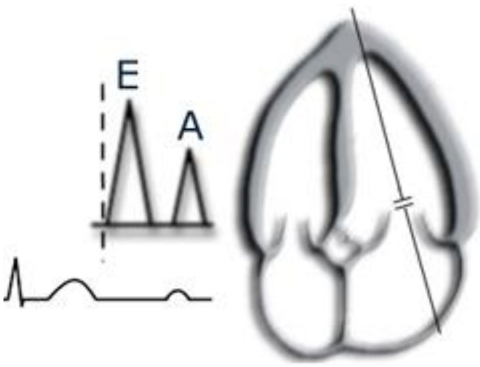
Diastolic left ventricular function

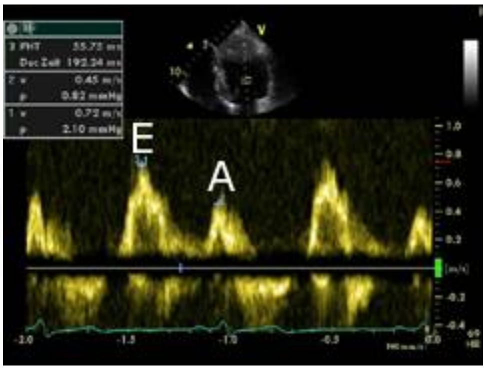
Mitral inflow velocities examination

Pulsed wave Doppler (PW-Doppler) allows the measurement of velocities at the level of the sample volume. Two flow velocity envelopes can be seen during diastole in persons with sinus rhythm: the E-wave, representing the early, passive filling of the left ventricle, and the A-wave, that happens late in diastole, representing the active filling, the atrial contraction.

PW-Doppler sample volume is placed at the tips of the mitral valve in the left ventricle. It is a preload and afterload dependent parameter.

- Note: in newborns (particularly premature newborns) the E-wave is normally smaller than the A-wave (E:A ratio < 1) with a “pseudo normalized” E:A ratio (as demonstrated below) representing increased LV blood flow (e.g. HSPDA or in "Cold Shock"). In "warm shock", Hypovolemia or PPHN the E:A ratio should be <1 .



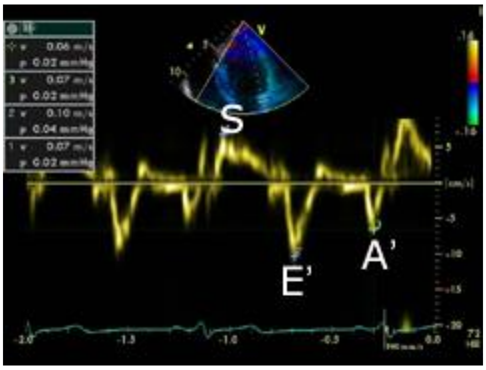


Mitral annular velocities examination

Slow wall velocities can be assessed with Tissue Doppler Imaging (TDI). The sample volume, when placed at the medial mitral annulus, shows slower velocities as when placed at the lateral annulus. The E/E' relationship will be different according to each case, making more difficult the interpretation of results.

PW-TDI sample volume is place at the level of the lateral mitral annulus.

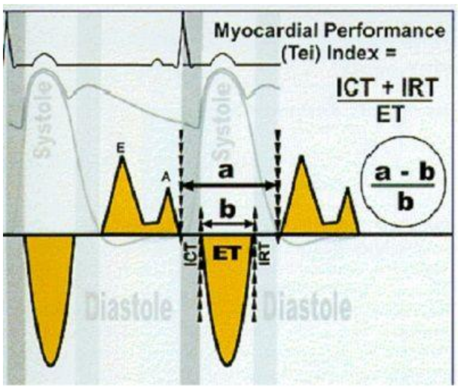
spectral tissue Doppler (TDI) display shows an ante grade systolic, and two retrograde waves, E' (passive LV filling) and A'-wave (atrial contraction).



Diastolic and Systolic left ventricular function

Myocardial performing Index – MPI

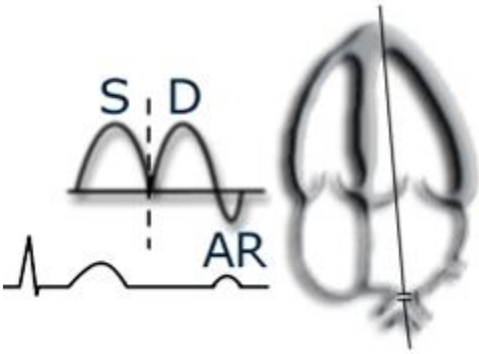
The myocardial performance index (MPI), or Tei index, is a Doppler echocardiographic parameter and defined as the sum of the isovolumic contraction and relaxation times (ICT and IRT) divided by the ejection time (ET).[1,2] MPI has been demonstrated to be a reliable and reproducible parameter for the evaluation of left ventricular systolic and diastolic dysfunction in many kinds of heart disease in human.[2–5] Furthermore, a number of studies have documented that MPI is independent of heart rate,[6] arterial pressure,[7] and preload.[8]

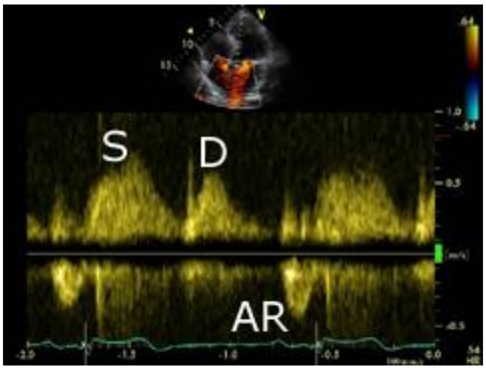


Pulmonary venous flow examination

Pulmonary venous flow velocities can be assessed with PW-Doppler. Localization of pulmonary veins with color Doppler is relatively easy, and allows to place sample volume at the right position.

pulmonary venous flow can be assessed with PW-Doppler from the apical four-chamber view.





PW Doppler spectral display shows a larger systolic (S), a diastolic (D) and a smaller end- diastolic wave (AR), the atrial contraction.

Assessment of LV systolic function

A knowledge of the LV systolic function is crucial in the understanding of and management of unstable hemodynamics or a failing heart in the ICU. As with fluid status assessment, a composite of different measures should be used rather than any one. The different methods commonly used in the echocardiographic assessment of LV systolic function are:

- Ejection fraction - M-mode LV dimensional method
- Simpsons method
- Doppler measurement of stroke volume...and therefore cardiac output

Ejection fraction

This refers to the percentage of the end diastolic LV blood volume that is ejected out of the LV during systole. The normal ejection fraction is above 50%. It is a widely used

measure of LV contractility. Simplicity and familiarity are advantages of the EF as a measure of LV systolic function.
For a certain degree of contractility (the intrinsic contractile strength of the myocardium or the amount of work that the heart can perform at a given load), the stroke volume (SV) of the ventricle is determined by the preload (the end diastolic ventricular volume, pressure or stretch) and afterload (the force opposing ejection).
The ideal indicator of myocardial contractility should not be affected by preload or afterload.
Ejection fraction (an indicator of contractility) is less dependent of loading conditions as compared to SV. However, the EF is afterload dependent and is depressed in situations with a high afterload. EF is measured in the ICU in three ways.

M-mode LV dimensional method:

First obtain a parasternal long axis view and place a M-mode cursor is placed through the septal and posterior LV walls just beyond the tip of the mitral leaflets.
In the resultant M-mode image take measurements of the RV internal dimension, interventricular septum thickness, LV internal dimension and LV posterior wall thickness at end-diastole (timed on ECG or point of largest LV internal dimension) and at end-systole (ECG timed or point of smallest LV internal dimension).

