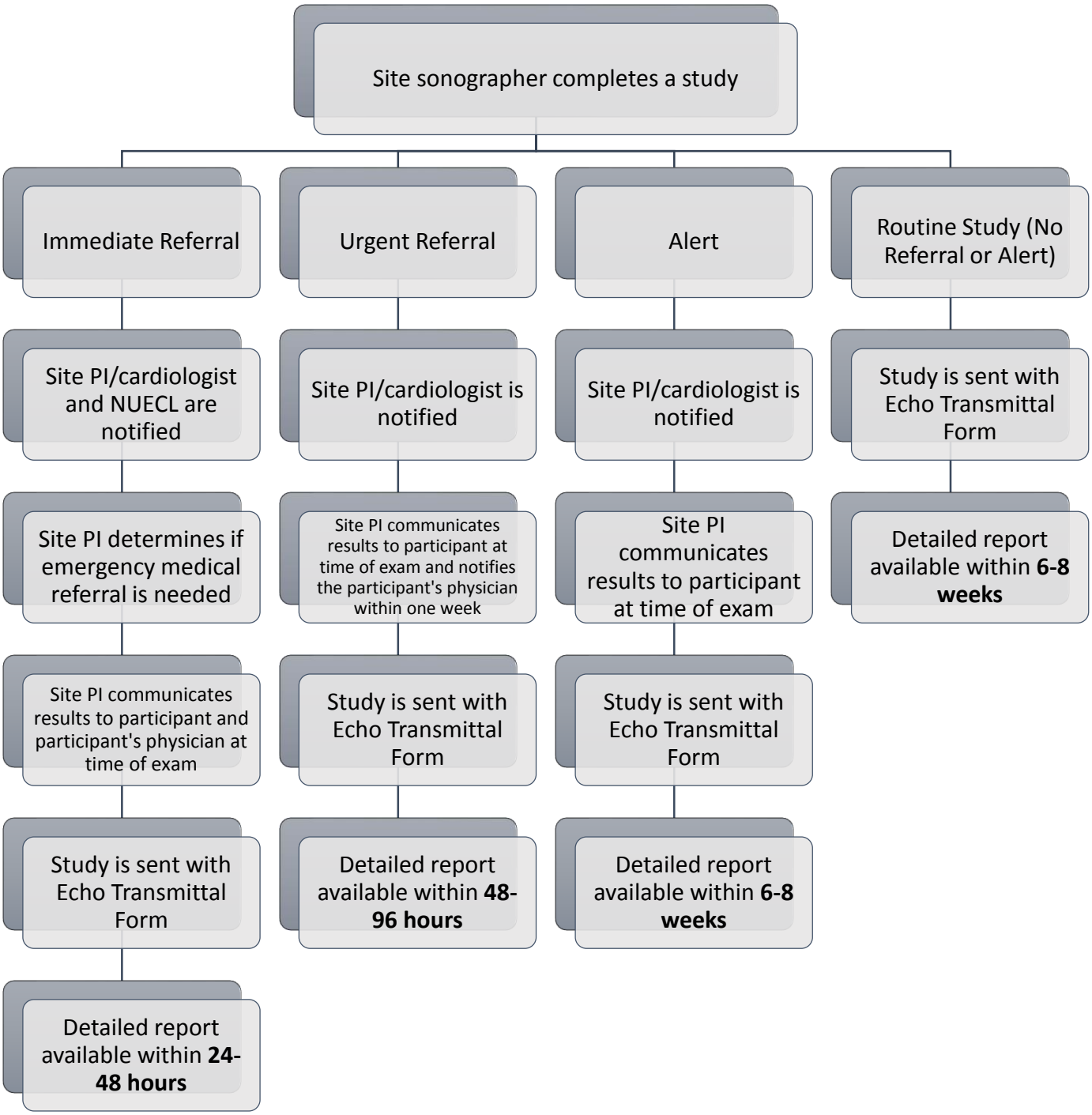
- Severe left ventricular or right ventricular enlargement
- Severe stenosis of any valve
- Severe regurgitation of any valve
- Moderate or greater pericardial effusion without evidence of tamponade

ALERTS

Alerts are medical findings that may have adverse health consequences to the participant if left untreated. In the case of an alert, the site sonographer is expected to notify the site PI at the time of the echocardiogram. The site PI will review the images and verify the study findings, then communicate the results to the participant at the time of the clinic visit. An alert is indicated by the sonographer on the Echo Transmittal Form, accompanied by a description of the findings. The study is then transmitted to the NUECL and an echocardiographic report will be generated and e-mailed to the site within 6-8 weeks.

Abnormalities that should be classified as alerts include:

- Mild or moderate stenosis of any valve
- Moderate mitral or aortic regurgitation
- Moderate or greater dynamic LVOT obstruction (gradient at rest or with Valsalva $\geq$40 mmHg)
- Intra-cardiac shunt
- Moderate to severe pulmonary hypertension (RVSP>45 mmHg)
- Evidence of RV pressure or volume overload
- Low ejection fraction ($\leq$40%) or wall motion abnormality


Site sonographer completes a study
Immediate Referral
Urgent Referral
Alert
Routine Study (No Referral or Alert)
Site PI/cardiologist and NUECL are notified
Site PI/cardiologist is notified
Site PI/cardiologist is notified
Study is sent with Echo Transmittal Form
Site PI determines if emergency medical referral is needed
Site PI communicates results to participant at time of exam and notifies the participant's physician within one week
Site PI communicates results to participant at time of exam
Detailed report available within **6-8 weeks**
Site PI communicates results to participant and participant's physician at time of exam
Study is sent with Echo Transmittal Form
Study is sent with Echo Transmittal Form
Study is sent with Echo Transmittal Form
Detailed report available within **48-96 hours**
Detailed report available within **6-8 weeks**
Detailed report available within **24-48 hours**

ECHO QUALITY ASSESSMENT

Upon receipt of each study echocardiogram, all echos will be evaluated for adherence to protocol and image quality. Feedback will be provided to the site sonographer via the Echo Quality Control/Feedback Form (Appendix B). The feedback process is intended to improve future image quality and ensure protocol compliance. Detailed information about the echo feedback process can be found in the Quality Control section on page 42 of this document.

GUIDELINES FOR ECHO OPTIMIZATION

GENERAL

For patients in sinus rhythm, at least **three** full cardiac cycles must be recorded for each view. For patients in atrial fibrillation (or any other irregular rhythm), at least **ten** full cardiac cycles must be recorded for each view.

An adequate ECG signal showing a clearly identifiable QRS complex must be visible on the screen

No measurements should be recorded on the images acquired at the site

2D IMAGING

- Gain, TGC, dynamic range, and compression should be adjusted to optimize endocardial definition and minimize artifacts
    - Tissue harmonic imaging should be used throughout the examination
    - It is important to visualize all LV walls and endocardial borders adequately to ensure accurate quantitative analysis
    - Generally, it is most difficult to visualize the endocardium at the apex, lateral LV wall, and anterior LV wall; pay particular attention to these areas
- Avoid foreshortening of the ventricle and maximize left ventricular length
    - Apical foreshortening seriously affects the calculation of ventricular volumes as well as the results of strain analysis; it should be avoided at all costs
    - In the standard apical view, the LV appears as a truncated ellipse with a tapered apex; a foreshortened view makes the ventricle appear spherical, with a rounded apex (Example 1)
    - If the view appears to be foreshortened, bring the transducer down an intercostal space and angle more steeply; having the patient take a breath in will also sometimes bring out a better view
- Frame rate
    - It is critical that the frame rate for the dedicated strain views falls between **50-80 fps**; otherwise, strain analysis cannot be performed
    - Decreasing the depth of the image, narrowing the sector width, reducing the number of focal points, and lowering the transducer frequency are helpful techniques for increasing frame rate
- Stabilize the image before recording
    - Excessive translational motion can be avoided by acquiring images during quiet respiration or having the patient hold a breath in or out
    - The entire endocardium and epicardium must be within the sector scan throughout the cardiac cycle

COLOR DOPPLER IMAGING

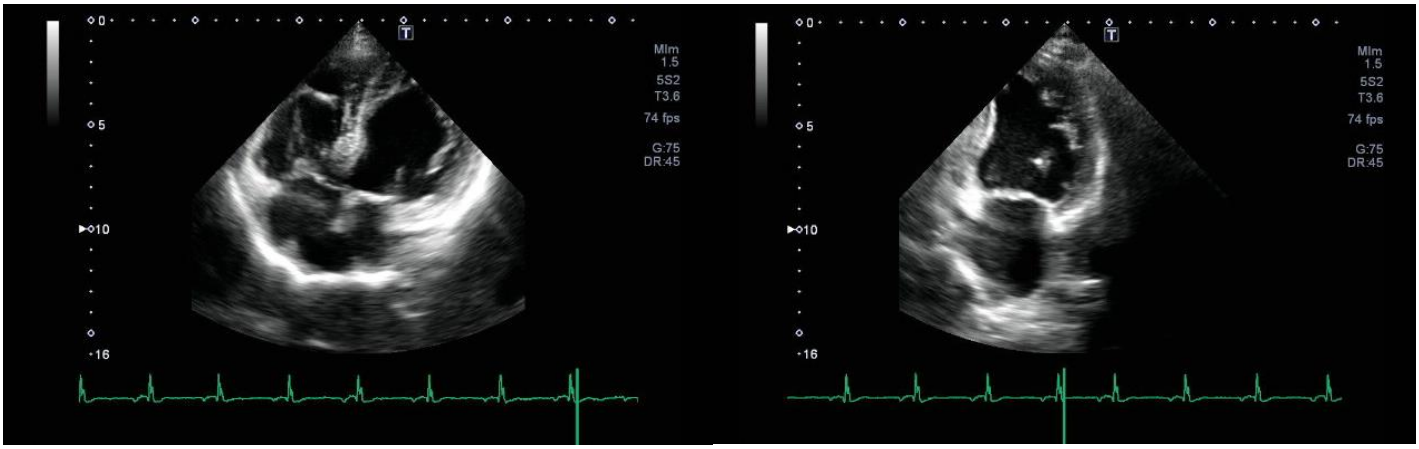
- The Nyquist limit should be set near **60 cm/s** throughout the exam, with the color gain set at a level just below where background noise appears
- The color Doppler sample box should be set to capture only the region of interest; use a small, narrow color box to improve signal quality

SPECTRAL DOPPLER IMAGING

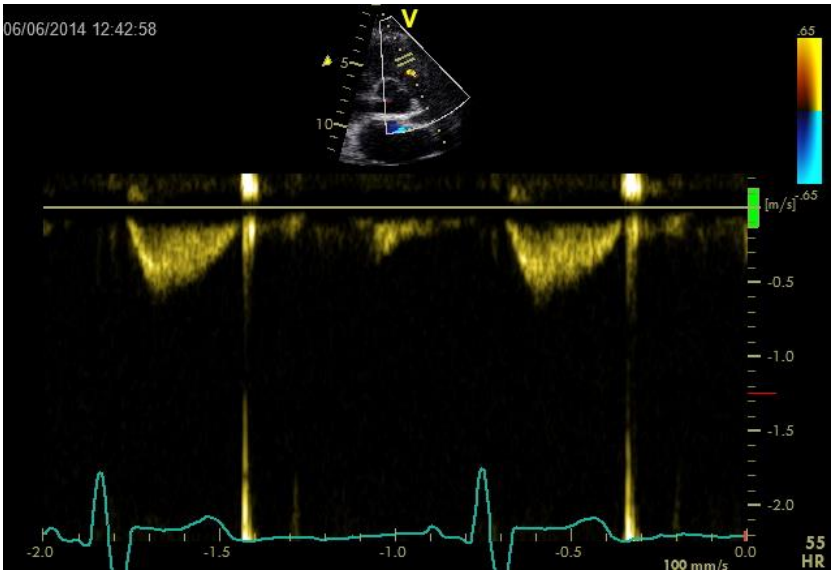
- It is critical to align the ultrasound beam parallel with the direction of blood flow
- Optimize baseline shift and velocity so that the spectral envelope of interest occupies approximately ¾ of the screen (Example 2)
- The gain should be adjusted to just below the level where background noise appears; the compress, reject, and wall filter controls should also be utilized to generate a clear, well-defined waveform
- A sweep speed of **50 mm/s** is acceptable unless otherwise noted

TISSUE DOPPLER IMAGING

- The ultrasound beam should be aligned parallel to the longitudinal motion of the ventricle, with the sample side on the ventricular side of the annulus. Avoid placing the sample volume within the atrium or too far into the left ventricle.
- Optimize baseline shift and velocity so that the spectral envelope of interest occupies approximately ¾ of the screen
    - A low velocity scale is best for recording Tissue Doppler velocities (**± 20 cm/s** is recommended)
    - A sweep speed of 50 mm/s is acceptable
    - Gain should be adjusted to eliminate background noise and ensure a clear signal; excessive gain must be avoided, as this causes spectral broadening and overestimation of tissue velocities
- A low pass filter should be utilized to separate the high amplitude, low velocity tissue-generated data from the low amplitude, high velocity signals originating from blood flow (current ultrasound systems have a preset function that should be used to automatically optimize TDI signals)



Example 1: These images demonstrate foreshortening of the apical four chamber and two chamber views. Note the rounded appearance of the LV apex in both images, as well as the off-center position and misalignment of the heart



Example 2: This image demonstrates an example of incorrect Doppler scale. The scale should be adjusted so that the flow pattern of interest occupies ¾ of the screen

REQUIRED ECHO VIEWS FOR CORE LAB EVALUATION

- The NUECL should not receive any echos containing protected health information (PHI). All echos should be de-identified using the following labeling system:
  - Last name field: MESA 6
  - First name field: Acrostic ID
  - ID field: 7 digit study ID
- All clips should be at least 3 beats (10 beats if the patient is in atrial fibrillation or irregular rhythm)
- Acquire all Doppler and M-mode clips at a sweep speed of 50 mm/s
- Ensure that a clear ECG signal is present on the screen
- Prior to the examination, record the patient's height and weight on the echo transmittal form
- The following table lists the required views for each study. A condensed version of the protocol can be found in the MESA Echo Protocol Pocket Guide on page 65 of this document.

ECHO PROTOCOL

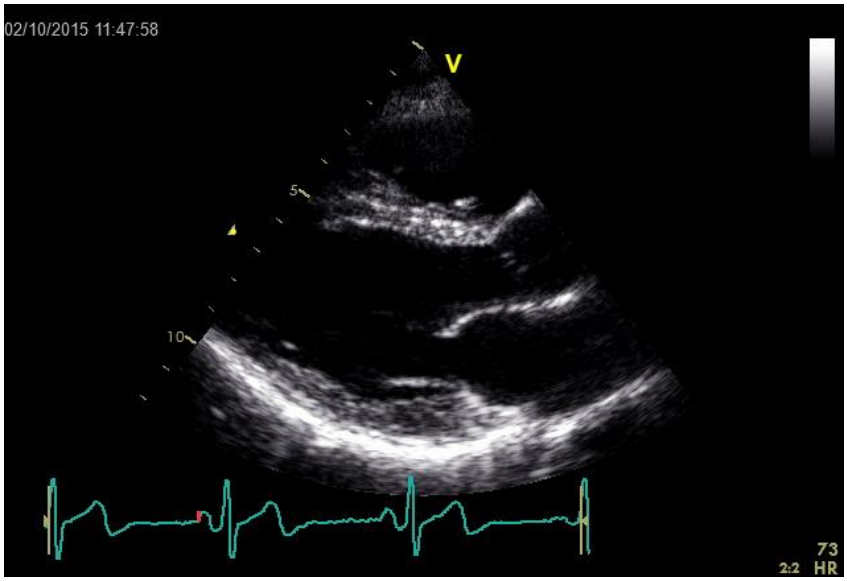
Imaging Window	Images to Acquire	Tips to Remember
Parasternal Long Axis View	2D clip optimizing the left ventricle	
	Color Doppler on the mitral and aortic valves	
Parasternal Short Axis View	2D clip at the papillary muscle level, optimizing LV endocardium	FR 50-80 FPS
	2D clip at the basal level showing the tricuspid valve, aortic valve, and RVOT/pulmonic valve	
	Color Doppler on the tricuspid valve/right atrium	
	CW Doppler of the tricuspid valve for TR jet	
Apical Four Chamber View	2D clip demonstrating all four chambers	FR 50-80 FPS
	2D clip at decreased depth optimizing LV endocardium	FR 50-80 FPS
	2D clip optimizing the left atrium	FR 50-80 FPS
	Color Doppler on the mitral valve/left atrium	
	Color M-mode of mitral inflow	
	PW Doppler of MV inflow at leaflet tips	
	PW TDI at the septal and lateral mitral annulus	

Apical Four Chamber View: Focused on the Right Ventricle	2D clip optimizing the RV and RA	FR 50-80 FPS
	Color Doppler on the tricuspid valve/right atrium	
	PW Doppler of TV inflow at leaflet tips	
	CW Doppler of the TR jet	
	PW TDI at the lateral tricuspid annulus	
Apical Five Chamber View	Color Doppler on the LVOT/aortic valve	
	PW Doppler of LVOT	
	CW Doppler of aortic valve	
Apical Two Chamber View	2D clip including the left ventricle and left atrium	FR 50-80 FPS
Apical Three Chamber View	2D clip including the left ventricle, left atrium, and aortic valve	FR 50-80 FPS
Subcostal View	2D clip of the IVC with sniff	Acquire at least 5 beats
	PW Doppler of the abdominal aorta at the level of the diaphragm	Sweep speed 200 mm/s
Suprasternal View	PW Doppler of the descending thoracic aorta	Sweep speed 200 mm/s Measure distance between suprasternal notch and tip of xiphoid process (in cm), annotate on screen

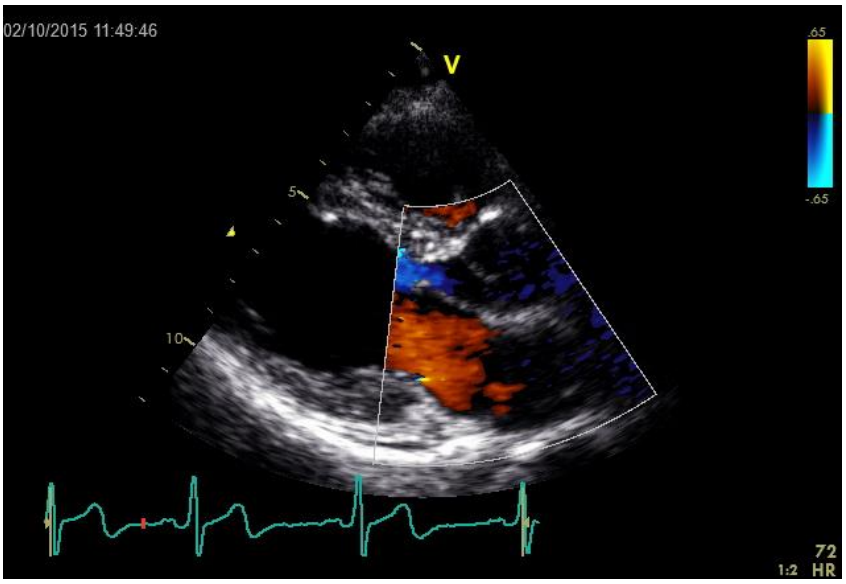
Passive Leg Raise		Annotate all images
	2D clip of LV optimizing the LV and LA (A4C window)	FR 50-80 FPS
	2D clip optimizing the RV and RA	FR 50-80 FPS
	PW Doppler of MV inflow at leaflet tips	
	PW TDI of the septal mitral annulus	
	PW TDI of the lateral mitral annulus	
	PW Doppler of LVOT	

