# ECHO MASTERCLASS —THE VALVES

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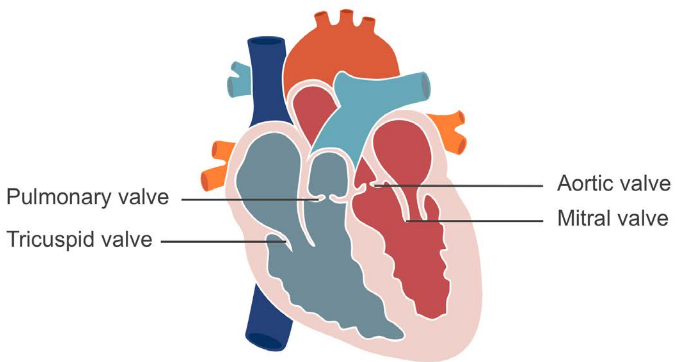
Chapter 1

# SETTING THE SCENE

# Getting an overview of valve disease

Heart valve disease affects about five million adults in the USA who present with some form of clinically relevant disease. Aging is linked to an increased prevalence of heart valve disease, and heart valve abnormalities lead to high morbidity and mortality.

Normal heart valve function can be disrupted in a variety of ways that can be grouped into primary and secondary (or functional) causes. Primary valve disease involves abnormalities of the valve structure, whereas secondary or functional disease describes a situation in which the function of a normal valve is disrupted as a consequence of abnormalities in associated structures.

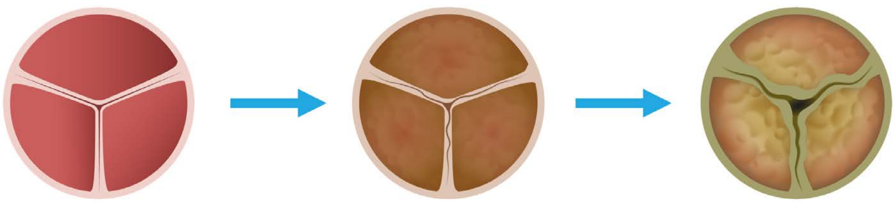



Narrowing (stenosis) and / or leakage (regurgitation) are the potential consequences of valve abnormalities.

Valve disease can occur as a consequence of a congenital abnormality, age-related calcification, inflammation or infection.

With regards to congenital abnormalities, variation in the number of cusps present on the aortic valve is the most common finding when performing echo studies in adult patients.

Calcific valve disease is common and the number of patients will continue to grow as the population ages. There are possible links between this condition and atherosclerotic disease, with similar risk factors and pathophysiological processes. Damage to the surface tissue of the valve can lead to infiltration and inflammation of the valve tissue. Over time, the disrupted tissue becomes calcified, leading to a decrease in the flexibility and movement of the valve leaflets.

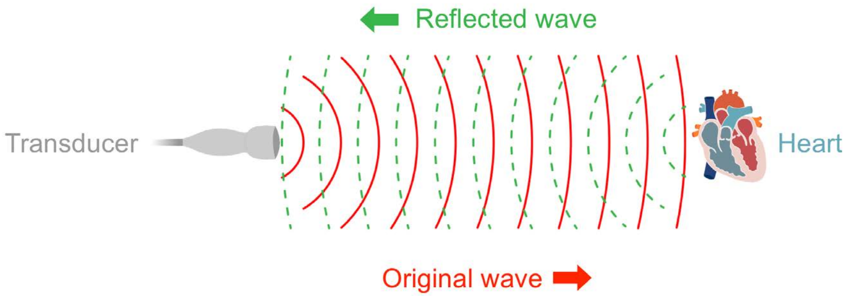


Inflammation of the endocardium, the surface layer of tissue covering the chambers and heart valves, is known as endocarditis. It is usually due to infection. It is rare, but it is a major health condition with significant risks.

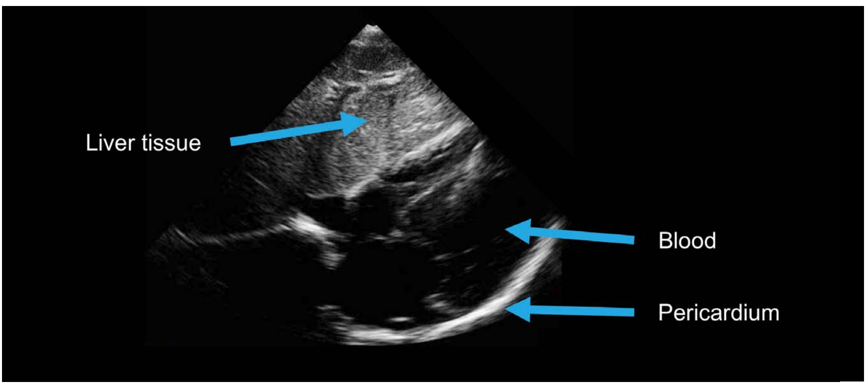
Rheumatic valve disease is less prevalent in Western populations; however, it remains an issue in less developed countries.

# Reviewing the principles of echocardiography

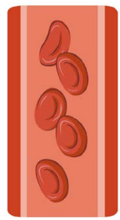
Echocardiography is based on the principle of detecting ultrasound waves generated by a piezoelectric transducer, which are transmitted into the body and reflected back from the structures of the heart.




The amount of reflection depends on the density of the tissue and the speed at which the ultrasound travels through the tissue. Taken together, these give the acoustic impedance of the tissue. Differences in acoustic impedance result in an ability to identify different structures.

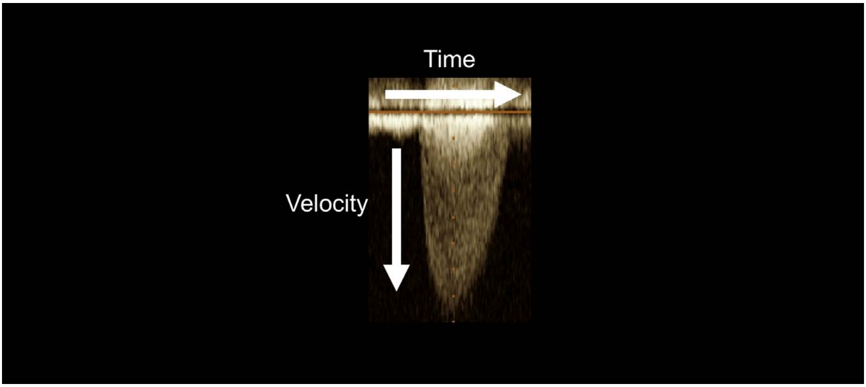


Ultrasound signals reflected by red blood cells moving in the blood is the key to Doppler echocardiography, a type of cardiac ultrasound that is used to assess blood flow within the heart. The principles of Doppler ultrasound can be applied in a variety of ways to provide detailed information about movement of blood through the heart valves. The basic principle of the Doppler technique is usually explained with reference to sound moving towards and away. Think of watching a racing car or high-speed train passing you. Their sound will be relatively high pitched as they approach and lower as they move away from you.

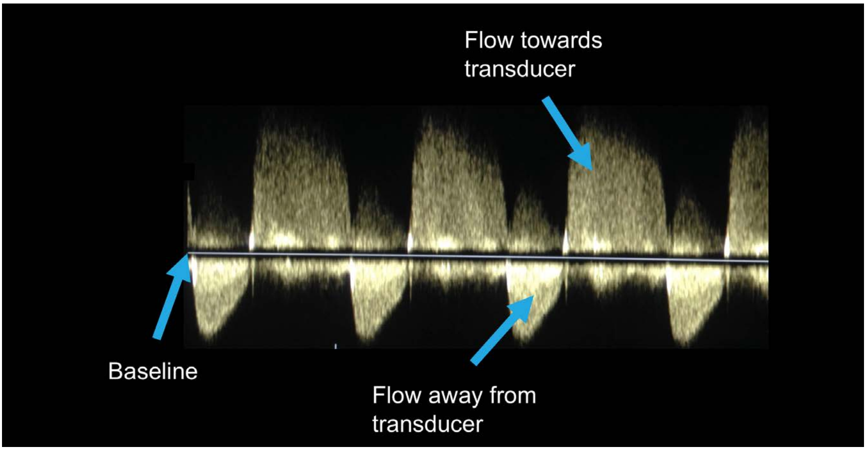


The same occurs in cardiac ultrasound where red blood cells moving towards the transducer will increase sound wave frequency, and those moving away from the transducer will decrease the sound wave frequency. By detecting the difference between these frequencies (the Doppler shift), it is possible to use the Doppler equation to calculate the velocity of the blood flow. The Doppler equation includes a measure of the angle between the ultrasound beam and the direction of blood flow. This means that in order to detect a Doppler shift, and derive a velocity from the Doppler equation, it is important to ensure that the ultrasound beam is parallel to the blood flow.

In Doppler mode, ultrasound machines perform the mathematical calculations required in a process known as spectral analysis. The output is a spectral Doppler, which portrays the velocity on the y-axis and time on the x-axis.



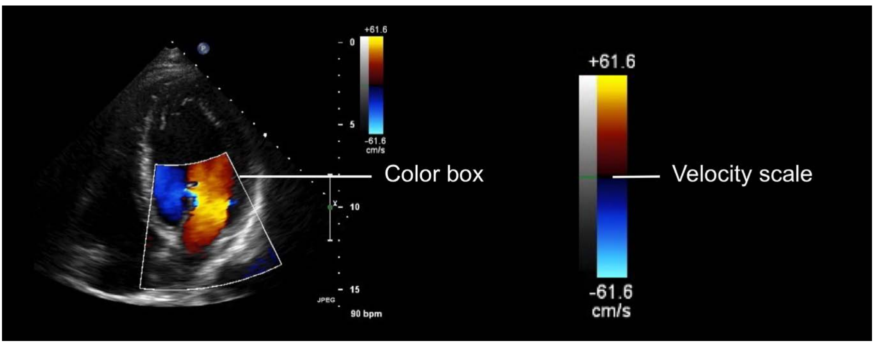

By convention, flow moving towards the transducer is shown by spectral Doppler signals above the baseline and flow moving away from the transducer is shown by signals below the baseline.




Three Doppler based tools are routinely used in the assessment of heart valves: continuous wave Doppler, pulsed wave Doppler, and color flow Doppler. Continuous wave Doppler relies on uninterrupted transmitting and receiving of ultrasound. This technique has both strengths and limitations. It is very useful for detecting high-velocity blood flow, but as signals from across the full length of the ultrasound signal are recorded simultaneously, it is not possible to locate the precise point within the heart at which a given flow is occurring.

On the other hand, pulsed wave Doppler does allow for sampling of blood flow velocity from specific points. In this technique, a pulse of ultrasound is transmitted, then after a fixed amount of time, the transducer samples the returning signals. The time is adjusted to reflect the depth of interest. This is determined by the operator who moves a marker, referred to as the sample volume on the Doppler cursor, to specific locations within the heart.

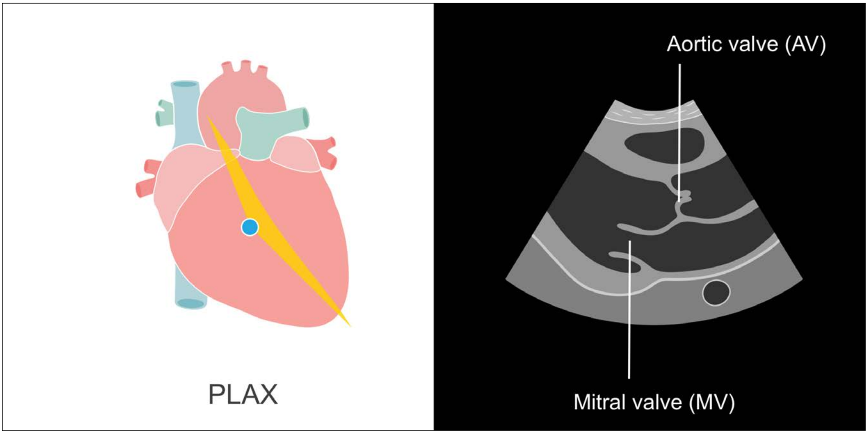
Color flow Doppler imaging is based on the principles of pulsed Doppler echocardiography. In color flow imaging, the single sample volume is replaced by multiple sample volumes incorporated along many scan lines, as defined by a color box placed over the area of interest. Velocities are then calculated for each sample volume and displayed using a color scale. By convention, usually red denotes blood flowing towards the transducer and blue marks blood flowing away from the transducer (BART convention). A velocity scale is shown on the screen when using color flow Doppler that indicates the relationship between the shade of color and the blood velocity.

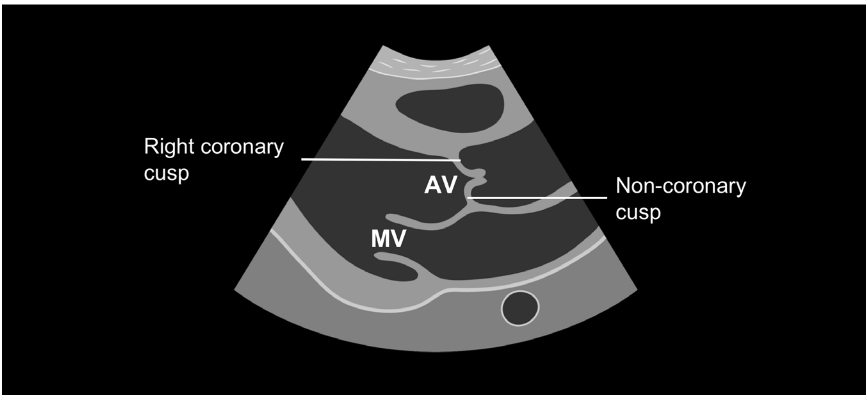


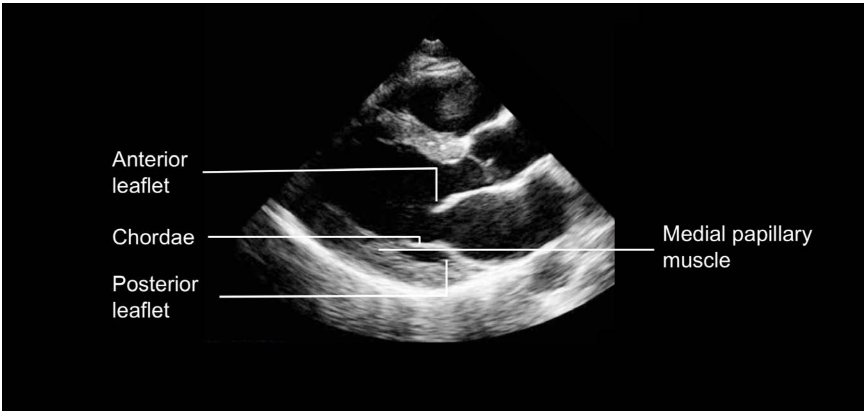
# Covering echocardiography views

The valves can be seen from almost all the standard views of the heart but a full evaluation of the valves will require imaging from a variety of windows.

The standard parasternal long-axis approach usually provides clear views of both the aortic and mitral valves.

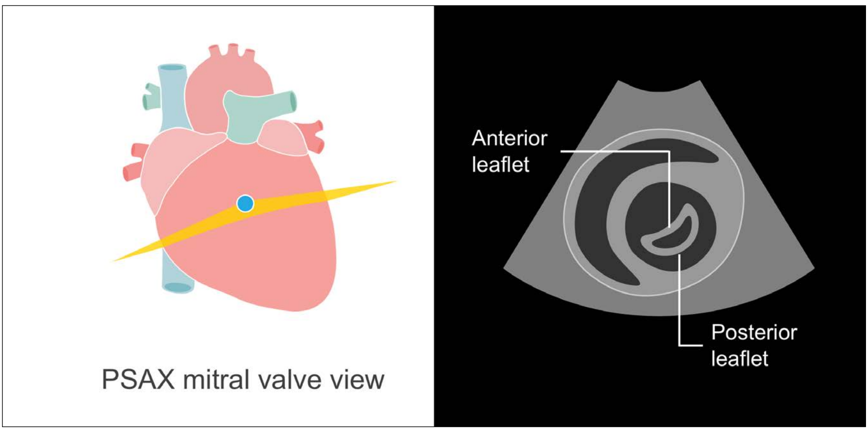


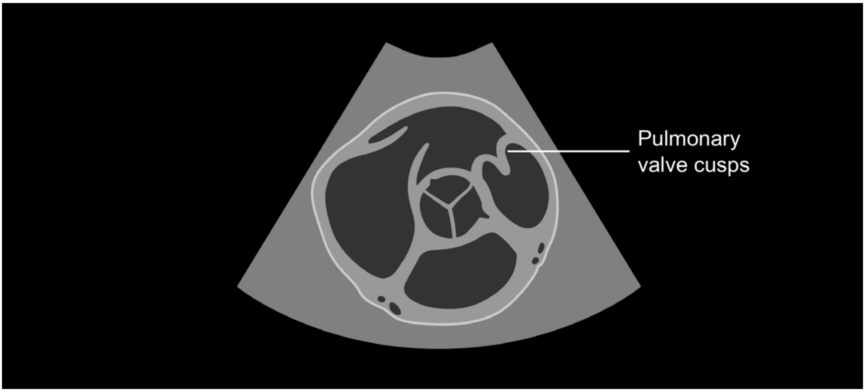



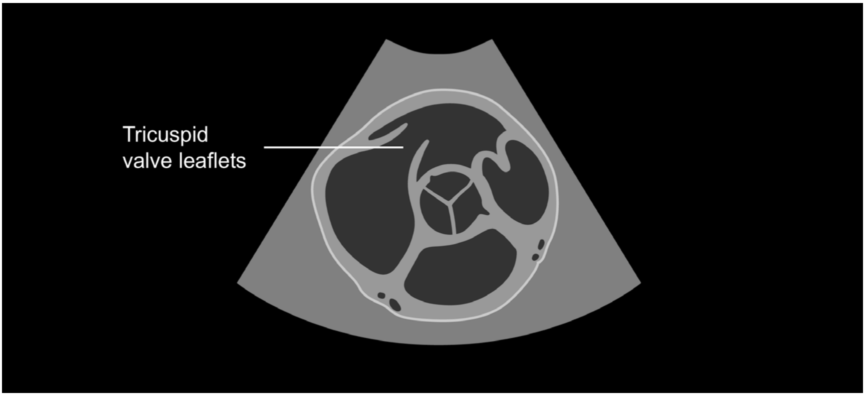


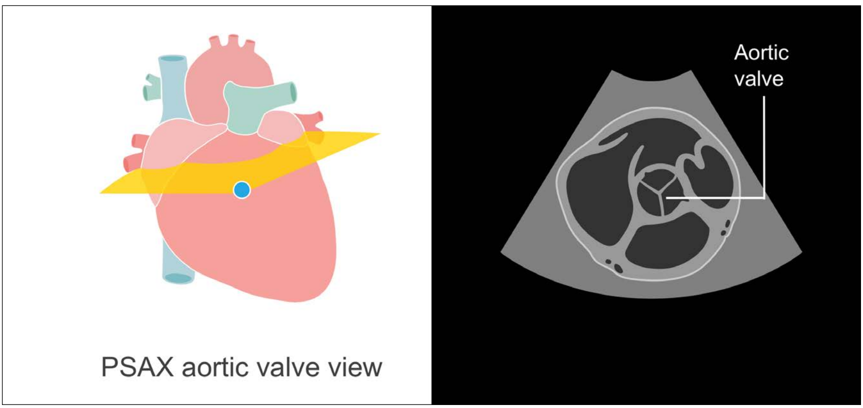

The parasternal ventricular inflow tilt view shows the tricuspid valve, and tilting superiorly will give the right ventricular outflow, where the pulmonary valve can be identified.

The parasternal short-axis is obtained by rotating the probe 90 degrees in a clockwise direction from the long-axis view. This view gives useful structural information, particularly for the aortic valve and mitral valve. The pulmonary and tricuspid valves are also seen.