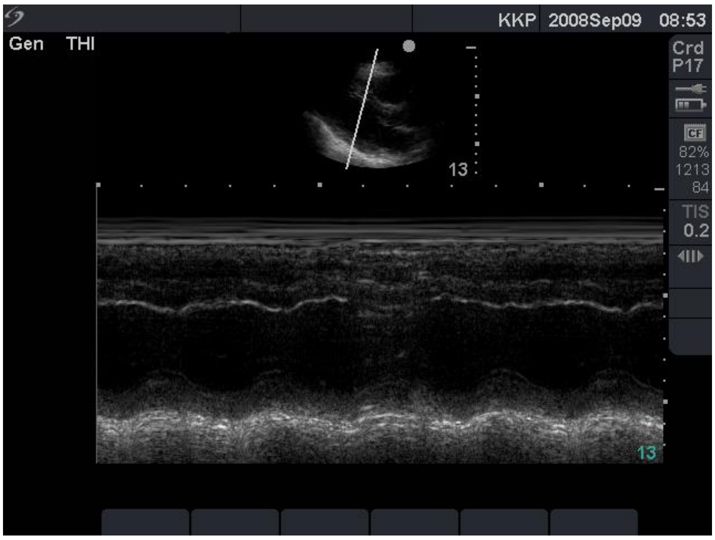


Fig.1 M-mode of the LV in PLAX view

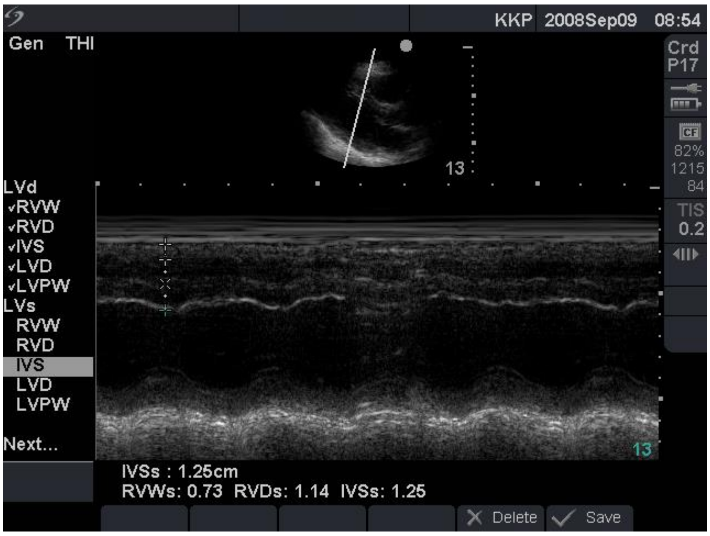


Fig.2 Systolic measurements with a caliper in progress

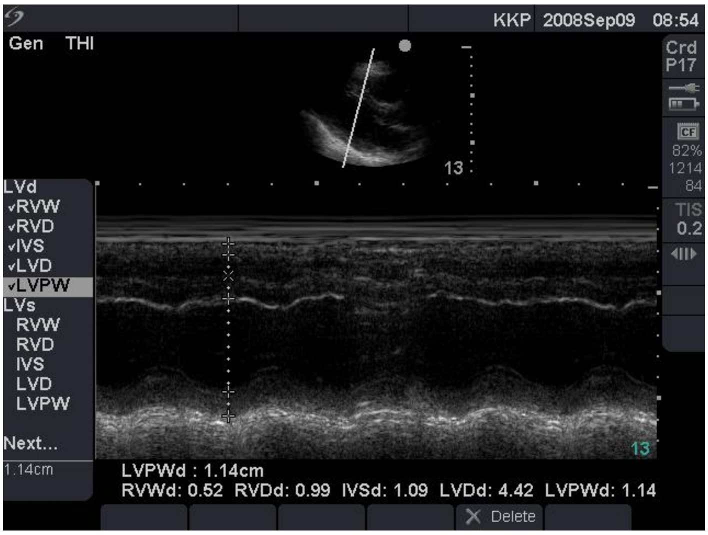


Fig.3 Diastolic measurements done with the calipers

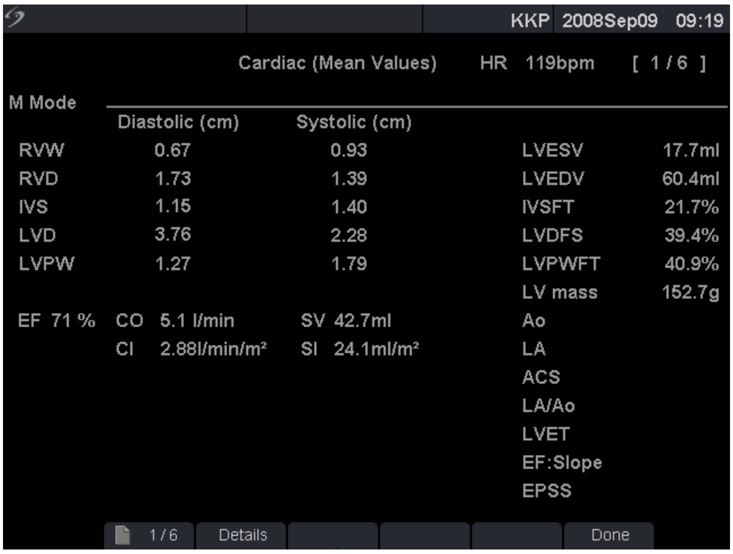


Fig.4 Report of EF and FS generated

With this information, most machines will be able to generate two numbers, the fractional shortening and the ejection fraction.
Fractional shortening is (LVEDd-LVESd) / LVEDd expressed as a percentage. The normal value is 30% to 45%.
Ejection fraction is calculated from derived volumes, which are computed based on the "cubed" or "Teichholtz" equations. The geometric assumptions made with the cubed method limits its usefulness in the abnormal ventricle. In dilated and spherical ventricles, the ratio of long to short axis in the ventricle increases and LV volumes will be overestimated. Using a derived formula by Teichholz instead of the cubed equation compensates for ventricles of abnormal size but only in the absence of asynergy (no RWMA's):
The normal ejection fraction is 50% to 75%.

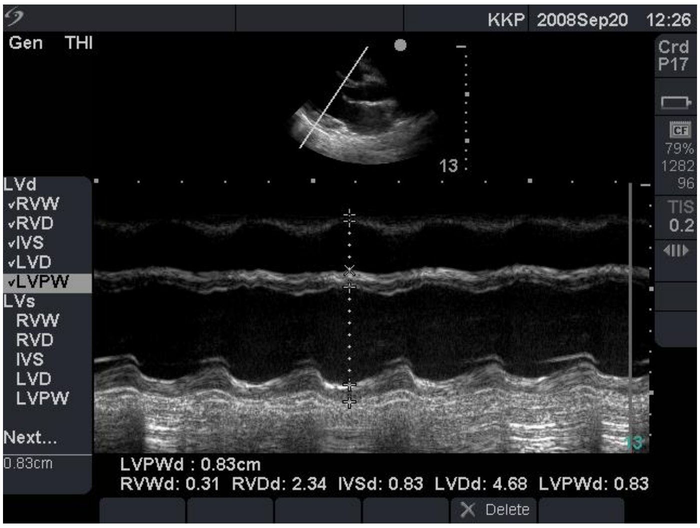


Fig.5 M-mode of LV showing moderate LV dysfunction

While the M-mode method of calculation of EF is easy to learn and perform, it has some drawbacks. The M-mode assessment provides information about contractility along a single line. In a patient with coronary artery disease and regional wall motion abnormalities, the severity of the dysfunction may be underestimated if only a normal region is interrogated or overestimated if the M-mode beam transits through the wall motion abnormality exclusively.
Another disadvantage of the M-mode assessment is that it does not reflect the true minor axis dimension. This is particularly common in elderly patients and in some patients with

emphysema, in whom there is an angulation of the interventricular septum. In such cases, the M-mode beam traverses the ventricle in a tangential manner and often overestimates the true internal dimension

2-D method of Simpson

In this method, acquire A4C or A2C views, making sure that the endocardial borders are visualized well. Freeze the image and scroll backward and forward to identify a frame at end diastole. This can be timed using the appearance of the ventricle - identifying a frame where the ventricle appears to have the largest volume; or with the ECG trace, where the peak of the R wave corresponds to end-diastole.
Open the "calculations" menu and select "LV volumes" and "A4C diastolic" or "A2C diastolic", whichever is appropriate. Place the cursor on the endocardial border where the anterior mitral leaflet meets the interventricular septum and trace the entire endocardial border of the left ventricle. You do not have to trace around the papillary muscles. Once this is done, the LV volume in diastole will be calculated.