PARASTERNAL LONG AXIS ACQUISITION

- To acquire images from the parasternal long axis window, the transducer is placed to the left of the sternum, usually in the third or fourth intercostal space, with the patient in the left lateral decubitus position
    - The transducer notch faces up, towards the patient's right side
- The image obtained represents a section through the long axis of the left ventricle; the anterior and posterior mitral valve leaflets and the right and non-coronary aortic valve leaflets are visible
- The proximal interventricular septum should be horizontal and continuous with the aortic root, and the endocardium at the septum and posterior wall should be well-defined
    - If the appropriate imaging plane is used, the left ventricular apex is not visible and the heart should not appear tilted
    - Moving the transducer up an intercostal space generally improves the orientation of the heart (if necessary)
- Adjust the 2D image to optimize endocardial definition, with the focus near the level of the interventricular septum. Make sure that the LVOT is open and that the aortic valve leaflets are clearly visible. Capture one three beat clip:

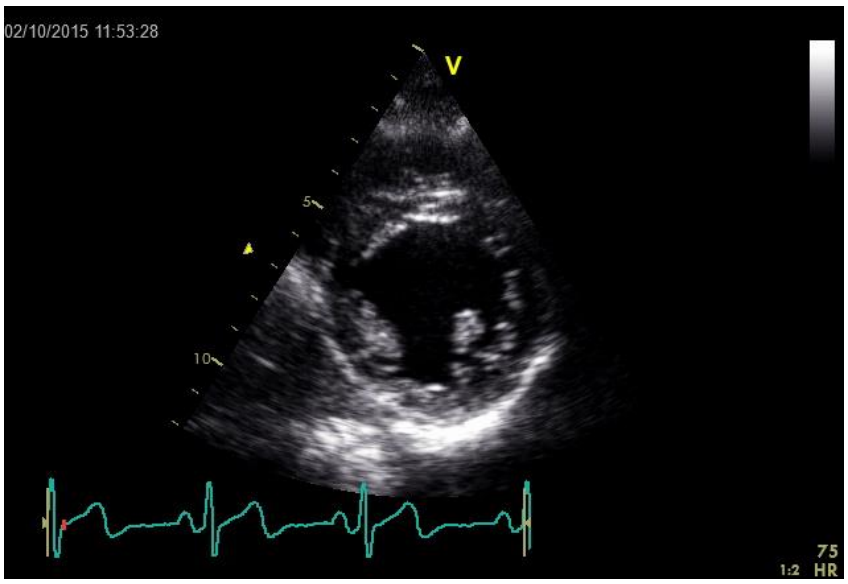


- Turn on color Doppler and place the sample box over the mitral and aortic valves (making sure to cover the entire left atrium) to evaluate for regurgitation
- Keep the color sector as narrow as possible to increase frame rate, and the Nyquist limit near 60 cm/s
- Capture one three beat clip:



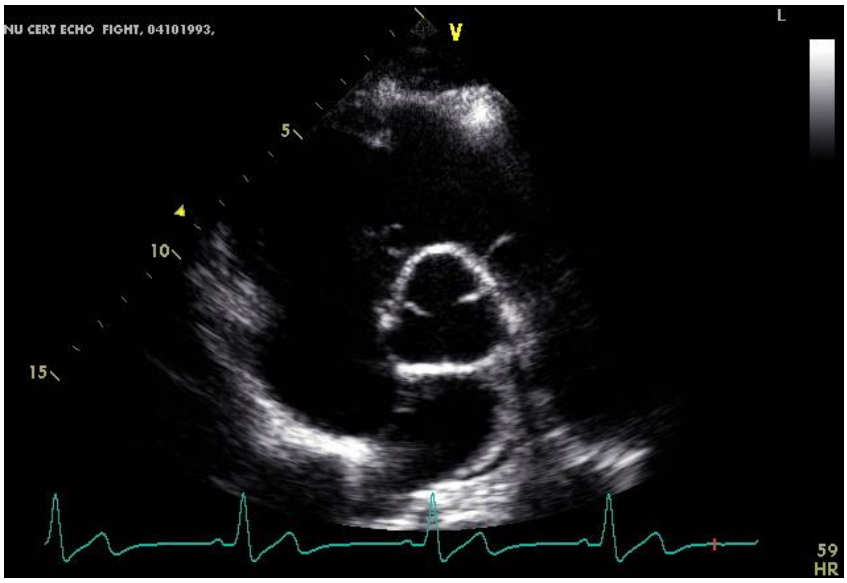
PARASTERNAL SHORT AXIS ACQUISITION – PAPILLARY MUSCLE LEVEL

- From the parasternal long axis position, rotate the transducer clockwise 90° so that the plane of the ultrasound beam is approximately perpendicular to the plane of the long axis of the left ventricle
    - The notch on the transducer is pointed superiorly, toward the patient's head
- The anterolateral and posteromedial papillary muscles are visible, and the left ventricle is circular in shape
    - An elliptical or oblong shape suggests an off-axis cut through the ventricle; moving the transducer up an intercostal space and angling down should improve the alignment of the ultrasound beam perpendicular to the long axis of the heart
    - Avoid the mitral valve apparatus, particularly the chordae; only the papillary muscles should be visible
    - The frame rate should be set between **50-80 fps**
- Capture one three beat clip:

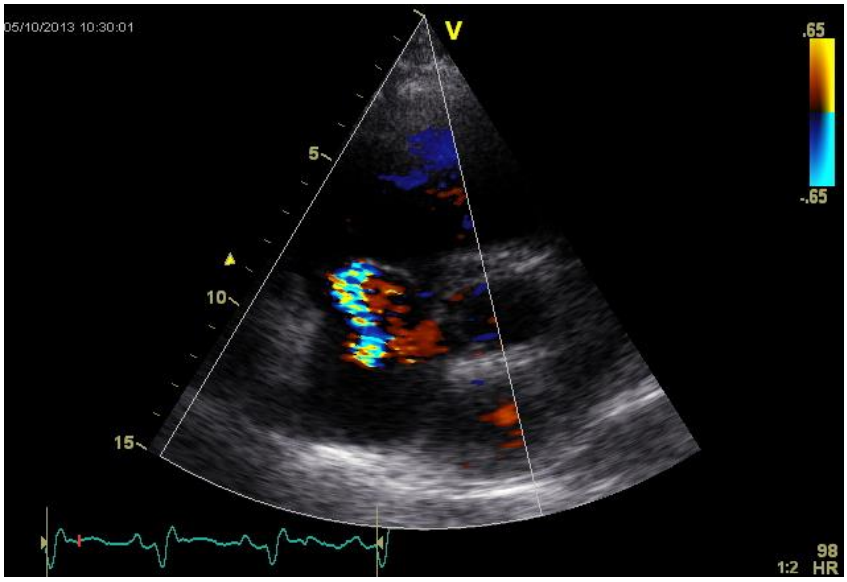


PARASTERNAL SHORT AXIS ACQUISITION – BASAL LEVEL

- From the papillary muscle level, the transducer is tilted superiorly until the great arteries are sectioned transversely
- The tricuspid valve, right ventricular outflow tract, pulmonic valve, aortic valve (with all three leaflets visible), and both atria are demonstrated in cross section
- Capture one three beat clip:

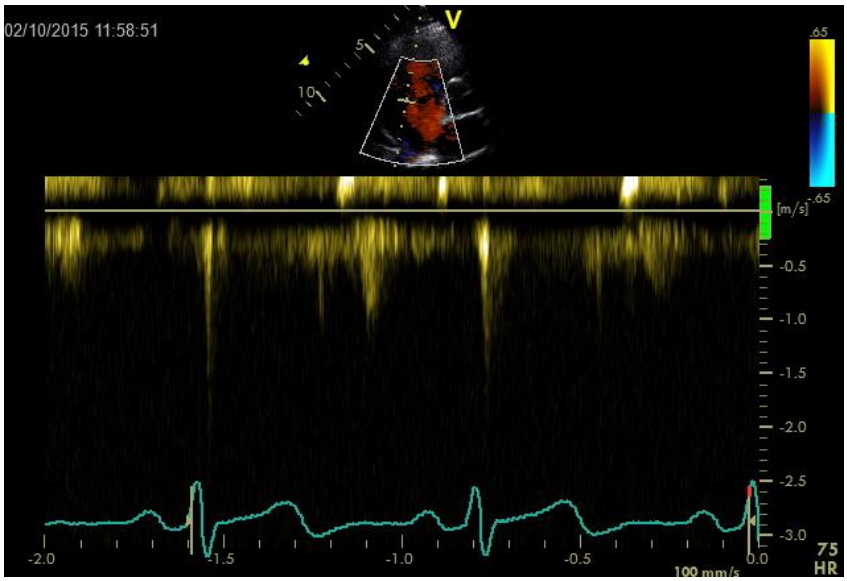


- Turn on Color Doppler and place the sample box over the tricuspid valve, covering the entire right atrium, to evaluate for tricuspid regurgitation
- Keep the color sector as narrow as possible and the Nyquist limit near 60 cm/s
- Capture one three beat clip:



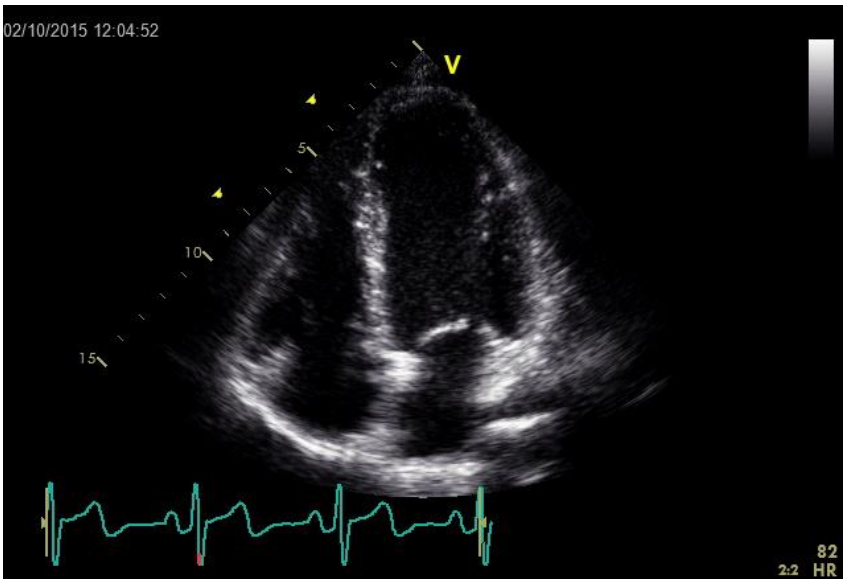
- Turn on continuous wave Doppler and place the cursor through the tricuspid regurgitation jet, as parallel to the regurgitant flow as possible

- Adjust the baseline and scale to capture the peak TR velocity
- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:

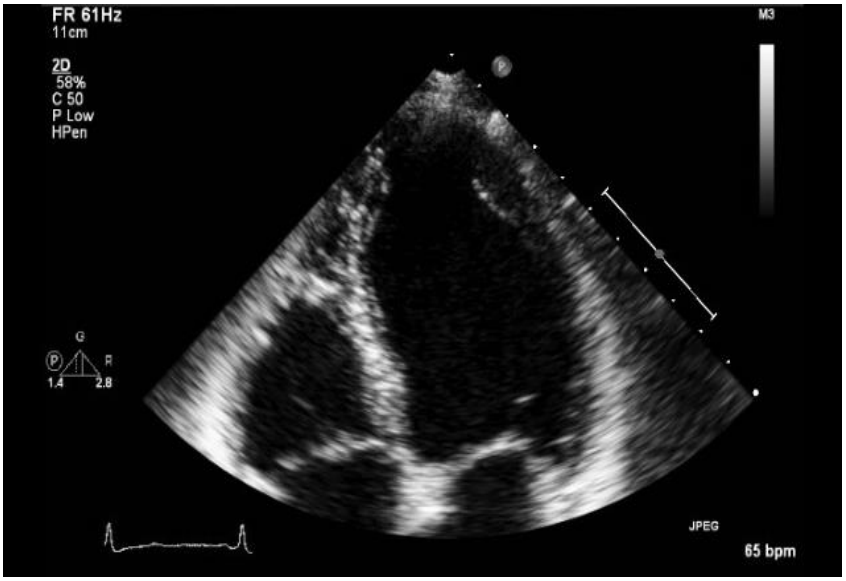


APICAL FOUR CHAMBER ACQUISITION

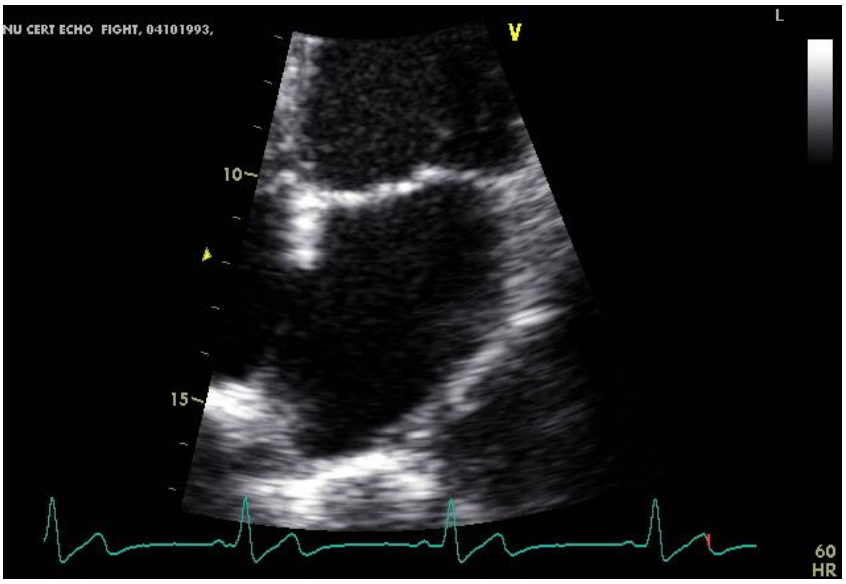
- To acquire images from the apical window, the patient should be placed in a steep left lateral decubitus position with the left arm raised to spread the ribs.
    - A cut-out mattress is often helpful to allow visualization of the true left ventricular (LV) apex and avoid foreshortening
- The apical window can be identified initially by palpation of the LV apex; the transducer is then placed on the apical window with the notch pointing down and to the right and the ultrasound beam angled superiorly and medially (towards the patient's right scapula)
- A true four chamber view displays all four chambers of the heart as well as the ventricular and atrial septa, mitral valve and tricuspid valve
    - The aortic valve and coronary sinus should not be visualized
- Make sure to properly align the image and capture the left ventricle in full; the long axis of the heart should be vertically oriented on the screen
- The frame rate should be between **50-80 fps**
- Adjust the 2D image to optimize endocardial definition, with the focus near the mitral annulus, and capture one three beat clip optimizing visualization of all four chambers during systole and diastole:



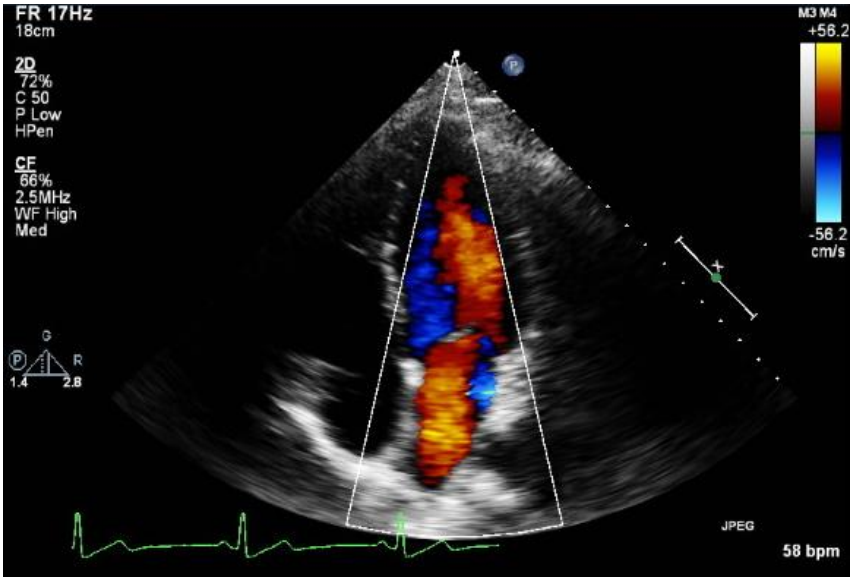
- Decrease the depth of the image and focus on the left ventricle alone, making sure that the endocardium is clearly defined throughout the cardiac cycle, the walls of the heart remain within the imaging sector, and the ventricle is not foreshortened
    - The frame rate should be between **50-80 fps**
- Capture one three beat clip:



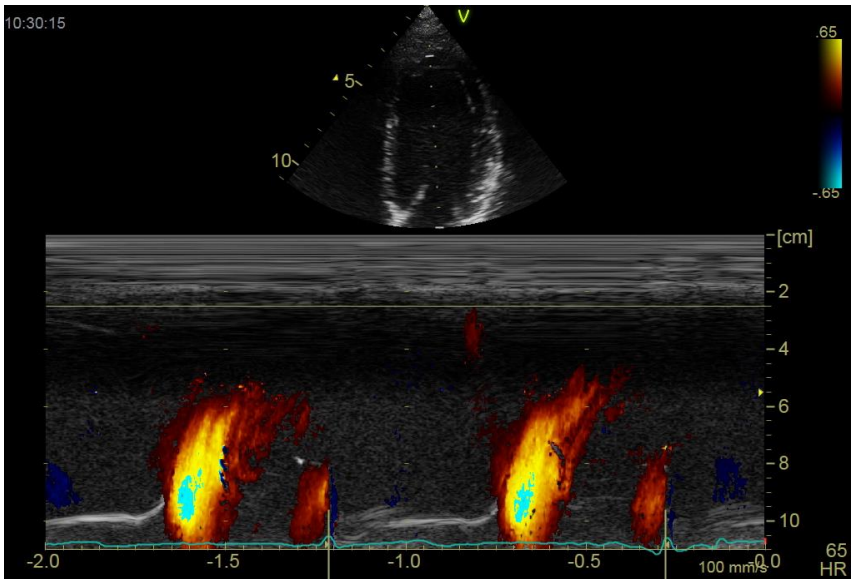
- Next focus on the left atrium, making sure to avoid foreshortening so that the entire atrium is displayed
    - The frame rate should be between **50-80 fps**
- Capture one three beat clip:



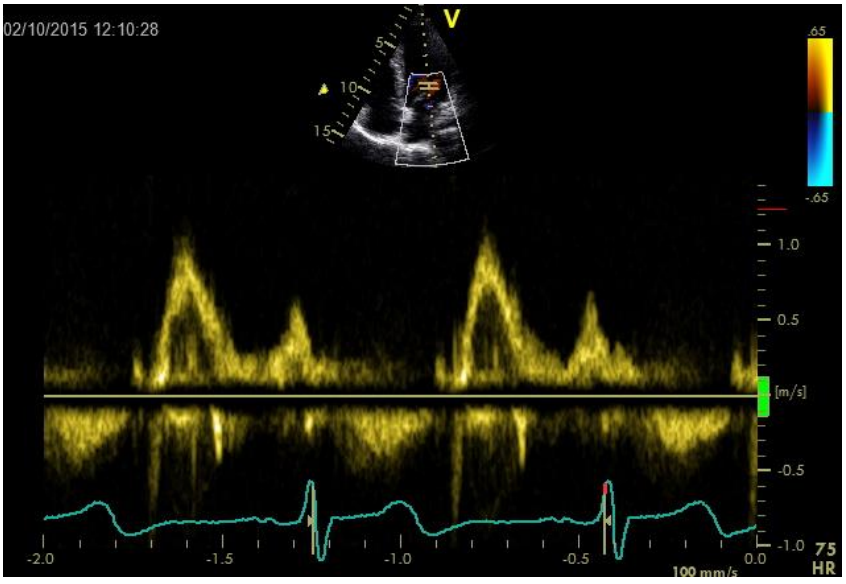
- Turn color Doppler on and position the sector over the mitral valve, making sure to cover the entire left atrium; keep the color sector as narrow as possible and the Nyquist limit near 60 cm/s
- Capture one three beat clip, optimizing mitral regurgitation (if present):



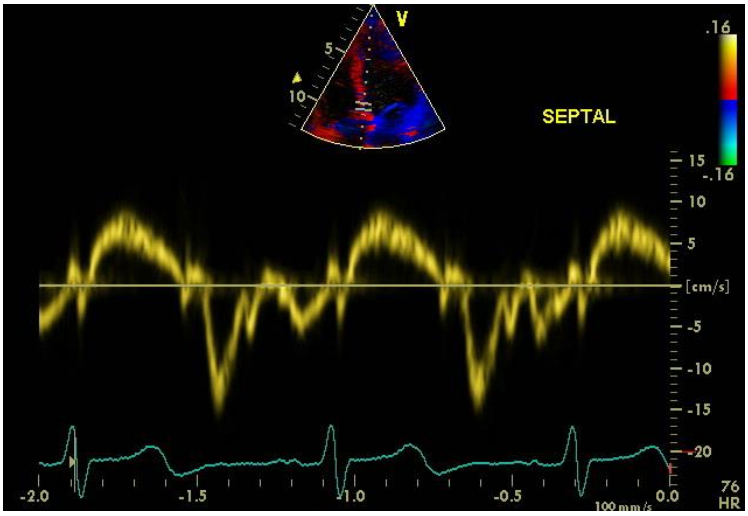
- Decrease the depth to include the left ventricle, mitral annulus, and a small piece of the left atrium
- Adjust the color box to cover the entire left ventricle (from base to apex) as well as a small piece of the left atrium. Turn M-mode on and position the cursor parallel to mitral inflow in the center of the flow stream.
- Capture at least three cardiac cycles:



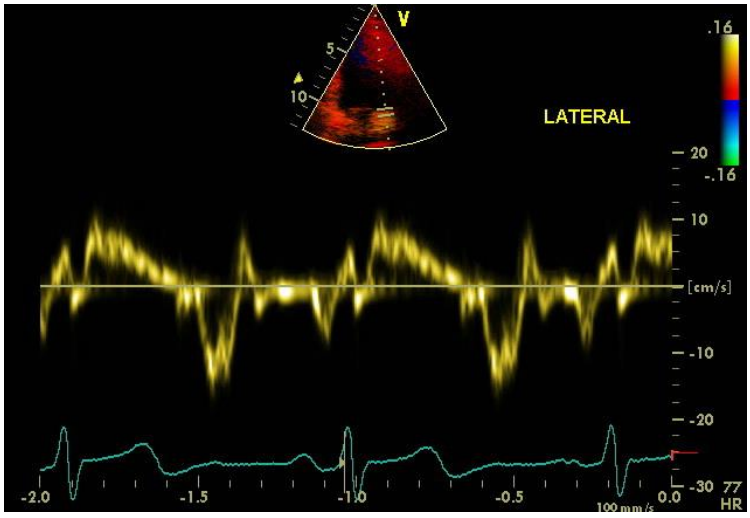
- Turn on pulsed wave Doppler and position the sample volume at the mitral leaflet tips to record the mitral inflow velocity curve, as parallel to flow as possible
    - It is important to record Doppler flow at the leaflet tips, because velocities are maximal at this location; if the sample volume is placed closer to the annulus, the velocities will be lower due to the larger cross sectional area for flow
- Adjust the baseline and Doppler scale to visualize the peak E and A wave velocities
- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:



- From the four chamber view, turn on color TDI and position the PW sample volume on the ventricular side of the septal mitral annulus, near the junction of the anterior mitral leaflet and ventricular septum
    - Sample volume size and position should be adjusted so that it remains within the region of interest inside the myocardium throughout the cardiac cycle
    - As with other Doppler modalities, PW TDI is angle dependent, so the sample volume must be aligned with the direction of the motion to be interrogated
- Optimize the instrument settings to generate a clear, well defined spectral trace (including systolic and diastolic waveforms)
    - After optimizing the Doppler waveform, annotate 'Septal' on the image, adjust the sweep speed to 50 mm/sec and record at least three cardiac cycles during quiet respiration:

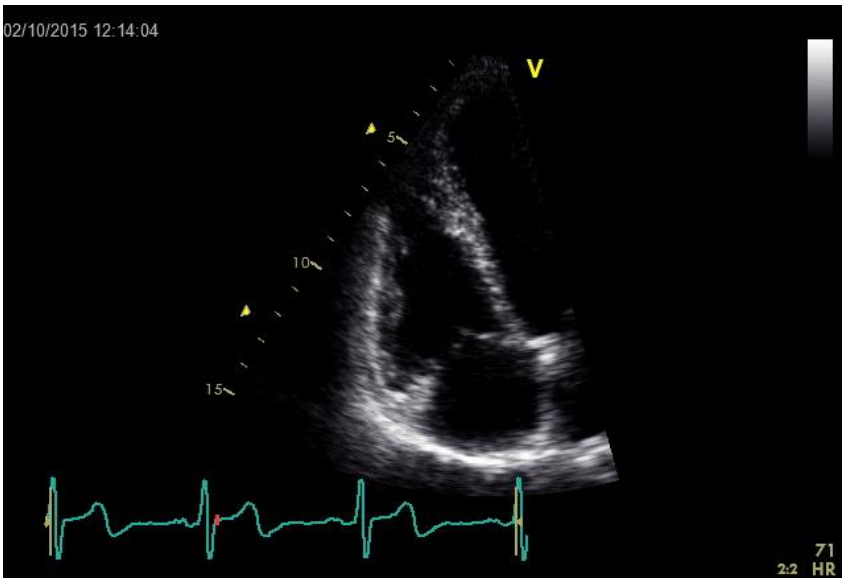


- Adjust the 2D image so that the motion of the lateral LV wall is parallel to the line of Doppler interrogation, then position the sample volume on the ventricular side of the lateral mitral annulus
    - Repeat the image acquisition process described above (annotating 'lateral' on the image):

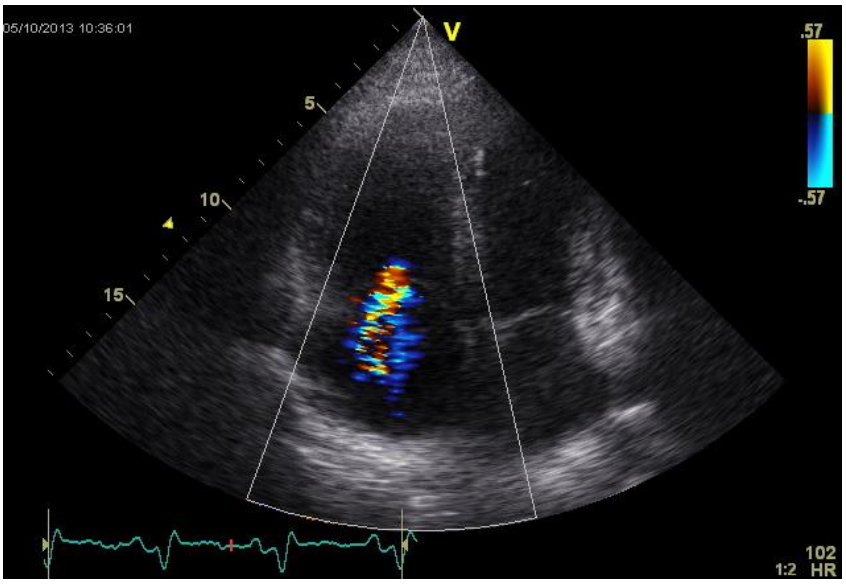


APICAL FOUR CHAMBER ACQUISITION – FOCUS ON RIGHT VENTRICLE

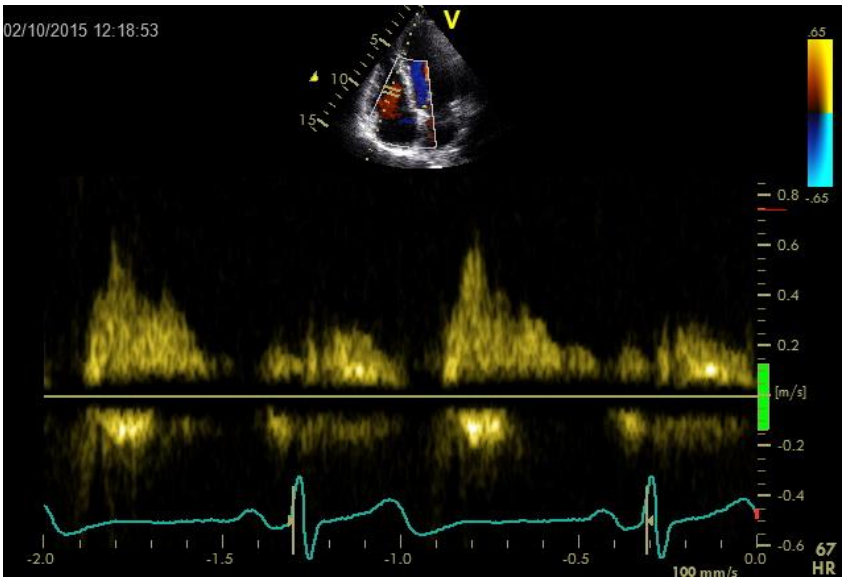
- From the apical four chamber view, angle the transducer to optimize visualization of the right ventricle, right atrium, and tricuspid valve
    - If necessary, move the transducer up an intercostal space and angle anteriorly to improve visualization of the right heart structures
    - Make sure that the entire endocardium of the ventricle is well defined and remains within the sector throughout the cardiac cycle, paying particular attention to the apex
    - Make sure that the right ventricle is not foreshortened and that the LVOT has not opened up
    - The frame rate should be between **50-80 fps**; if necessary, acquire an second clip with decreased depth and sector width to ensure adequate frame rates
- Capture one three beat clip:



- Turn on color Doppler and position the sector over the tricuspid valve, making sure to cover the entire right atrium; keep the color sector as narrow as possible and the Nyquist limit near 60 cm/s
- Capture one three beat clip, optimizing tricuspid regurgitation:

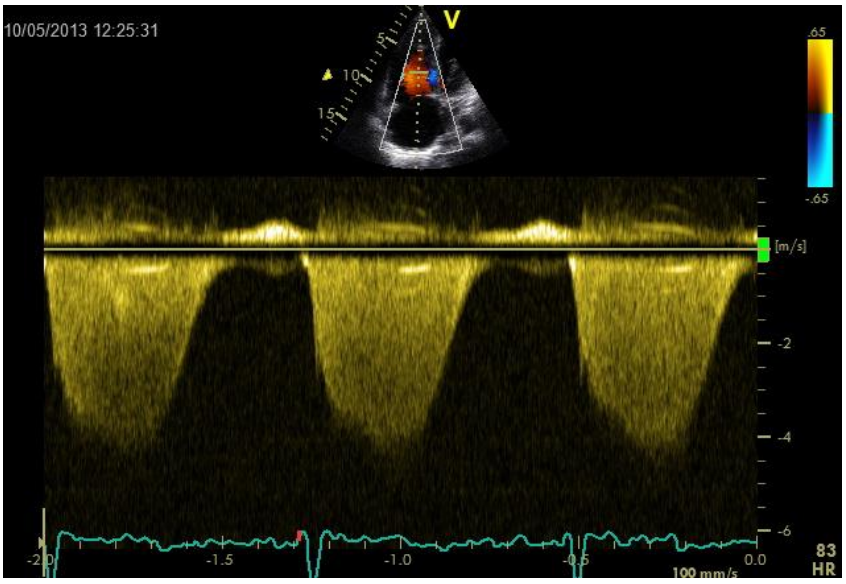


- Turn on pulsed wave Doppler and position the sample volume at the tricuspid leaflet tips, as parallel to flow as possible, to record the tricuspid inflow velocity curve
    - It is important to record Doppler flow at the leaflet tips, because velocities are maximal at this location; if the sample volume is placed closer to the annulus, the velocities will be lower due to the larger cross sectional area for flow
- Adjust the baseline and Doppler scale to visualize the peak E and A wave velocities
- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:

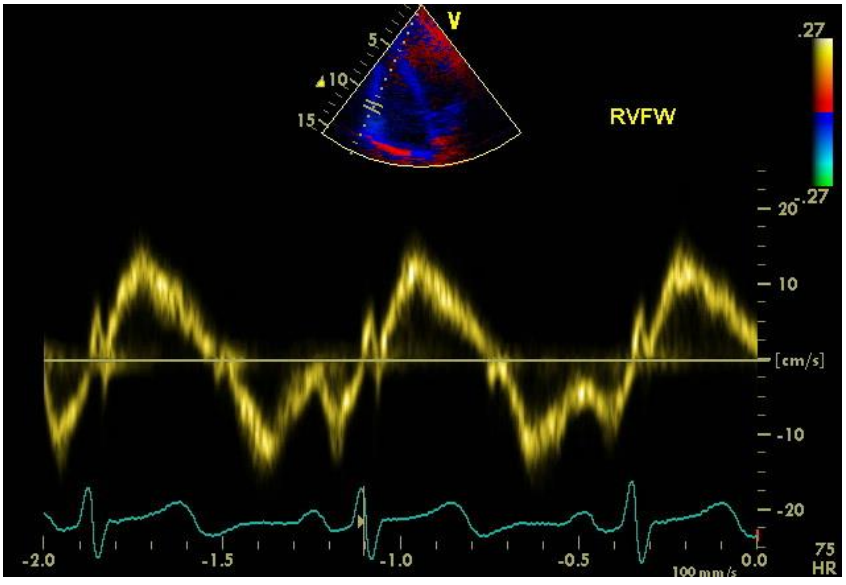


- Turn on continuous wave Doppler and place the cursor through the tricuspid regurgitation jet, as parallel to the regurgitant flow as possible
- Adjust the baseline and scale to capture the peak TR velocity

- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:

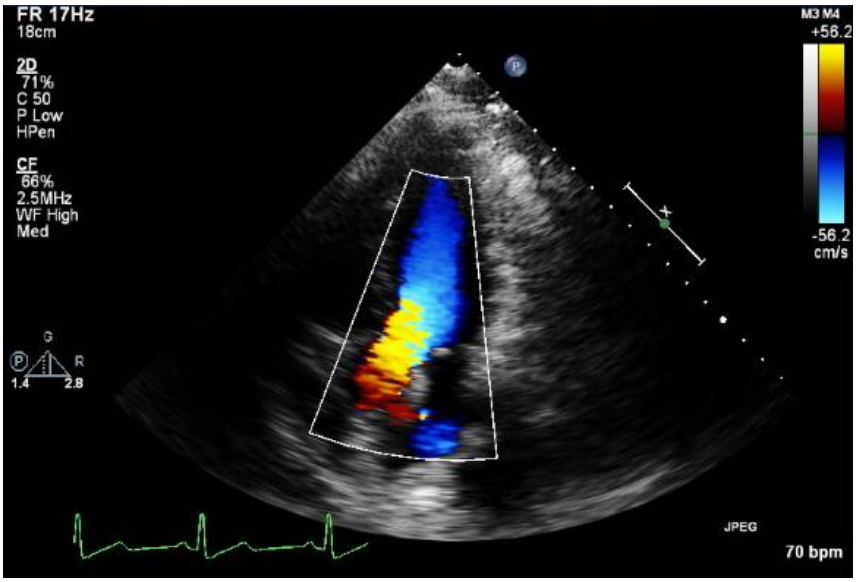


- Decrease image depth to include the RV and tricuspid annulus and optimize the 2D image, with the focus on the tricuspid valve
- Activate color TDI and position the sample volume on the ventricular side of the lateral tricuspid annulus, at the junction of the RV wall with the tricuspid valve; the myocardium should stay within the sample volume throughout the cardiac cycle
    - If necessary, adjust the image so that the motion of the tricuspid annulus is parallel to the cursor
- Switch to PW TDI and optimize the instrument settings to generate a clear, well defined waveform
- After optimizing the Doppler tracing, record at least three cardiac cycles during quiet respiration:

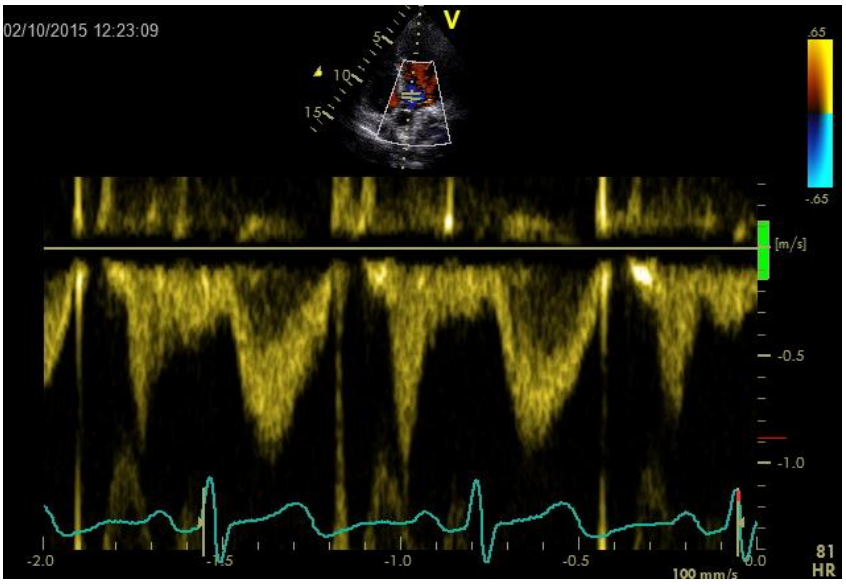


APICAL FIVE CHAMBER ACQUISITION

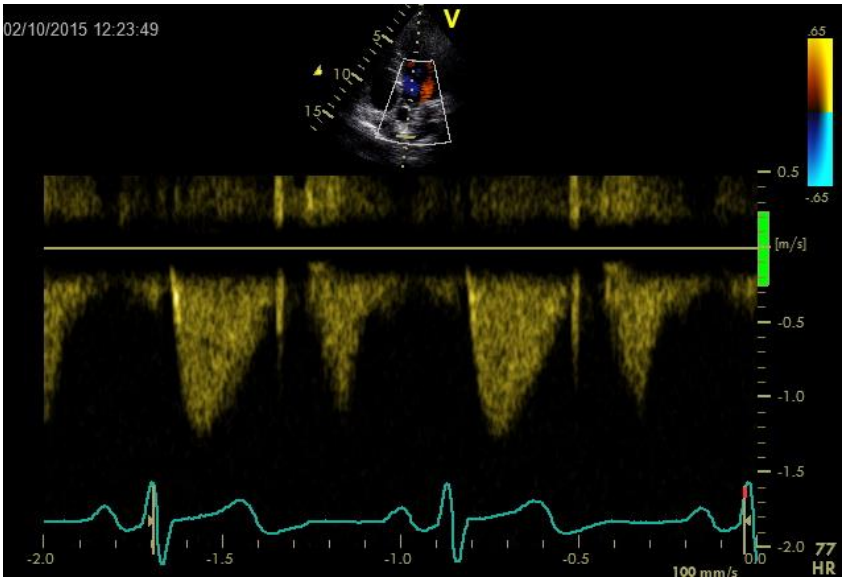
- From the four chamber view, angle the transducer anteriorly until the aortic valve and root appear
    - Maximize the left ventricular length, making sure not to foreshorten the true long axis of the LVOT
- Turn color Doppler on and position the sector over the aortic valve and left ventricle, making sure to capture the aortic insufficiency jet (if present); keep the color sector as narrow as possible and the Nyquist limit near 60 cm/s
- Capture one three beat clip:



- Turn on PW Doppler and place the sample volume in the LVOT, approximately 0.5 cm proximal to the aortic valve
    - Align the sample volume as parallel to the direction of blood flow as possible
    - Only the closing click should be visible
- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:

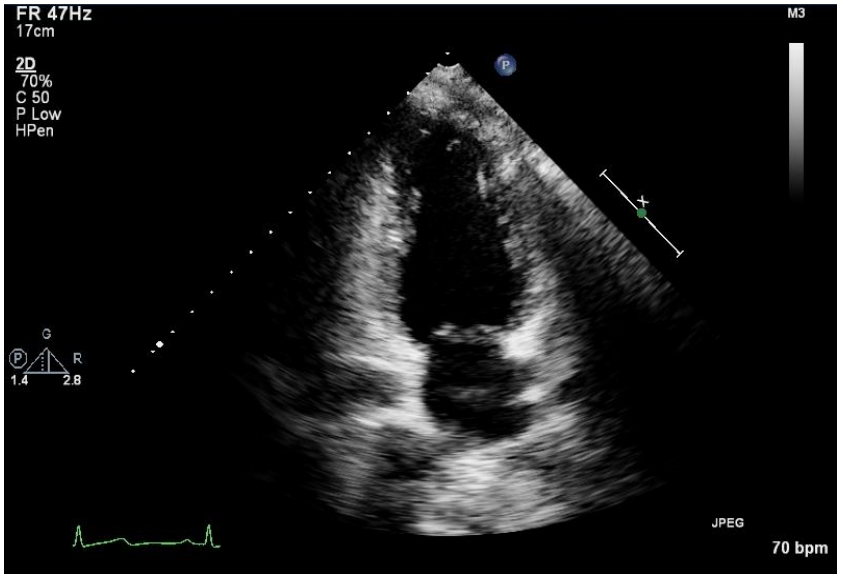


- Turn on continuous wave Doppler to record the aortic valve profile
- After optimizing the Doppler waveform, record at least three cardiac cycles during quiet respiration:



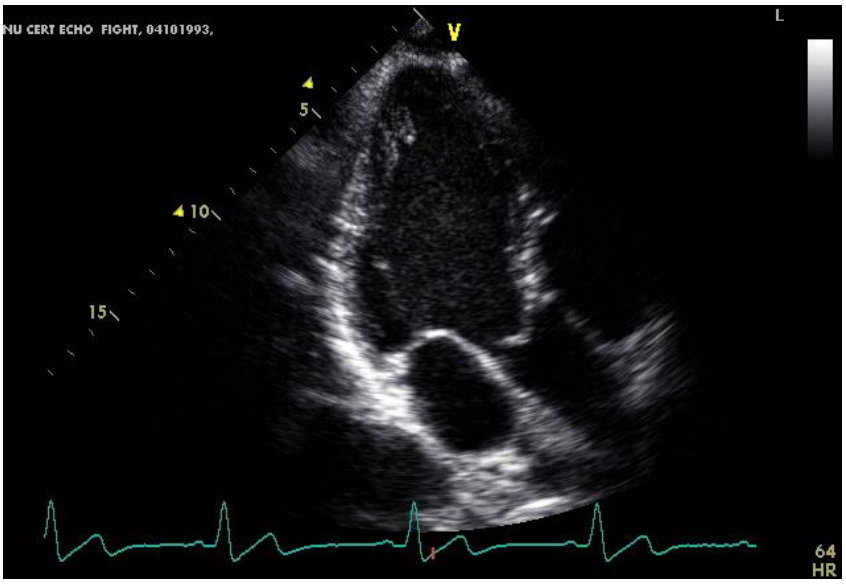
APICAL TWO CHAMBER ACQUISITION

- From the four chamber view, rotate the transducer counterclockwise approximately 60°, so that the scan plane transects both the inferior and anterior walls of the LV
    - Transducer angle or position on the chest may need to be adjusted to visualize both walls of the ventricle adequately
- A true two chamber view displays the left ventricle, mitral valve, and left atrium
    - The right ventricle and LV outflow tract should not be visualized
    - The frame rate should be between **50-80 fps**
- Capture one three beat clip optimizing visualization of both chambers during systole and diastole:



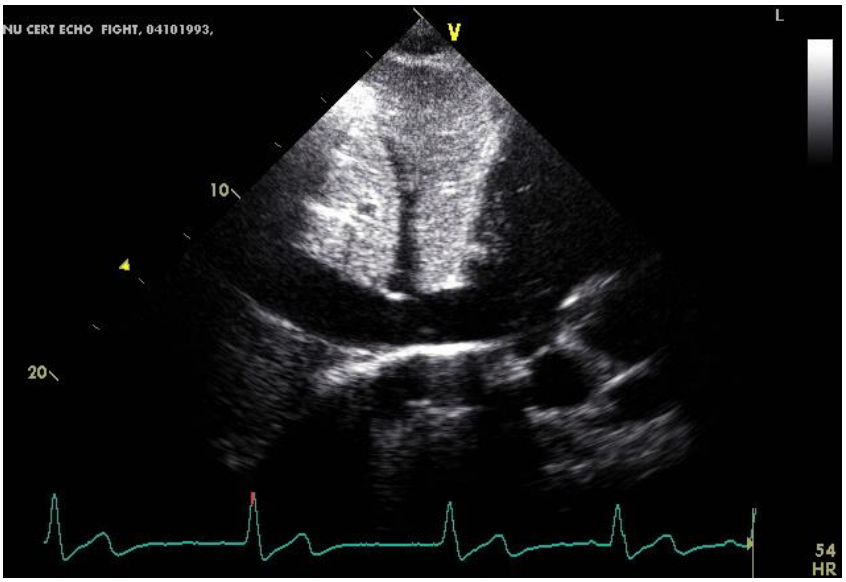
APICAL 3 CHAMBER VIEW

- From the two chamber view, rotate the transducer counterclockwise another 60° (120° from the four chamber view) until the aortic valve and proximal ascending aorta appear
- From this view, the aortic valve, LVOT, and mitral valve are demonstrated in long axis, similar to the parasternal long axis view
    - The frame rate should be between **50-80 fps**
- Capture one three beat clip optimizing visualization of both chambers and the aortic valve during systole and diastole:

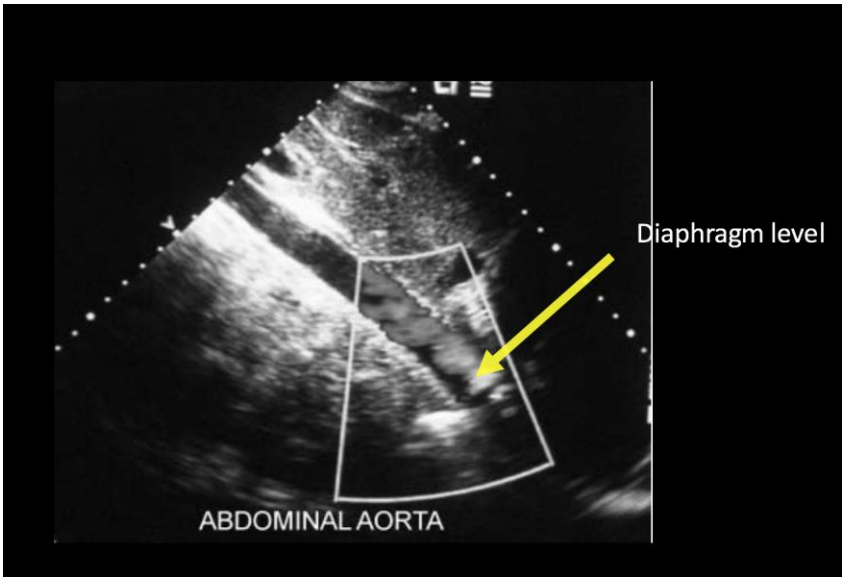


SUBCOSTAL VIEW

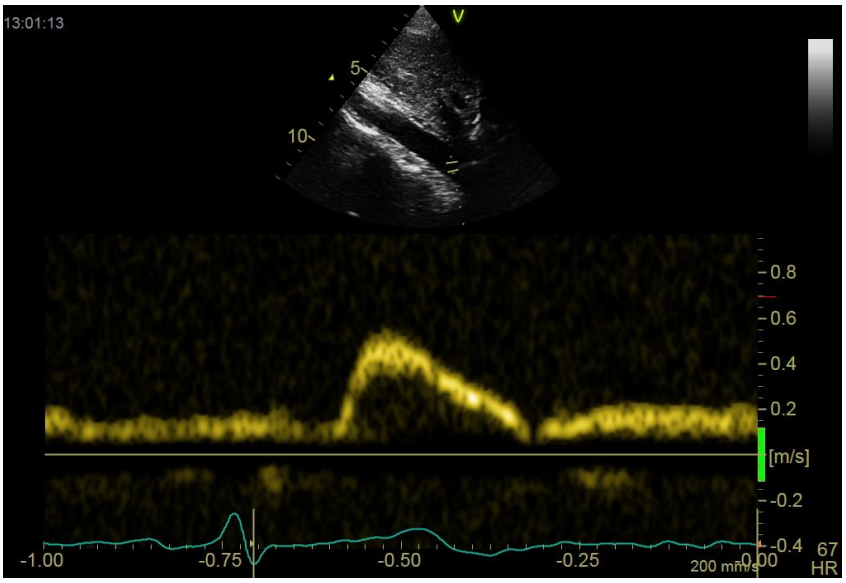
- To acquire images from the subcostal window, the patient should be supine with the legs bent at the knees (if necessary) to relax the abdomen
- Place the transducer in the midline or slightly to the patient's right, with the notch pointed up; angle the transducer until the IVC and its point of entry into the RA are visible
- Instruct the patient to take a 'sniff' in through the nose to demonstrate the collapse of the IVC
- Capture one five beat clip (longer if necessary), making sure to show the IVC at its maximum and minimum diameter (with sniff):



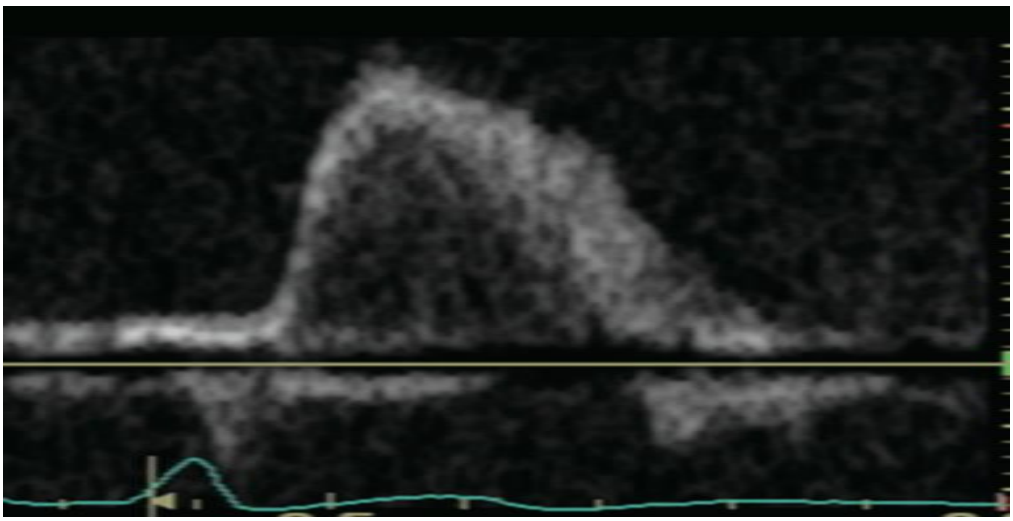
- Angle the transducer to the patient's left to visualize the abdominal aorta. Turn on PW Doppler and place the sample volume at or immediately below the level of the diaphragm. Please note that for this acquisition, it is more important to place the sample volume in this anatomic location, rather than placing the sample volume as parallel to flow as possible. Flow velocity is not important for this study; the timing of the flow relative to the QRS complex is the important aspect.

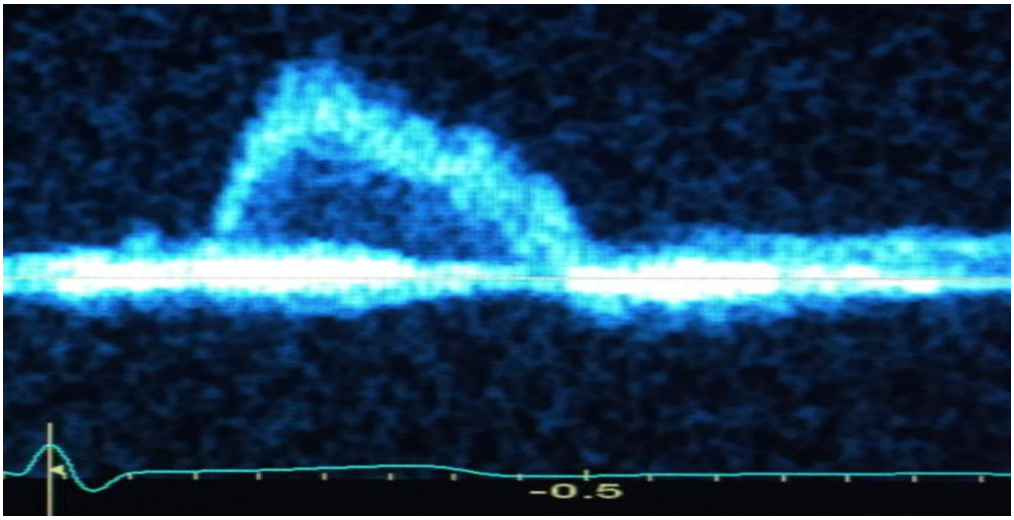


- After optimizing the Doppler waveform, adjust the sweep speed to 200 mm/sec and record at least three to five cardiac cycles during quiet respiration. It is important that the full QRS is captured in the image, at the left of each captured beat. For this acquisition, minimize or eliminate the wall filters so that the foot of the systolic flow wave is better seen.

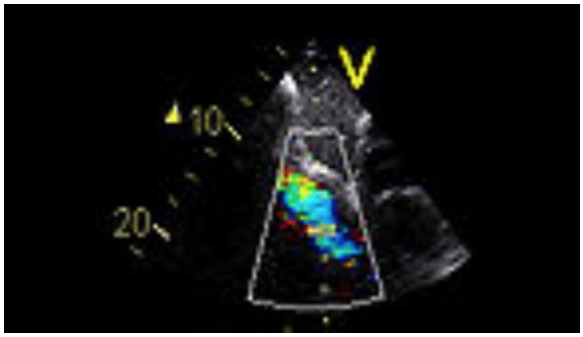


- Below are acquisitions performed with minimal wall filtering and with no wall filtering:



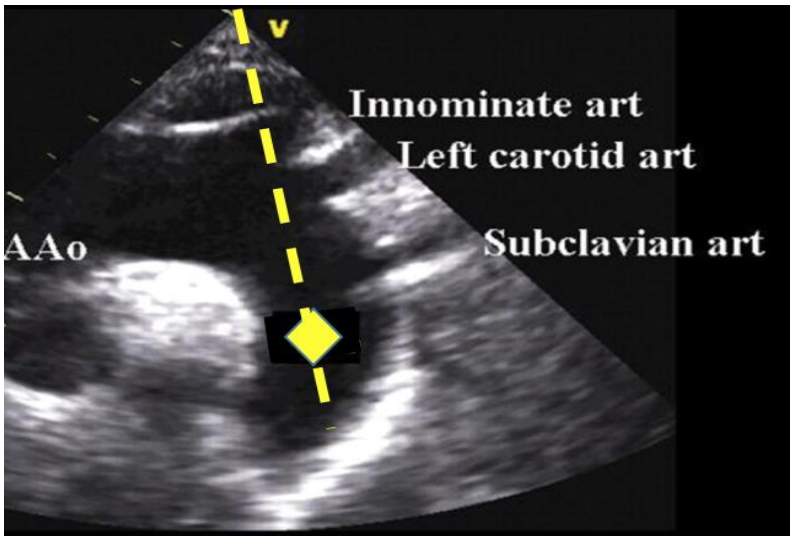


- For this acquisition, please make sure that the diaphragm level is represented in the 2D image displayed on top of the Doppler spectrum. The core lab needs to be able to tell how "far" from the diaphragm the PW Doppler interrogation was performed. Below is an example performed slightly below the diaphragm level. If you can't get a good signal exactly at the diaphragm level and you must interrogate slightly below it, this is acceptable as long as this is clearly displayed in the anatomic image that is recorded at the top of the Doppler spectrum.