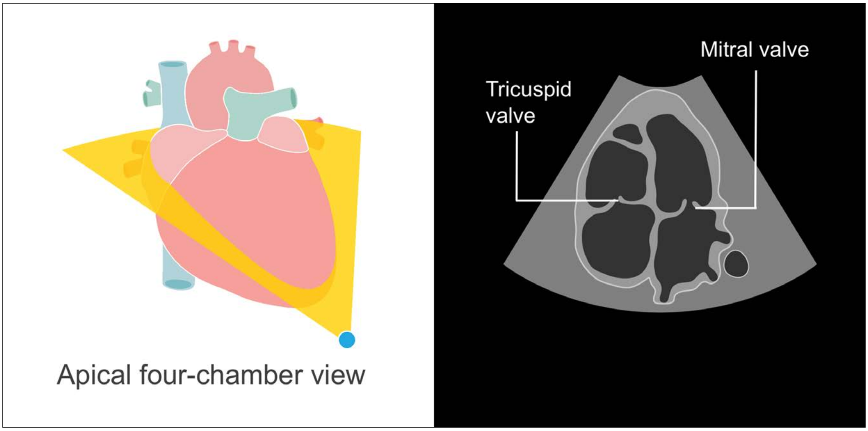


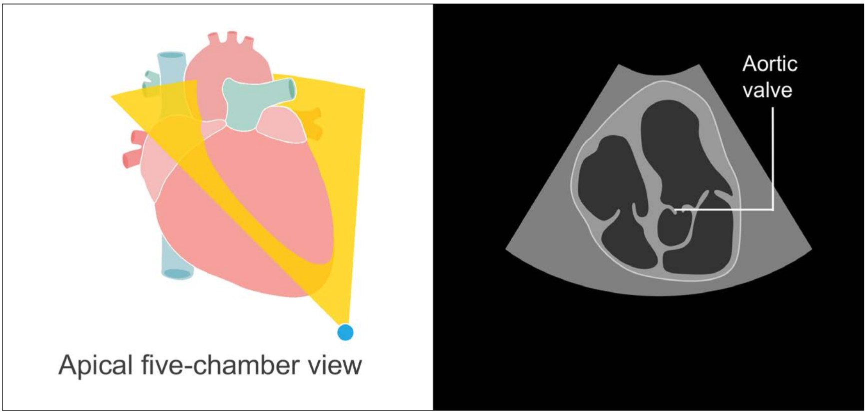

Pulmonary
valve cusps


Tricuspid
valve leaflets

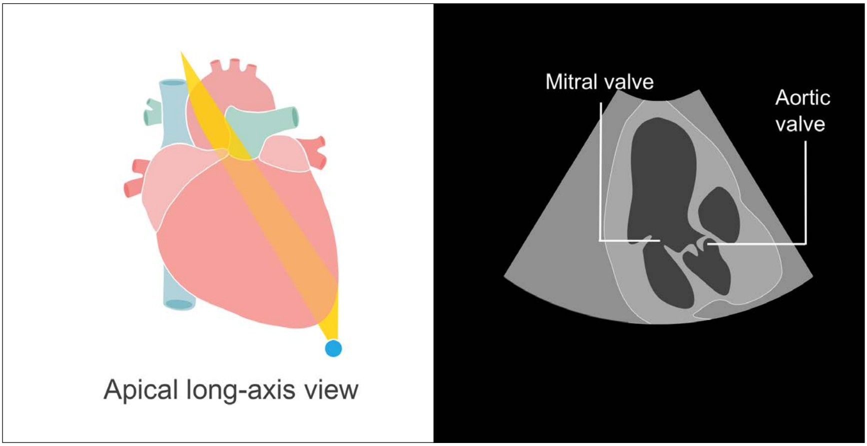

PSAX aortic valve view
Aortic
valve

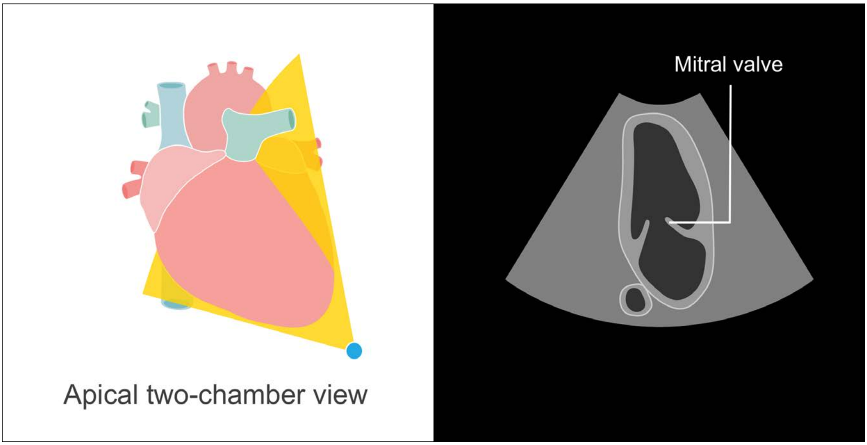
The apical four-chamber view allows us to see the mitral and tricuspid valves and their associated structures. The so-called five-chamber view allows the aortic valve to be seen.



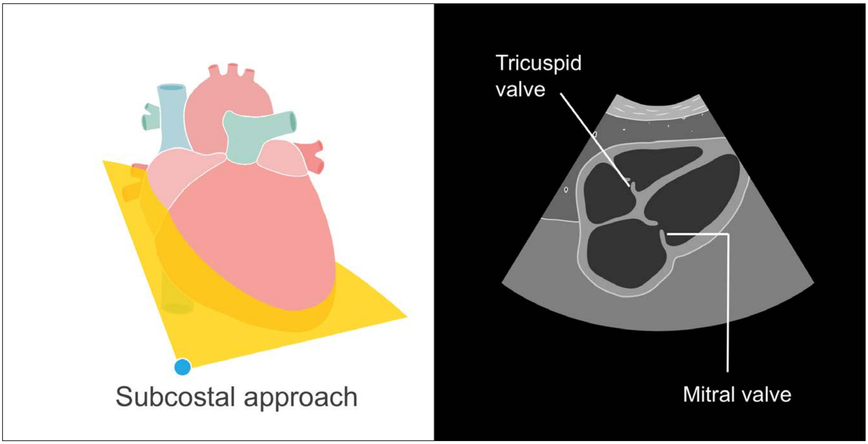



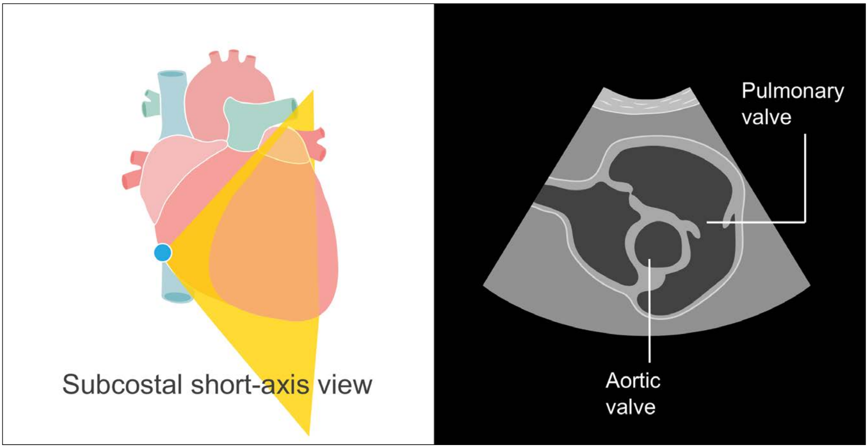
The apical two-chamber view shows the mitral valve, and the apical long-axis view shows the aortic and mitral valves.



From the subcostal window, all valves can be seen.

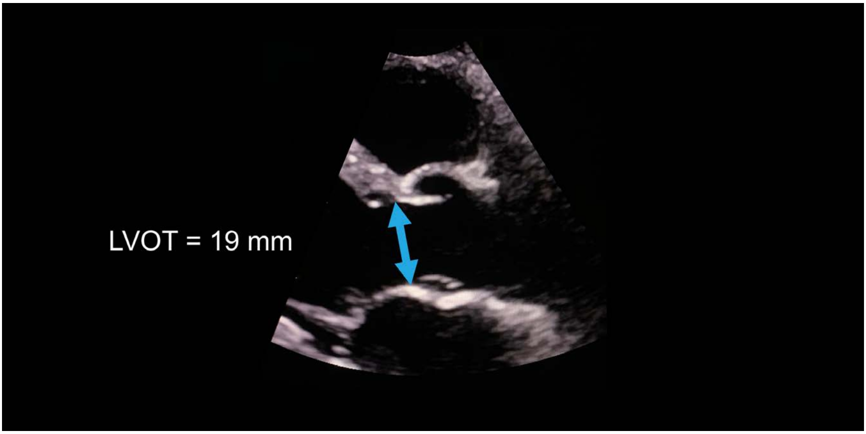


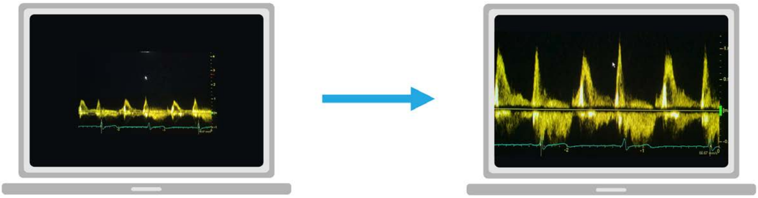
# Making accurate measurements

A comprehensive assessment of heart valve structure and function requires measurements to be made from two-dimensional images of the heart and from the waveforms generated during Doppler investigations. Accurate measurements are very important, particularly when the values are used within calculations to provide quantitative assessment of valve function.

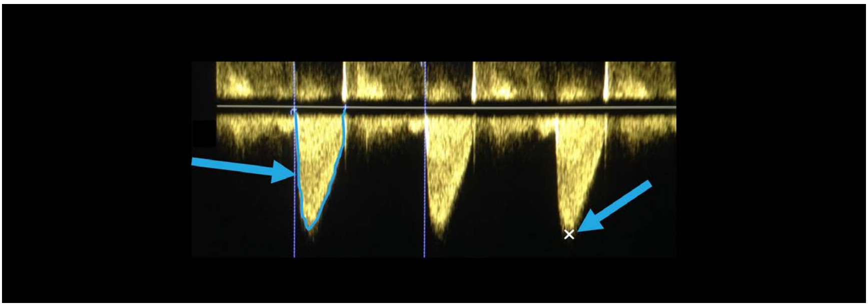
Obtaining clear views, optimizing the image, and using the zoom function are all particularly helpful in improving the accuracy of measurements from two-dimensional imaging.



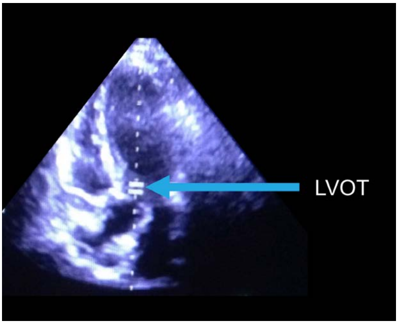

The diameter of the left ventricular outflow tract is a standard measurement that should be routinely obtained. This is performed from a zoomed parasternal long-axis view and is measured using an inner-edge to inner-edge approach at the base of the aortic valve cusps during mid-systole. When making Doppler recordings, it is good practice to adjust the velocity scales to ensure that the waveform fills the display, thereby enabling easier and more accurate measurements to be made.

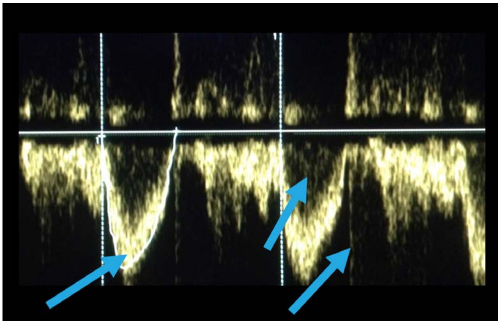


Continuous wave Doppler measurements are made by ensuring that the Doppler cursor is aligned with the blood flow to obtain the highest velocity signal. Measuring peak velocity is achieved by placing the cursor at the peak of the intense velocity signal. Mean velocity values are acquired by tracing around the spectral velocity curve.

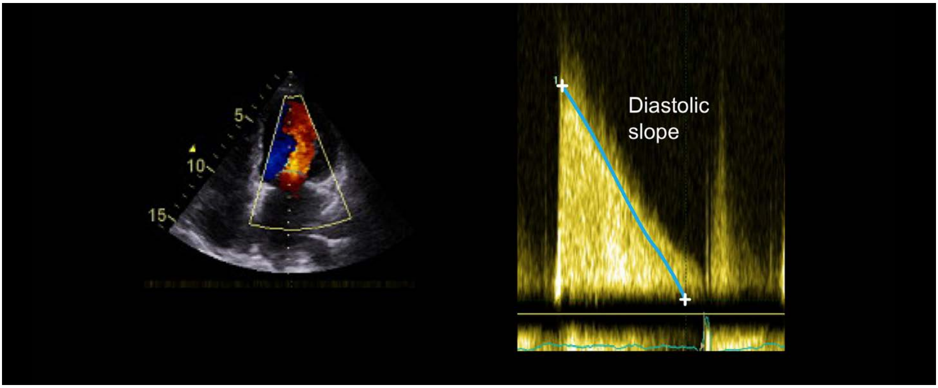


Location specific Doppler measurements are made using pulsed wave Doppler. The position of the sample volume is adjusted to give a smooth velocity curve with a clearly defined peak. Ideally the central aspect of the Doppler trace will appear less dense, and a closing click (as the valve shuts) will also be visible on the recording. The presence of an opening click indicates that the sample volume is positioned too close to the valve.

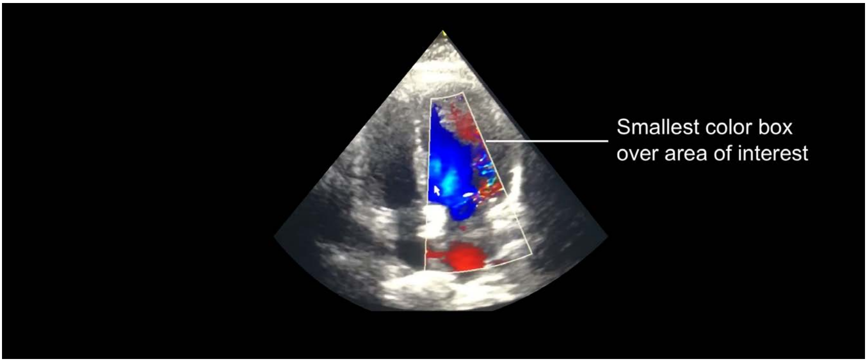


Valve pressure half-time measurement is achieved by positioning the sample volume of the pulsed wave Doppler at the tip of the valve and drawing a line from the maximum velocity along the diastolic slope.




Color Doppler is optimized by ensuring that the smallest color box size necessary to cover the area of interest is used, thereby giving the highest possible frame rate. The gain should initially be increased until the speckled appearance of random noise is just visible and then reduced slightly until the speckled appearance disappears.


Smallest color box
over area of interest

# Writing a report

A comprehensive report brings together all the information gathered during the echo study and forms the basis of patient management. The details of the report will help with deciding when to proceed with intervention for valve disease.

Your written text should describe what you observed during the study. In patients with valve disease, it is likely that the sections relating to valves that are abnormal will be particularly detailed.

When writing the report, it is best to integrate information from each of the views and different echo modalities to produce a clear and concise explanation of what has been seen.

Measurements should be stated clearly within the report and ideally displayed with reference to normal ranges.

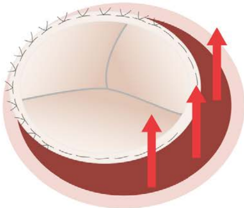
An overall conclusion that summarizes the study should be given in a separate section. This should be written in a style that can be understood by non-specialist staff. It must make a clear statement about the key abnormality as well as identifying other relevant findings. For serial studies, it can be very helpful to include a comment that explains how the findings of the study compare to those from the previous study.

The following is key information to include in your report when valve stenosis is present.

- Appearance of the valve
- Stenosis severity
- Left ventricular dimensions and systolic function
- Assessment of subvalvular apparatus for atrioventricular valves
- Function of other valves
- Right ventricular function and pulmonary artery pressure


The following is key information to include in your report when valve regurgitation is present.

- Severity of regurgitation
- Cause of regurgitation
- Left ventricular and aortic root dimensions
- Left ventricular function
- Function of other valves
- Right ventricular function and pulmonary artery pressure



The following is key information to include in your report about prosthetic valves.

- Valve type and position
- Any signs of obstruction
- Doppler measurements of flow through the valve
- Severity and source of regurgitation
- Left ventricular dimensions and function

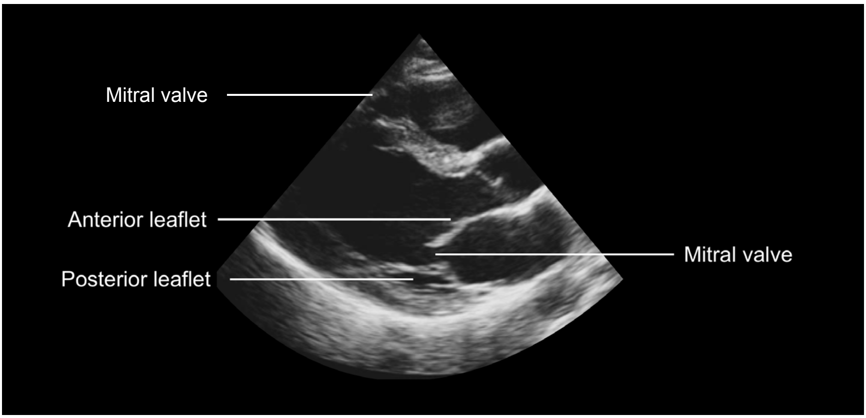
Chapter 2

# MITRAL VALVE DISEASE

# Introducing normal mitral valve echo anatomy

The mitral valve tends to be a dominant feature in most of the standard echo windows. In the parasternal long-axis view, this valve can be seen very clearly, providing an ideal view from which to assess overall appearance and movement of the valve leaflets.

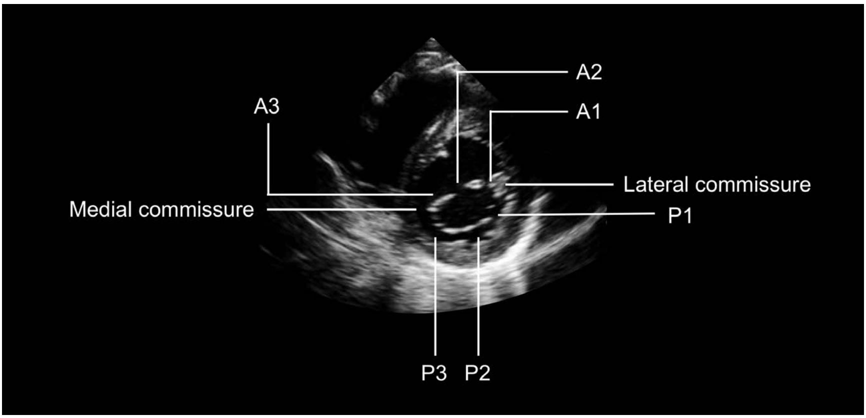
The leaflets appear similar, as both are thin structures, and both appear equally bright in echogenicity. The anterior leaflet is longer than the posterior leaflet, and when opening, it virtually touches the ventricular septum. When the valve closes during ventricular systole, the leaflets meet at their tips. The point of contact where the leaflets overlap is known as the apposition zone.




A true parasternal long-axis view cuts through the central aspect of the mitral valve, regions known as the anterior A2 and posterior P2 aspects of the valve; however, slight variation in positioning can mean that this is not always the case. Other regions of the valve are imaged if the ultrasound cut of the heart is more oblique. Chordae can be seen extending from the leaflet tips and connecting to papillary muscles on the posterior wall. These are likely to be the medial or posteromedial papillary muscles.

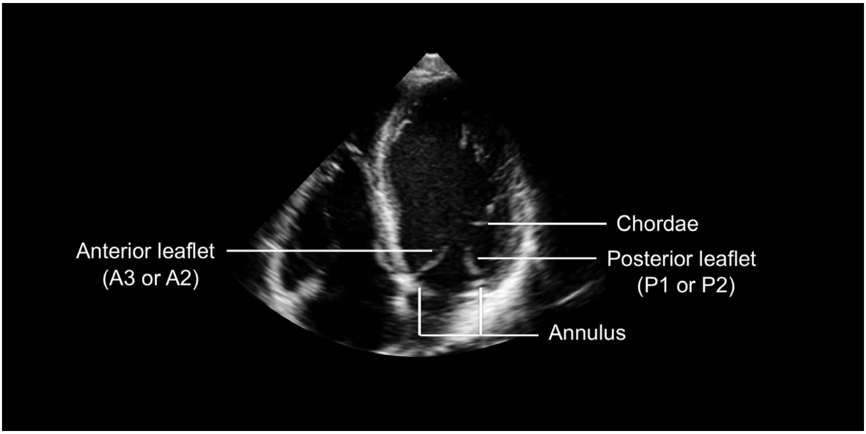
The short-axis view can be ideal for appreciating the subdivisions of the mitral valve leaflets. The anterior leaflet is towards the top of the image. Anatomically, the posterior leaflet is divided into three sections or scallops, known as P1, P2, and P3. In the parasternal short-axis view, these regions are seen in reverse, with P3 on the left or medial side, P2 in the middle and P1 on the right or posterior side of the image. The anterior leaflet is segmented into three regions to match, known as A1, A2, and A3. The mitral valve commissures can also be identified as the lateral and medial points on the annulus where the anterior and posterior leaflets meet.