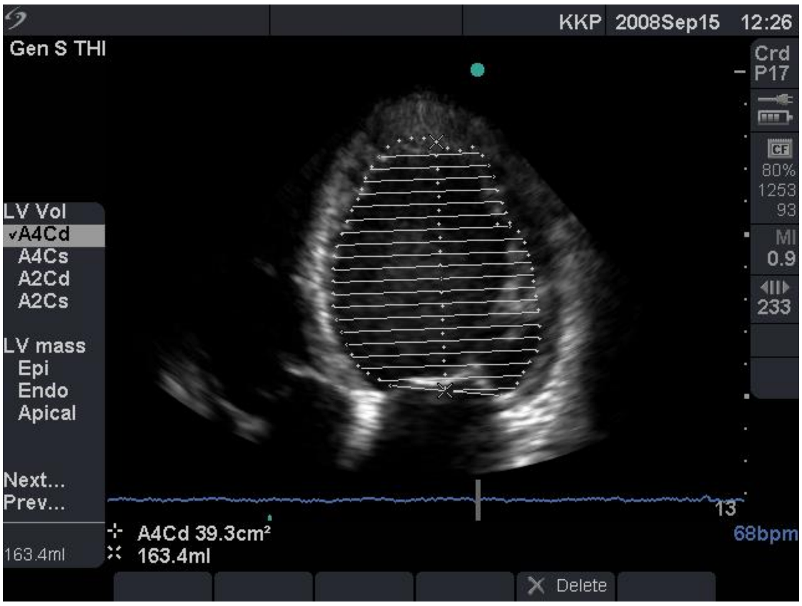


Fig.6 Calculation of LV volume in end-diastole

The frozen image is then scrolled forward or backward to identify a frame at end-systole. Again this can be done by identifying a frame where the ventricle appears to have the smallest volume, or correlating with the ECG trace, where the peak of the T wave corresponds to end-systole. Select "systolic LV volume" on the calculations menu and trace the outline of the endocardial border of the LV. Once this is done, the LV volume in systole will be calculated.

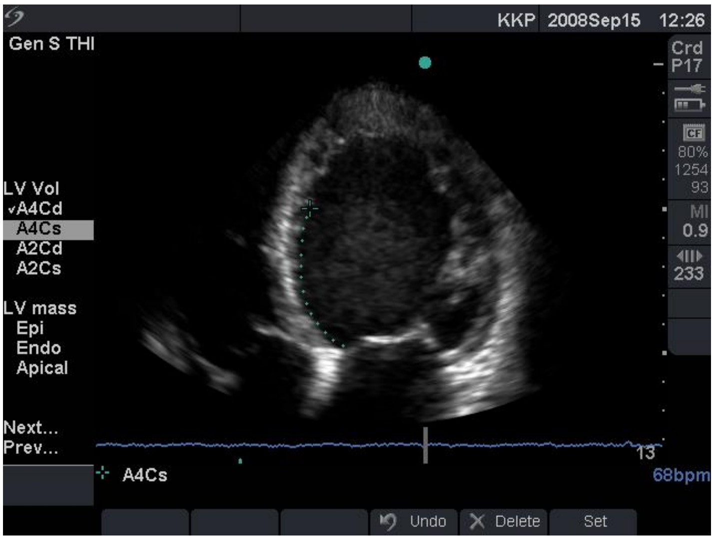


Fig.7 Tracing endocardial border in end-systole

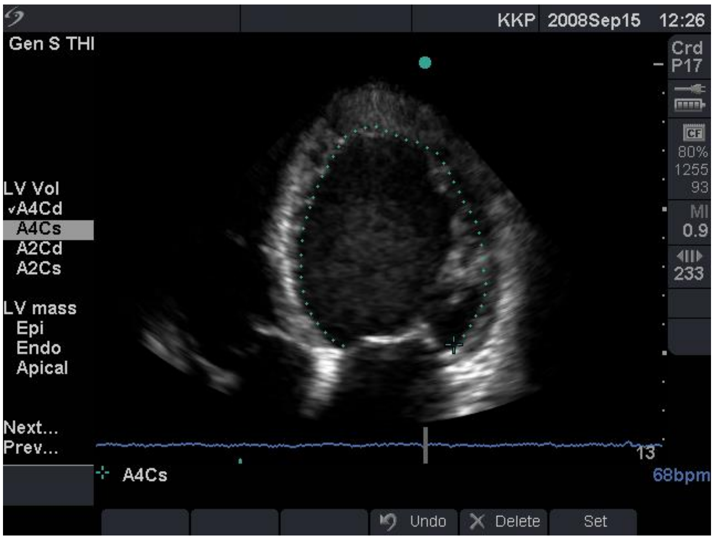


Fig.8 Tracing of endocardium in end-systole completed

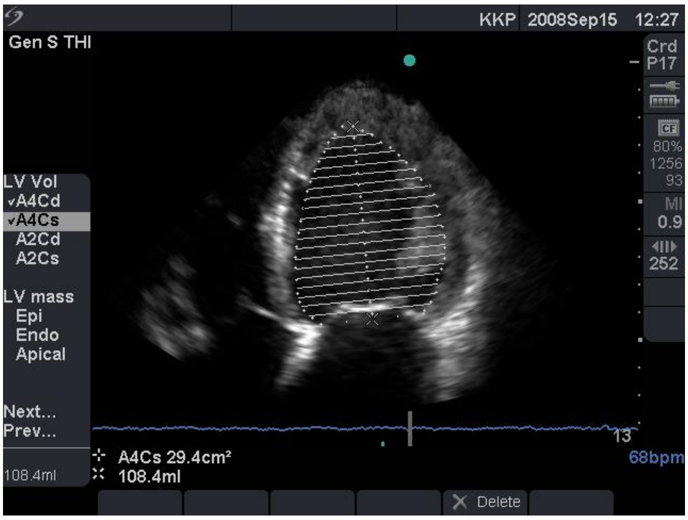


Fig.9 Calculation of volume in end-systole

The machine will then calculate the ejection fraction by using the formula:

Ejection fraction = LVEDV – LVESV/LVEDV

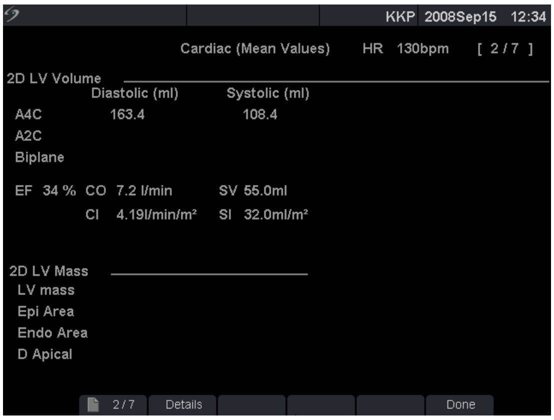


Fig.10 Report of ejection fraction generated

This method is more accurate if this procedure is done in both A4C and A2C views, but this is also more time consuming. Although this is a good method of estimating LV function, it suffers from a few drawbacks.

1.It is sometimes difficult to place the probe at the exact apex to get a full view of the LV cavity. This leads to foreshortening of the LV cavity and underestimation of LV volumes.
2.Because they are parallel to the ultrasound beam, some parts of the endocardial border are not well delineated, causing uncertainty in deciding where to trace the outline of the LV cavity. This results in inter and intra-observer variability of LV Volumes and EF.
3.Another cause of such variability is the choice of frame at end diastole and systole.
4.The LV volumes are calculated using some assumptions made about the shape of the LV cavity, which are not always valid, particularly in a heart with regional LV dysfunction.

However, this remains one of the most widely used methods to calculate LVEF.

Doppler assessment of cardiac output

Although the above techniques are useful to assess the contractility of the myocardium, what is really of interest to the intensivist is the net result of myocardial stretch and contractility....the stroke volume and cardiac output.
Although cardiac output can be calculated using doppler at any of the valve orifices of the heart, the mitral or tricuspid annuli, the RVOT or the LVOT, the measurement is done most commonly at the LVOT.

First measure the LVOT diameter on a Parasternal Long Axis view. This is done by zooming into the LVOT on the PLAX view using the zoom tool and freezing the image. The images are scrolled backward and forward to capture a frame in which the aortic valve leaflets are wide open. The LVOT diameter is measured adjacent to the points of attachment of the leaflets. The machine will then calculate the cross sectional area (CSA) of the LVOT.