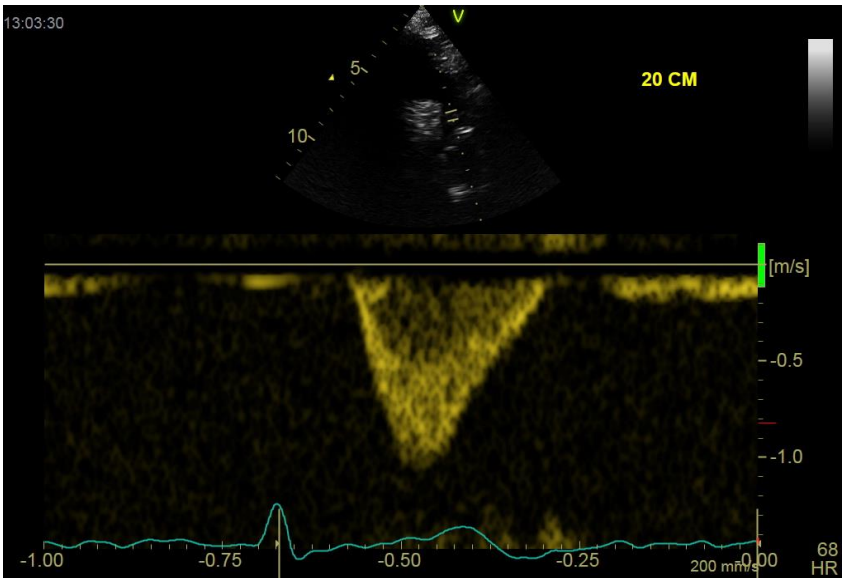


SUPRASTERNAL VIEW

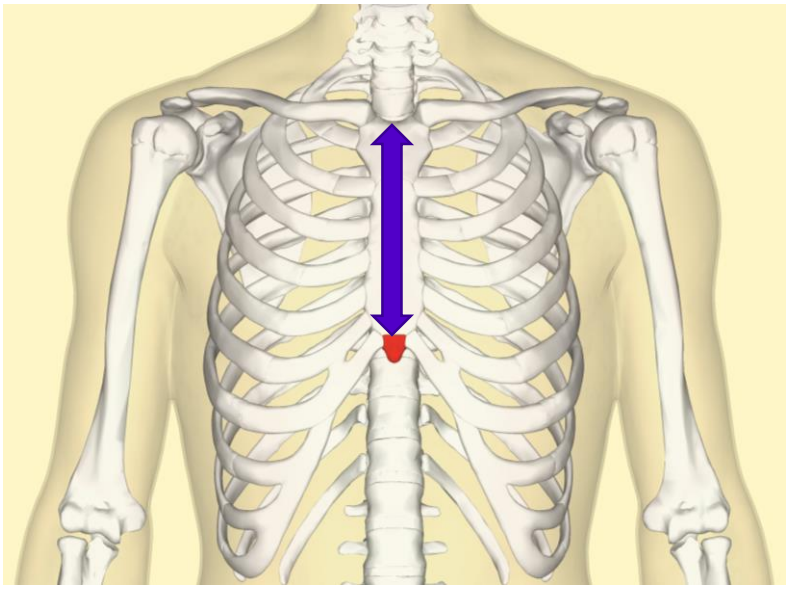
- To acquire images from the suprasternal window, the patient should remain in the supine position. Place the transducer in the suprasternal notch and angle the transducer inferiorly until the aortic arch is visible.
- Turn on PW Doppler and place the sample volume in the proximal descending aorta, immediately distal to the left subclavian artery.

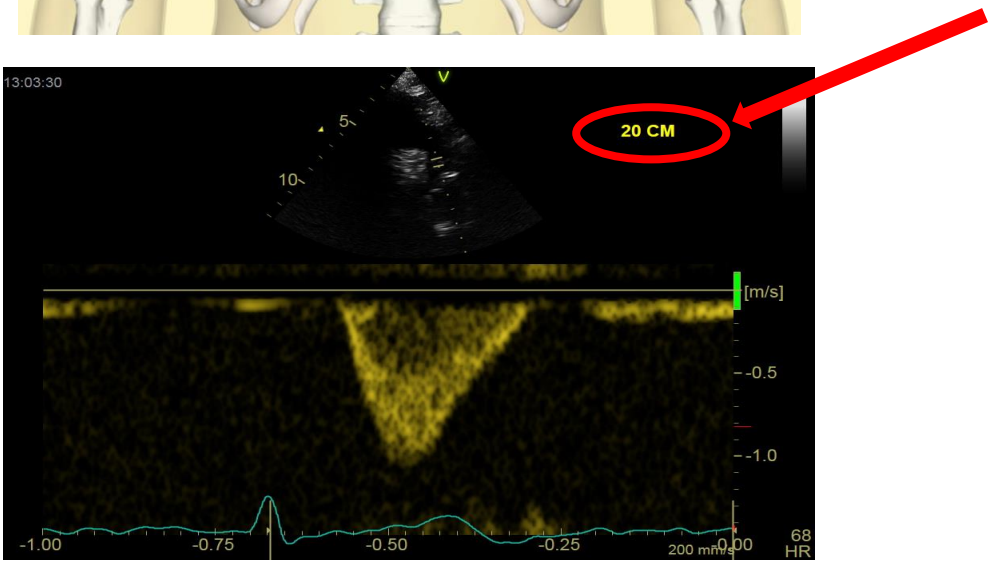


- After optimizing the Doppler waveform, adjust the sweep speed to 200 mm/sec and record at least three to five cardiac cycles during quiet respiration. It is important that the full QRS complex is captured in the image, at the left of each captured beat (similar to interrogations of abdominal aortic flow). For this acquisition, minimize or eliminate the wall filters so that the foot of the systolic flow wave is better visualized.



- Using a standard tape measure, measure the distance from the suprasternal notch to the tip of the xiphoid process using a standard tape measure. Record the distance in centimeters (cm) on the PW Doppler image of the proximal descending aorta flow.





ADDITIONAL IMAGES – LEGS ELEVATED USING WEDGE PILLOW

- With the patient in the supine position, prop the legs up using a large wedge-shaped pillow
    - Instruct the patient to keep the legs straight to facilitate venous return to the heart

- Annotate 'legs up' on the screen and acquire the following images:
    - 2D clip optimizing the LV and LA **FR 50-80 fps**)
    - 2D clip optimizing the RV and RA (FR **50-80 fps**)
    - PW Doppler of mitral inflow at mitral leaflet tips
    - Tissue Doppler Imaging at septal mitral annulus
    - Tissue Doppler Imaging at lateral mitral annulus
    - PW LVOT Doppler

QUALITY CONTROL OF FIELD SITES

Quality Control Feedback Form

A detailed quality control/feedback form (Appendix B) will be filled out at the NUECL for each echocardiogram at the time of study interpretation. All studies are scored for image quality and protocol adherence. It is expected that each site will maintain 90% adherence to the items listed on the feedback form. If a study receives a cumulative score of less than 90%, a copy of the completed form with detailed feedback will be sent to the site via e-mail. Comments and technical tips will be provided, when applicable, to help site sonographers acquire the best possible images.

The following parameters will be scored on the feedback form:

Parasternal long axis view	Apical 3 chamber view
Parasternal short axis view	Subcostal view
Apical 4 chamber view	Legs elevated with wedge
Apical 5 chamber view	Endocardial definition (applies to all images)
Apical 2 chamber view	Image settings (applies to all images)

Scores by parameter range from 1-4:

1: Poor – Unable to quantitate images

2: Fair – Variable image quality, some views can be measured but not all

3: Satisfactory – Image quality is satisfactory. All measurements can be performed, but improvements to image quality may be necessary.

4: Excellent: Image quality is excellent and all measurements can be obtained.

When a score of 1, 2 or 3 is given, the 'indication' field will also be completed by the NUECL, indicating whether image quality is suboptimal due to patient body habitus or sonographer error. In order to maintain 90% adherence, sonographers must obtain a total of at least 36 points out of the 40 available points for each exam. If a study is deemed inadequate due to technical error, additional images may be requested. A pattern of consistently inadequate or poor quality studies will result in discussion between the NUECL staff and field center PI and sonographer, and possibly re-training of the sonographer.

Quarterly Report Cards

Report cards will be sent to each site to provide a comparison of how the quality of studies submitted by that site compares to the other study sites. These report cards will be sent out monthly for the first six months, then quarterly for the remainder of the exam.

Ongoing Phone Conferences

In order to facilitate communication between the NUECL and each study site, phone conferences will be held monthly for the first six months, then quarterly for the remainder of the exam. Each site echo PI, site sonographers, and NUECL staff will attend these calls. Image quality issues, protocol review, technical assistance, and questions from site sonographers will be discussed.

QUALITY CONTROL OF NUECL

Intra- and Inter-observer Variability

Variability will be evaluated on a quarterly basis throughout the duration of the study. A 5% sample of the echocardiograms performed each quarter will be randomly selected for the assessment of variability. These studies will be assigned a new ID in order to ensure that the re-reads are performed in a blinded fashion. Key echo parameters, including biplane ejection fraction, biplane left atrial volume, left ventricular wall thickness and dimensions, mitral inflow velocities, tissue Doppler e' velocities, and biplane left atrial strain, will be assessed. Each of the selected studies will be re-read by the same reader to assess for intra-observer variability. Each study will also be re-read by a second reader to assess for inter-observer variability. Variability testing will include equal representation of studies from each field center. If significant variability (>10%) is identified, the studies in question will be reviewed by all NUECL readers to identify the source of error.

Temporal Drift

To assess for temporal drift, blind re-reads will be performed on the same set of 10 studies every six months for the duration of the study. Key echo parameters, including biplane ejection fraction, biplane left atrial volume, left ventricular wall thickness and dimensions, mitral inflow velocities, tissue Doppler e' velocities, and biplane left atrial strain, will be assessed.

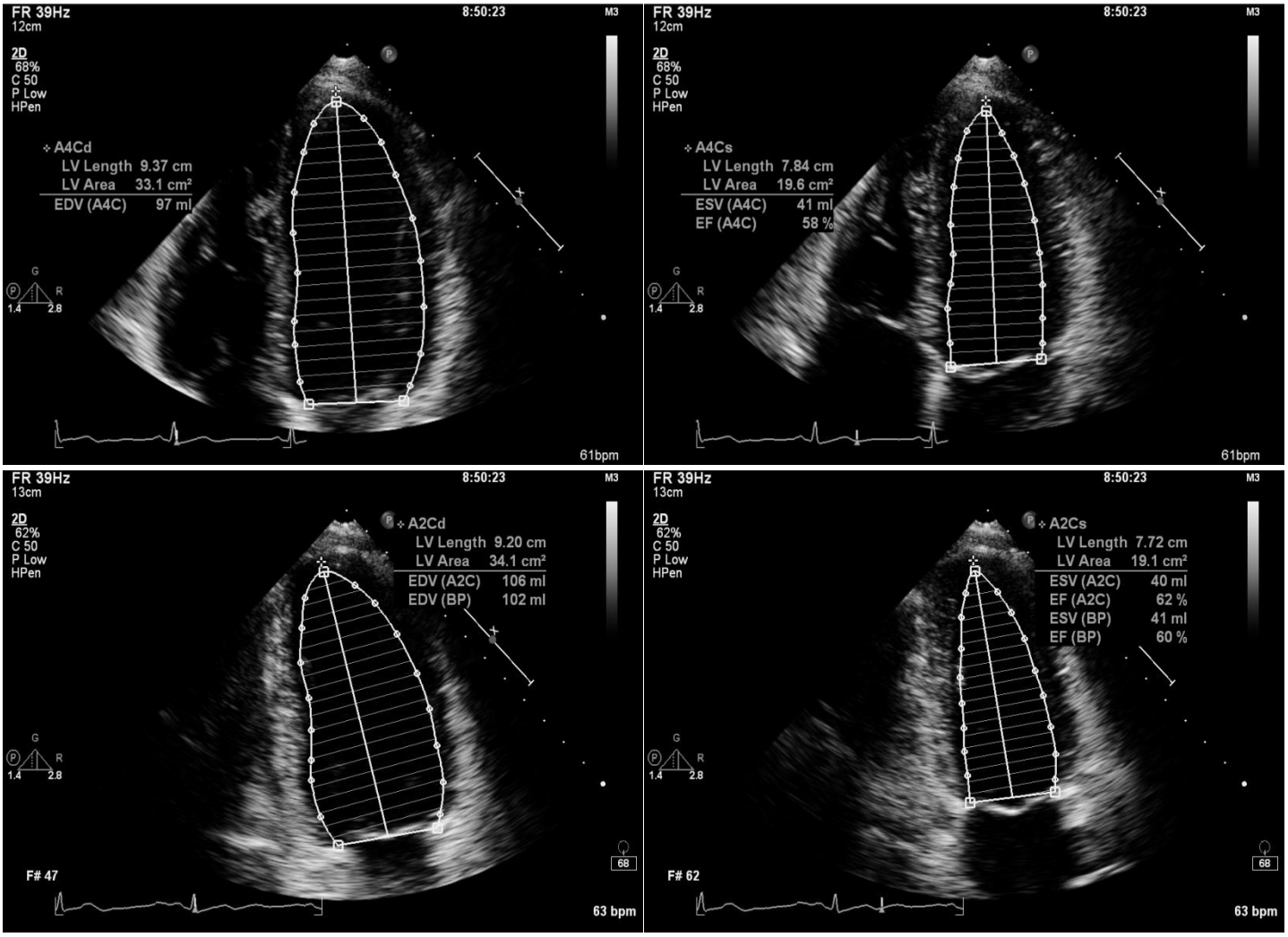
ASSESSMENT OF LEFT VENTRICULAR SIZE AND SYSTOLIC FUNCTION

Calculation of Ejection Fraction using Simpson's Biplane Method of Discs

- Left ventricular ejection fraction (LVEF) is the most popular echocardiographic expression of global LV function
    - LVEF is a simple measure of how much of the end-diastolic volume is pumped out of the LV with each contraction, calculated using the following equation:

$$\text{LVEF} = \frac{\text{End diastolic volume - End systolic volume}}{\text{End diastolic volume}} \times 100\%$$

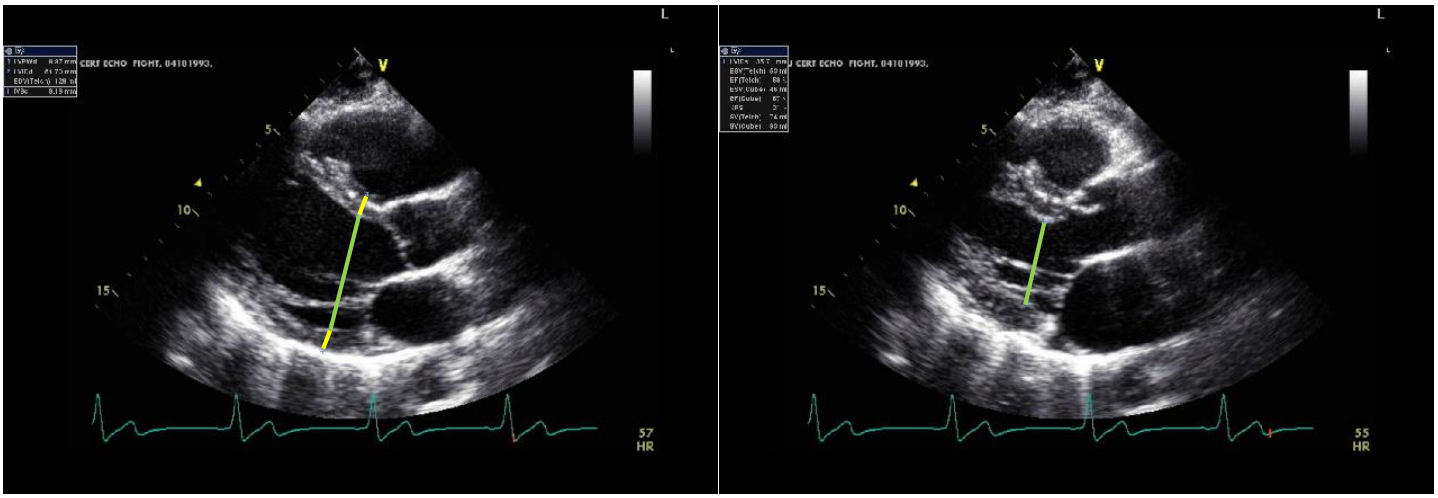
- The most commonly used approach for calculation of ventricular volumes and LVEF is the Simpson's biplane method of discs
    - This method is accurate even when LV geometry is distorted and is recommended in the consensus guidelines of the American Society of Echocardiography
    - To perform the Simpson's method, the endocardial border is manually traced, following the expected curvature of the ventricular wall and excluding the papillary muscles and areas of trabeculation
        - The manually traced endocardial border is used to calculate the volume of a series of stacked parallel elliptical disks from the base to the apex of the ventricle; these volumes are then summated to determine the total LV volume
- To calculate the ejection fraction, the endocardial border is manually traced at end-diastole and end-systole
    - The ventricular volumes calculated using this method are inserted into the equation above to determine LVEF in the four chamber and two chamber views; the two EF measurements are averaged to determine biplane LVEF (see Example 3)
- The following measurements are recorded by the core lab:
    - Apical 4 Chamber View
        - End diastolic volume (ml)
        - End diastolic area (cm^2)
        - End systolic volume (ml)
    - Apical 2 Chamber View
        - End diastolic volume (ml)
        - End systolic volume (ml)



Example 3: Still frames of the apical four chamber and apical two chamber views used to calculate LV volumes and EF using the Simpson's method

Left Ventricular Linear Dimensions

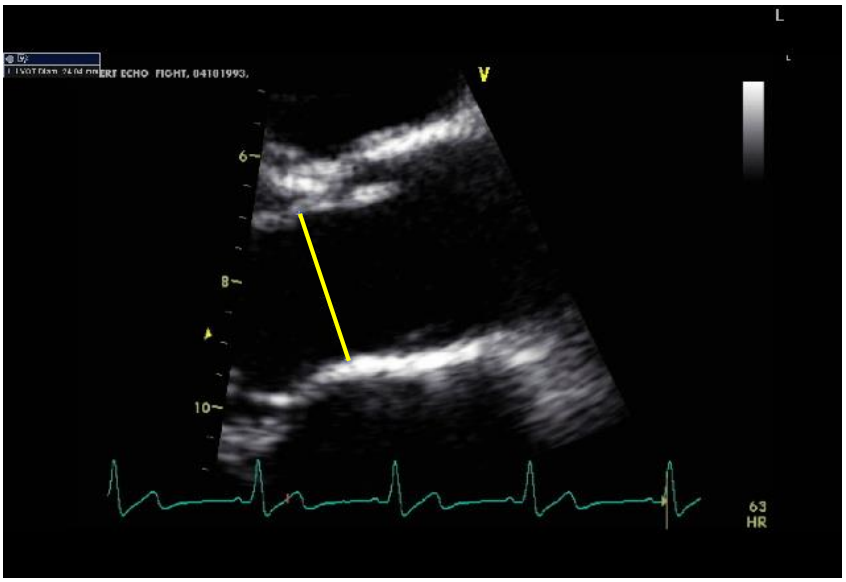
- Measurements of left ventricular dimensions and wall thickness are widely used in both clinical practice and research to evaluate left ventricular mass, size, and systolic function.
- In our laboratory, LV dimensions and wall thickness measurements are made from the 2D parasternal long axis view, as recommended by the American Society of Echocardiography. The measurement is made at the level of the LV minor axis, perpendicular to the long axis of the LV, approximately at the mitral valve leaflet tips.
- The following measurements are recorded by the core lab:
    - Septal wall thickness at end diastole (cm)
    - Posterior wall thickness at end diastole (cm)
    - Left ventricular internal dimension at end diastole (cm)
    - Left ventricular internal dimension at end systole (cm)
    - Left ventricular mass index
    - Relative wall thickness



Example 4: Still frames demonstrating the appropriate measurement of left ventricular wall thickness and left ventricular internal dimension (at end diastole and end systole)

Left Ventricular Outflow Tract Diameter

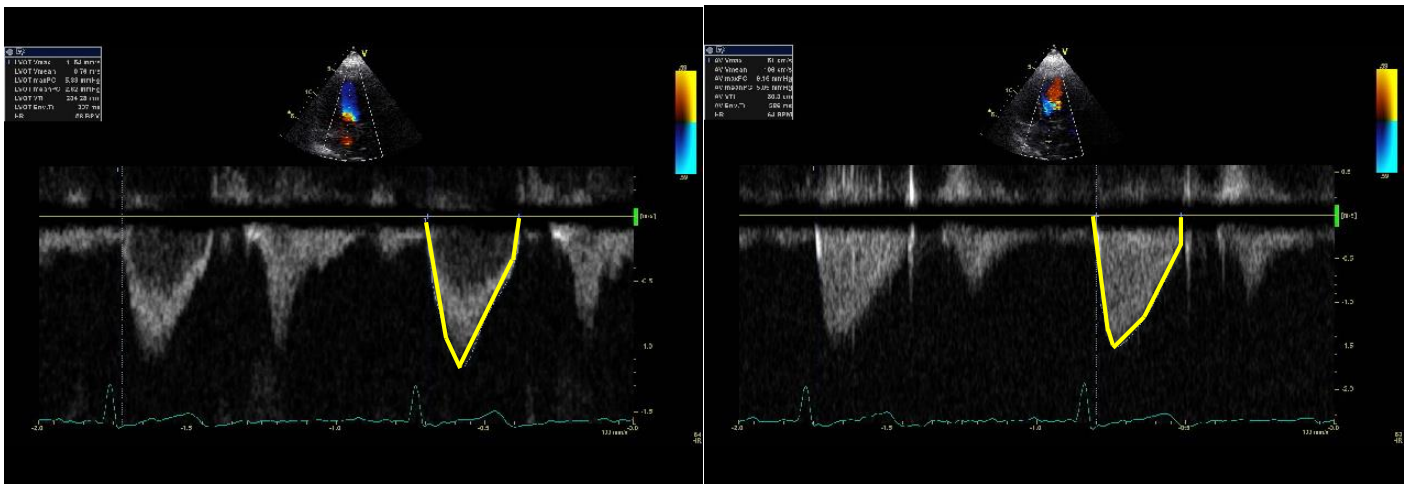
- The LVOT diameter (cm) is used to calculate stroke volume and cardiac output.
- The LVOT diameter is measured in the parasternal long axis view at mid-systole from the interface of the septal endocardium to the anterior mitral leaflet, parallel to the aortic valve plane and within 0.5-1.0 cm of the valve orifice.