The apical four-chamber view presents the anterior mitral valve leaflet on the septal or left side of the image and the posterior leaflet on the lateral



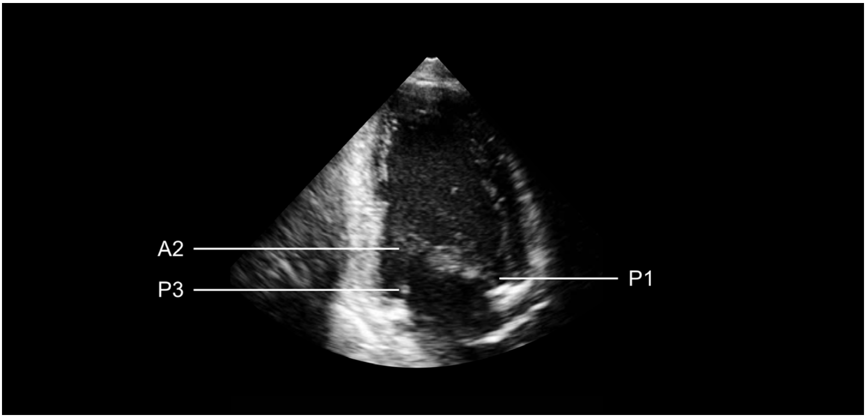
wall to the right. It is usual to see aspects of the anterior leaflet (A3 or A2) and the posterior leaflet (P1 or P2) from this approach. Chordae can be seen extending to the lateral papillary muscles. The saddle shaped mitral valve annulus is seen in its major dimension in the apical four-chamber view.

The mitral valve is clearly seen from the apical two-chamber approach. From here, it is mainly aspects of the posterior leaflet that are visible.




The anterior leaflet is actually being seen *en face*.

In a true apical two-chamber view, P3 appears on the left side, A2 in the middle, and the P1 scallop on the right side of the image. It is important to remember this arrangement when assessing both the structure and blood flow through the valve using this view.




The apical long-axis view reveals a very similar arrangement to the parasternal long-axis view; however, as the mitral valve appears slightly deeper in the image, the structures may not be quite as clear due to reduced resolution. The apical long-axis view is useful for assessing blood flow through the valve with color flow mapping since the orientation of the valve is more appropriate for Doppler interrogation.

# Recognizing an abnormal mitral valve

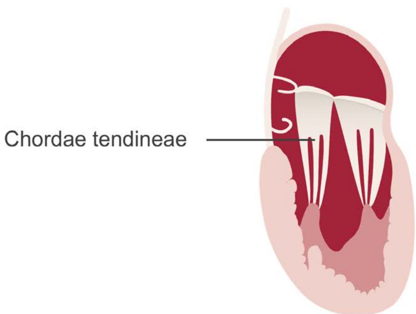
A detailed and accurate assessment of the mitral valve requires a methodical approach, taking into account all aspects of the valve and associated structures.

Inspect both the anterior leaflet and the posterior leaflet in turn.

- Are they thin and pliable or do they appear rather thickened with restricted movement?

Look closely at the mitral valve annulus.

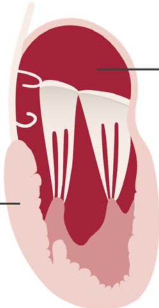
- Think about how bright it appears. If it is bright, does this seem to be limited to one region? Look from different views to make a full assessment.




What do you think about the chordae, extending from the tips of the leaflet to the papillary muscles?

- Perhaps they appear thicker than usual or maybe they seem rather bright, which would indicate the presence of calcification. You need to make a similar judgement about the papillary muscles.

Look at the ventricle and the atrium, especially the ventricular wall myocardial tissue below and in the region of the papillary muscle.

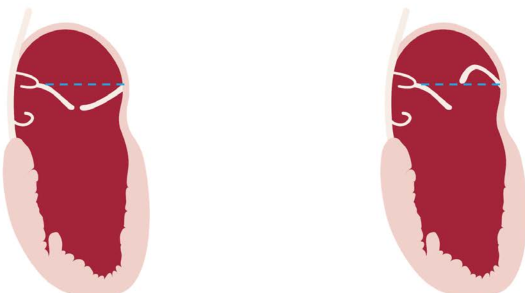



- It may appear thin or scarred, particularly in patients with coronary artery disease.
- Within the left atrium, you are looking for signs of thrombus on the walls, particularly in patients who are in atrial fibrillation.
- Consider the size of the chambers too. Dilated atria are often associated with mitral valve disease, and dilated ventricles can affect the size of the mitral valve annulus.

The pattern of changes to the mitral valve leaflets can suggest the underlying cause of the problem. Thickening of the leaflet tips suggests rheumatic heart disease. There may also be thickening and calcification elsewhere along the leaflets. The stiffened tips tend to result in restricted movement with the valve appearing to bow or dome during diastole, causing a *hockey stick* appearance when the valve opens. If you see this, it's particularly important to take a close look at the subvalvular structures. The chordae may also be calcified, appearing fused or shorter than usual.


Degenerative mitral valve disease, involving disrupted tissue that gradually thickens over time, is a more common finding in populations where there is little rheumatic fever. You will see thickening of the valve leaflets along their entire length rather than just at the tips. This can vary from fibroelastic deficiency to a condition referred to as Barlow's disease.

In fibroelastic deficiency, some regions of the thickened leaflets may move abnormally and on occasion bow in towards the left atrial chamber upon closure. Look closely at the valve leaflets in the long-axis views (parasternal and apically). If you can see either or both of the leaflets moving more than 2 mm above the annulus into the atrium, then you have identified the presence of a leaflet prolapse.

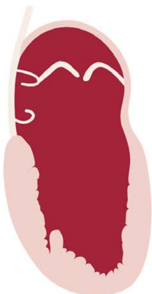


Patients with connective tissue disorders, for example Marfan's syndrome, may present with long anterior leaflets that can bow or prolapse during diastole.

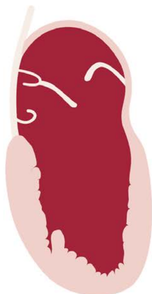
It is important to record whether both or one of the leaflets are involved.

- Both leaflets = symmetric prolapse
- Single leaflet = asymmetric prolapse

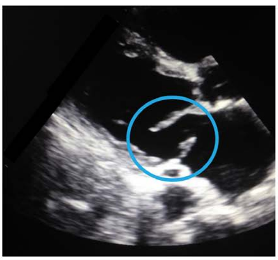
The latter is associated with a greater risk of significant valve degeneration, rupture of chordae, and a resulting flail leaflet.

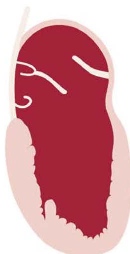


Symmetric



Asymmetric

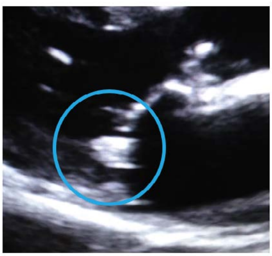


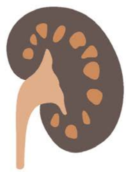


At the extreme end of the degenerative process is a Barlow valve.

There can be excessive leaflet tissue, resulting in a large valve size with diffuse myxomatous changes, as well as thickened, elongated, and often ruptured chordae with bowing and prolapsing of the now hypermobile leaflets.

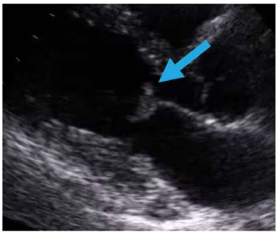
An echobright appearance to the mitral valve annulus can be a relatively common feature when scanning older patients, and may also be present in patients with renal disease. It is usually first spotted in the parasternal long-axis view in the region of the posterior annulus. It is important to check whether the posterior leaflet is affected by this calcification, as its function may be relatively normal with no significant impairment of the leaflet itself.





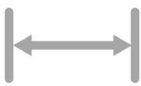
More widespread annular calcification detected from other views, particularly the short-axis view, should be noted. This may lead to disturbance of valve function with mitral regurgitation occurring, as reduced flexibility of the annulus can impair valve closure.

The appearance of mobile structures attached to the valve leaflets suggests the presence of vegetations and this is typically associated with infective endocarditis. Over time, perforations in the leaflets may occur as a result of the infection.





Valve leaflets can appear abnormal in patients with cardiomyopathies. In this example of an infiltrative cardiomyopathy with excessive thickening of the ventricular walls, the valve leaflets are also thickened, which can result in poor coaption.



Other conditions can affect the function of an otherwise normal mitral valve. This is where checking the left ventricular walls constitutes an important part of the assessment. For example, in patients with coronary heart disease, ischemia in the region of the papillary muscles can result in normal valve leaflets having difficulty in closing, their movement being affected by the altered papillary muscle function and resultant changes to the chordae. Often this restriction results in a tethering effect, leading to poor apposition of the leaflets.

Significant ischemia or myocardial infarction can result in papillary muscle rupture.

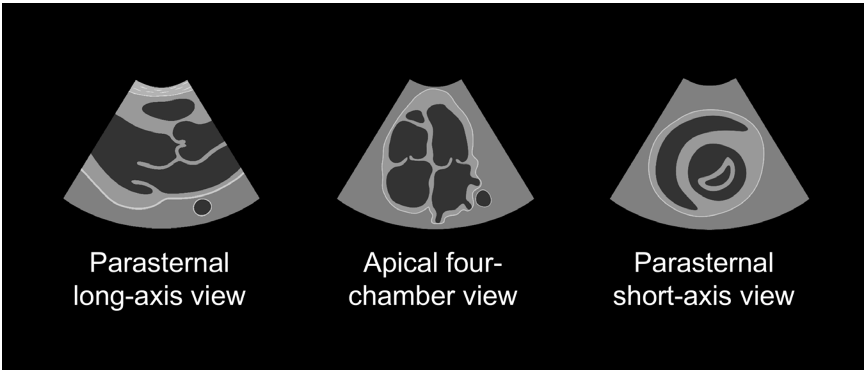
The associated leaflet will be free to move with the blood flow, giving a flail appearance. The ruptured muscle and loose chordae should be visible moving between the left ventricle and atrium.

Mitral valve dysfunction in patients with dilated cardiomyopathy involves changes similar to those seen in ischemic heart disease. Distortion of the mitral valve leaflets, due to changes in the subvalvular apparatus, can lead to apical tenting of the leaflets. Disruption of the annulus in the form of stretching is also likely to occur, impairing the ability of the otherwise normal valve leaflets to close correctly.

By taking a methodical approach to carefully inspect the mitral valve and its associated structures, you will be able to identify relevant abnormalities to inform your report.

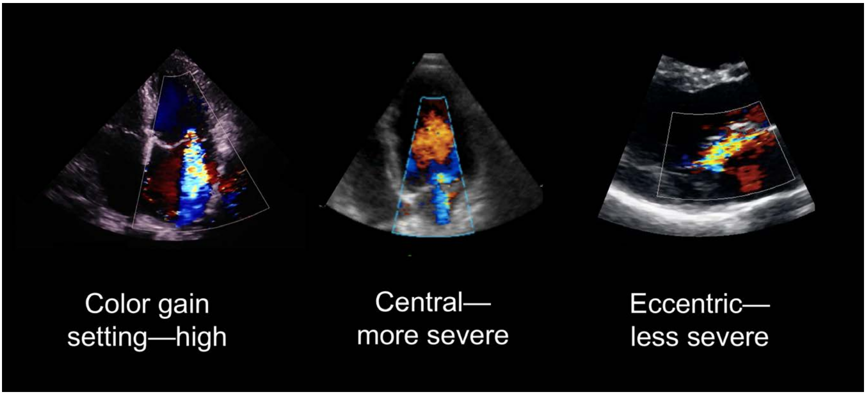
# Identifying mitral valve regurgitation

It's standard practice to use color flow Doppler in almost every view when performing an echocardiogram. This is particularly important when assessing mitral valve structure and function. Blood flow through the valve should be carefully inspected. The parasternal long-axis and apical windows are particularly useful for this purpose, with the short-axis view also providing helpful information.

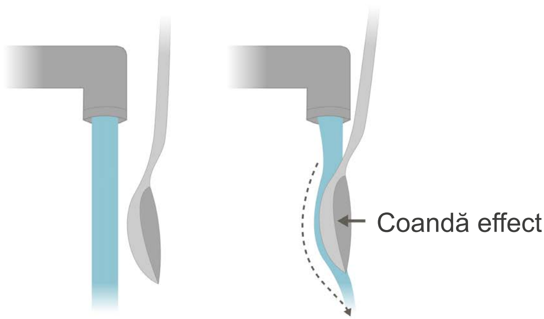



Place the color box over the mitral valve and size it accordingly: large enough to capture the region of interest above and below the valve, but as small as possible to ensure an optimal frame rate. Turbulent forward flow through the valve noted in either the parasternal or apical view is suggestive of a restricted opening of the valve leaflets. The presence of mitral regurgitation, usually seen as a predominantly blue jet moving away from the probe, should be sought. Once identified, color Doppler can be used to determine the overall direction of regurgitant flow. Consider whether it is central or whether it is directed towards one of the atrial walls in an eccentric direction.

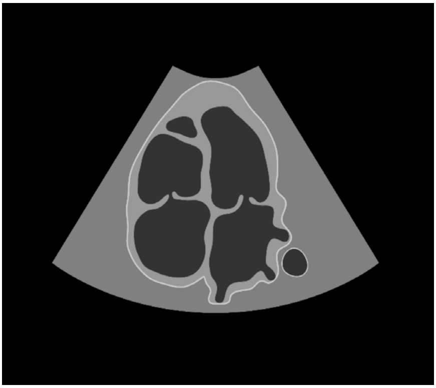
It is also worth observing the size of the jet relative to the size of the atrium. However, how far the jet actually extends into the left atrium is not particularly helpful. There are some important points to bear in mind. High color gain settings may lead to an overestimation of the amount of regurgitation. Similarly, centrally directed jets may appear more severe to the eye than eccentric jets.

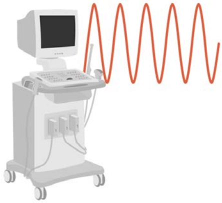



Eccentric jets might spread out across the wall of the left atrium, as a result of the Coandă effect (which occurs when liquid clings to the underside of an overhanging surface). This gives the visual impression of mild regurgitation when in fact there is significantly more.

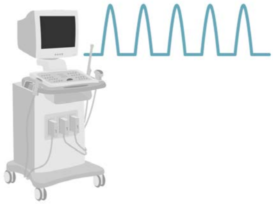


The apical four-chamber view is the preferred approach when using either continuous or pulsed wave Doppler due to the alignment with flow.



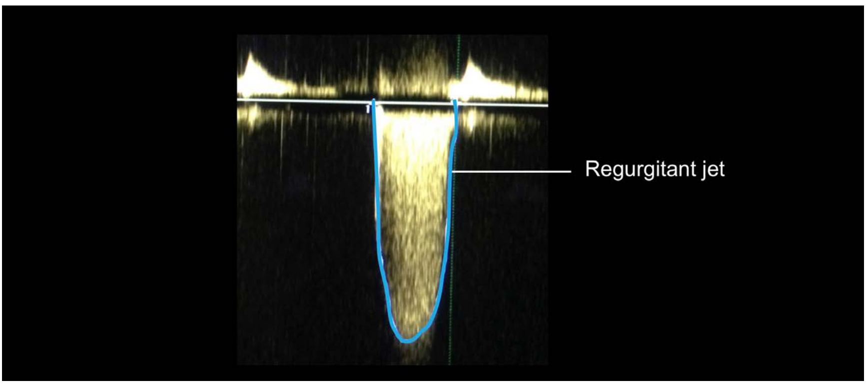


Continuous Doppler

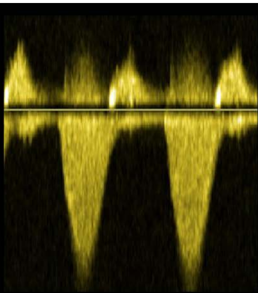


Pulsed Doppler

Look closely at the Doppler signal. Regurgitant jets will be seen as high-velocity signals, extending below the baseline, and occurring during systole.

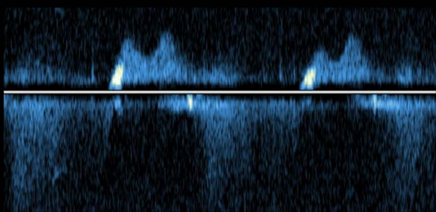


For regurgitant jets, dense, strong, bright, Doppler signals tend to be associated with moderate to severe regurgitation.



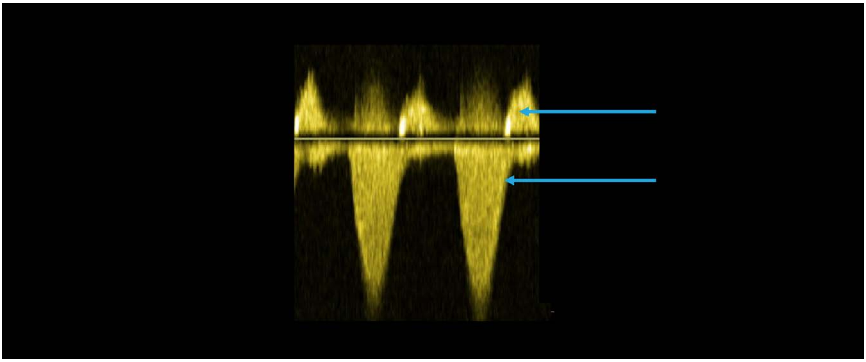
Severe regurgitation

Faint, weak signals are more likely to indicate mild regurgitation.



Mild regurgitation

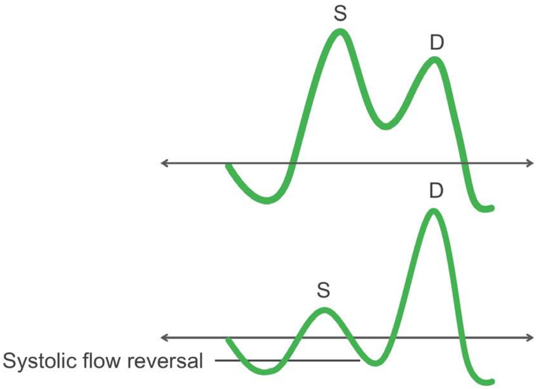
As a guide, compare the density of the regurgitant signal with the density of the mitral valve inflow signal. In severe regurgitation, the jet will be of a similar density to that of the inflow. However, once again it is important to consider the direction of the flow. If the flow is not in line with the ultrasound beam, then a true signal might not be captured, and underestimation may occur.



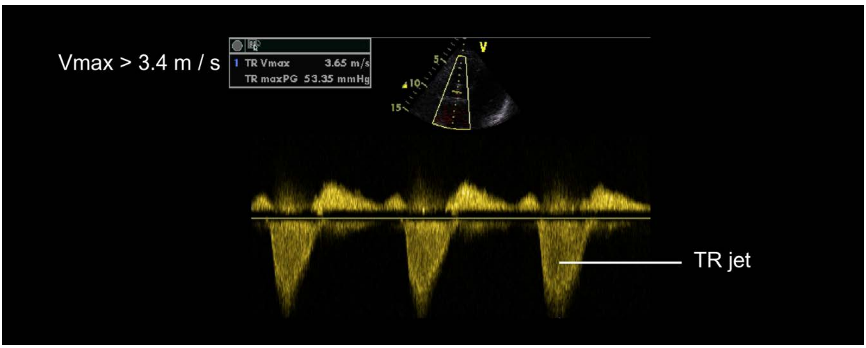
In your assessment of mitral regurgitation, it is important to include a measurement of left ventricular size, ventricular function, and left atrial size. In cases of chronic mitral regurgitation, the left ventricle will progressively dilate due to the overall increased stroke volume arising from the additional regurgitant volume. The left ventricular dimensions at end-systole and end-diastole are important for assessing the ventricle's response to volume overload. Over time, left ventricular dilation can lead to reduced ventricular function.

Left atrial size will increase in the presence of significant mitral regurgitation. However, there are other possible causes of dilated left atria, such as hypertension. Therefore, observing a dilated left atrium does not necessarily imply severe mitral regurgitation. It is worth remembering that a normal left atrial size generally excludes severe chronic mitral regurgitation.

Severe mitral regurgitation entering the left atrium will force the blood already present in the atrium back into the pulmonary veins and, in some cases, it is possible to demonstrate this using Doppler.



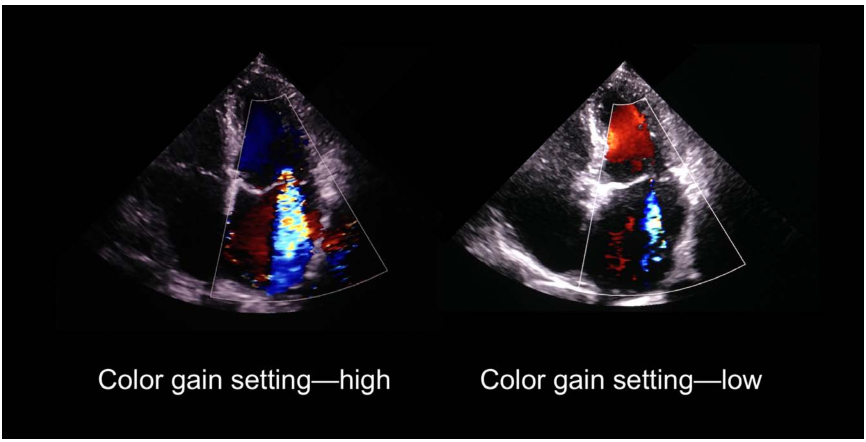

Pulmonary pressures are usually higher than normal in chronic severe mitral regurgitation. Assessment of any tricuspid regurgitation in patients with mitral regurgitation is good practice. Evidence of raised pulmonary pressures should be derived from the tricuspid regurgitation jet as detected by continuous wave Doppler. If this is a good-quality signal, and is > 3.4 m / s, then pulmonary hypertension is likely present.