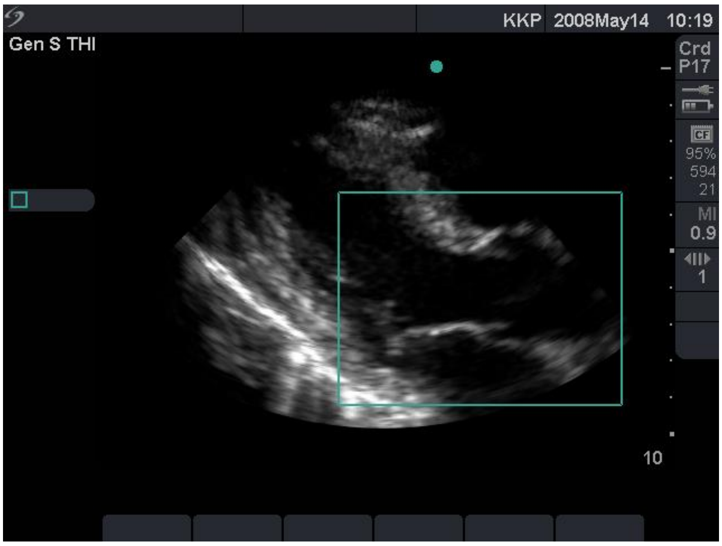


Fig.14 Zooming in on the LVOT in the PLAX view

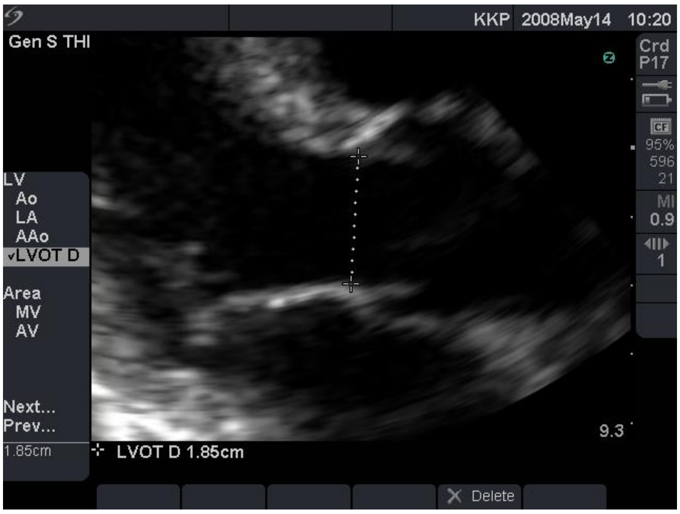


Fig.15 Measuring the LVOT diameter at attachments of the aortic leaflets

Next, obtain an apical 5-chamber view of the heart. As mentioned earlier, the A5C view is obtained from the A4C by slight anterior angulation of the transducer towards the chest wall. The 5th chamber added is the LVOT.
Place the Pulsed Wave Doppler cursor in the LVOT as close to the aortic valve as possible without including it in the sample volume. Acquire the PWD trace. The trace may be considered satisfactory if the closing click of the aortic valve is visualized. However, if the opening click is distinctly seen before the ejection waveform, it means that the sample volume is too close to the aortic valve and needs to be moved a little away from the valve before another tracing is obtained.

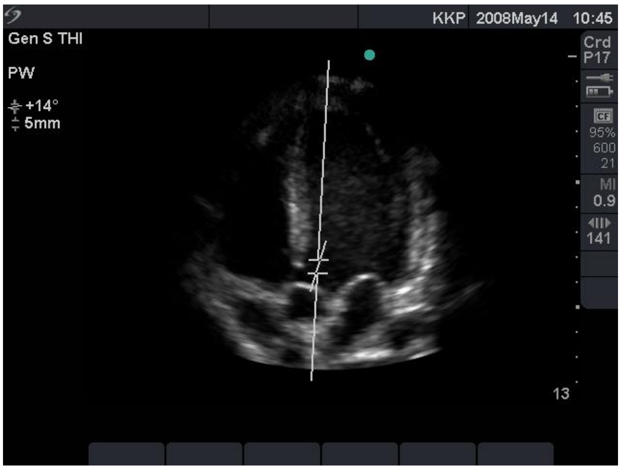


Fig16. Placement of the PWD cursor in the LVOT in A4C view

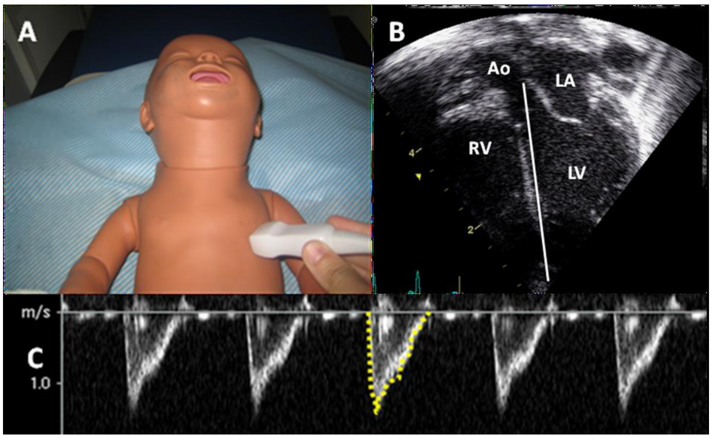


Fig.17 Tracing the PWD waveform obtained in the LVOT

Then choose LVOT VTI from the "calculation" menu and manually trace the PWD waveform. Some machines may be able to do this automatically. The machine will calculate the area under the curve and represent it as a Velocity Time Integral (VTI) in cm/s. Repeat the VTI measurement thrice to reduce sampling bias.
The stroke volume at the LVOT is then obtained by multiplying the LVOT VTI with the LVOT CSA.

LVOT VTI X LVOT CSA = Stroke volume

Stroke volume X Heart rate = Cardiac output

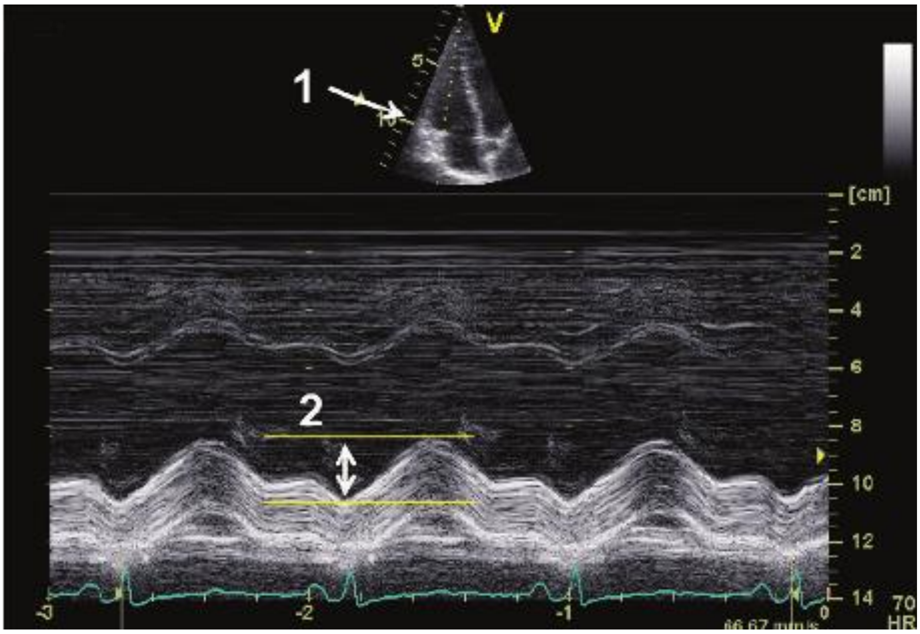
Cardiac output = Cardiac index
Body surface area

This is a simple, non-invasive method of measuring cardiac output in ICU patients. It correlates well with measures of cardiac output obtained by thermodilution (r=0.95) with a tendency to underestimate it by about 0.24 l/min.
This measurement can be done repeatedly to see the trend of cardiac output. The LVOT CSA does not need to be calculated for repeat measurements as it does not change.

There are problems however with this technique.
1.Sometimes an adequate A5C view may not be obtainable. In such a case, an Apical 3-chamber view can be tried.
2.The LVOT may not be aligned with the direction of the PWD, leading to underestimation of velocities. In this situation, an apical 3-chamber view may sometimes offer better alignment. The other workaround is to use an angle correction factor. Although this is generally not advocated, it may be acceptable if the angle is kept to less than 20 degrees.
3. 4.In patients who are taking deep breaths, the entire cardia may move with respiration making it very difficult to ensure that the PWD sample volume stays at the same place in the LVOT through the respiratory cycle. This can lead to variations in the VTI with respiration, which is not due to hypovolemia.