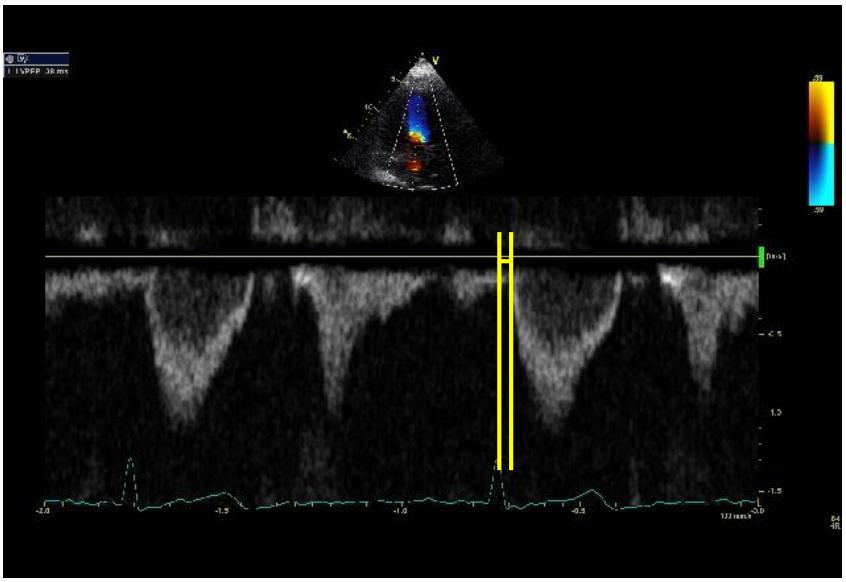
Example 5: Still frame demonstrating the appropriate measurement of left ventricular outflow tract diameter

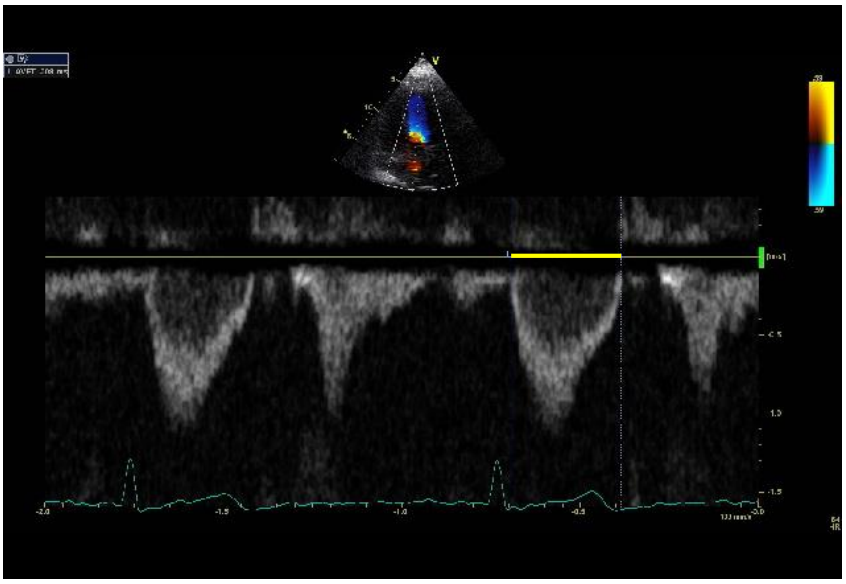
Left Ventricular Outflow Measurements

- PW and CW quantification of aortic outflow is performed from the apical five chamber view. The VTI is measured by tracing the outer border of the waveform from both the PW LVOT Doppler recording and the CW Doppler recording taken across the aortic valve (Example 6).
- The pre-ejection period and ejection time are also measured from the PW LVOT Doppler waveform. The pre-ejection period is measured from the peak of the R wave to the onset of systolic flow. The ejection time is measured as the time interval from the onset to the end of systolic flow.
- The following measurements are recorded by the core lab:
    - LVOT VTI (cm)
    - LV pre-ejection period (ms)
    - LV ejection time (ms)
    - Aortic valve VTI from the CW Doppler signal (cm)



Example 6: Still frames demonstrating the appropriate measurement of VTI from both the PW LVOT Doppler recording (left) and the CW aortic valve Doppler recording (right)



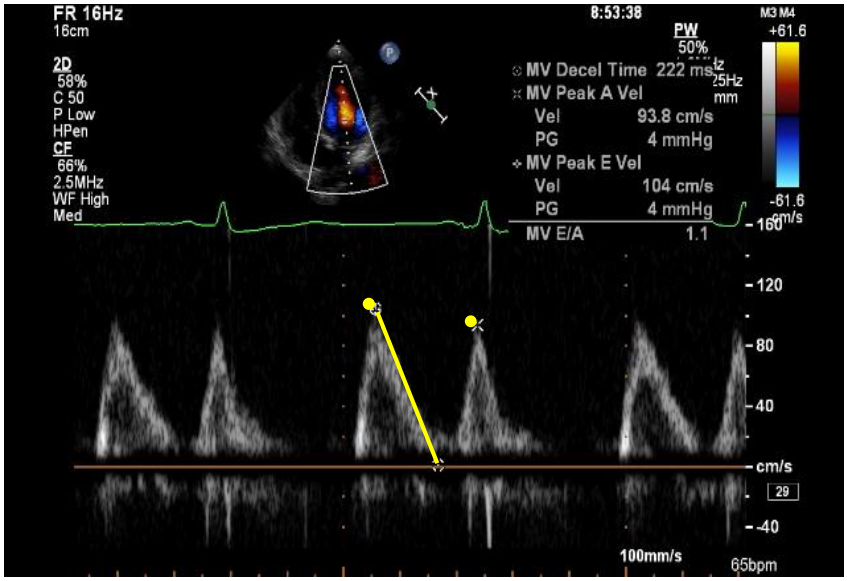


Example 7: Still frames demonstrating the appropriate measurement of the pre-ejection period (top) and the ejection time (bottom)

ASSESSMENT OF LEFT VENTRICULAR DIASTOLIC FUNCTION

Mitral Inflow

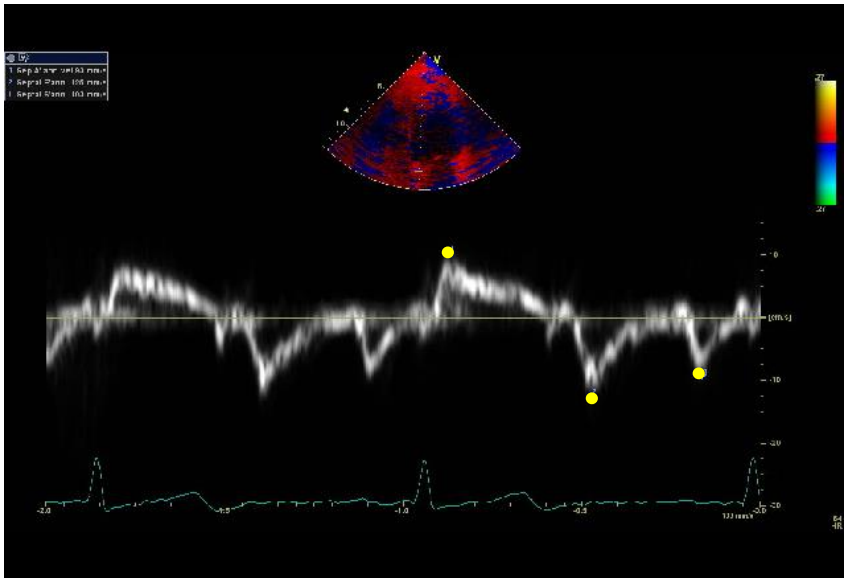
- There are two waveforms associated with mitral inflow: the early (E) wave represents passive filling of the ventricle, and the later (A) wave represents active filling during atrial systole
- The peak velocities of the E and A waves are measured (and the E/A ratio is determined), along with the deceleration time of the E wave (the time from the peak E velocity to its extrapolation to the baseline); these parameters are used to determine the presence and grade of diastolic dysfunction



Example 8: Still frame demonstrating the appropriate measurement of peak E and A wave velocities and E wave deceleration time

Tissue Doppler

- The PW TDI trace consists of three basic waveforms: systolic (s'), early diastolic (e') and late diastolic/atrial (a')
- The peak velocity of the all three waves is measured from both the septal and lateral mitral annulus
    - The peak e' velocity is the best and most sensitive echocardiographic indicator of LV relaxation, and is reduced in the presence of diastolic dysfunction
    - In addition, calculation of the E/e' ratio allows for the noninvasive estimation of LV end diastolic pressure (the higher the ratio, the higher the pressure)



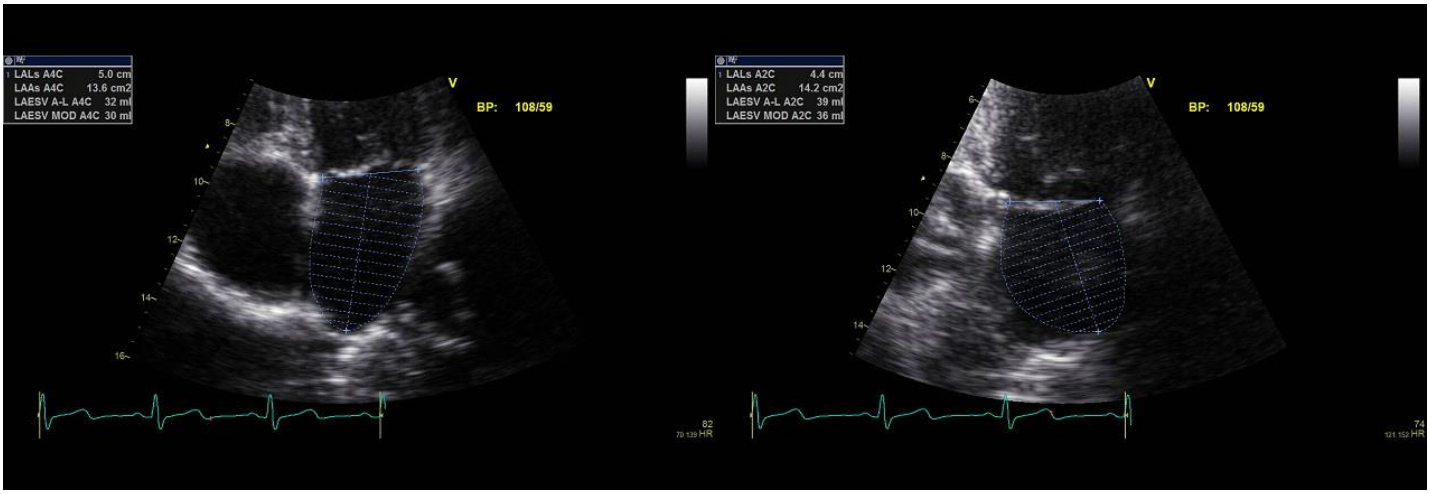
Example 9: Appropriate caliper placement for the measurement of s', e', and a' velocities

Derived Measures of Diastolic Function

- The following derived variables will be recorded by the core lab:
    - E/A ratio
    - E/e' ratio (septal)
    - E/e' ratio (lateral)

Left Atrial Volumes

- Left atrial enlargement is a marker of both the severity and chronicity of diastolic dysfunction and the magnitude of LA pressure elevation.
- Left atrial volume is measured from both the apical four chamber and apical two chamber view at the end of ventricular systole, when the LA chamber is at its greatest dimension. In our laboratory, the biplane method of discs is used to calculate LA volume, similar to the application used for LV measurements.
    - To perform the Simpson's method, the left atrial contour is traced, taking care to exclude the pulmonary veins and left atrial appendage. The inferior border of the atrium is represented by the plane of the mitral annulus.
    - The manually traced endocardial border is used to calculate the volume of a series of stacked parallel elliptical disks from the base of the atrium to the mitral annulus; these volumes are then summated to determine the total LA volume (Example 10).



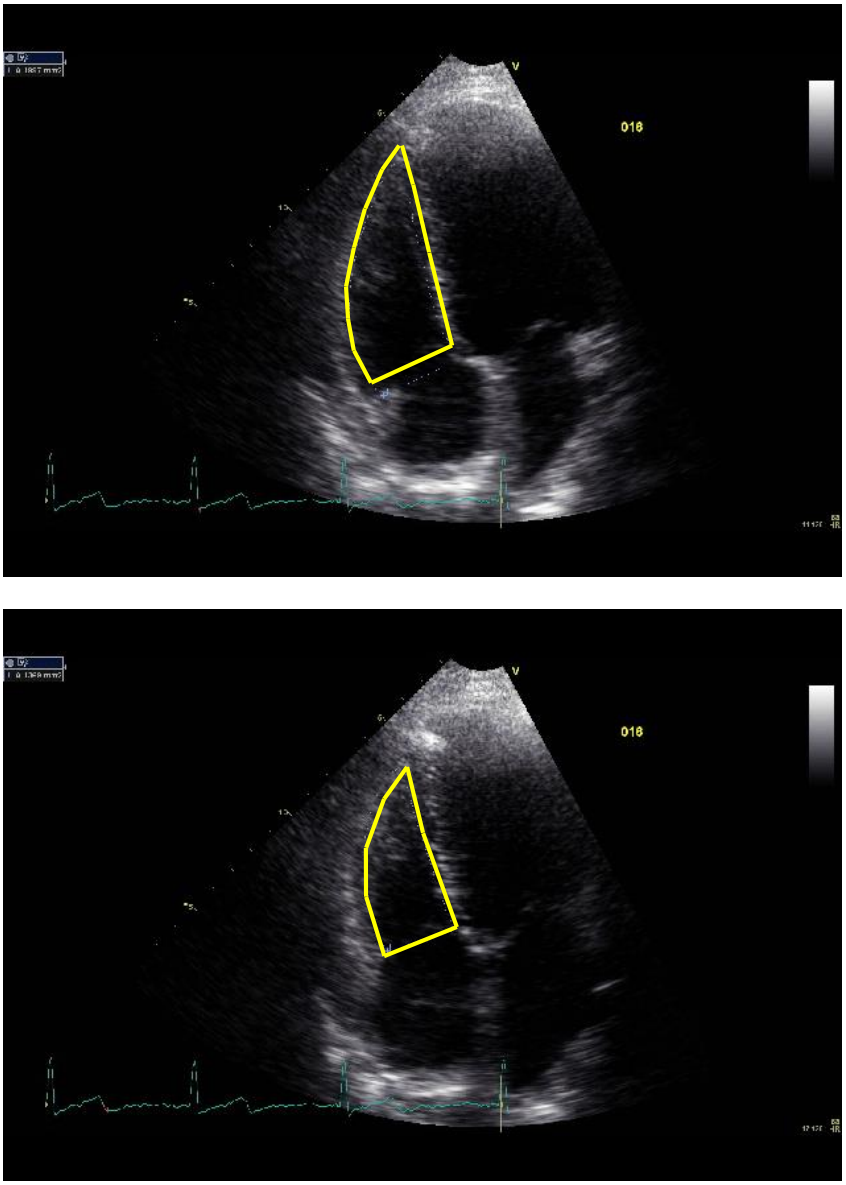
Example 10: Still frames of the apical four chamber and apical two chamber views used to calculate LA volumes using the Simpson's method

ASSESSMENT OF RIGHT VENTRICULAR SIZE AND FUNCTION

Measurement of Right Ventricular Areas and Fractional Area Change

- The complexity of estimating right ventricular volume and function with 2D echocardiography has been well documented. Due to the irregular shape of the right ventricle and the difficulty associated with obtaining standardized echocardiographic views of this chamber, the American Society of Echocardiography does not currently recommend the use of volume tracings to quantify the right ventricle. Instead, right ventricular areas are the recommended method of choice for evaluating right ventricular systolic function.
- In our lab, right ventricular areas are traced at both end diastole and end systole from the apical four chamber view to calculate right ventricular fractional area change. The right ventricular end diastolic area is also utilized as an indicator of RV size. The RV endocardium is traced in both systole and diastole from the lateral tricuspid annulus, along the free wall to the apex, and then back to the medial annulus, along the interventricular septum (Example 11). RV trabeculations, papillary muscles, and the moderator band are included in the cavity area.
- Fractional area change is calculated using the following equation:

$$\frac{\text{End diastolic area - End systolic area}}{\text{End diastolic area}} \times 100\%$$



Example 11: Still frames demonstrating the appropriate method for tracing right ventricular areas at end diastole (top) and end systole (bottom)

Measurement of Right Atrial Area

- Right atrial area has been shown to be more representative of actual RA size than linear dimensions.
- Right atrial area is traced at the end of ventricular systole by following the RA endocardium from the lateral aspect of the tricuspid annulus to the septal aspect, excluding the area between leaflets and annulus, the IVC, SVC, and right atrial appendage.