# Quantifying mitral regurgitation based on color imaging

Once mitral regurgitation has been identified, the next stage is to give an indication of severity using a grading scale of mild, moderate or severe. Current guidelines promote both semi-quantitative and quantitative methods for measuring the amount of mitral regurgitation. These methods vary in their complexity and each method has limitations, meaning that an integrative approach should be used with the findings from a number of these methods being considered.

It is important to note that measuring the regurgitant jet area, whether directly or indexed to the left atrium area, is not recommended for assessing severity because the jet area is highly dependent on machine settings and the mechanism of mitral regurgitation. High and low color gain settings can make the regurgitation appear more or less severe than it actually is.



There are two measurements that can generally be applied relatively easily.

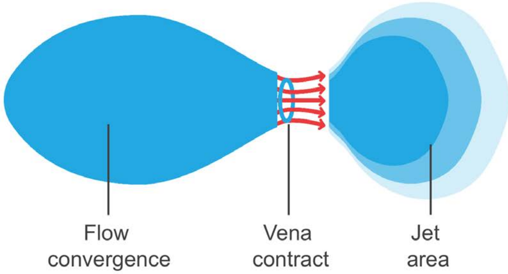
1. Measurement of the vena contracta (a semi-quantitative assessment).
2. Measurement of flow convergence as judged by the proximal isovelocity surface area or PISA (a quantitative approach).

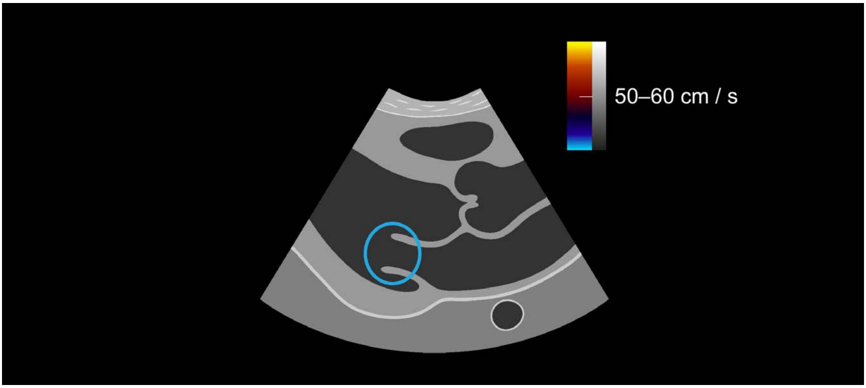
The PISA measurement can then be used to provide a range of other quantitative measures such as the regurgitant flow rate, regurgitant orifice area, and the regurgitant volume.

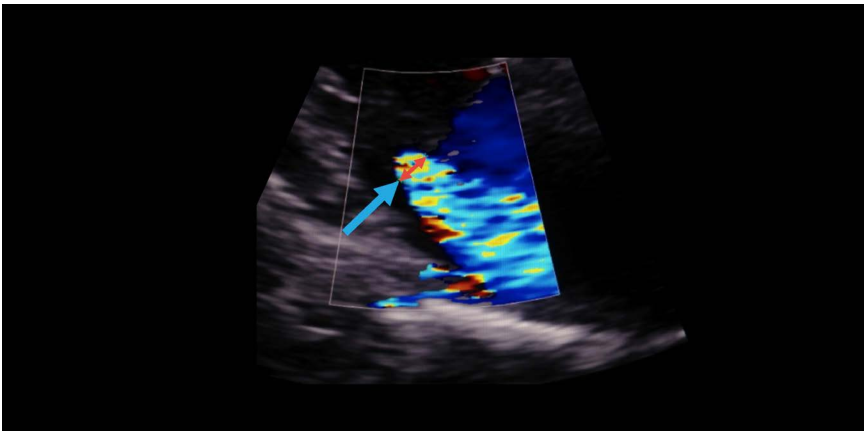
Measurement of the vena contracta is a reasonably simple semi-quantitative method to apply. It's a technique that is quick to perform, doesn't rely on complex machine setting adjustments, and allows for rapid assessment to separate mild mitral regurgitation from something that is more significant.

A parasternal long-axis view is ideal for carrying out this assessment. Further image optimization should be performed (i.e., by zooming in on the region of interest). Color flow imaging should be selected with a Nyquist limit set at around 50–60 cm / s and the color box placed over the valve. The size of the box should be reduced to cover the valve leaflet region. These adjustments ensure that both spatial and temporal resolution is optimized. A loop is then acquired, stored, and reviewed frame by frame to identify the narrowest diameter of color flow on the atrial side (just distal to / beyond the valve). Caliper measurements of the diameter can be made.

It is important to do this as carefully as possible, the measurements are small, so it's easy for slight errors to result in significant overestimation.


Flow convergence
Vena contract
Jet area


50–60 cm / s

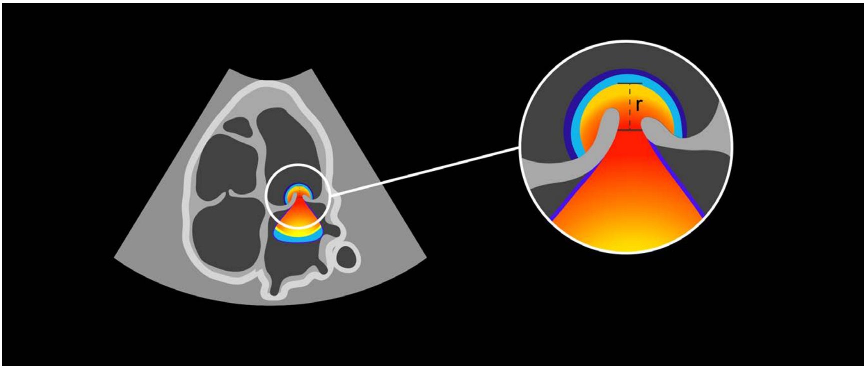


- A vena contracta measurement of < 3 mm most likely indicates mild mitral regurgitation.
- A vena contracta measurement of > 7 mm suggests severe mitral regurgitation.
- A measurement of > 3 and < 7 mm indicates that further quantifying tools should be used.

Measurement of the vena contracta is a quick and easy tool to apply, particularly in situations where there is some uncertainty as to whether the mitral regurgitation is mild or more significant. This includes times when there are confounding issues like an eccentric jet or a large regurgitant area.

The PISA technique is a quantitative technique that relies on acceleration in the rate of regurgitant flow just before the valve. Hemispheric layers of blood, each of which have the same velocity at a certain distance from the valve orifice, are formed. By adjusting the color scale to lower the velocity at which aliasing appears (generally between 15 and 40 cm / s), all of the hemispheres with a higher velocity will have the same aliasing phenomenon. This results in a blue-red interface in the shells at the point where the aliasing occurs.

You now know the velocity of the blood at this point as it will be the same as the aliasing velocity you have selected on your color scale setting. The radius of the first hemisphere is then measured on a zoomed view, and this measurement is used to calculate the surface area of the hemisphere.




The PISA method enables calculation of the PISA. Based on this, the calculation of the regurgitant flow rate, regurgitant orifice area, and regurgitant volume, can be made.

Volume flow rate is calculated as the product of surface area of flow and the flow velocity.

Hence the volume flow rate at the area of flow convergence (PISA) can be derived.

The volume flow rate at the regurgitant orifice itself will be the product of the regurgitant orifice area (ROA) and the flow rate of the regurgitant jet.

By the law of mass conservation, the volume flow rates at each point must be equal.

**Regurgitant orifice flow rate = flow convergence volume flow rate**

Therefore, the continuity equation can be used to calculate the ROA as demonstrated through the formula below.

## Relevant formula

As stated above, volume flow rate is calculated as the product of surface area of flow and the flow velocity.

To calculate the flow convergence volume flow rate, we require the surface area of the flow (PISA) and the velocity of the flow at this point (aliasing velocity).

**PISA (proximal isovolumic surface area) = $2\pi r^2$**

Hence, the flow convergence volume flow rate (regurgitant flow rate) will be the following.

**PISA x aliasing velocity = $2\pi r^2 \times v$**

The regurgitant flow rate in mL / s is the equivalent of the instantaneous regurgitant volume (RVinst)

To calculate the regurgitant orifice area flow rate, we require the surface area of the flow (ROA) and the velocity of the flow at this point (mitral regurgitation jet velocity).

So, we can measure the maximum mitral regurgitation jet velocity from a CW Doppler trace.

We can then solve the continuity equation to calculate the regurgitant orifice area (ROA).

**Regurgitant orifice area**

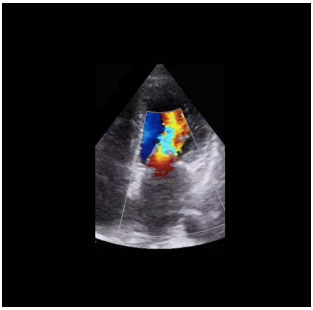
- Regurgitant flow rate (or RVinst) / VMR
- Regurgitant orifice area of < 20 $mm^2$ indicates mild mitral regurgitation
- Regurgitant orifice area of ≥ 40 $mm^2$ indicates severe mitral regurgitation

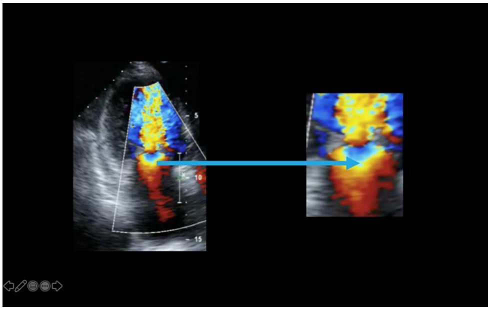
The **regurgitant volume (RV)** calculated over the systolic flow period (expressed in mL / beat) can be derived from the following.

- Regurgitant volume = ROA x VTIMR
- Regurgitant volume of < 30 mL / beat indicates mild mitral regurgitation
- Regurgitant volume of ≥ 60 mL / beat indicates severe mitral regurgitation

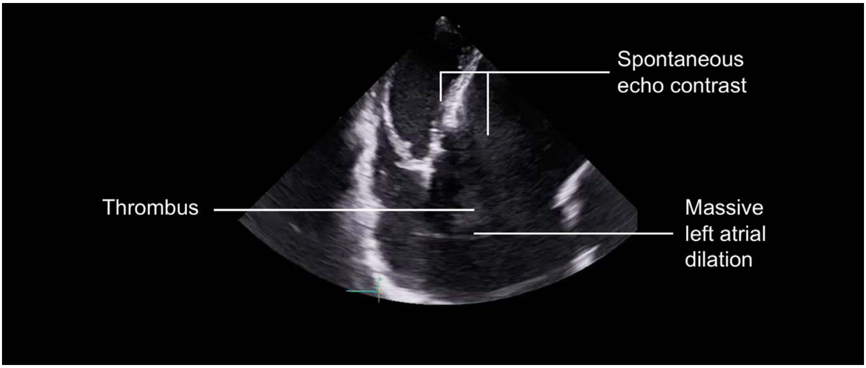
# Grading mitral stenosis

When using color flow Doppler in the presence of mitral stenosis, flow accelerating towards the valve is usually seen, followed by a lengthy jet passing from the valve and spreading out towards the apex of the left ventricle. Looking closely, you can often see clear evidence of proximal flow acceleration within the left atrium in the form of a very obvious, hemispherical PISA.

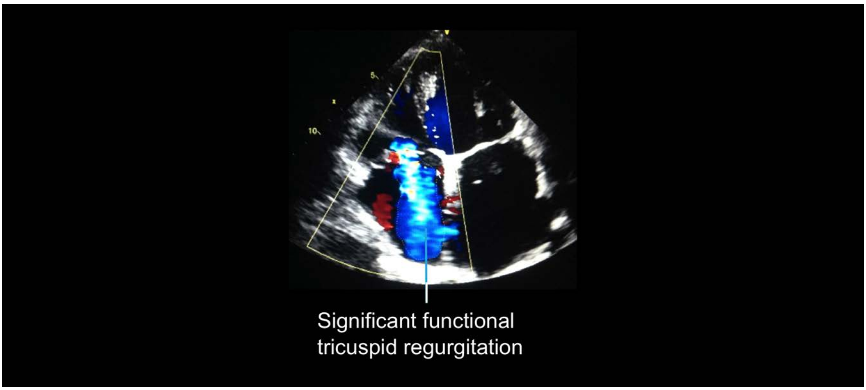




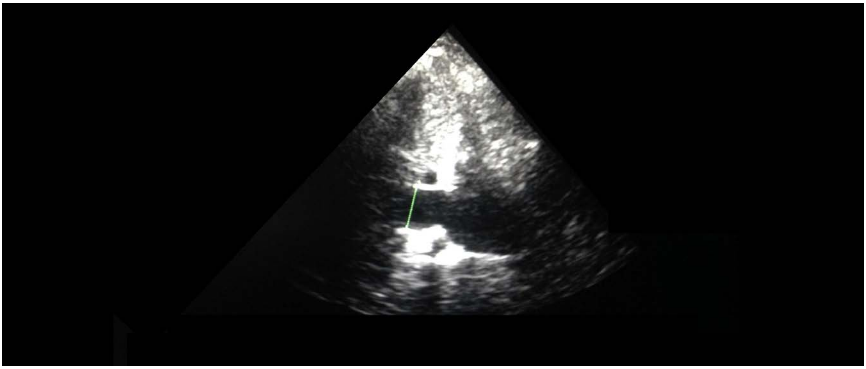
Left atrial dilation occurs as a consequence of chronic elevation of left atrial pressure. Over time, structural changes within the left atrial wall myocardial tissue result in fibrosis, which reduces the ability of the atrium to contract. An enlarged atrium with reduced contractility causes blood movement to slow down or pool; this can lead to thrombus formation. This often occurs within the left atrial appendage but thrombi can also form on the chamber wall or atrial septum. Spontaneous echo contrast appearing like smoke in the left atrium is seen when there is stasis of blood.



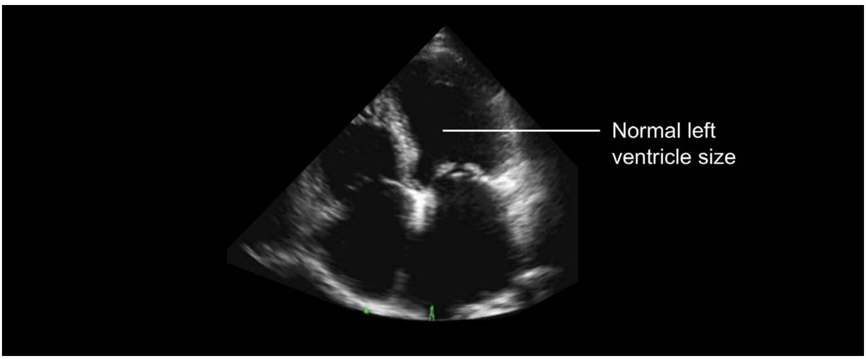

The increased pressure within the left atrium will be transmitted back through the pulmonary venous system, leading to abnormal findings within the right side of the heart. Pressure overload on the relatively thin-walled right ventricular chambers can lead to dilation. Right atrial size, together with both right ventricular size and function should be assessed. Functional tricuspid valve regurgitation may be significant due to right ventricular dilation.




Increased pulmonary venous pressure leads to pulmonary hypertension. Over time, this can result in permanent increases in pulmonary vascular resistance due to pulmonary vascular bed damage. All patients with mitral stenosis should have their pulmonary pressure estimated. This is done by measuring the tricuspid regurgitation peak velocity, the inferior vena cava diameter, and assessing the inferior vena cava compliance in response to inspiration.

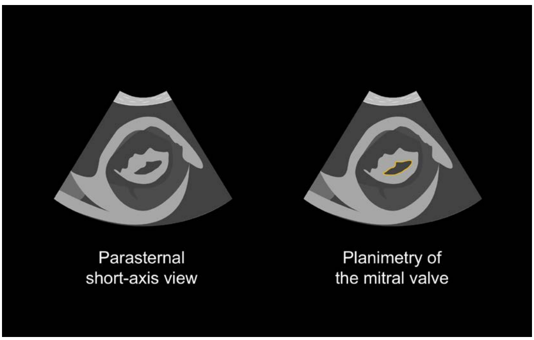


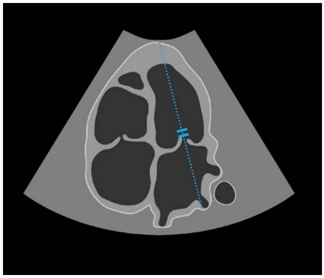
In patients with mitral stenosis, left ventricular size and function usually remain within normal range. However, it is likely that diastolic function will be impaired as a result of the limited flow through the mitral valve.



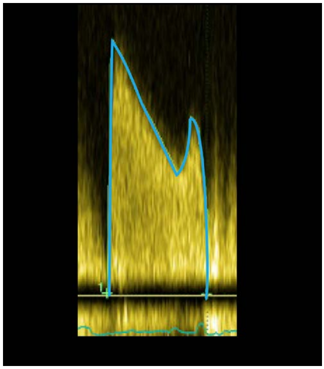
# Quantifying mitral valve stenosis

It is possible to assess mitral valve opening by performing a technique known as planimetry. This will depend on how clearly the valve can be seen from the parasternal short-axis view. In patients with clear images, it is a very useful technique for measuring the mitral valve area and can give an accurate assessment. Careful imaging of the valve is required, with the aim of ensuring that you are looking at the tips of the mitral leaflets. This is usually best achieved by scanning between the apex and left atrium a number of times to judge the point at which the tips of the valve are reached by seeing the smallest opening. A loop can then be acquired and assessed frame by frame until the point of maximal opening in mid- diastole is found. Most echo machines will have a preset mitral valve planimetry tool within their software that can be used to draw around the opening, which can usually be clearly identified between the blood pool and the calcified leaflets at the black / white interface. The calculated valve area can then be used as one of the measurements on which to base your final judgement of the amount of stenosis present.



Pulsed wave Doppler assessment is key to the assessment of mitral stenosis. From the apical window, Doppler can almost always be appropriately aligned with the flow through the valve and the pulsed wave sample volume positioned at the opening tips of the valve.

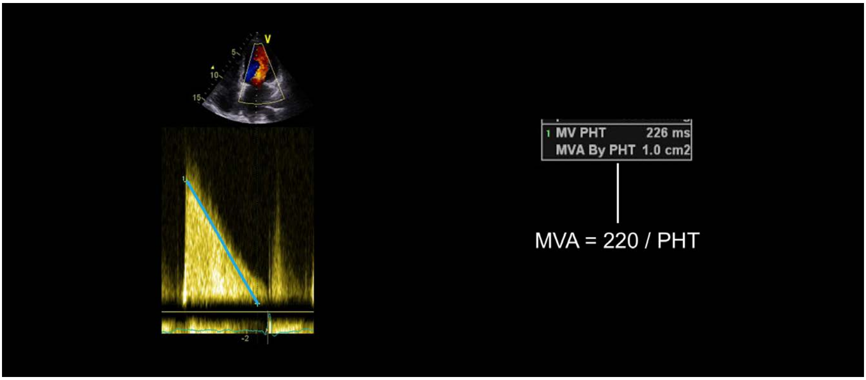


The diastolic signal can be measured using software tools to give a range of values. Drawing around the trace can be used to give measurements of velocity and pressure in the form of peak and mean values. The mean pressure gradient across the valve is particularly useful, as it is less dependent on other factors.

The pressure half-time (PHT) is the time taken for the pressure to drop to half of its original value, and it is a very useful measurement. The pressure half-time is derived by tracing the slope of the E-wave deceleration on the transmitral Doppler spectral display.

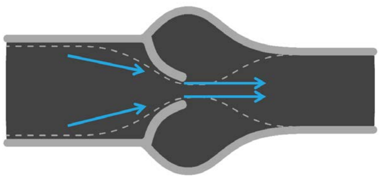
This is then converted to a valve area using a standard formula that will be available in your echo software package.

**Mitral valve area = 220 / pressure half-time**

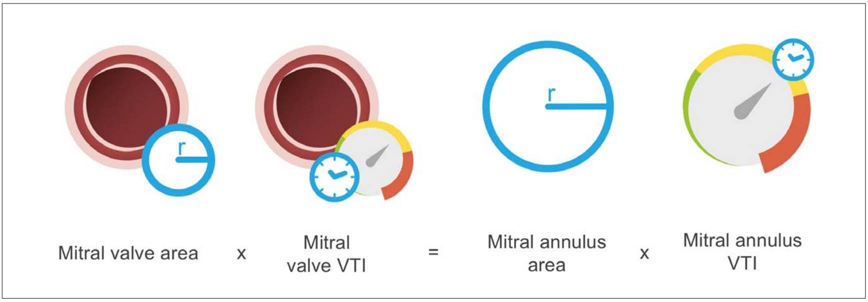



This measurement can be used in patients with atrial fibrillation; however, an average of measurements from five cycles should be taken.