Right Ventricular systolic Function -TAPSE

Tricuspid annular plane systolic excursion (TAPSE) in a normal individual. In the four chamber view a straight line (M mode) is drawn through the lateral tricuspid valve annulus (arrow 1). The level of excursion of the tricuspid valvar plane during systole (TAPSE, in mm) corresponds with RV ejection fraction

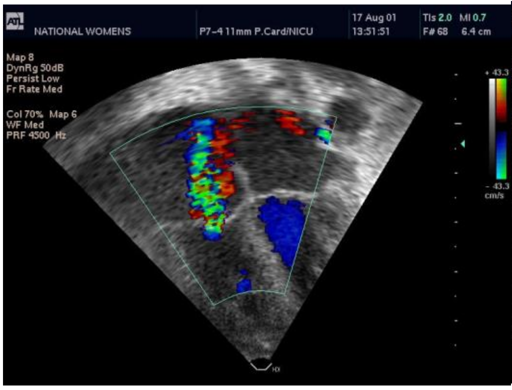


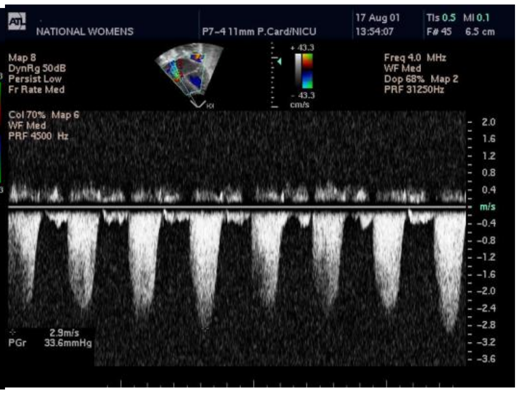
Tricuspid Regurgitation

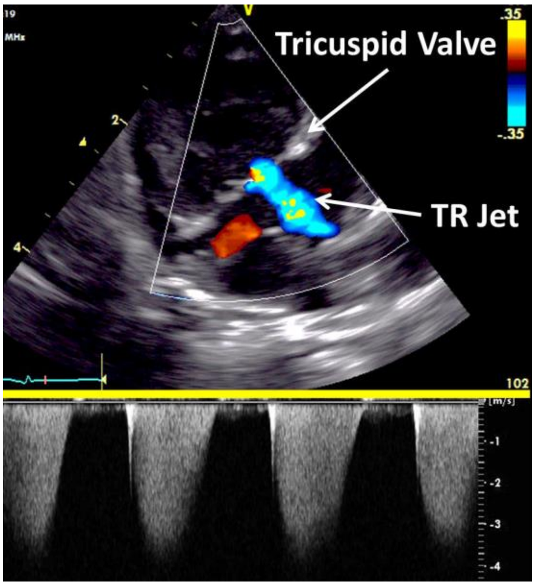
This is the most accurate way of determining PAP.

The jet of blood leaking through the tricuspid valve is interrogated with Doppler. The peak velocity of the tricuspid regurgitation (TR) jet is a direct indicator of the right ventricular pressure (and therefore PAP).

Using the Bernoulli equation ($p = 4v^2$, where p is the pressure drop (mmHg) and v is the velocity of blood flow (m/sec)), the pressure in the RV can be calculated by: RV pressure = RA pressure + (4 x (TR jet velocity)^2).

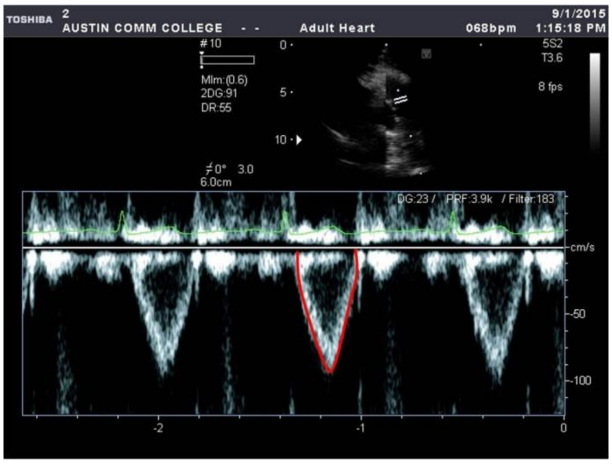






RVOT VTI

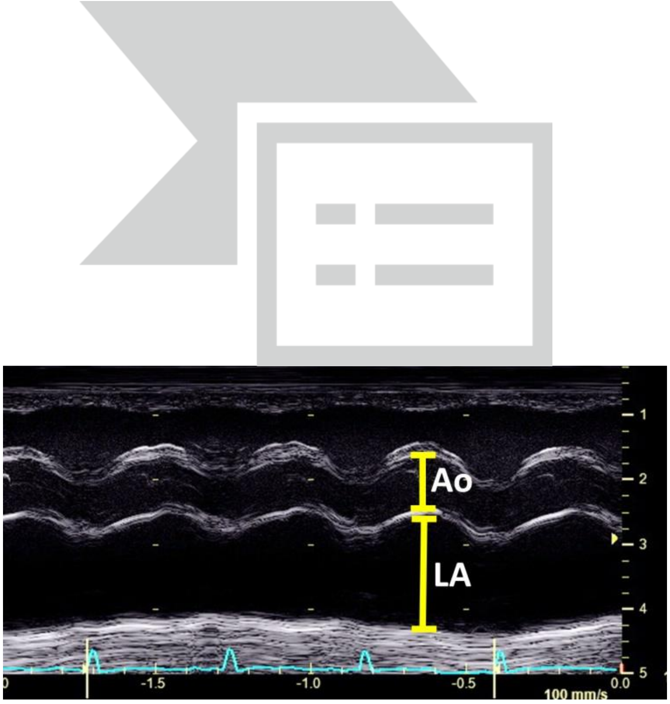
Obtain a pulsed Doppler spectrum of the RVOT from the PSAX view at the base. Place the sample volume just proximal to the pulmonic valve cusps. The spectrum should demonstrate a bright modal velocity and open window. Trace the modal velocity.



Left Atrial to Aortic root ratio

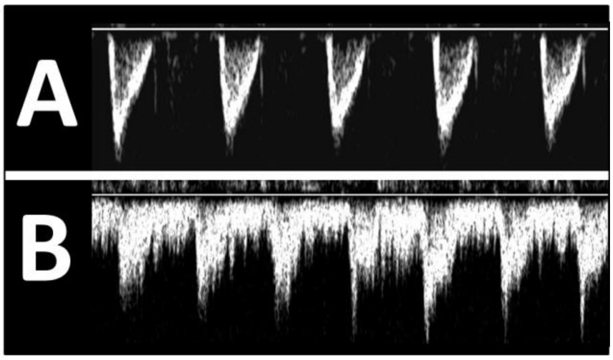
The increase in effective pulmonary blood flow may be estimated by the left atrial to aortic ratio. The LA:Ao uses the relatively fixed diameter of the aorta to assess the degree of left atrial volume loading. This ratio correlates significantly with increased pulmonary flow attributable to excessive transductal flow; optimal threshold ratio > 1.5 has been is associated with a significant PDA.

The cursor is placed at the plain of the aortic valve hinges to include the maximal diameter of the LA. LA:Ao can be measured using this view to obtain an M-mode tracing (yellow line). The cursor should be perpendicular to the aortic wall at the level of the aortic valve.



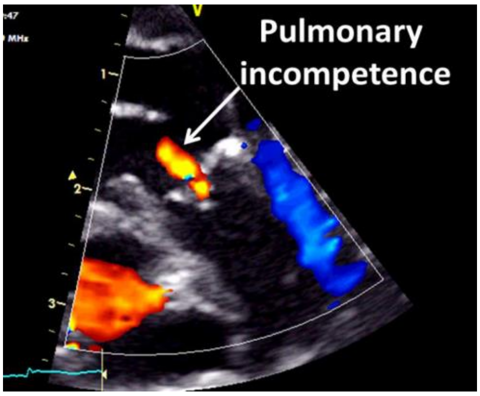
Left Pulmonary Artery

The presence of diastolic blood flow in the left pulmonary artery is also a useful indicator of ductal significance; specifically, a high end diastolic velocity is representative a large left to right shunt and increased pulmonary perfusion. The peak systolic velocity of LPA flow in addition to the end diastolic velocity should be measured. Color Doppler should be used to identify flow in the left pulmonary artery. PWD should be used to with the gate placed just beyond the level of bifurcation.

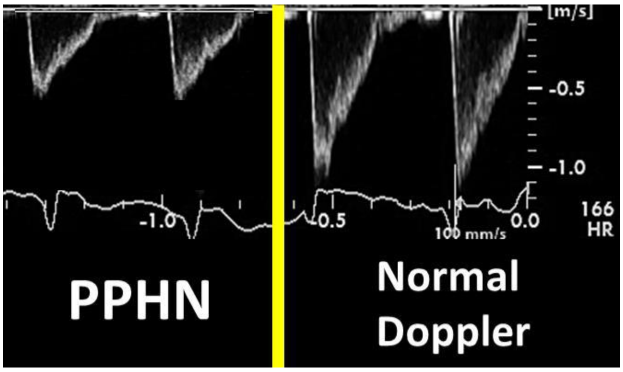


Pulmonary Artery Flow (A) Normal flow in the left pulmonary artery. In the absence of a significant duct there is usually no flow in the diastolic phase. (B) Turbulent flow with a significant end diastolic velocity, a sign of a large PDA.