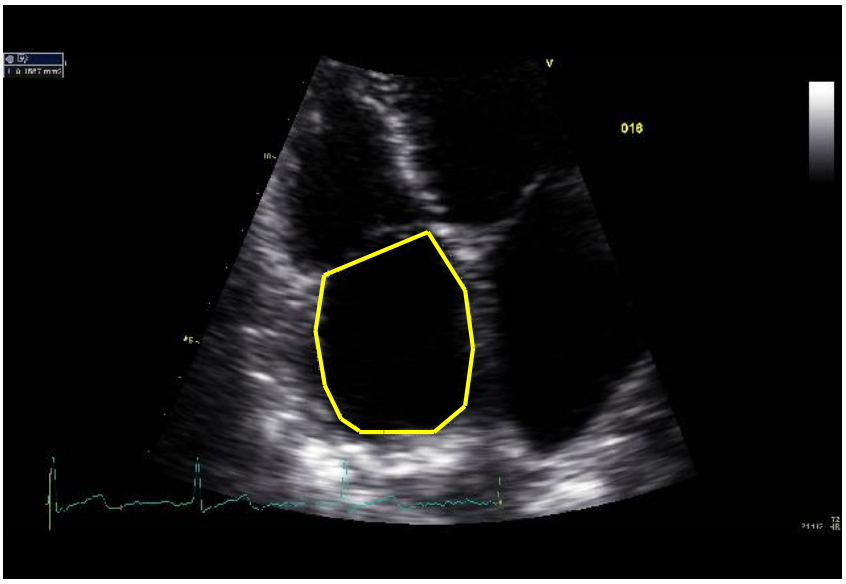
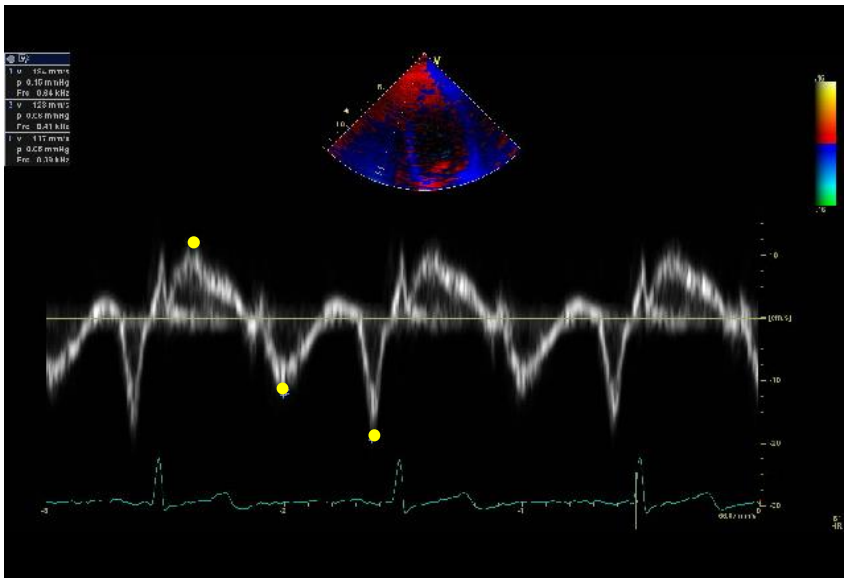


Figure 12: Still frame demonstrating the appropriate method for tracing right atrial area

M-Mode and Doppler Evaluation of Right Ventricular Function

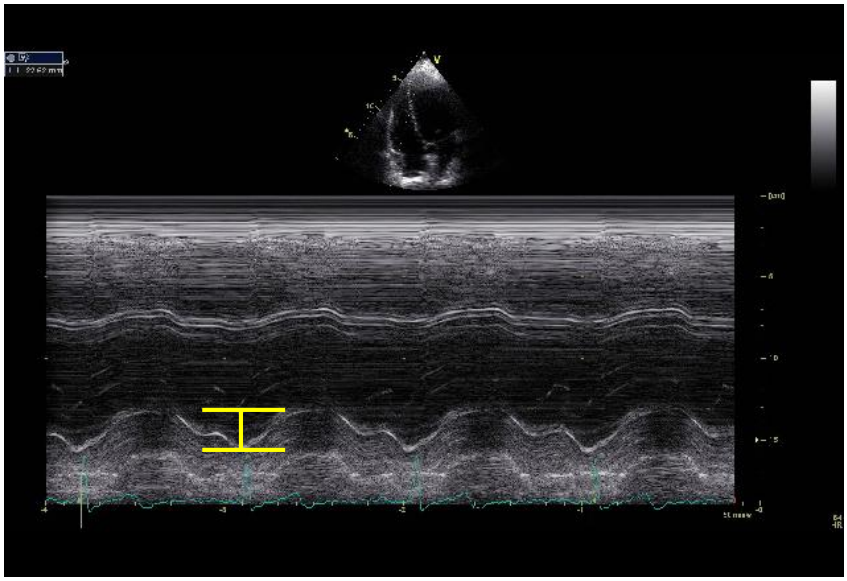
- Tissue Doppler assessment of the right ventricle at the lateral annulus is a simple, reproducible technique that can be used to assess right ventricular systolic function. Using the same methods outlined above for quantifying the TDI waveform of the left ventricle, the s', e', and a' wave are recorded (Figure 13).



Example 13: Appropriate caliper placement for the measurement of s', e', and a' velocities

Tricuspid Annular Plane Systolic Excursion (TAPSE)

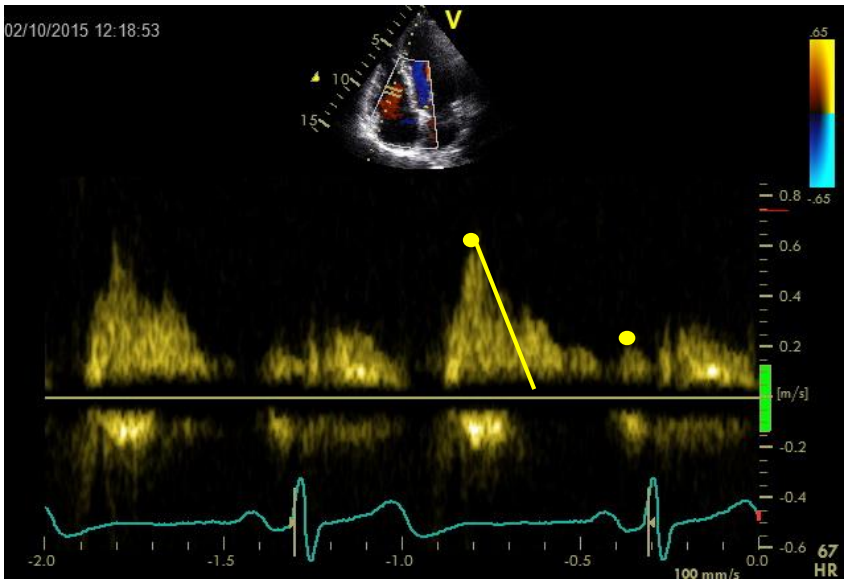
- Tricuspid annular plane systolic excursion (TAPSE) is a method to measure the distance of systolic excursion of the RV annular segment along its longitudinal plane, from a standard apical four chamber window. The greater the descent of the base in systole, the better the RV systolic function.
- TAPSE is acquired by placing an M-mode cursor through the lateral tricuspid annulus during offline analysis. The amount of longitudinal motion of the annulus at peak systole is measured (Example 14).



Example 14: Still frame demonstrating the appropriate method for measurement of TAPSE

Tricuspid Inflow

- As with the mitral valve, there are two waveforms associated with tricuspid inflow: the early (E) wave represents passive filling of the ventricle, and the later (A) wave represents active filling during atrial systole
- The peak velocities of the E and A waves are measured (and the E/A ratio is determined), along with the deceleration time of the E wave (the time from the peak E velocity to its extrapolation to the baseline); these parameters are used to determine the presence and grade of diastolic dysfunction in the right ventricle.



Example 15: Still frame demonstrating the appropriate measurement of peak E and A wave velocities and E wave deceleration time

PULMONARY ARTERY SYSTOLIC PRESSURE MEASUREMENT

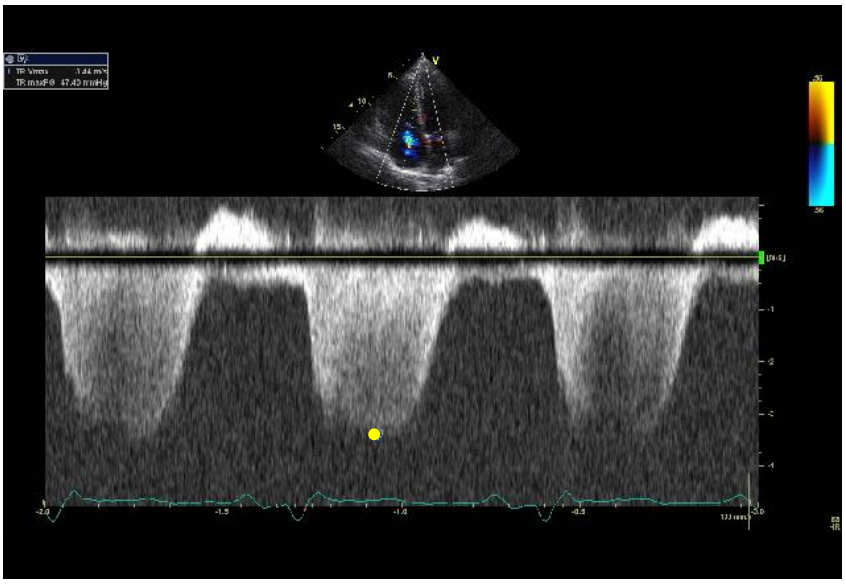
Tricuspid Regurgitant Jet

- The most reliable method for estimating pulmonary systolic pressure noninvasively is based on measurement of the velocity of the tricuspid regurgitant jet.
    - This velocity reflects the right ventricular to right atrial pressure difference ΔP, as stated in the Bernoulli equation:

$$\Delta P_{RV\text{-}RA} = 4(V_{TR})^2$$

    - When added to an estimate of right atrial pressure (RAP), RV systolic pressure is obtained. In the absence of pulmonic stenosis, RV systolic pressure is equal to pulmonary artery systolic pressure, so that

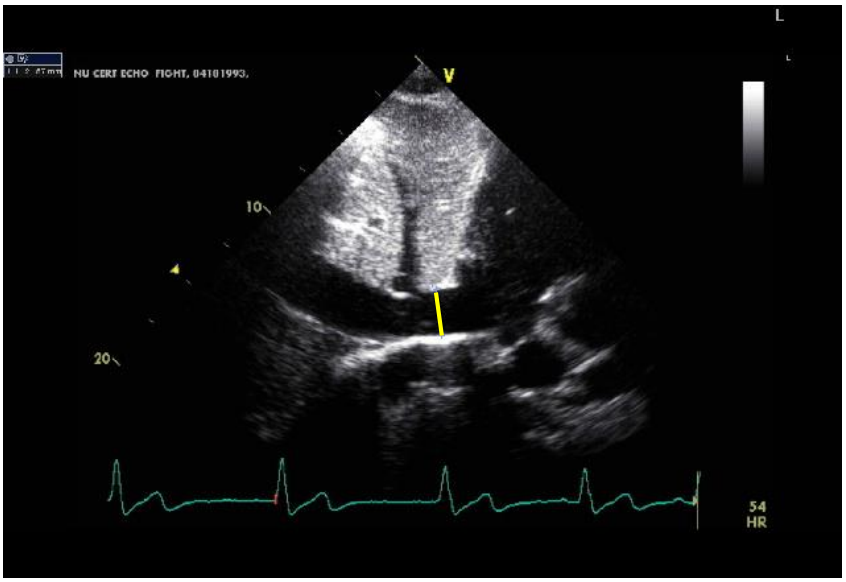
$$PAP_{SYSTOLIC} = 4(V_{TR})^2 + RAP$$

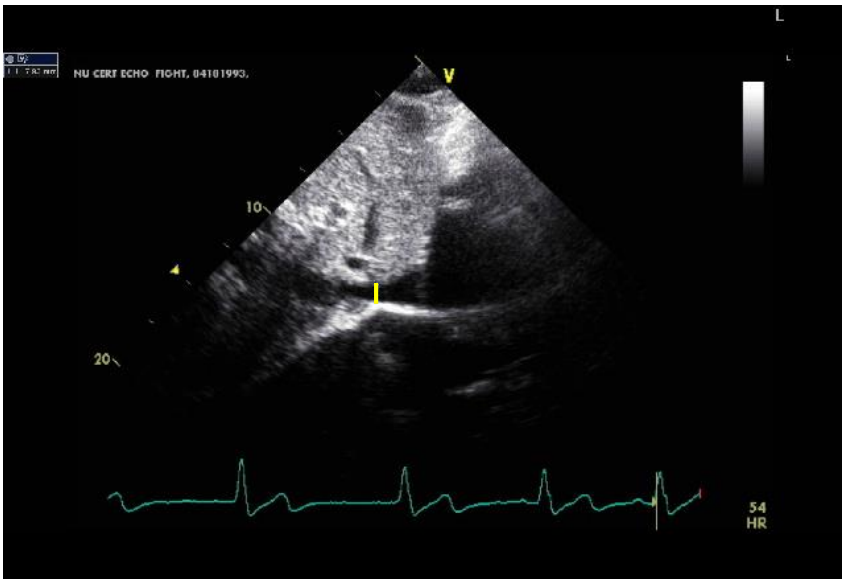


Example 16: Still frame demonstrating the appropriate measurement of tricuspid regurgitation peak velocity

Inferior Vena Cava Dimensions

- Right atrial pressure is best estimated from an evaluation of the inferior vena cava during respiration or after a 'sniff'
    - If the IVC is normal in diameter and collapses with respiration, the RA pressure is normal
    - Failure to collapse with respiration and/or dilation of the inferior vena cava is associated with higher RA pressures
- The maximum diameter of the IVC and minimum diameter (after sniff) are recorded by the core lab



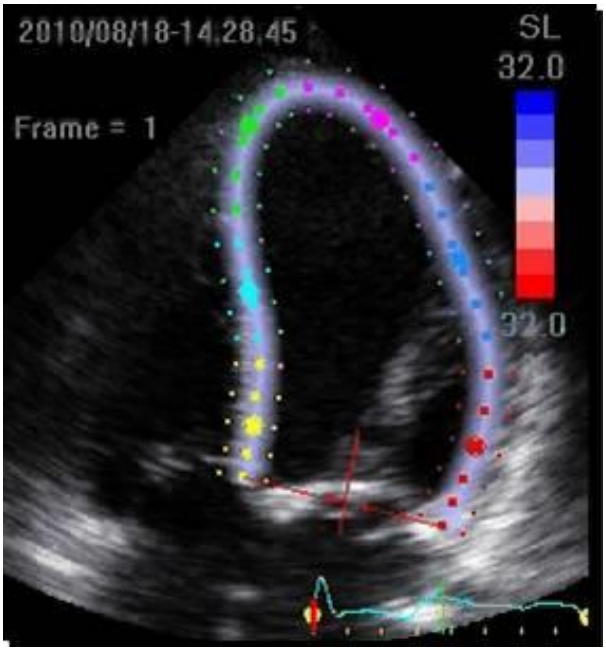


Example 17: Still frame demonstrating the measurement of maximum (top) and minimum (bottom) IVC diameter before and after sniff

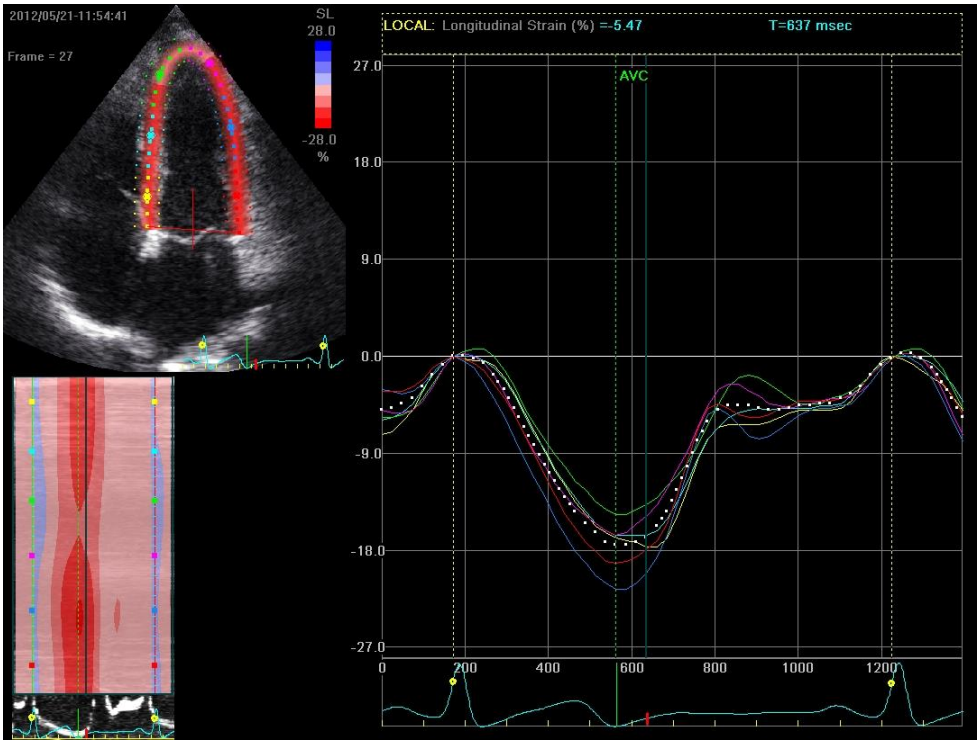
SPECKLE TRACKING ECHOCARDIOGRAPHY

- Strain is a measure of the deformation of a material, expressed as the fractional or percentage change from the object's original dimension
    - When applied to the evaluation of cardiac function, strain is an index of the change in myocardial length during contraction and relaxation, and can have positive or negative values which reflect lengthening and shortening, respectively
    - Strain rate is the rate of this change in length, calculated as the difference between two velocities normalized to the distance between them.
- Longitudinal strain represents deformation along the long axis of the ventricle
    - During systole, the myocardium contracts from the base to the apex of the heart, reflected as a shortening in the length of the wall; consequently, longitudinal strain decreases to a negative value during systole and moves back toward the positive direction during diastole
    - Longitudinal strain analysis can also be performed on the left atrium, resulting in two waveforms: a negative peak during atrial systole (corresponding to the P wave) and a positive peak during atrial filling or diastole
- Circumferential and radial strain are typically measured from the parasternal short axis window
    - Circumferential strain represents deformation along the curvature of the ventricle and can only be measured from the PSAX view
        - During systole, the circumference of the ventricle decreases, reflected as a shortening of the wall
        - Circumferential strain decreases to a negative value during systole and moves back toward the positive direction with an increase in ventricular circumference during diastole
    - Radial strain represents deformation towards the center of the ventricle and can be measured from multiple segments in both the PSAX and A4C views