There are limitations to using the pressure half-time technique to calculate the mitral valve area. When severe aortic regurgitation is observed, changes within the left ventricular pressure can lead to the pressure half-time measurement overestimating the valve area. Similarly, underestimation of valve areas may occur using this method if there is reduced left ventricular function.

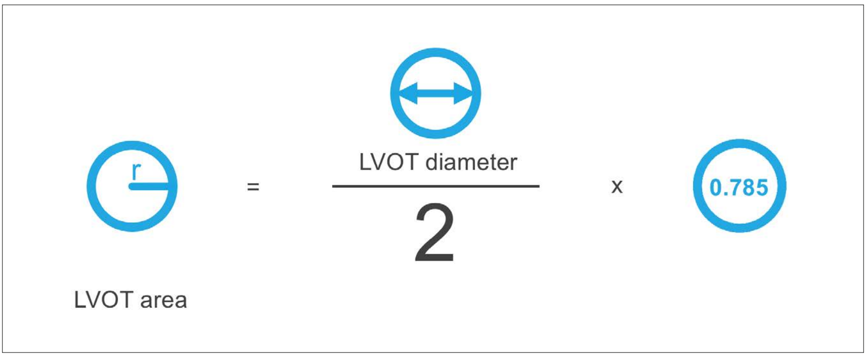


An alternative approach to assessing the valve area is to use the continuity equation. This is based on the assumption that the volume of blood flowing through the mitral annulus should be equal to the volume crossing the mitral valve orifice.



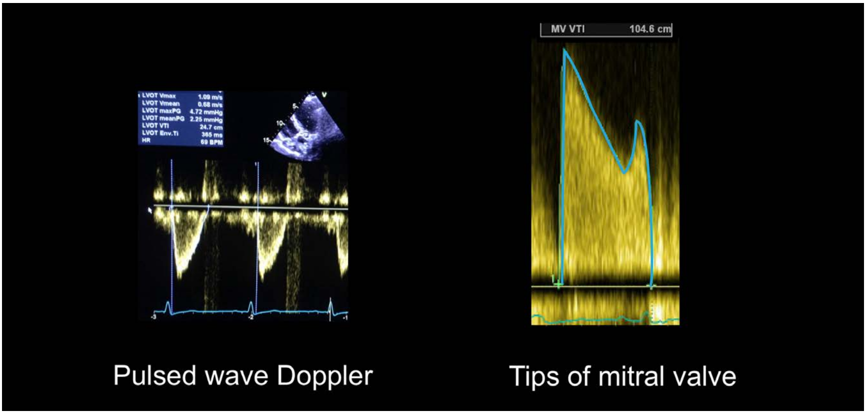

Software within your echo machine will be able to perform this calculation automatically when provided with the appropriate measurements.

Stroke volume can be calculated by multiplying the cross-sectional area by the velocity-time integral (VTI). For the purposes of mitral annular flow assessment, the stroke volume passing through the left ventricular outflow tract is used as a substitute for the stroke volume across the mitral annulus. The left ventricular outflow diameter is measured from a zoomed in view of the outflow tract in the parasternal long-axis window. The LVOT area can then be calculated as LVOT diameter divided by 2 times 0.785. This is based on the formula for the area of a circle squared ($\pi r^2$).



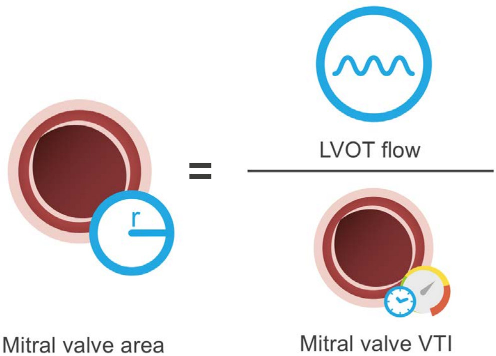
Pulsed wave Doppler is used to measure the VTI. A recording from the tips of the mitral valve can be used to determine the mitral valve VTI.

A pulsed wave Doppler recording of the flow in the left ventricular outflow tract can be obtained from the apical five-chamber approach. Tracing around the waveform will provide a measure of the LVOT VTI to use in the flow calculation.




Flow across LVOT or the stroke volume = LVOT area multiplied by the LVOT VTI.

The mitral valve area can be calculated as LVOT flow divided by MV VTI.



# Managing your patient

Guidelines for the management of patients with mitral valve disease, including the criteria for intervention, have been produced by the American College of Cardiology / American Heart Association.

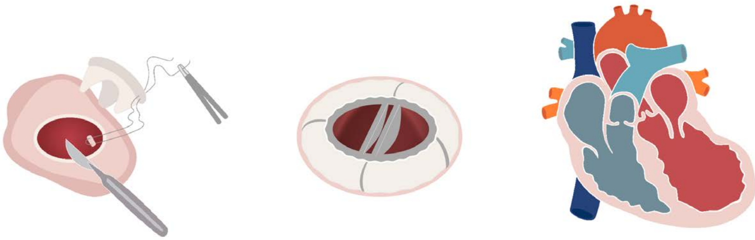
Asymptomatic patients with mitral stenosis should have an annual follow up to assess for any disease progression and indications for an intervention.

| Mitral valve area | Guidelines for follow up |
|---|---|
| > 1.5 $cm^2$ | 3–5 years |
| 1.0–1.5 $cm^2$ | 1–2 years |
| < 1.0 $cm^2$ | 1 year |

For those with symptomatic mild mitral stenosis, percutaneous mitral balloon commissurotomy may be considered. Percutaneous mitral balloon commissurotomy is recommended for symptomatic patients with severe mitral stenosis and favorable valve morphology in the absence of left atrial thrombus or moderate to severe mitral regurgitation.

Symptomatic patients with severe mitral stenosis and evidence of significant heart failure symptoms should be considered for mitral valve repair or replacement.

There are different approaches to the treatment of mitral regurgitation, depending on whether the regurgitation is primary or secondary. Patients with symptoms and severe primary mitral regurgitation, due to valve disease, should be recommended for intervention unless there are contraindications.

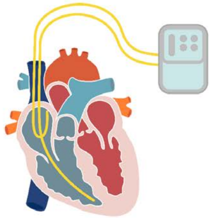


Valve repair | Valve replacement | Left ventricular dysfunction

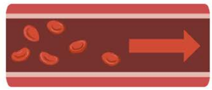
Valve repair or replacement will improve symptoms. Asymptomatic patients with evidence of left ventricular dysfunction also require intervention.

Surgical intervention for severe secondary mitral regurgitation is only considered after optimal medical therapy and other procedures (e.g., cardiac resynchronization therapy and revascularization) have been tried without success.

Medication



Cardiac resynchronization



Cardiac revascularization

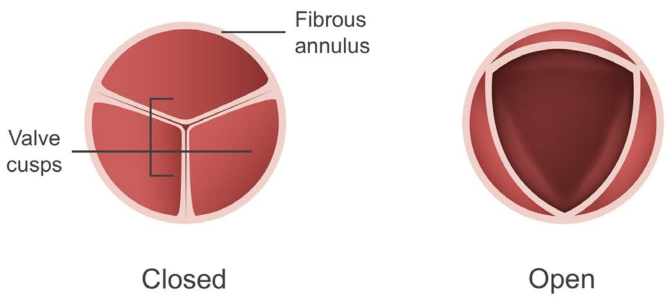
*It's important to recognize that the assumptions made when using this technique mean that it is not appropriate to use in the presence of significant mitral or aortic regurgitation.*

Chapter 3

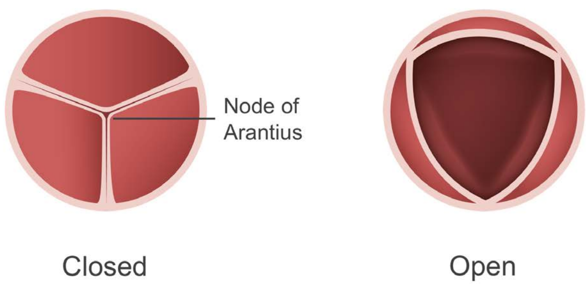
# AORTIC VALVE DISEASE

# Mastering normal aortic valve echo anatomy

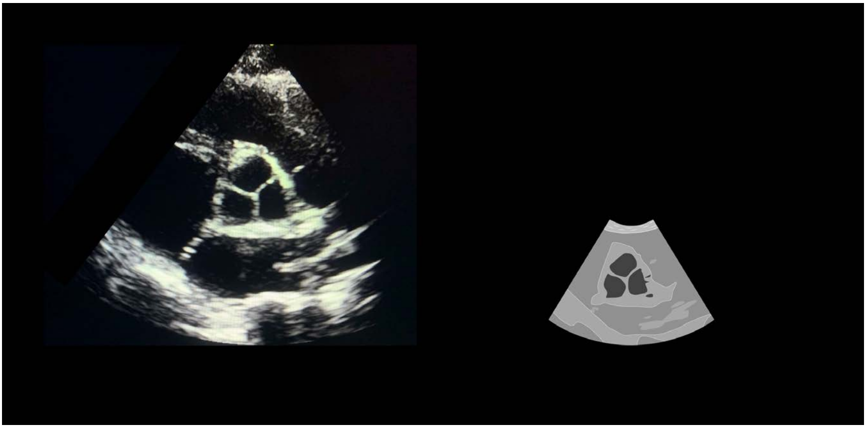
A normal aortic valve is trileaflet, with equally sized cusps that are supported by a fibrous annulus and separated by three commissures.




The cusps are semilunar, or crescent-shaped, with an upward curving free edge. The slightly thickened tip is referred to as the node of Arantius.

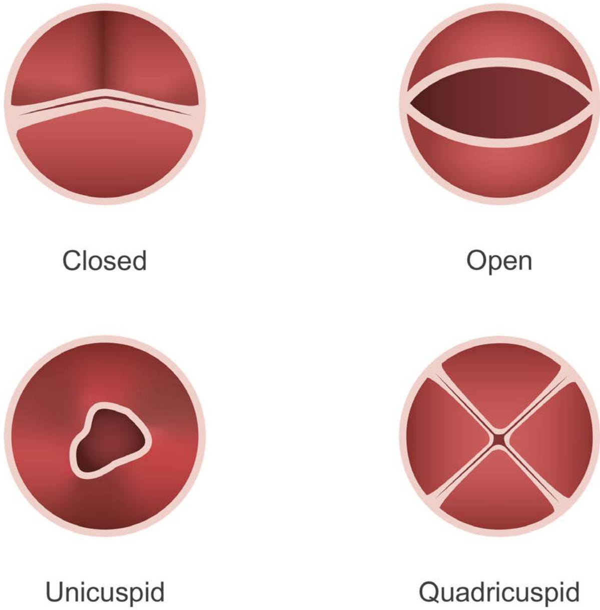


During diastole (when the valve is closed) the three nodes from each cusp meet in the centre with the closure lines forming a Y shape, when viewed from the short-axis approach.



Sometimes, thin, filament-like structures might be seen on the ventricular side of the valve cusps. These are known as Lambl's excrescences and are generally thought to be a normal variant; however, they may arise due to gradual degeneration of the cusps. It is important to bear this feature in mind, as they might be mistaken for vegetations in an otherwise well individual.

Bicuspid valves are a congenital malformation occurring in 1–2% of the population. Rarely, unicuspid and quadricuspid valves can be discovered. Abnormal cusp formation can result in valvular stenosis and regurgitation in later life.



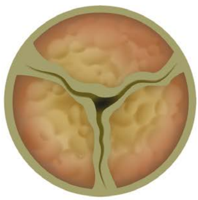

Where the proximal aortic root meets the left ventricular outflow tract, there are three bulges that provide support for the corresponding aortic valve leaflets. These are the sinuses of Valsalva, and are named according to the origin of the coronary arteries. The right and left sinuses give rise to their respective coronary arteries, the third sinus is referred to as the noncoronary sinus, as there is no associated artery.

The sinotubular junction is the point at which the sinuses narrow and join the proximal tubular portion of the ascending aorta.

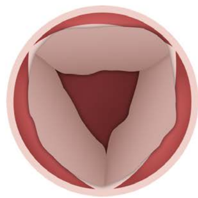
When viewed in long-axis, a normal aortic valve will be seen to open rapidly as thin structures that lie parallel to the aortic walls during systole.

# Recognizing an abnormal aortic valve

The most common causes of aortic stenosis are calcific degeneration and rheumatic valve disease.



Calcific degeneration

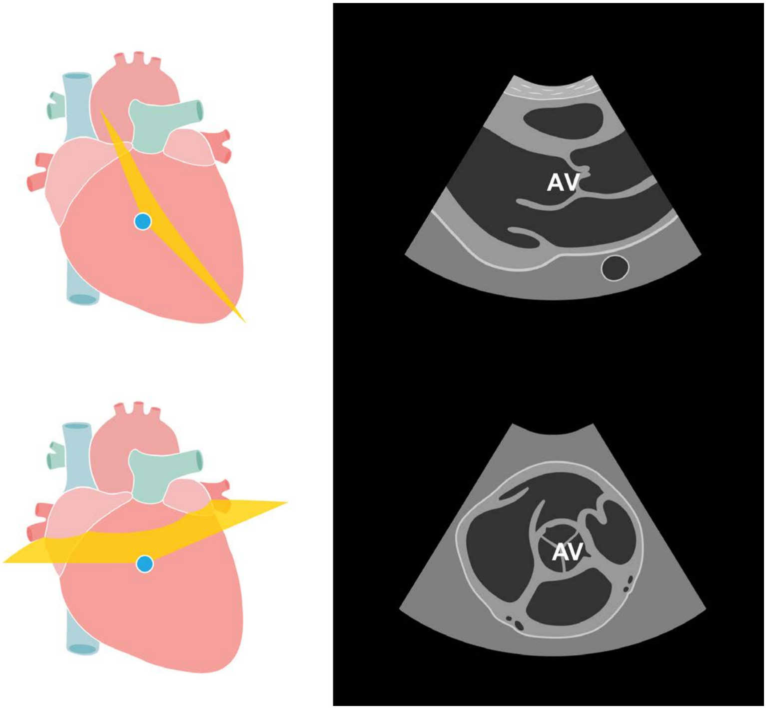


Rheumatic heart disease

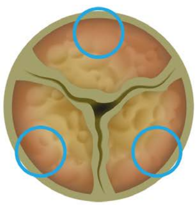
Calcific degeneration can affect trileaflet aortic valves, particularly in patients over the age of 75. Calcific degeneration in bicuspid valves is often the underlying cause of aortic stenosis in patients under the age of 65.

Rheumatic heart disease is now less common in North America and Europe but it is still prevalent worldwide.

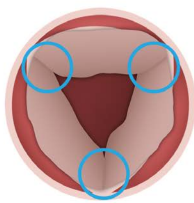
The underlying basis for aortic stenosis can usually be determined by carefully inspecting both the parasternal long-axis and short-axis views of the aortic valve.




Calcific degeneration involves the central and basal aspects of the cusps, whereas rheumatic aortic stenosis is typified by commissural fusion.



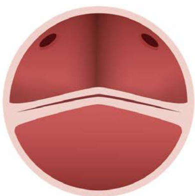
Calcific degeneration



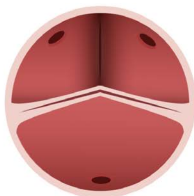
Rheumatic

In aortic stenosis, it can be difficult to be confident about the cusp configuration when calcium deposits mask the number of cusps.

A unicuspid valve has a single slit-like commissure, and the opening is eccentric and restricted. A true bicuspid valve has two cusps of roughly equal size with two associated sinuses and a single commissure. Some clues that might suggest the presence of a bicuspid arrangement include an asymmetric appearance to the calcification and the lack of a star-shaped appearance to the valve orifice when opening during systole. A seam, or raphe, may be present between cusps, giving the impression of three separate cusps. By observing valve opening in systole, however, the number of distinct cusps is apparent. Fusion of two cusps can create the appearance of a bicuspid valve but if there are three sinuses, then the valve is trileaflet with cusp fusion.



Bicuspid valve

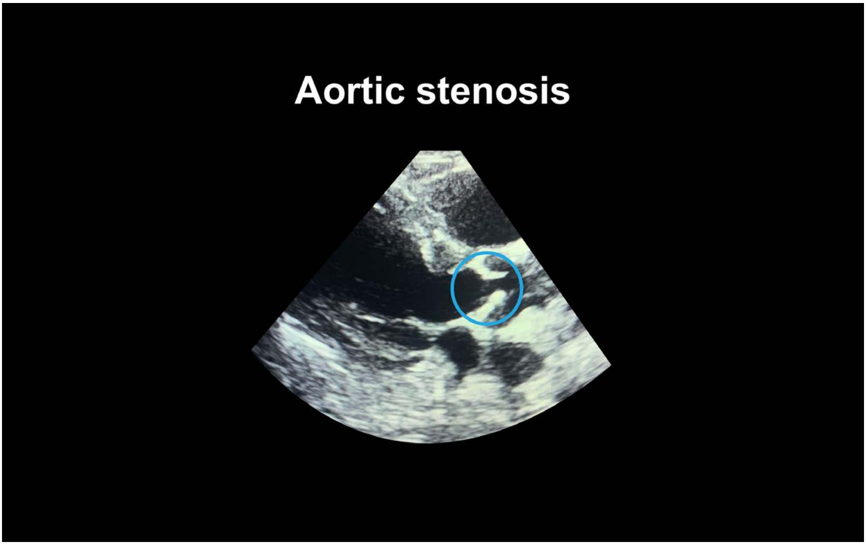


Pseudo-
bicuspid valve

A visual assessment of the amount of calcification present on the valve should be made. Mild calcification is present when some areas of echobright calcification can be seen on the cusps. Moderate calcification is suggested by larger areas of echobright appearance.

Severe calcification presents as extensive calcification with thickening and a strong echobright appearance.

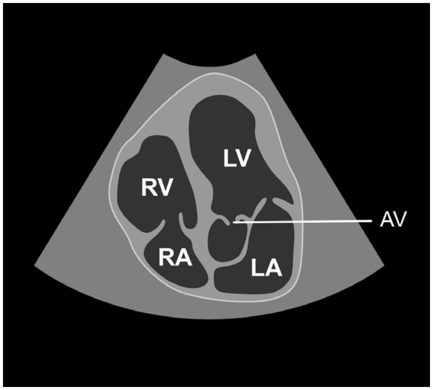
In aortic stenosis, the thickened and restricted cusps show reduced mobility. During systole, they are no longer seen parallel to the wall of the aorta and the tips may point towards the centre of the aorta.



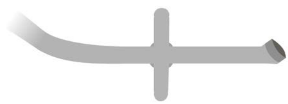

Significantly reduced movement of the cusps suggests severe aortic stenosis, but visual inspection is not sufficient to make a definitive diagnosis.

# Measuring an accurate aortic valve gradient

Current best practice recommendations require Doppler-based measurements to provide the peak jet velocity through the aortic valve and a recording of the mean pressure gradient across the aortic valve.




Continuous wave Doppler is used to measure the velocity of blood crossing the aortic valve. You need to be confident that you are measuring the maximum velocity, so it is very important to make this assessment from as many views as possible. This usually means that the standard apical approach should be used; however, additional recordings should be taken from the right sternal edge and the suprasternal notch.



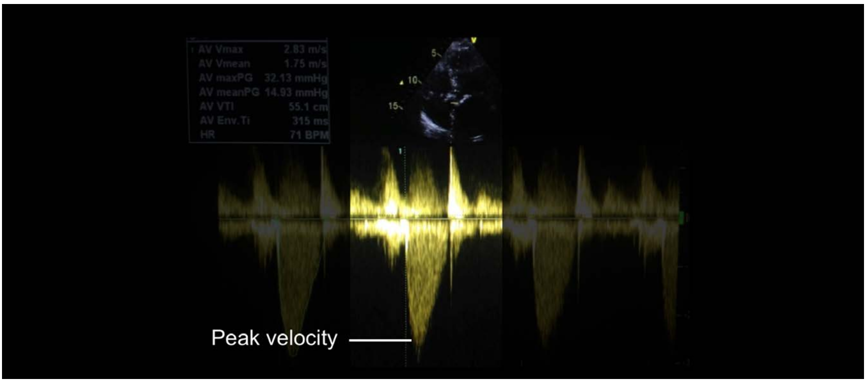
Interestingly, studies have shown that the right sternal edge will generally provide the maximum velocity. A stand alone continuous wave Doppler probe can prove very useful here, with its smaller footprint being better suited to being aligned with blood flow. However, the use of this probe requires practice, so you should make an attempt to use this probe on a regular basis.