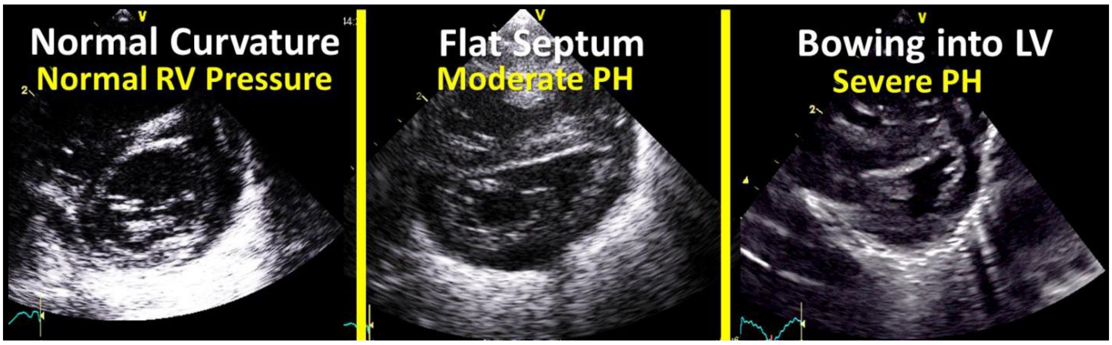
Parasternal long axis RV outflow view- Pulmonary incompetence:



Low pulmonary blood flow:

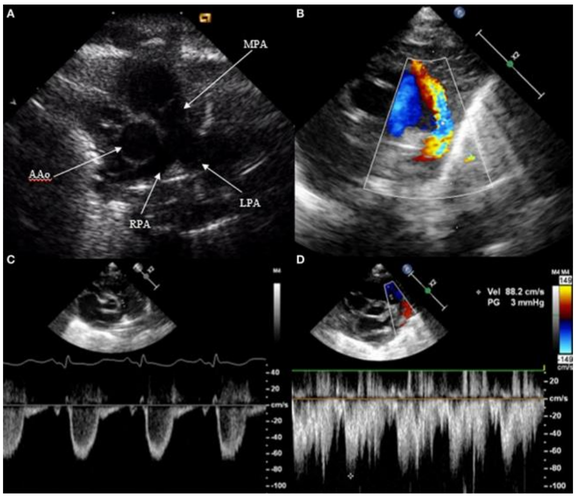


Septal morphology short axis view



Ductal View

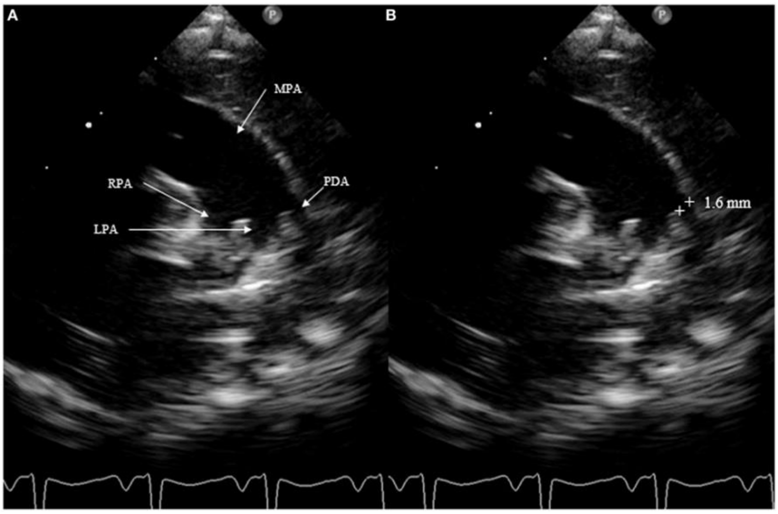
The ductus is a dynamic vessel of variable architecture, with an unpredictable response to treatment. It is not possible to directly quantify the magnitude of transductal flow, however the impact on the pulmonary and systemic circulations are measurable. Two-dimensional echocardiography and Doppler methods can be used to perform a comprehensive evaluation of the significance of the ductal shunt.



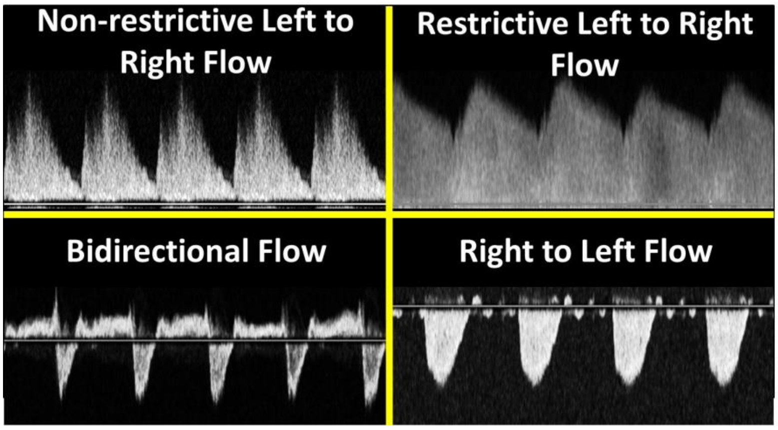
Ductal Size

The most commonly used view for measuring the size of the DA is the high left parasternal short axis window, also called “ductal view.” Concentrating on the main pulmonary artery, the origin of the right pulmonary artery, which is not always visible, and of the left pulmonary artery can be visualized; the DA is positioned to the left of it. The DA should be measured at its narrowest point, before its entry into the main pulmonary artery Measurement of the ductal size is not very accurate. It is not recommended to use the color Doppler, which can exaggerate the size. Measurements must always be performed using a consistent technique. A PDA is considered small at <1.5 mm, moderate when it ranges between 1.5 and 3 mm, and large if the dimension exceeds 3 mm. SAX should not be chosen to measure ductal size because it is not always possible to differentiate the left pulmonary artery from the DA.

The PDA can also be viewed from a suprasternal "ductal view" – from the suprasternal view of the aortic arch angulate laterally until the branch pulmonary arteries and the PDA are visible:



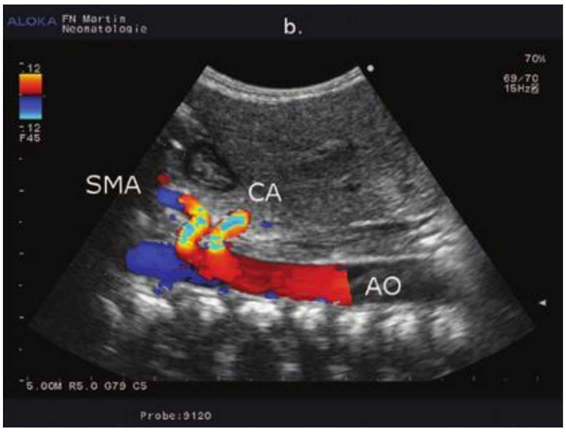
Measurement of patent ductus arteriosus (PDA) size on suprasternal view. MPA, main pulmonary artery; RPA, right pulmonary artery; LPA, left pulmonary artery.

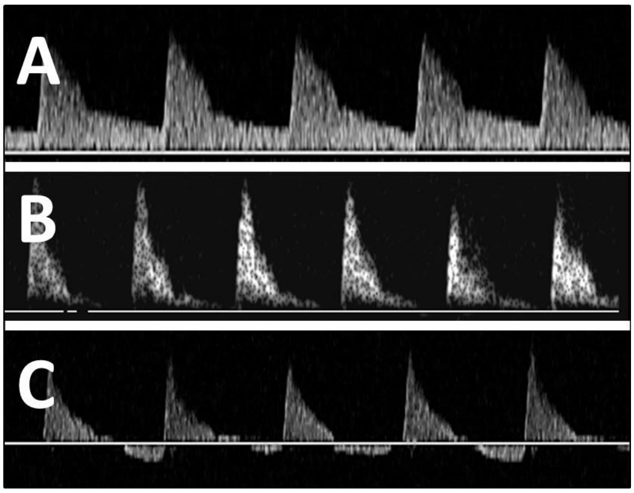


Abdominal Aorta Sagittal View

The effect of ductal steal on systemic perfusion may be quantified using echocardiography. The use of pulse-wave Doppler to assess flow through the celiac artery can indicate the impact of a PDA on gut perfusion. Celiac artery blood flow falls in the presence of a PDA compared to controls despite a rising LVO especially in diastole. The presence of absent or reversed flow during diastole is an indication of moderate or severe ductal steal.