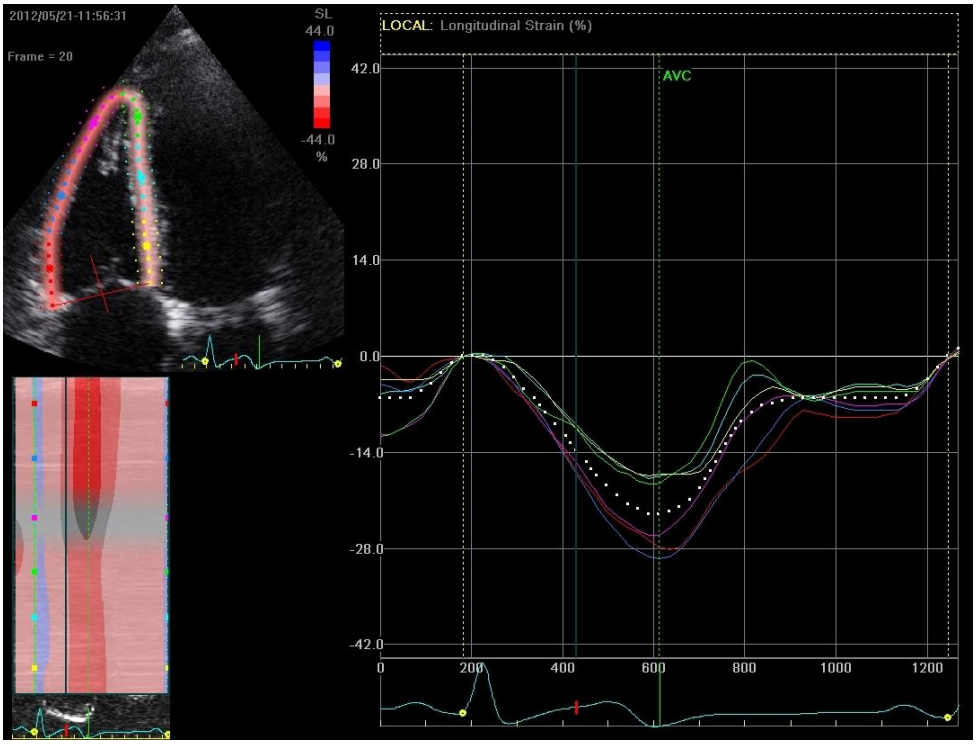
        - Unlike longitudinal and circumferential strain, which are represented by negative curves, radial strain is a positive curve reflecting increased myocardial thickness during systole and decreased thickness during diastole
- Strain is assessed on the basis of 2D echo using speckle tracking (STE), which is a non-Doppler based technique that analyzes myocardial deformation by tracking speckles in the 2D image
    - Speckles are small bright spots in the myocardium used as natural acoustic markers
    - Each region of the myocardium has a unique pattern of speckles; tracking these patterns as they move during the cardiac cycle provides local displacement information, from which strain can be derived
- STE analysis is performed offline using a speckle-tracking algorithm incorporated into a specialized workstation
    - A cardiac cycle is selected from the 2D loop based on frame rate (50-80 fps), absence of artifacts, myocardial visualization, and contrast of endocardial and epicardial borders
    - The image is frozen at end-systole and the endocardium is traced, excluding areas of trabeculation and the papillary muscles
    - After tracing is complete, the software automatically generates a corresponding epicardial tracing to define the region of interest; the width of this region may be adjusted manually to ensure that the outer tracing is just within the epicardial border (see Example 18)
- After the region of interest is defined, the software divides the wall into six standard anatomic segments for regional speckle tracking analysis, automatically tracking and accepting segments of good quality and rejecting poorly tracked segments
- The STE algorithm generates curvilinear strain graphs that provide a profile of strain with time
    - Peak strain measurements are recorded from the six segments in each view, providing regional values; these values are then averaged across all six segments to generate global strain measurements (see Example 19)
- Peak global and segmental systolic strain values are commonly used to assess global myocardial contractility and regional function
    - STE-based calculations of strain have proven to be highly reproducible and accurate quantitative parameters of global and regional contractile function that are more sensitive than conventional methods and less dependent on loading conditions
    - An increase in stress on the heart wall, no matter the cause, results in a decrease in strain; therefore, reductions in systolic strain indicate the presence of myocardial dysfunction
- The core lab performs strain analysis on the following views, recording peak global strain values (in the case of left atrial strain, both peak positive and peak negative values are recorded):
    - Longitudinal strain
        - Left ventricle (4, 2, and 3 chamber views)
        - Right ventricular free wall (see Example 20)
        - Left atrium (4 and 2 chamber views) (see Example 21)
    - Circumferential strain
        - Left ventricle (PSAX view) (see Example 22)
    - Radial strain
        - Left ventricle (PSAX view) (see Example 22)
    - Early diastolic strain rate
        - Left ventricle (4 chamber view) (see Example 23)



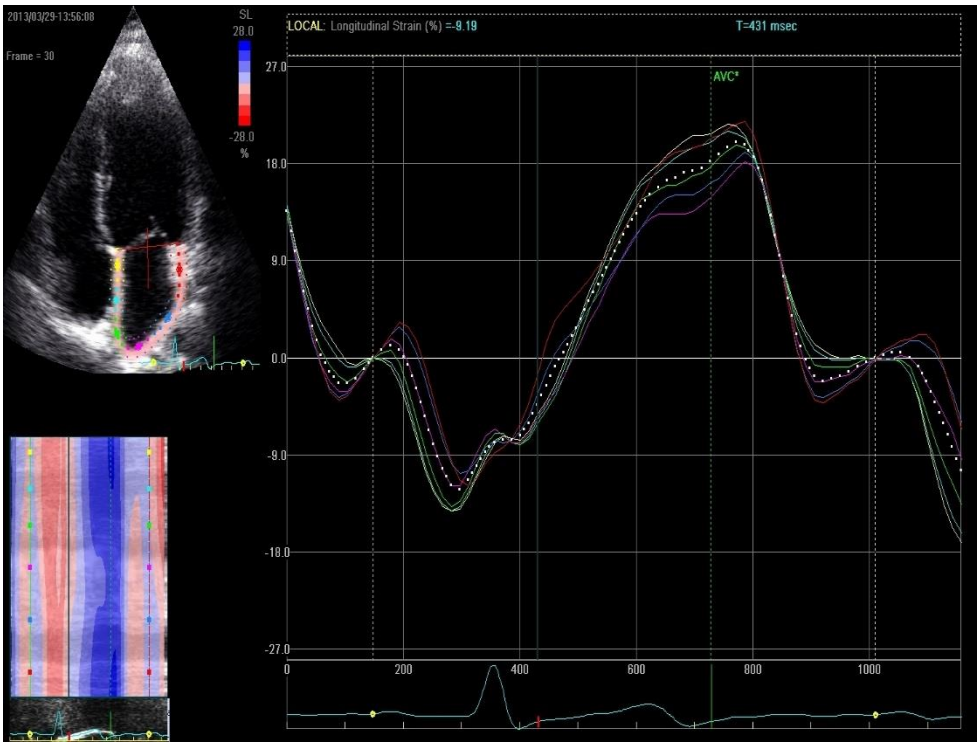
Example 18: This image shows the user-defined region of interest for STE in the apical 4 chamber view; the three rows of dots represent the three layers of the cardiac wall (endocardium, myocardium, and epicardium)



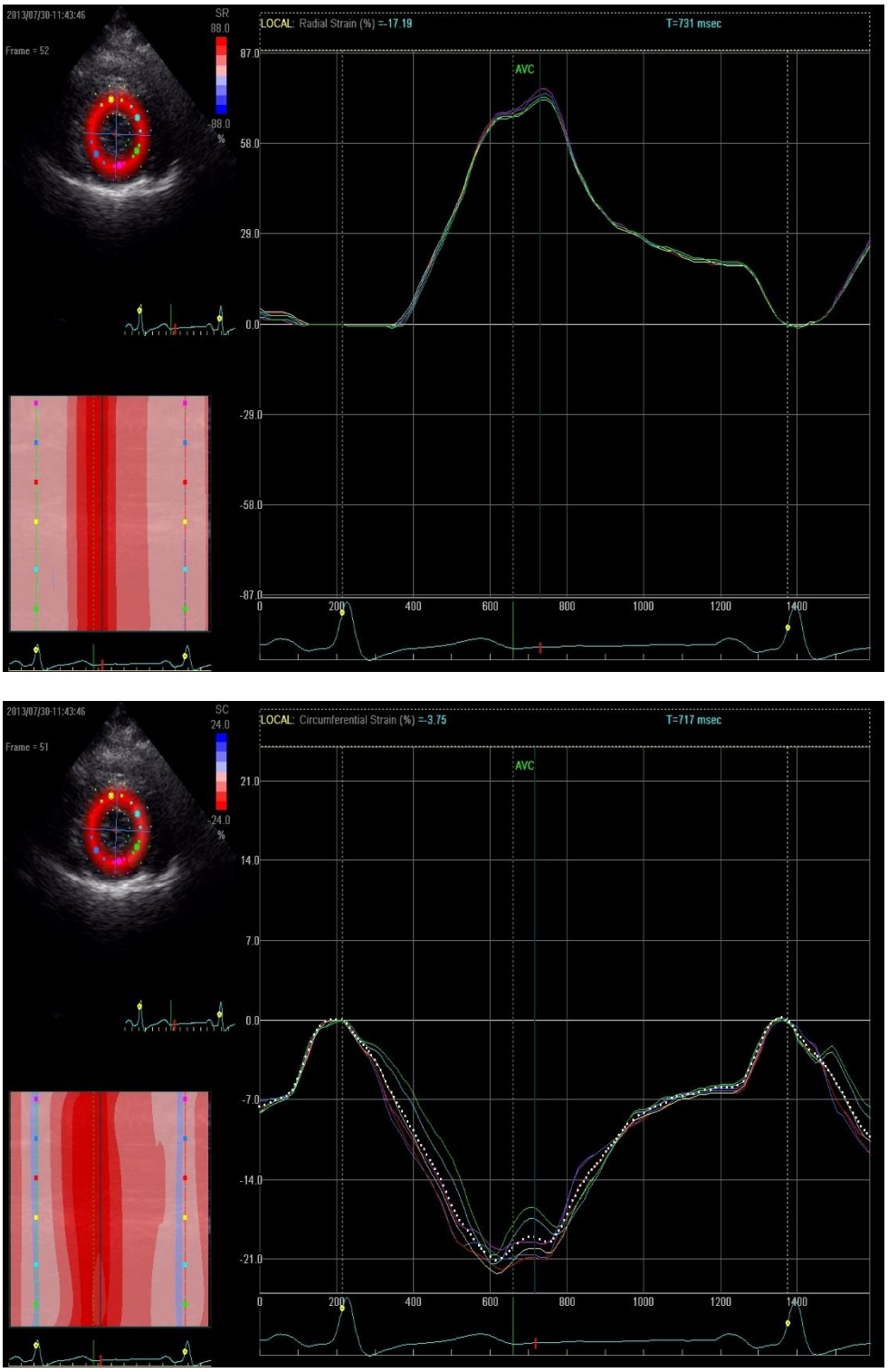
Example 19: Longitudinal strain graph from the apical four chamber view; the colored lines represent the six ventricular segments, while the white dotted line represents global longitudinal strain



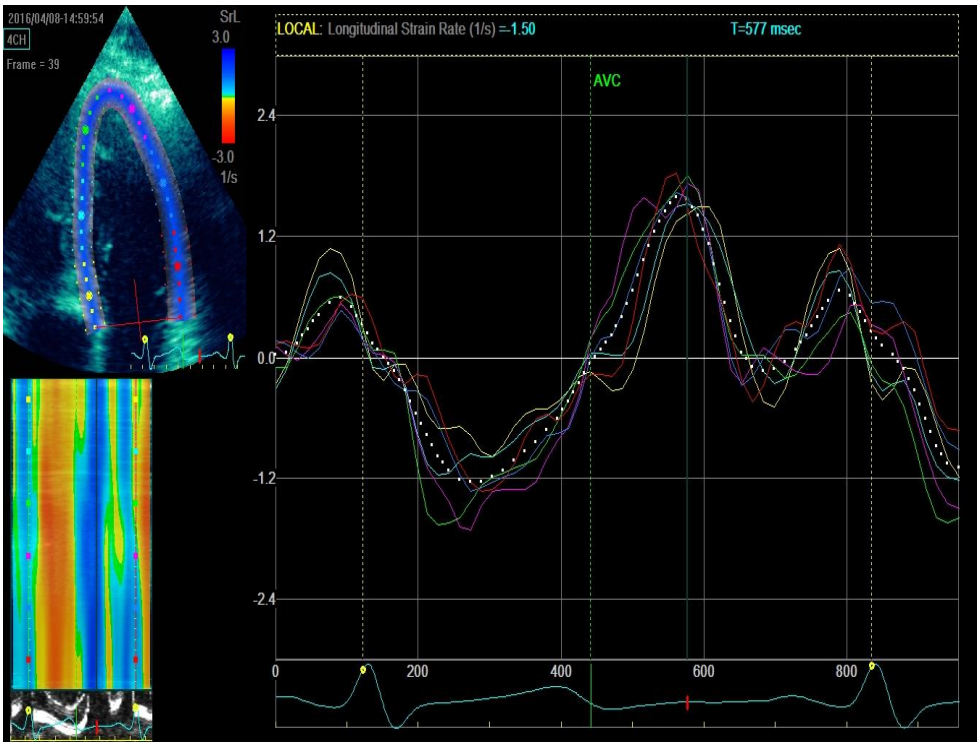
Example 20: Longitudinal strain graph of the right ventricle from the apical four chamber view; note that the strain values for the three free wall segments (red, blue, and purple) are much higher than the values for the three septal segments (yellow, teal, and green). The pattern for RV strain is more variable than the pattern for LV strain because the complex shape of the RV causes wall stress to be distributed unevenly. The values for the three free wall segments are averaged to calculated RV free wall strain.



Example 21: Longitudinal strain graph of the left atrium from the apical four chamber view. Note that the ECG gating for left atrial strain corresponds to the P wave on the ECG (as opposed to the R wave used in ventricular strain). The left atrial strain graph includes two peaks: a negative peak, corresponding to atrial contraction, and a positive peak corresponding to atrial filling.



Example 22: Radial (top image) and circumferential (bottom image) left ventricular strain graphs recorded from the parasternal short axis view. Radial strain appears as a positive value, while circumferential strain appears as a negative value.



Example 23: Left ventricular strain rate, recorded from the apical four chamber view. The early diastolic strain rate (the first positive wave after aortic valve closure) is recorded by the core lab.

ASSESSMENT OF RESPONSE TO INCREASE IN PRELOAD (PASSIVE LEG RAISE MANEUVER)

- At the end of the echocardiographic examination, a pillow is used to prop up the legs while the patient rests in the supine position. When the legs are raised, blood flows from the veins of the leg to the heart, thereby increasing preload. The passive leg raise maneuver allows for the determination of cardiac response to increase preload, which can help with the diagnosis of early heart failure. The following measurements are repeated during the passive leg raise maneuver:
    - Mitral E and A wave velocities
    - Septal and lateral e' velocities
    - LVOT VTI
    - Peak TR velocity
    - Left ventricular strain, A4C view
    - Early diastolic left ventricular strain, A4C view
    - Right ventricular free wall strain, A4C view
    - Left atrial strain, A4C view – peak positive and peak negative values

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MESA ECHO PROTOCOL: POCKET GUIDE	
Parasternal Window	
Parasternal Long Axis	☐ 2D clip ☐ Color Doppler on mitral and aortic valves
Parasternal Short Axis – Papillary muscle level	☐ 2D clip (FR 50-80 fps)
Parasternal Short Axis – Basal level	☐ 2D clip ☐ Color Doppler on tricuspid valve ☐ CW Doppler for TR jet
Apical Window	
Apical 4 Chamber	☐ 2D clip demonstrating all four chambers (FR 50-80 fps) ☐ 2D clip focused on the LV (FR 50-80 fps) ☐ 2D clip focused on the LA (FR 50-80 fps) ☐ Color Doppler on the mitral valve/left atrium ☐ Color M-mode of mitral inflow ☐ PW Doppler of mitral inflow ☐ PW TDI at septal mitral annulus ☐ PW TDI at lateral mitral annulus
Apical 4 Chamber – Focus on RV	☐ 2D clip focused on the RV and RA (FR 50-80 fps) ☐ Color Doppler on the tricuspid valve/right atrium ☐ PW Doppler of tricuspid inflow ☐ CW Doppler for TR jet ☐ PW TDI at lateral tricuspid annulus
Apical 5 Chamber	☐ Color Doppler on the LVOT/aortic valve ☐ PW Doppler of the LVOT ☐ CW Doppler of the AV
Apical 2 Chamber	☐ 2D clip demonstrating both chambers (FR 50-80 fps)
Apical 3 Chamber	☐ 2D clip demonstrating all three chambers (FR 50-80 fps)
Additional Views	
Subcostal	☐ 2D clip of the IVC with sniff ☐ PW Doppler of the abdominal aorta at the level of the diaphragm
Suprasternal Notch	☐ PW Doppler of the descending thoracic aorta ☐ Measure distance between suprasternal notch and tip of xiphoid process, annotate on PW Doppler screen
Legs elevated with wedge	☐ 2D A4C clip focused on the LV and LA (FR 50-80 fps) ☐ 2D A4C clip focused on the RV and RA (FR 50-80 fps) ☐ PW Doppler of mitral inflow ☐ PW TDI at septal mitral annulus ☐ PW TDI at lateral mitral annulus ☐ PW Doppler of the LVOT

MESA

Exam 6
Echocardiogram
Transmittal Form

Participant ID #: ☐☐☐☐☐☐☐ Acrostic: ☐☐☐☐☐☐☐

Technician ID: ☐☐☐☐ Date: ☐☐/☐☐/☐☐☐☐ (Month / Day / Year)

Transcribe from participant visit records:

Age ☐☐☐ Height ☐☐☐.☐ cm Weight ☐☐☐.☐ kg ○ Male ○ Female

Rhythm: ○ Normal sinus rhythm ○ Atrial fibrillation ○ Other

Heart Rate: ☐☐☐ bpm

Blood Pressure: Systolic ☐☐☐.☐ Diastolic ☐☐☐.☐

1. Were all required echo views obtained?

○ Yes
○ No → ***If NO, please explain:*** ☐

2. Are there any referral or alert findings?

○ No
○ Yes →

2a. What are the findings? (CHECK ALL THAT APPLY)

- ☐ Suspected tamponade
- ☐ Aortic aneurysm or dissection
- ☐ Abscess or obvious vegetation
- ☐ Intracardiac thrombus or mass
- ☐ Pseudoaneurysm
- ☐ Significant arrhythmia
- ☐ Severe left or right ventricular enlargement
- ☐ Severe regurgitation or stenosis of any valve
- ☐ Moderate or greater pericardial effusion - no evidence of tamponade
- ☐ Mild or moderate stenosis of any valve
- ☐ Moderate mitral or aortic regurgitation
- ☐ Moderate or greater dynamic LVOT obstruction
- ☐ Intra-cardiac shunt
- ☐ Moderate to severe pulmonary hypertension
- ☐ RV pressure or volume overload
- ☐ Low ejection fraction or WMA
- ☐ Other, please specify: ☐

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3. Comments for the echo reading center, including any problems encountered with the participant, image acquisition, or machine failure:

_____

_____

_____

RESULTS OF THE ARTERIAL PULSE WAVE EXAM:

O Complete →

Quality of Wave Form: O Good O Fair O Poor

Were multiple recordings performed? O Yes O No

O Incomplete →

Reason exam incomplete or not done:

- O Poor arterial waveform
- O Undetectable arterial waveform
- O Equipment malfunction
- O Time/staff/room constraints
- O Examinee refused or uncooperative
- O Examinee physically unable
- O Other [ ]

Comments: [ ]

MESA ECHO FEEDBACK FORM

Study ID:

Echo date: Click here to enter a date.

Date received by NUECL: Click here to enter a date.

Reviewed by: Choose an item.

Echocardiography			
Imaging Window	**Score**	**Indication**	**Comments**
Parasternal Long Axis View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Parasternal Short Axis View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Apical 4 Chamber View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Apical 5 Chamber View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Apical 2 Chamber View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Apical 3 Chamber View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Subcostal/Suprasternal View	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Legs Elevated with Wedge	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Endocardial Definition	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Image Settings	☐ 1 ☐ 2 ☐ 3 ☒ 4	☐ B ☐ S ☒ N/A	
Additional Comments: Total score: /40 %			

1= Poor 2= Limited 3=Satisfactory 4=Excellent B=Body Habitus S=Sonographer error

Reviewing sonographer signature: Lauren Nelson Date Click here to enter a date.