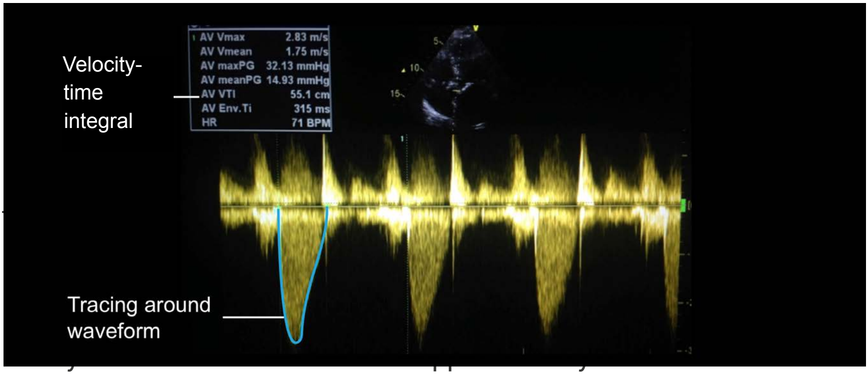
The maximum jet velocity recorded should be noted in the report, together with a comment that explains which echo window was used to make the measurement. This is useful reference information for subsequent scans.

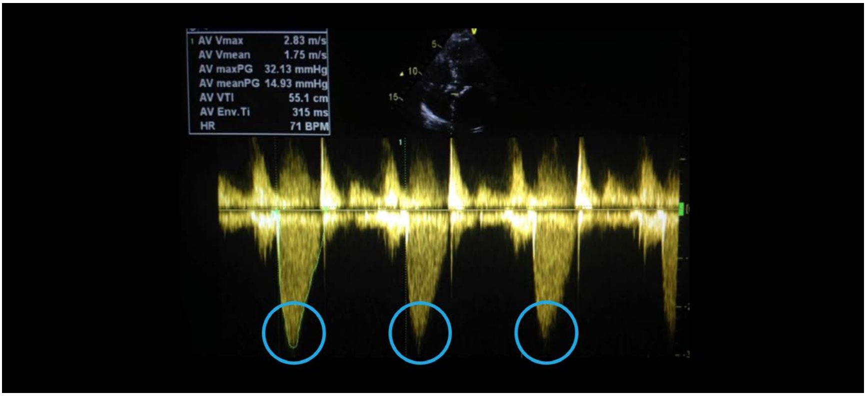
The recorded Doppler signal should be optimized such that it fills the vertical axis and is usually recorded at a time scale of between 50 and 100 mm / s.

A smooth, dense-edged Doppler signal with a clear maximum velocity is required and the peak velocity should be measured at the peak of the curve.

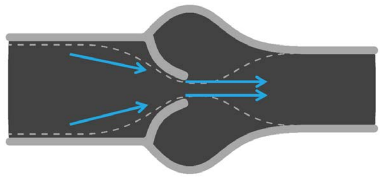
Tracing around the waveform on its outer edge provides the VTI, which is used to give the mean gradient.



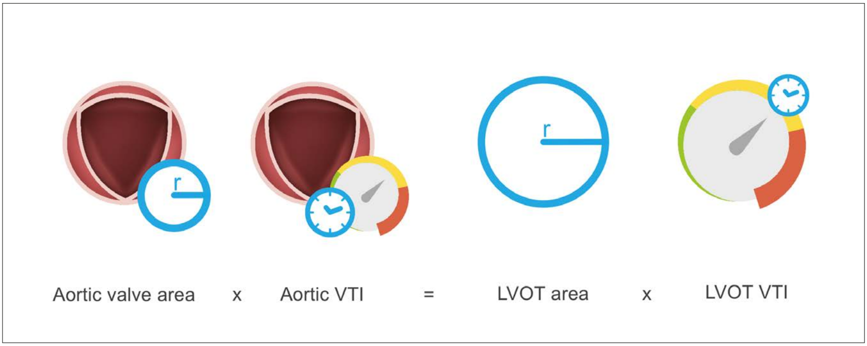

AV Vmax 2.83 m/s
AV Vmean 1.75 m/s
AV maxPG 32.13 mmHg
AV meanPG 14.93 mmHg
AV VTI 55.1 cm
AV Env.Ti 315 ms
HR 71 BPM
Velocity-time integral
Tracing around waveform

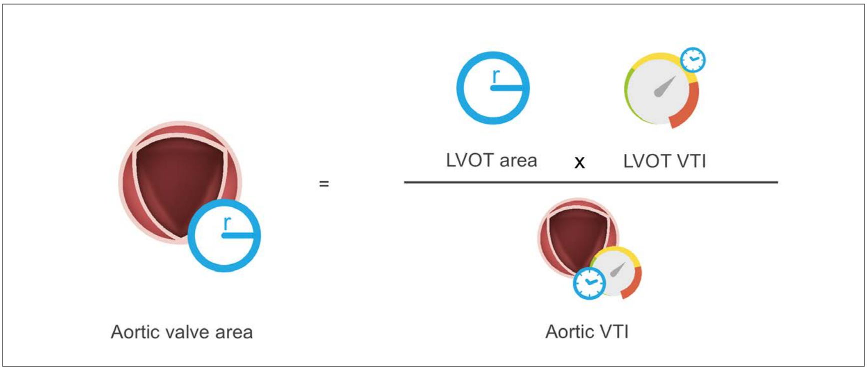

AV Vmax 2.83 m/s
AV Vmean 1.75 m/s
AV maxPG 32.13 mmHg
AV meanPG 14.93 mmHg
AV VTI 55.1 cm
AV Env.Ti 315 ms
HR 71 BPM

# Calculating the aortic valve area

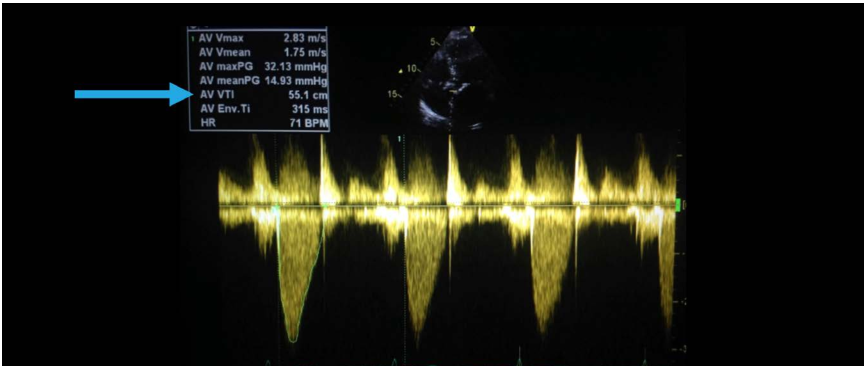


The effective aortic valve area is derived from a calculation known as the continuity equation. Three measurements are required to make this calculation: the VTI of the aortic valve, the VTI of the left ventricular outflow tract, and the left ventricular outflow tract area.

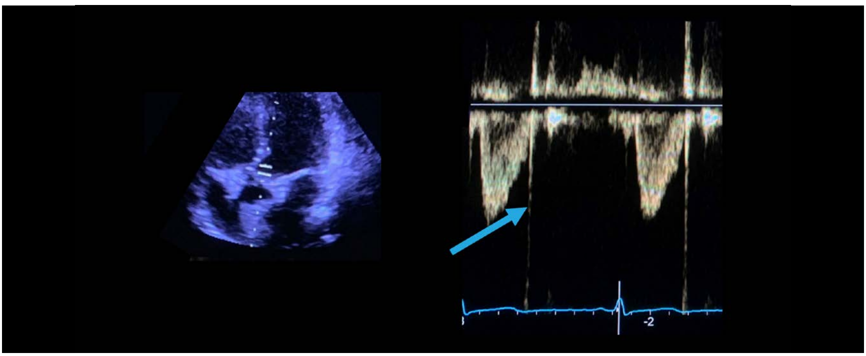


Record the maximum jet velocity, and then use the machine or reporting software to draw a trace around the waveform from which a VTI measurement will be obtained.

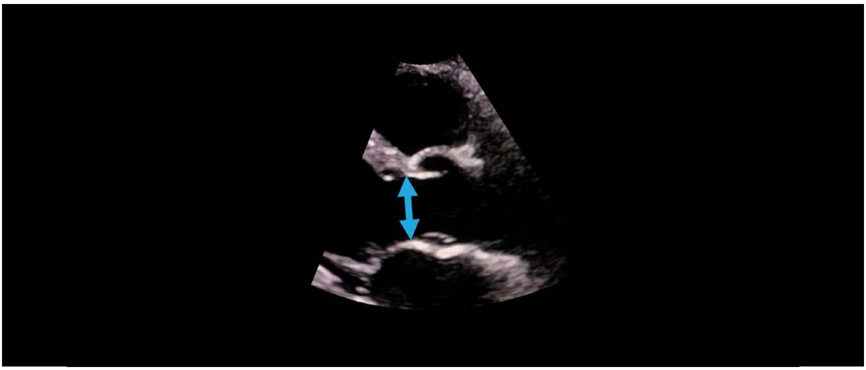



Pulsed wave Doppler is used to record the velocity in the left ventricular outflow tract, normally from the apical five-chamber window. The sample volume is adjusted to a position within the left ventricular outflow tract, just before the aortic valve. Ideally, an indication of the aortic valve closing click will be visible on the Doppler signal. When correctly sited, a smooth peaked velocity curve should be seen, from which a VTI measurement can be made by tracing around the waveform.

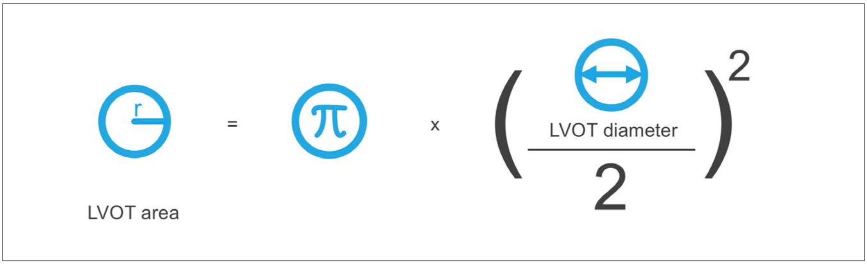


The third piece of information needed is a measure of the diameter of the LVOT. This measurement is probably best made at the annulus level where there are clear landmarks, though some prefer to aim for a similar position to where the pulsed wave Doppler recording has been made. The importance of making an accurate measurement at a consistent position is paramount. This diameter measurement is used to calculate the LVOT area, using the formula for the area of a circle squared ($\pi r^2$). Since distance values are squared, any measurement errors are magnified.

In order to improve measurement accuracy, a zoomed parasternal long-axis view should be used. Caliper measurements can then be applied to measure from the inner-edge to inner-edge of the outflow tract in mid-systole. Ideally, three or more beats should be measured for patients in sinus rhythm, with more for those in an irregular rhythm.

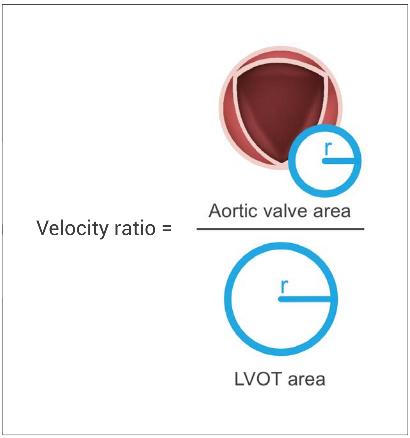


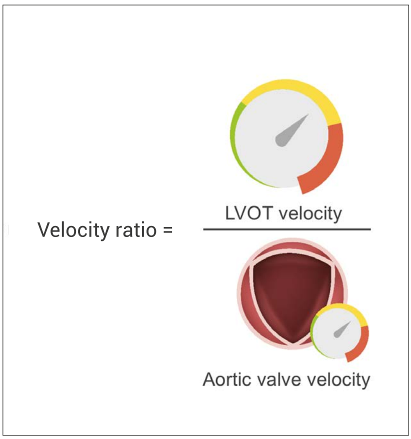
As a reminder, the continuity equation is based on the idea that the volume of blood passing through the LVOT is equal to the volume of blood that passes through the aortic valve.



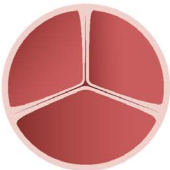

The LVOT area calculation is one of the major pitfalls of this technique. Inaccurate measurement of the LVOT diameter is exaggerated through the squaring of the value and in reality, the LVOT is not circular but more oval-shaped.

Calculation of the velocity ratio or VTI ratio can be performed and this is known as the dimensionless index. It expresses the size of the valve effective area as a proportion of the cross-sectional area of the LVOT.



- When there is no stenosis, the ratio should be about 1.
- A value of < 1 suggests some degree of stenosis
- Severe stenosis is present when the ratio is ≤ 0.25.



VTI ratio = 1

VTI ratio < 1

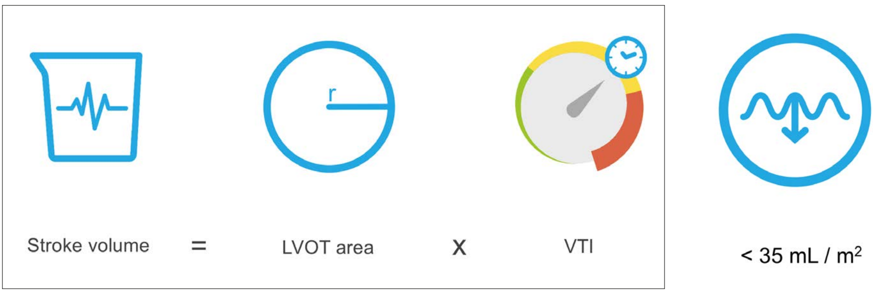
VTI ratio < 0.25

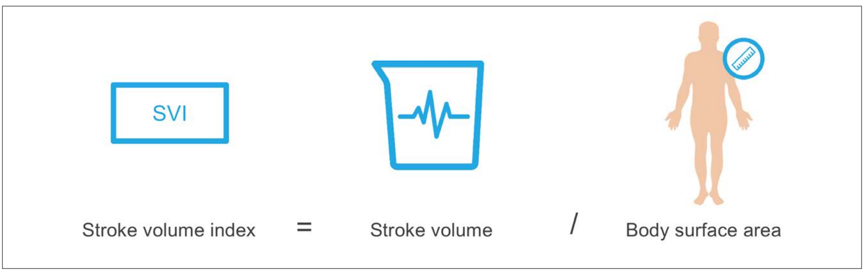
# Diagnosing low-flow states

Assessment of left ventricular function is important, as it provides useful prognostic information and guides patient management.

Impaired left ventricular function will affect the relationship between pressure changes across the valve and the aortic valve area. As a consequence, assessment of aortic stenosis severity will be affected when there is impaired left ventricular function, and will potentially be inaccurate.

Impaired left ventricular function resulting in reduced flow across the valve can lead to decreased cusp opening. In such a situation, the continuity equation calculated effective orifice area will be reduced, even though significant aortic stenosis might not be present.



# Recognizing discordant values

If peak velocity and gradient measurements are congruent with calculated valve area findings, then the classification of aortic stenosis is relatively straightforward.

| | Mild | Moderate | Severe |
|---|---|---|---|
| AV Vmax (m / s) | 2.6–2.9 | 3.0–4.0 | > 4.0 |
| Peak gradient (mmHg) | < 40 | 40–65 | > 65 |
| Mean gradient (mmHg) | < 20 | 20–40 | > 40 |
| EOA ($cm^2$) | > 1.5 | 1.0–1.5 | < 1.0 |

However, when your assessment of velocity, mean gradient, and valve area do not give rise to similar grades of severity, they are discordant, and classification is more challenging.

For example, a peak velocity of < 4 m / s suggests that no severe stenosis is present, but what if the calculated valve area is < 1.0 $cm^2$?

| | Mild | Moderate | Severe |
|---|---|---|---|
| AV Vmax (m / s) | 2.6–2.9 | 3.0–4.0 | > 4.0 |
| Peak gradient (mmHg) | < 40 | 40–65 | > 65 |
| Mean gradient (mmHg) | < 20 | 20–40 | > 40 |
| EOA ($cm^2$) | > 1.5 | 1.0–1.5 | < 1.0 |

This is not an unusual occurrence. When it happens, the first thing to do is to recheck the measurements: have they been made correctly and how confident are you in the values?

Consider the patient too—small patients tend to have small valves.

After excluding these possible reasons for the discrepancy, you can go on to consider other possible causes.

In patients with a reduced left ventricular systolic function (EF < 50%), consequent low-flow (< 35 mL / m$^2$) and severe aortic stenosis, the peak velocity and gradient may be low (i.e., < 4 m / s, < 40 mmHg). While the peak velocity and gradient are not indicative of severe aortic stenosis, the calculated valve area may be small, giving a value within the range for severe aortic stenosis (< 1.0 cm$^2$). This is referred to as low-flow, low-gradient aortic stenosis with reduced ejection fraction.

Such patients will benefit from low-dose dobutamine stress echocardiography, whereby the stroke volume and flow can be increased if contractile reserve is present, and the effect of this increased flow rate on the aortic valve can be assessed.

True severe aortic stenosis is found when the aortic stenosis jet velocity is increased to > 4 m / s and the valve area remains < 1.0 cm$^2$.

Should the valve area increase to > 1.0 cm$^2$, then the stenosis cannot be severe. If the stroke volume fails to increase by 20%, then there is no left ventricular contractile reserve, a poor prognostic sign.

# Diagnosing paradoxical low flow

Occasionally, it is possible to find discordant data, such as a low gradient, small effective orifice area, and a calculated low-flow rate, yet apparently normal left ventricular function. This situation reflects low-flow, low-gradient aortic stenosis with preserved ejection fraction, or paradoxical low flow.

As previously described, it's important to reassess all measurements before choosing a diagnosis of paradoxical low flow.

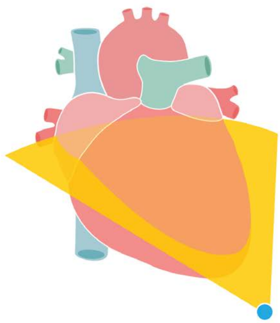
The low-flow state arises due to the presence of hypertrophy, leading to a small ventricular cavity size. Hence, there will be a small total ventricular blood volume that results in reduced blood flow across the stenotic valve, despite the presence of severe stenosis and a normal ejection fraction.

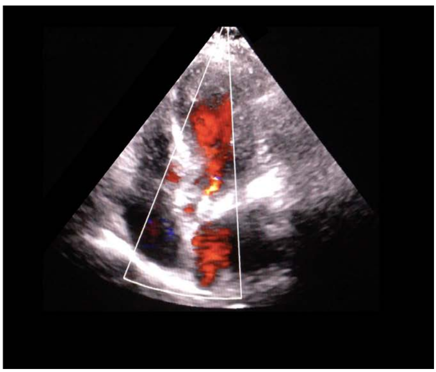
Knowledge of the patient's blood pressure is helpful; in this situation it is usually high. When considering low-flow, low-gradient aortic stenosis in the presence of a preserved ejection fraction, it is important to exclude measurement errors and severe hypertension. Once this has been done, further assessment incorporating clinical findings and additional imaging is recommended to judge whether severe aortic stenosis is likely or not.

# Identifying and grading aortic regurgitation

Aortic regurgitation is not a normal echo finding. It usually results from some form of pathology affecting the aortic valve or the aortic root. Bicuspid aortic valve, calcific degeneration, rheumatic disease, and Marfan's syndrome are relatively common causes of aortic regurgitation. Infective endocarditis, aortic dissection, and trauma can result in acute aortic regurgitation.

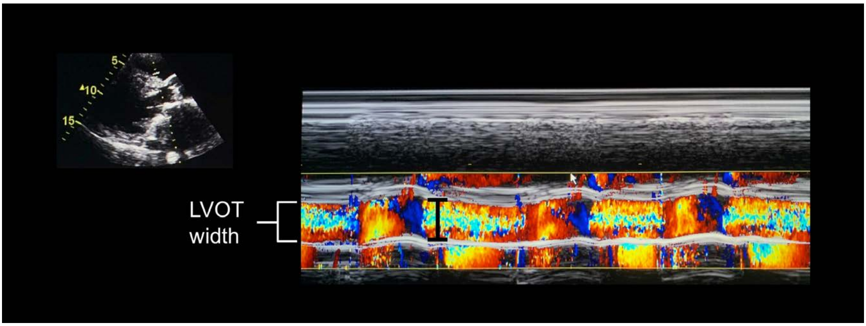
Color Doppler is usually the tool used to confirm the presence of aortic regurgitation, with blood flow seen moving backwards through the valve and outflow tract towards the left ventricle during diastole. This will almost always be visible when viewed from the apical window, typically appearing as a red or orange jet. However, the parasternal long-axis and short-axis views are key to assessing the origin of the regurgitation.

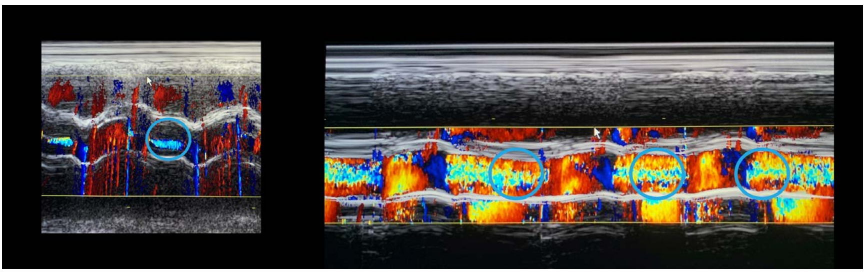




The length of the regurgitant jet should not be used as an indication of severity, but some information can be gained from the jet to help with this grading.