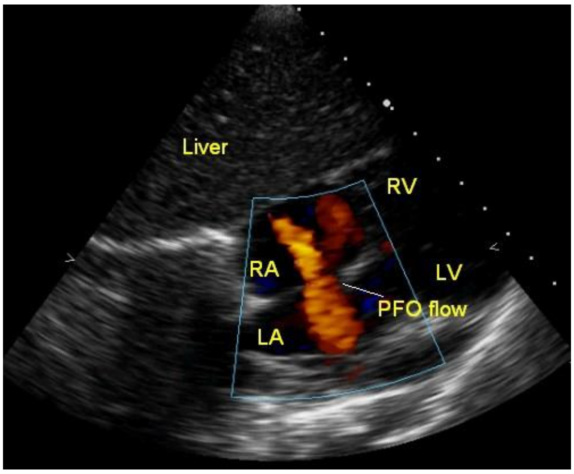
The pulsed wave Doppler obtained can demonstrate the presence of ductal steal by assessing the diastolic flow in the vessel. Panel (A) demonstrates normal flow. Panel (B) demonstrated absent end diastolic flow in moderate PDA steal and Panel (C) demonstrates revered diastolic flow in severe PDA steal.





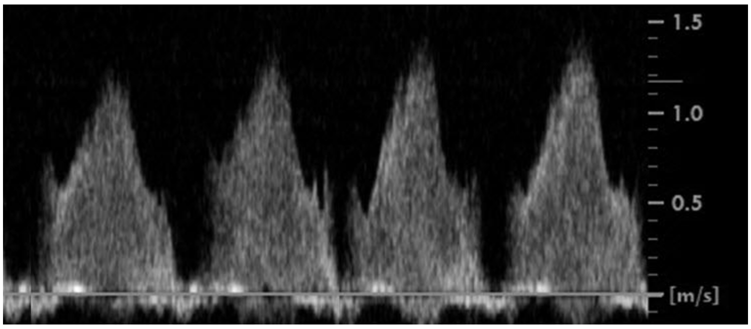
Atrial Subcostal View

Increased pulmonary venous return will lead to left atrial enlargement. In the presence of a PFO, the left to right shunt across the atrial level will increase in the setting of significant PDA due to the increased pulmonary venous return and increased left atrial pressure. The subcostal view is usually left towards the end of the examination as it causes discomfort to the infant. To assess the atria, the probe is positioned below the xiphoid process in an axial fashion with the marker pointing to the left. The beam is then angled towards the anterior chest wall until the atria come into view. Colour Doppler is applied to assess the presence or absence of an intra-atrial shunt. Pulsed wave Doppler should be used to assess the velocity of the shunt. The gate width of the cursor should be reduced to 1-2mm.



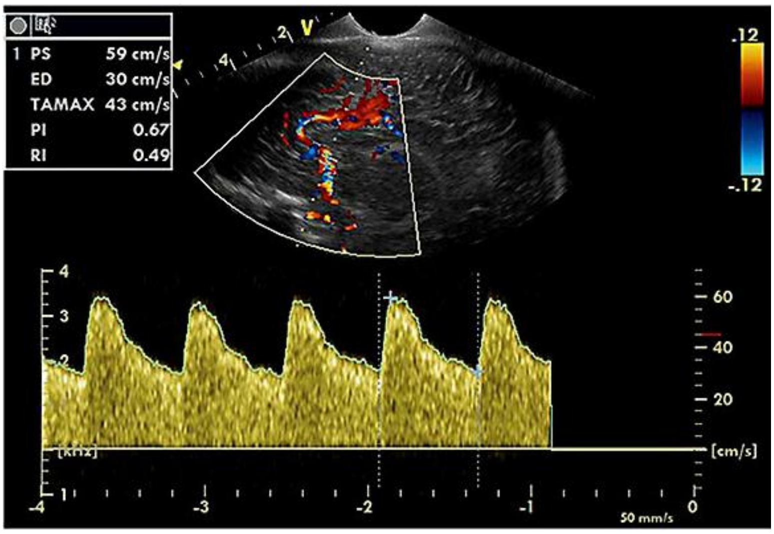
Echocardiogram from subcostal view showing the interatrial septum with a small defect and left to right flow across. Red color encodes flow towards the transducer at the top and hence a flow from left atrium (LA) to right atrium (RA). Whether it has to be called a small atrial septal defect (ASD) or a patent foramen ovale (PFO) is the question.

High velocity left to right flow at atrial level.



Anterior Cerebral artery

Resistive Index - RI from ultrasound Doppler. Image of measurements of the RI from the .anterior cerebral artery on day 4 using an ultrasound scanner with an 8.5-MHz transducer

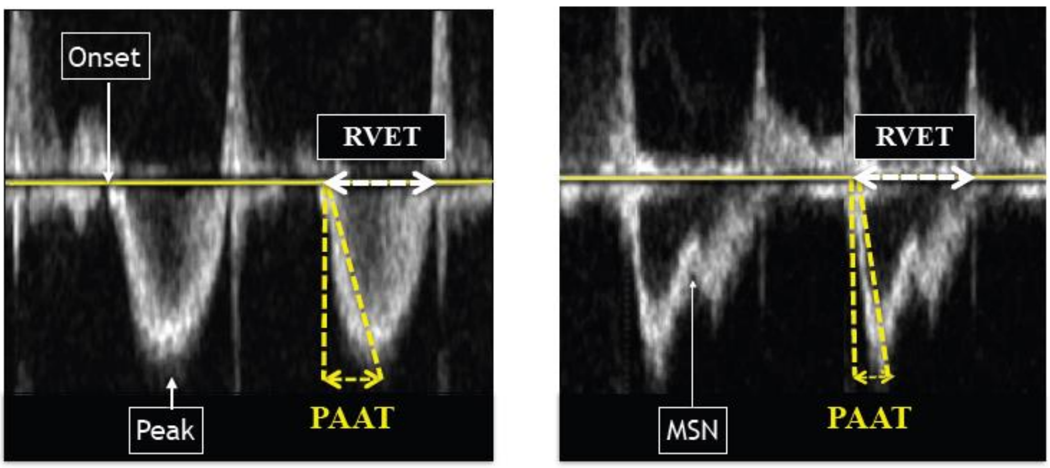


Pulmonary Artery Acceleration Time

Measurement of acceleration (AT) and ejection time (ET) in the main pulmonary artery Doppler waveform.