Measuring the width of the color jet, relative to the width of the left ventricular outflow tract, provides a guide towards grading the severity of aortic regurgitation. If the regurgitant jet occupies < 25% of the outflow tract, it is likely to be mild. If it occupies > 65% it is likely to be severe. In transthoracic echo, these measurements are best made from the parasternal long-axis window, and using color M-mode across the outflow tract (just below the aortic valve) can make measurement easier.



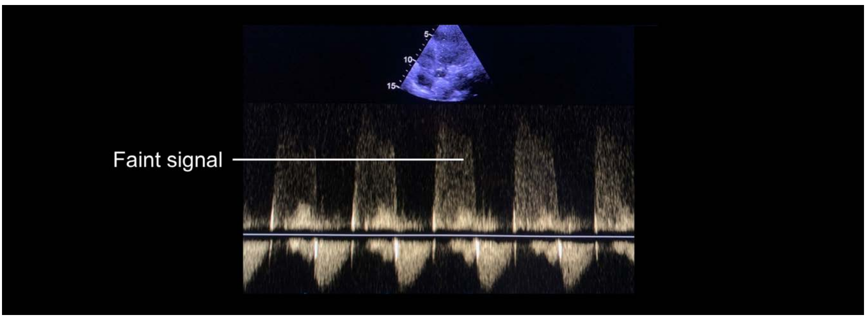



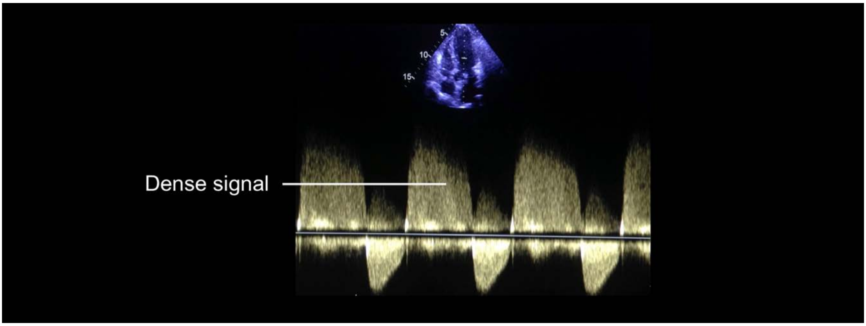
This technique works well for central jets of regurgitation, but will not be helpful in patients with eccentric or multiple jets.

Another semi-quantitative technique that can be used and is valid for eccentric jets is to measure the width of the vena contracta. This is the narrowest aspect of the color flow jet, and is best seen and measured in the parasternal long-axis view. Zooming in on the region of interest enables a more accurate measurement.

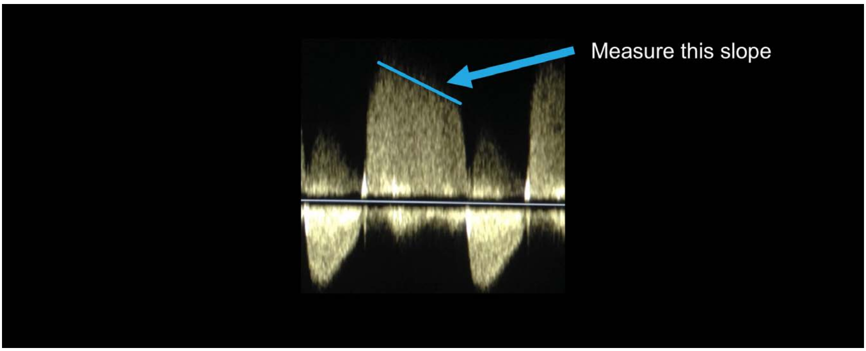
- A vena contracta of < 3 mm indicates mild regurgitation.
- A vena contracta of > 6 mm suggests severe regurgitation.


Continuous wave Doppler, measured from the apical five-chamber view, will detect aortic regurgitation. The density of the signal relates to the volume of regurgitation. A faint signal suggests mild regurgitation, and a dense jet is more likely in the moderate to severe range.



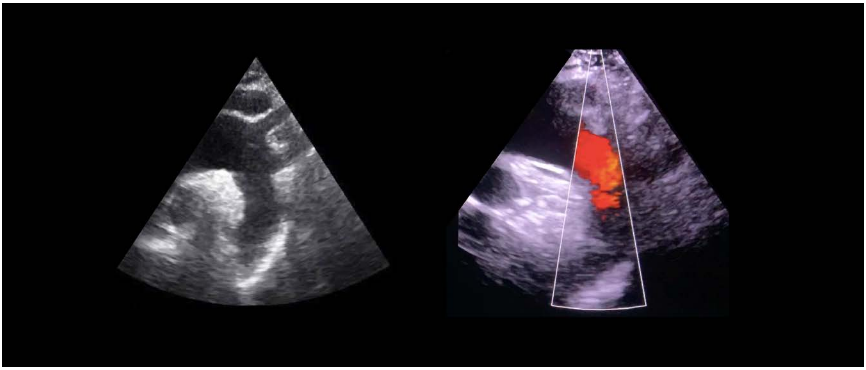


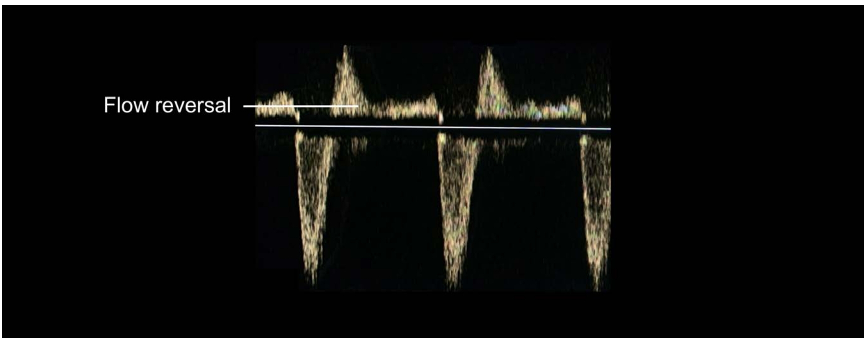

When a complete Doppler profile, or envelope, of the regurgitation is detected, a measurement of the pressure half-time can be made and used to guide the grading. A steep slope, measuring < 200 ms, indicates rapid equalization of pressure between the aorta and the left ventricle during diastole, suggesting severe aortic regurgitation. A pressure half-time of > 500 ms points towards mild aortic regurgitation.



# Using visual clues to help grade aortic regurgitation

Color and pulsed wave Doppler techniques can be used to look for the presence of diastolic flow reversal in the descending aorta. A brief burst of diastolic flow reversal may be a normal finding, but diastolic flow occurring throughout diastole (holodiastolic or pandiastolic flow) is abnormal and indicates at least moderate aortic regurgitation.





A jet of aortic regurgitation directed towards the mitral valve can disturb the normal movement of the anterior leaflet. Consequently, a fluttering effect might be seen on the anterior leaflet during two-dimensional echo and M-mode recording.

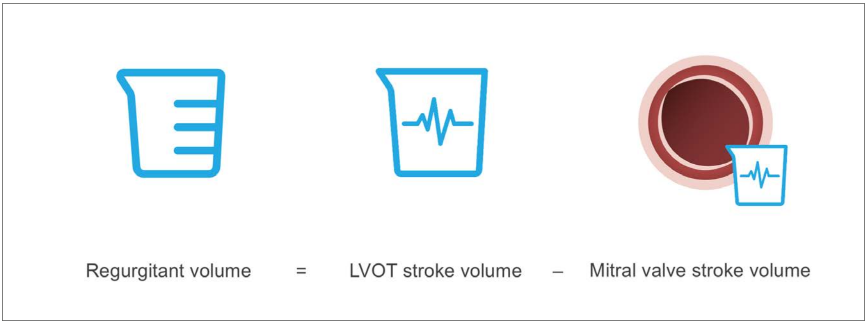
Fluttering effect

In more severe regurgitation, the leaflet function may become significantly impeded and appear deformed, with flattening occurring during diastole. This can disturb the blood flow through the mitral valve.

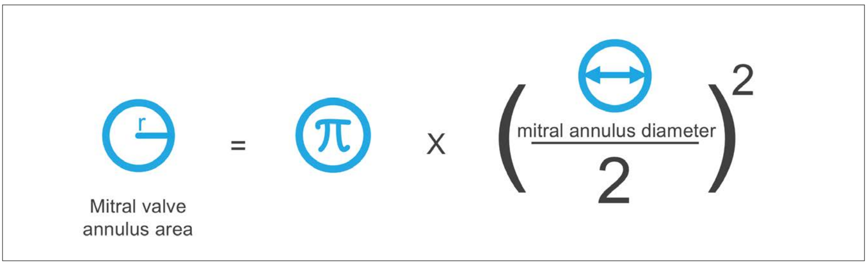
Left ventricular size is an important factor to consider when assessing aortic regurgitation. Chronic regurgitation can lead to dilation from the increased volume of blood. With mild aortic regurgitation, the left ventricular size is usually normal, whereas severe regurgitation will lead to increased left ventricular cavity dimensions.

# Quantifying aortic regurgitation

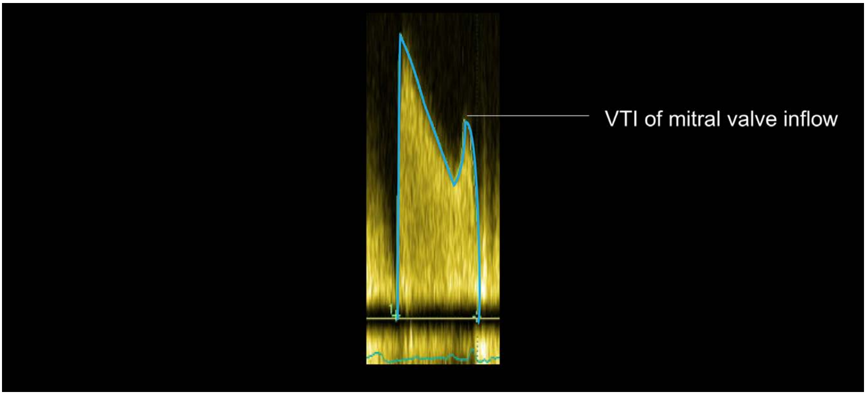
In a normal heart, the amount of blood entering the left ventricle from the left atrium will be almost equal to the amount that leaves through the aortic valve. In patients with aortic regurgitation, more blood is likely to be expelled during systole, as it will include not only the blood entering via the mitral valve, but also the amount that has re-entered the ventricle due to the regurgitation. Hence, left ventricular outflow will be greater than mitral valve inflow. The relationship between these two can be assessed to give a regurgitant volume from which the regurgitant fraction can be calculated.

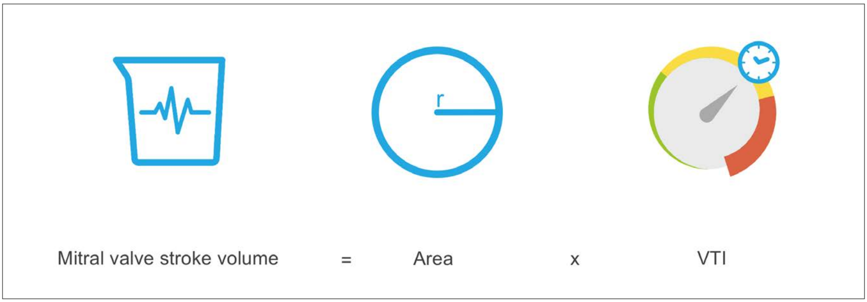



In order to assess the mitral valve flow, a measurement of the mitral valve annulus area is required. This measurement is derived by measuring the annulus during mid-diastole in the apical four-chamber view.

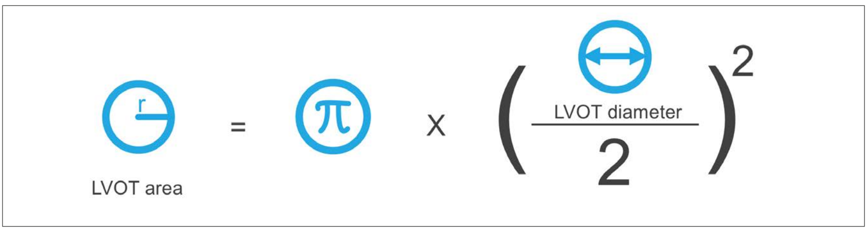


Pulsed wave Doppler waveforms, taken ideally at the annulus level in diastole, can be traced around to give the VTI of the mitral valve inflow. The mitral valve stroke volume can then be calculated by multiplying the cross-sectional area by the VTI.

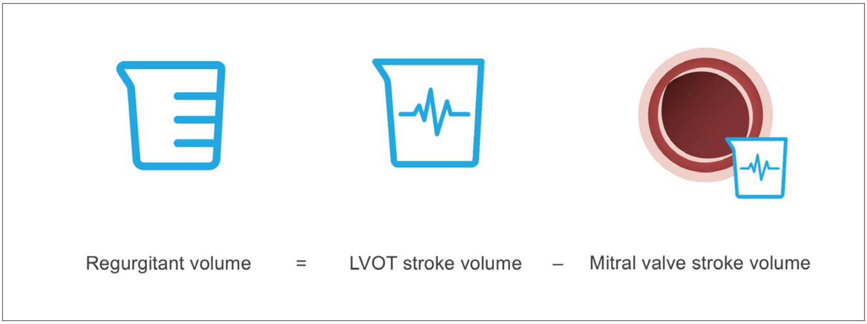


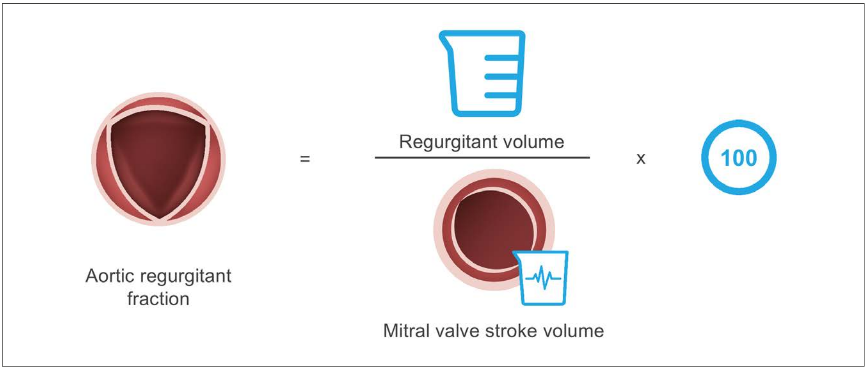

A similar approach is taken to derive the left ventricular outflow stroke volume. The outflow tract is measured from the parasternal long-axis window.



The VTI of the LVOT is measured in the apical five-chamber view and the stroke volume calculated.


- A value of < 30 mL is classed as mild and a value of > 60 mL as severe regurgitation.





- A value of < 30% is classed as mild and > 50% as severe regurgitation.

# Managing a patient with aortic valve disease

Best practice recommends that the decision to intervene, as well as the type of intervention for patients with significant valve disease, should be based on an individual risk-benefit analysis.

Ideally, such decisions are best done through a multidisciplinary heart valve team comprising relevant expertise in the management and outcomes of patients with valve disease.

- For asymptomatic patients with mild aortic stenosis, echo assessment is recommended every 3–5 years.
- For asymptomatic patients with moderate aortic stenosis, echo assessment is recommended every 1–2 years.

Patients with aortic stenosis can often remain asymptomatic for many years. When symptoms (shortness of breath, reduced exercise tolerance, angina, syncope) appear, there is a relatively rapid decline in survival rate.

Symptomatic patients with severe aortic stenosis require urgent intervention in the form of open-heart surgery. If surgery is not a possibility due to risks related to frailty or comorbidities, a transcatheter intervention may be appropriate.

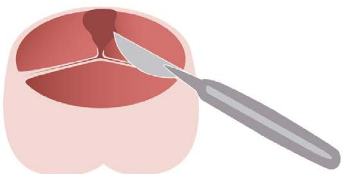
- Asymptomatic patients with a peak aortic velocity of > 4 m / s should be reviewed at least every six months.
- If the maximum velocity is noted to increase by > 0.3 m / s per year, then surgery should be considered.

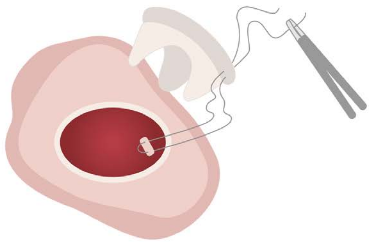
Asymptomatic patients with severe aortic stenosis and reduced left ventricular function are likely to benefit from surgery. Similarly, valve replacement is recommended for asymptomatic patients undergoing coronary artery bypass surgery.

For patient follow-up, it is essential to maintain the same approach and standards during serial echocardiography. Images taken from different views, and inconsistent approaches to measurement, can lead to erroneous findings. Follow-up requires care and precision in both image acquisition and interpretation.

Acute aortic regurgitation is often due to conditions such as aortic dissection and infective endocarditis, and urgent surgery is likely required. Intervention for chronic aortic regurgitation will be dependent on symptoms, left ventricular changes or aortic root abnormalities.

Surgical intervention in the form of valve repair, where possible, or valve replacement, is recommended for all symptomatic patients.





*Patients with mild to moderate aortic regurgitation should be reviewed on an annual basis, with an echo being performed every two years.*

In patients with severe regurgitation without symptoms, left ventricular impairment (ejection fraction < 50%) and left ventricular dilation (end-diastolic diameter > 7 cm; end-systolic diameter > 5 cm) should be used as deciding factors for intervention.

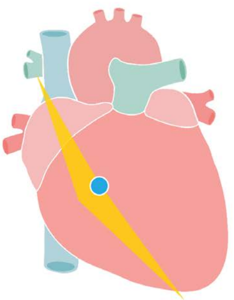
In genuinely asymptomatic patients, regular assessment of LV function and physical condition are crucial in identifying the optimal time for surgery. Hence, reviews every six months may be appropriate for these patients. Rapid progression of ventricular dilation or reduction in function is a reason to consider surgery.

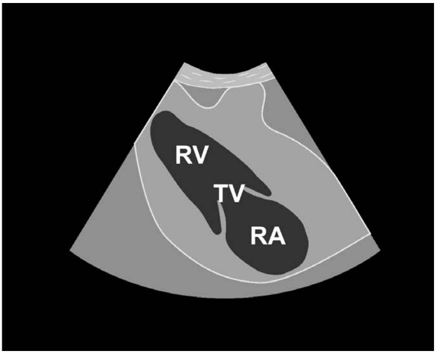
Chapter 4

# TRICUSPID VALVE DISEASE

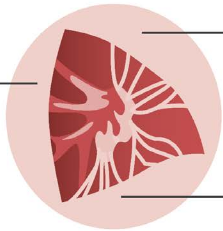
# Recognizing abnormal tricuspid valves

The first view of the tricuspid valve during a routine transthoracic echocardiogram usually occurs when performing the parasternal tilt view to explore the right ventricular inflow. Remember, this is achieved in the parasternal long-axis view, angling the probe downwards and to the right, towards the subject's right hip, bringing into view the right atrium, tricuspid valve, and right ventricle.






The tricuspid valve is the largest of the four heart valves, and is normally comprised of three leaflets; anterior, septal, and posterior.



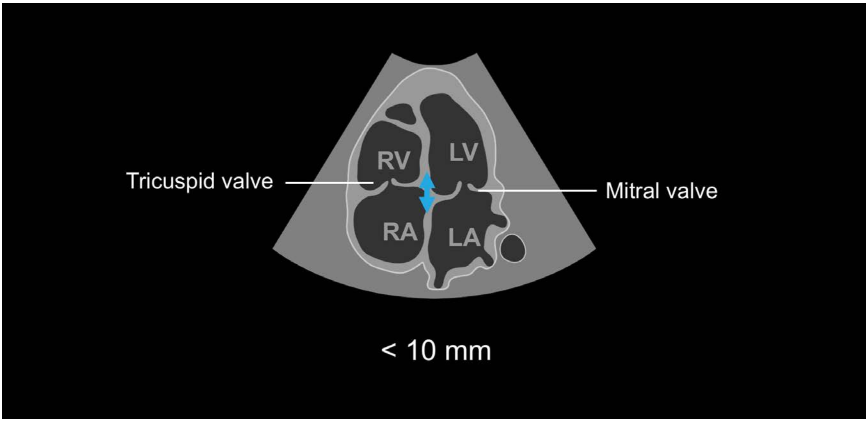

The subvalvular apparatus is similar to the mitral valve with a fibrous annulus, along with associated chordae and papillary muscles.

Identifying specific leaflets of the tricuspid valve (as viewed from the different echo windows) can be difficult, as very slight changes in position of the probe can result in the ultrasound beam being reflected from different aspects of the valve.

The two leaflets seen in the parasternal tilt view are usually the large anterior, and the septal leaflet of the tricuspid valve, though tilting the probe more inferiorly may give a view of the anterior and posterior leaflets. In this view, you may also be able to see two of the three papillary muscles usually associated with the tricuspid valve, with the moderator band attaching close to the anterior papillary muscle in the right ventricle.