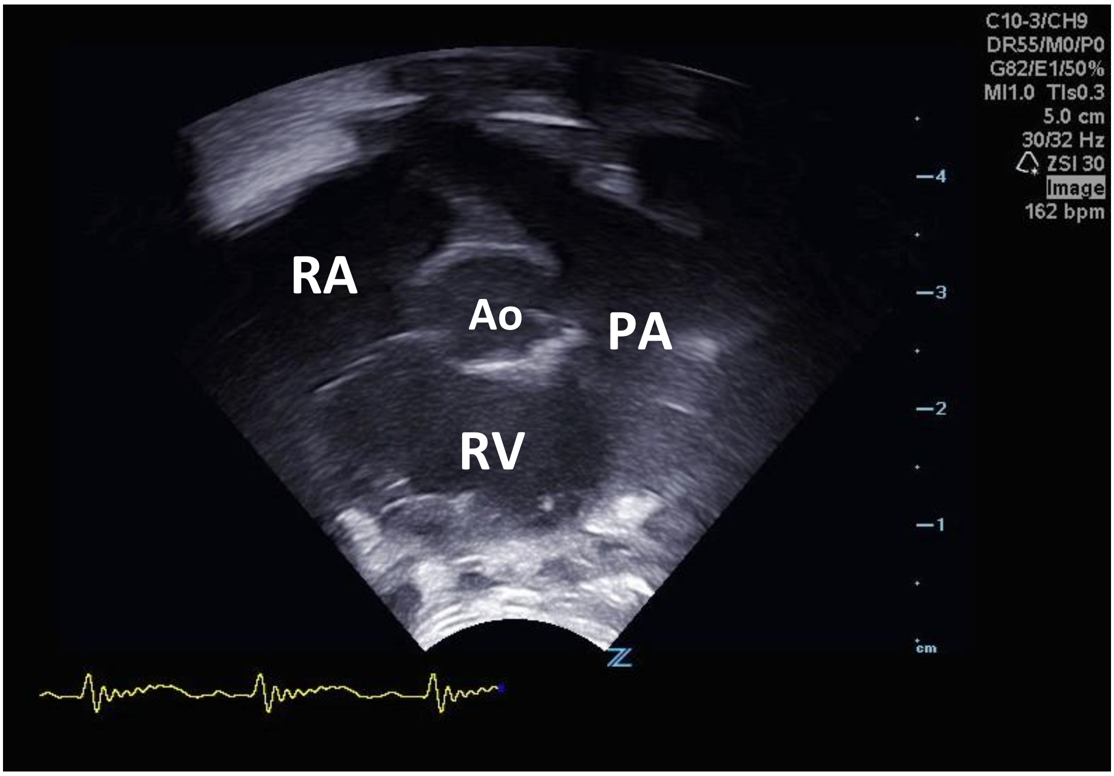
PAAT/PAET =

Pulmonary Artery Acceleration Time / Pulmonary Artery Ejection Time



RV 3 Chamber view

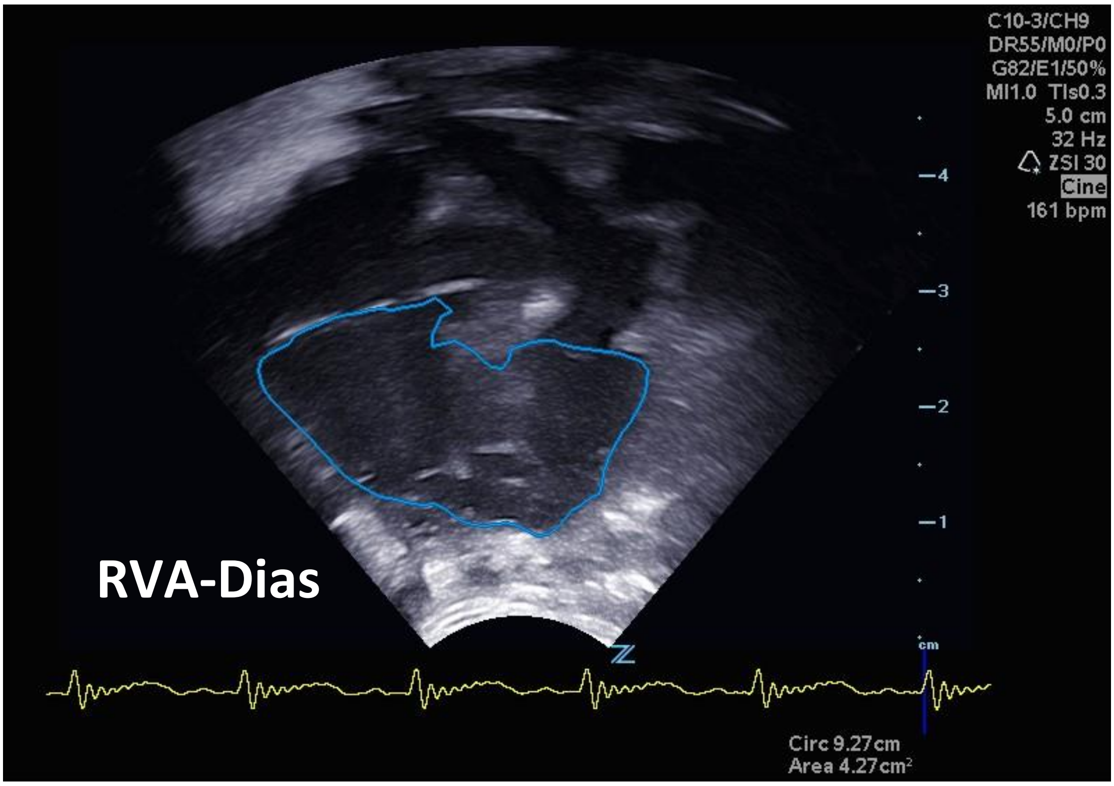
The RV 3 chamber view is a modified parasternal short axis view with the probe placed in an inferior position relative to the para-sternal short axis. This gives a better cross-section of the RV as well as a very well aligned view of the RVOT. As in the basilar cut of the Parasternal short axis, the Aortic, Tricuspid and Pulmonic valves should all be clearly visible in this image as follows:

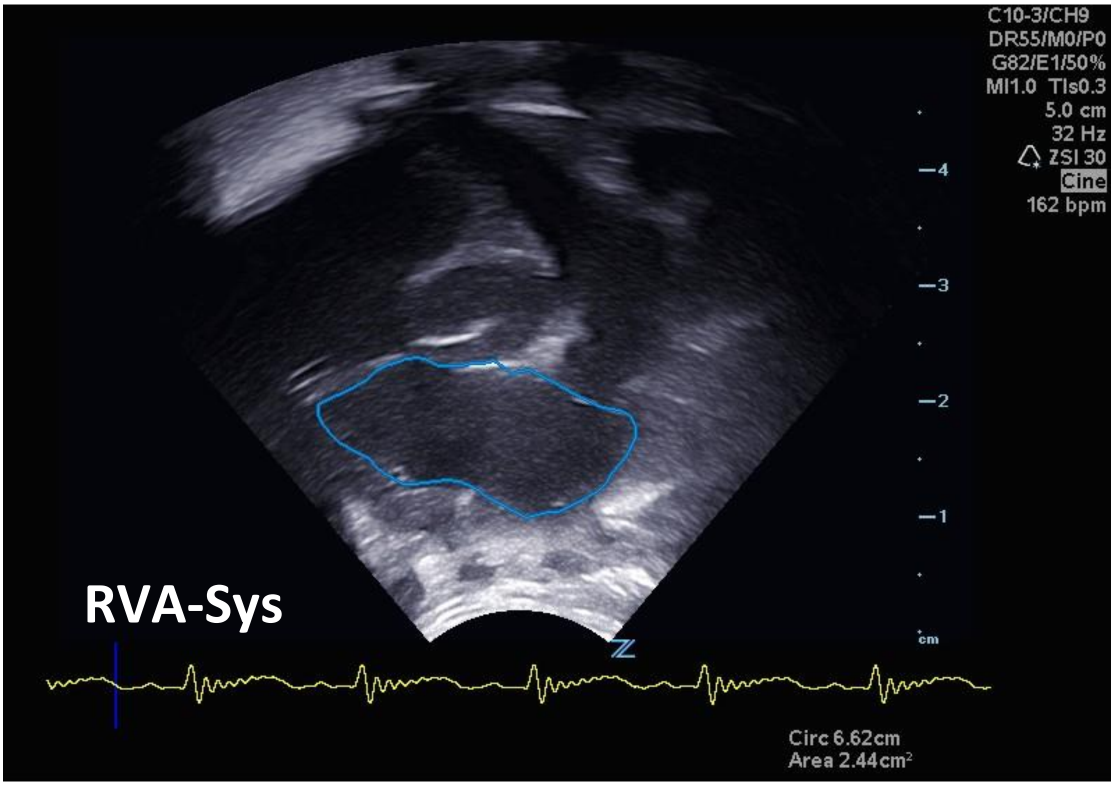


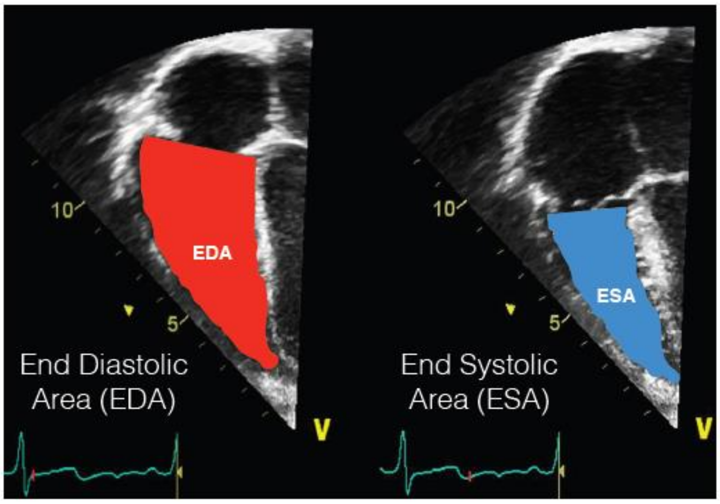
RV Fractional Area Change (RV-FAC)

This measurement is the equivalent to a 2D LV-Ejection Fraction, but contrary to the Biplane method, does not assume a geometric structure to the RV (as the RV does not have a symmetrical type volume like the LV). Hence, RV-FAC only uses a cross-sectional 2D percent change between systole and diastole to assess RV contractility and systolic function.

To measure RV-FAC, trace the inner myocardial border of the RV from the RV-3CV in both systole (RV-Area-S) and diastole (RV-Area-D). When aligned properly, the RV distinctively has a “hump” on the anterior border (most adjacent to the chest and probe) budging into the RV internal area.


C10-3/CH9
DR55/M0/P0
G82/E1/50%
MI1.0 TIs0.3
5.0 cm
32 Hz
ZSI 30
Cine
161 bpm
RVA-Dias
Circ 9.27cm
Area 4.27cm²


C10-3/CH9
DR55/M0/P0
G82/E1/50%
MI1.0 TIs0.3
5.0 cm
32 Hz
ZSI 30
Cine
162 bpm
RVA-Sys
Circ 6.62cm
Area 2.44cm²



RV-FAC = [(RV-Area-S)-(RV-Area-D)]/[RV-Area-S]

Normal values are generally > 30%