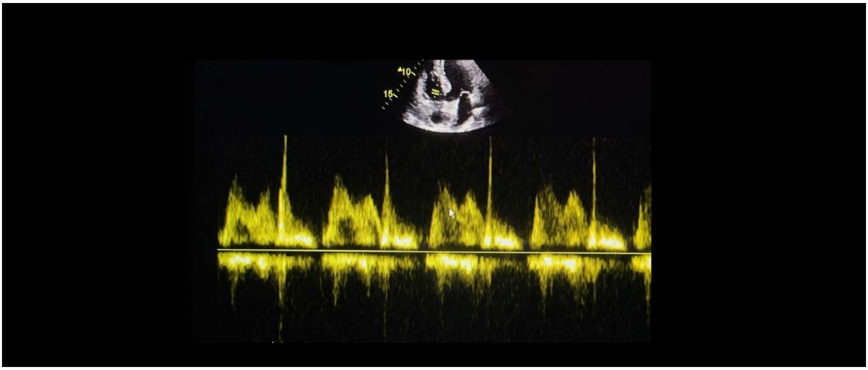
In the short-axis view, at the aortic level, it is generally assumed that the tricuspid valve leaflets seen here are the posterior and septal leaflets, though the anterior leaflet may be seen rather than the septal one, depending on the cut.

The apical four-chamber view usually gives a clear picture of the tricuspid valve. It is positioned slightly higher than the mitral valve, with the annulus being closer to the apex than the mitral annulus. The distance between the two should not exceed 10 mm in a normal heart. In this view, it is easy to identify the septal leaflet next to the interventricular septum. However, the leaflet seemingly attached to the free wall may be either the anterior or posterior leaflet of the valve, depending on the amount of probe angulation and rotation.




The subcostal approach is not widely used and is often difficult to achieve, but it is worth attempting to view the tricuspid valve from here. This requires some practice and involves modifying the standard subcostal view by rotating the probe ninety degrees in a counterclockwise direction from the standard subcostal four-chamber view, while remaining centred on the right ventricle. If a clear view of the tricuspid valve is achieved from this window, then all three leaflets of the valve should be visible in a short-axis, enface view.

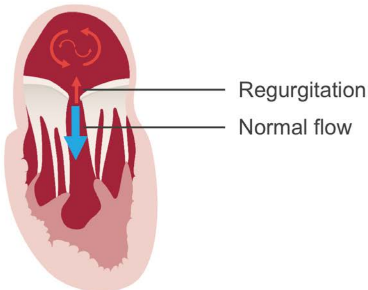
Blood flow through the tricuspid valve can be best assessed from either the apical window or the parasternal window.



The typical spectral Doppler pattern appears similar to the mitral valve; however, peak velocities are usually lower because of the low-pressure difference between the right atrium and right ventricle.

# Identifying and grading tricuspid regurgitation

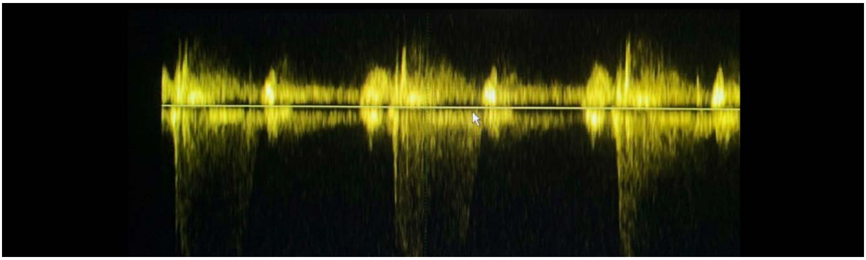
Normal tricuspid valve function relies on complex interactions between the valve leaflets, subvalvular apparatus, the tricuspid annulus, and both the right atrium and ventricle. Abnormalities affecting any one or more of these structures are likely to result in tricuspid regurgitation. A small amount of tricuspid regurgitation is a common finding during echocardiography, appearing as a small, central jet and typically described as trivial or mild.

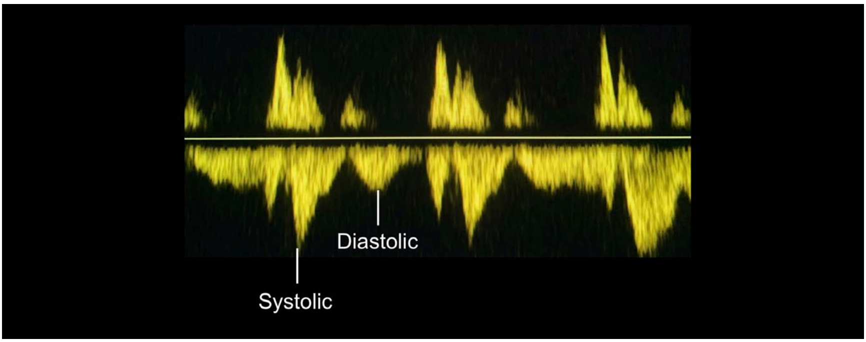



Tricuspid regurgitation

Organic tricuspid regurgitation may occur as a consequence of valve leaflet pathology due to endocarditis, carcinoid heart disease, trauma, radiation damage, and as a result of leads from pacemakers or defibrillators preventing the normal closure of the leaflets. However, it is more common to have functional tricuspid regurgitation, occurring secondary to some other cardiac pathology. This is usually due to left-sided heart disease leading to right-sided heart failure. This results in dilation, global right-sided dysfunction, right ventricular regional wall motion abnormalities, and right atrial dilation. Both pulmonary hypertension and dilation of the tricuspid annulus can result in secondary tricuspid regurgitation.

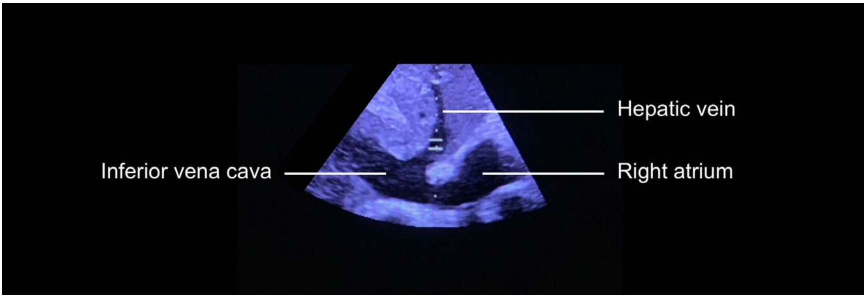
To evaluate severity of regurgitation, all views of the tricuspid valve should be inspected with both color and spectral Doppler.



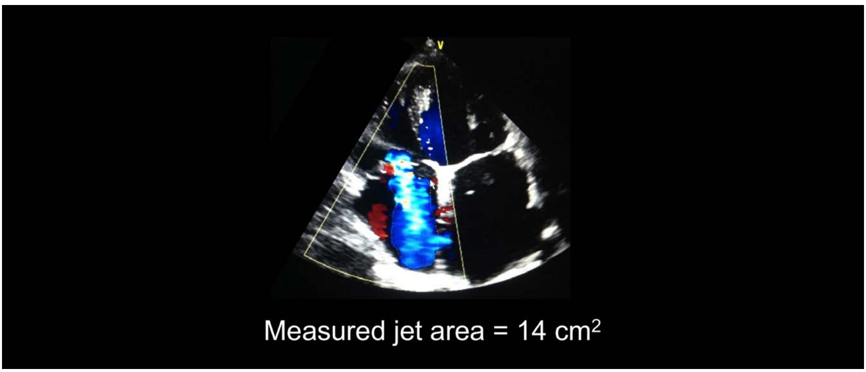



Semi-quantitative and quantitative approaches to assigning a grade to the regurgitation are recommended in the guidelines.

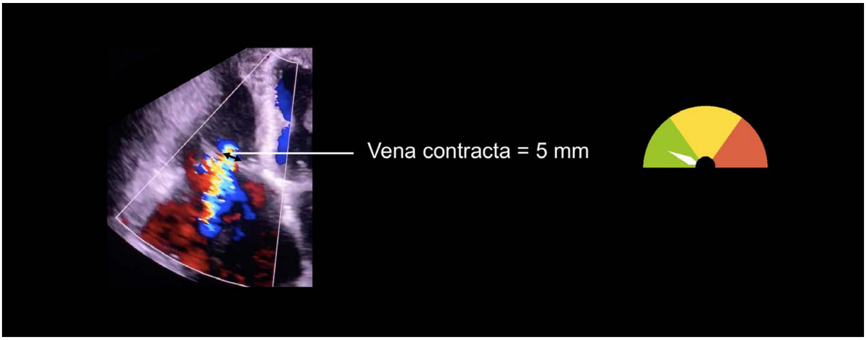
Color flow imaging allows for assessment of the jet area in the right atrium, the vena contracta at the valve orifice, and the flow convergence within the right ventricle. Spectral Doppler provides extra information based on the signal intensity and the shape of the waveform. Pulsed wave Doppler is useful for assessing blood flow in the hepatic veins.




A regurgitant jet area of > 10 $cm^2$ is generally accepted as evidence of severe tricuspid regurgitation, but it is important to note that this measurement can be affected by the systolic pressure difference between the right ventricle and the right atrium. The pressure difference may be very low in situations where there is very severe or torrential tricuspid regurgitation, in which case the jet area will be small, and the severity underestimated.

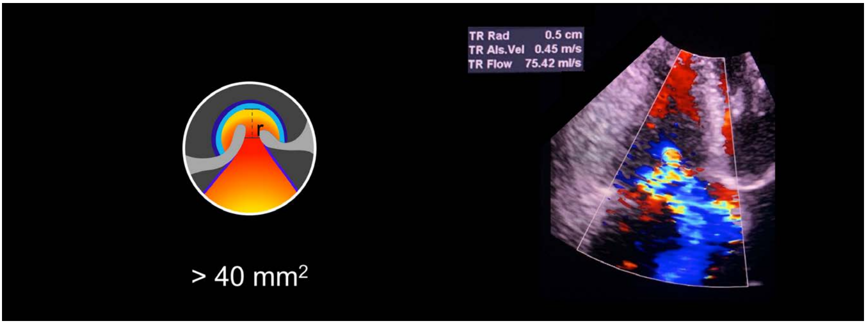


Measurement of the vena contracta can be made in the parasternal tilted right ventricular inflow view or the apical four-chamber approach. A measurement of > 7 mm is suggestive of severe tricuspid regurgitation.

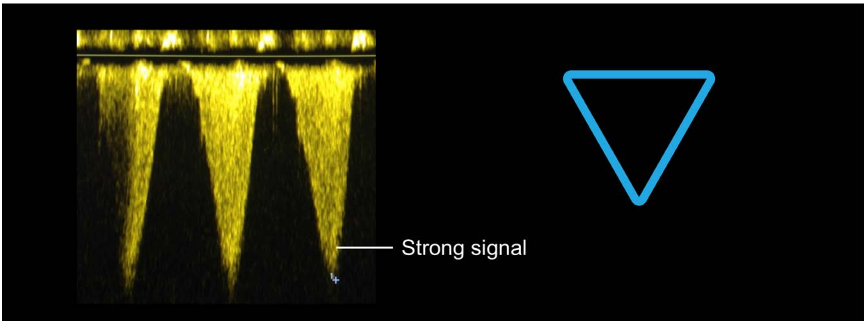



A quantitative approach, similar to that used for the mitral valve, can be undertaken. For example, an effective regurgitant orifice area can be measured using a PISA assessment. However, it is important to note that significant underestimation might occur when applying this technique to the tricuspid valve due to the size and shape of the orifice area, which is often star-shaped or elliptical, rather than round. Low-flow rates across the valve also affect the calculation. Guidelines suggest that an effective orifice area of > 40 $mm^2$ indicates severe tricuspid regurgitation.

Assessing the shape and density of the continuous wave Doppler waveform of regurgitation can help to determine severity.




A strong or dense signal may well signify severe regurgitation, particularly when linked to a pointed, triangular shaped jet.




When imaging from the subcostal approach, pulsed wave Doppler can be positioned in the hepatic veins and can provide information to confirm the presence of severe regurgitation. Systolic flow reversal might be seen for example when significant regurgitation is present.

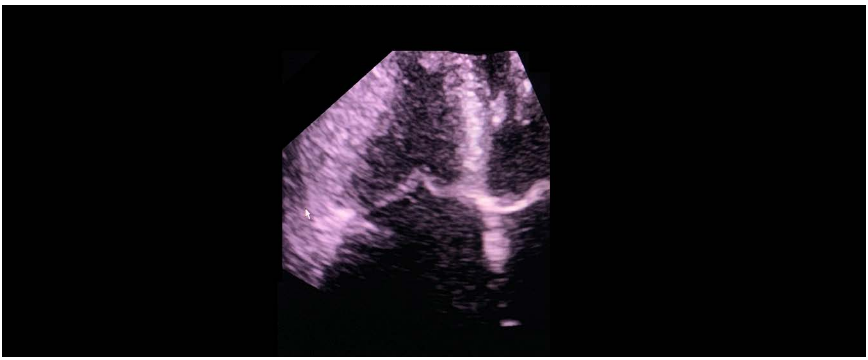
The range of approaches for assessing tricuspid regurgitation provides plenty of opportunity to draw together information pointing towards a diagnosis of either mild or severe tricuspid regurgitation, initially based on a semi-quantitative approach. If the severity grading remains unclear, quantitative calculations might be applied.

# Assessing tricuspid valve stenosis

Organic tricuspid stenosis is rare, but it should be considered when assessing patients with a history of rheumatic fever. In particular, when rheumatic mitral stenosis is present, the possibility of concomitant tricuspid stenosis should be ruled out. Other disorders that might give rise to a stenotic tricuspid valve include carcinoid heart disease, anti-phospholipid syndrome, and Ebstein's disorder.

Functional tricuspid stenosis can occur due to thrombus or intracardiac masses. It should also be considered in patients who have had devices inserted. This includes pacing devices with leads passing through the tricuspid valve or septal closure devices, which when incorrectly placed, might disrupt normal leaflet function.

Thickened tricuspid leaflets are not particularly easy to identify, so a visual inspection might not detect organic tricuspid stenosis. However, a visual inspection may highlight a stenosis resulting from implanted devices.



Continuous wave Doppler through the tricuspid valve, probably best measured in the apical four-chamber view, may be helpful in identifying increased forward velocities through a stenotic valve.

The mean pressure gradient is measured by assessing the velocity-time integral of the tricuspid valve inflow.

- A mean pressure gradient of > 5 mmHg is consistent with the presence of significant tricuspid stenosis.
- Pressure half-time measurement can also be made, with values > 190 ms, indicating severe tricuspid stenosis.

# Using guidelines for patient management

Tricuspid stenosis is rare and might be an incidental finding. Transthoracic echo should be used to assess the anatomy of the valve and the associated structures. Transthoracic echo is indicated to both determine the cause and evaluate the severity of tricuspid regurgitation. In addition, measurement of right-sided chamber size and function, together with inferior vena cava size and pulmonary artery systolic pressure assessment, is required. Don't forget to include a thorough assessment of the left heart, including the mitral valve.

Untreated, severe tricuspid regurgitation has a poor prognosis, yet evidence suggests that relatively few patients are provided with appropriate treatment. This is partly due to a lack of awareness of the significance of the issue, and partly due to a lack of knowledge about the options for treatment.

Tricuspid valve intervention is a Class I recommendation for patients with severe tricuspid stenosis undergoing surgery for left-sided valve disease. Tricuspid valve surgery is also recommended for symptomatic patients with isolated, severe tricuspid stenosis. If such patients are shown to have no significant tricuspid regurgitation, then percutaneous balloon tricuspid commissurotomy may be considered.

Tricuspid valve repair may be beneficial for patients with mild or greater functional tricuspid regurgitation at the time of left-sided valve surgery, with either tricuspid annular dilation or evidence of right heart failure.

Tricuspid valve repair may be considered for patients with moderate functional tricuspid regurgitation and pulmonary artery hypertension at the time of left-sided valve surgery.

Tricuspid valve surgery can be beneficial for symptomatic patients due to severe primary tricuspid regurgitation, who are unresponsive to medical therapy.

Tricuspid valve surgery may be considered for asymptomatic or minimally symptomatic patients with severe primary tricuspid regurgitation and right ventricular dilation or dysfunction.

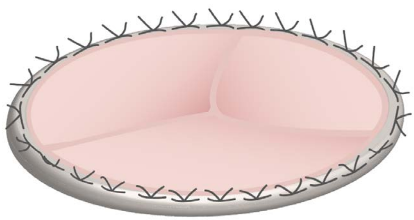
Tricuspid valve repair is a rapidly developing field, with both surgical and catheter based interventional approaches being performed.

In terms of surgical approaches to repairing the tricuspid valve, an annuloplasty ring is generally inserted with the aim of recreating a normal annular size and shape.

Valve replacement | Annuloplasty | Coaptation device

Bioprosthetic valves tend to be used when a decision is made to replace the valve. However, surgical approaches to tricuspid valve treatment are associated with significant mortality.

Consequently, there is significant interest in transcatheter approaches to treating tricuspid regurgitation, with a range of approaches that have been developed. There are significant challenges to overcome, particularly in terms of the lack of suitable anchoring structures and the relatively large size of the valve. Three categories of percutaneous approaches are currently being used: valve replacement, annuloplasty, and coaptation devices.



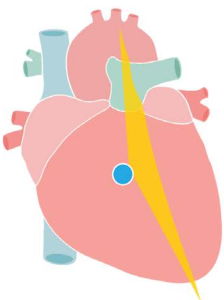
Chapter 5

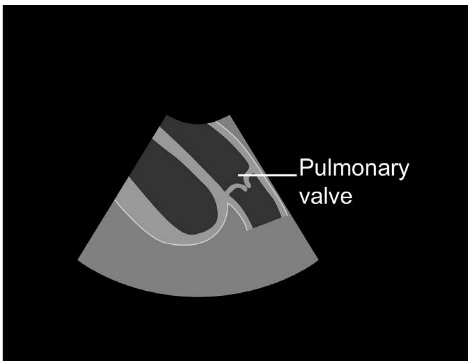
# PULMONARY VALVE DISEASE

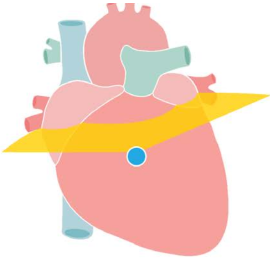
# Recognizing an abnormal pulmonary valve

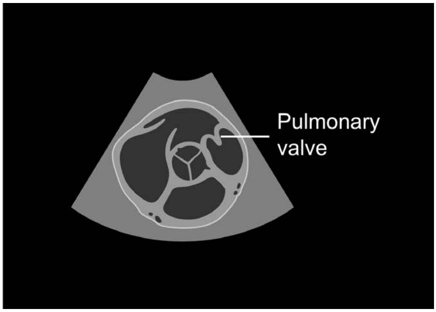
Abnormalities of the pulmonary valve often arise due to congenital heart disease and consequently are initially dealt with in infancy. When detected in adults, pulmonary valve abnormalities are likely to be due to some form of intervention in childhood, perhaps a previous surgical repair or balloon dilatation. However, pulmonary valve abnormalities can also occur with endocarditis and other rare conditions such as cardiac carcinoid disease and rheumatic disease.

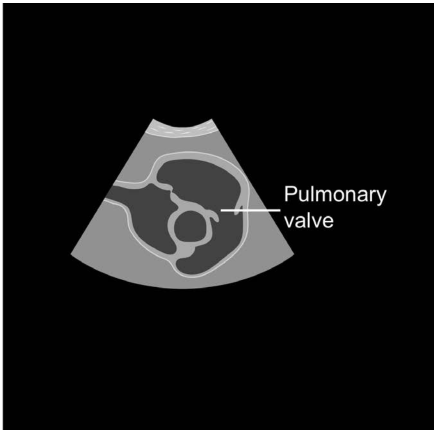
There are three standard views for seeing the pulmonary valve: the parasternal long-axis right ventricular outflow view, the parasternal short-axis at the aortic valve level, and the subcostal short-axis approach.



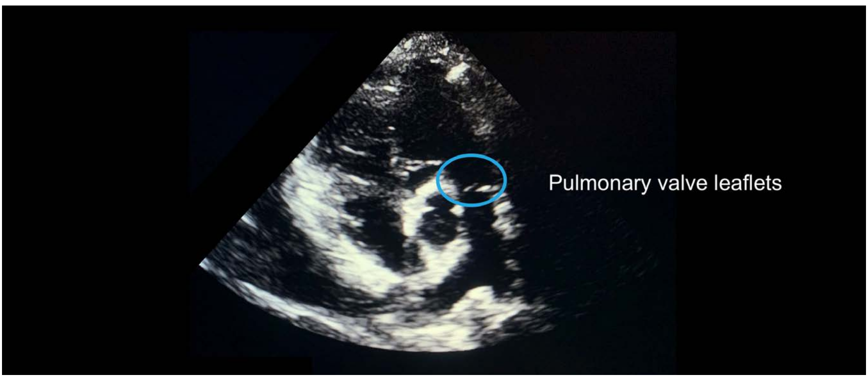






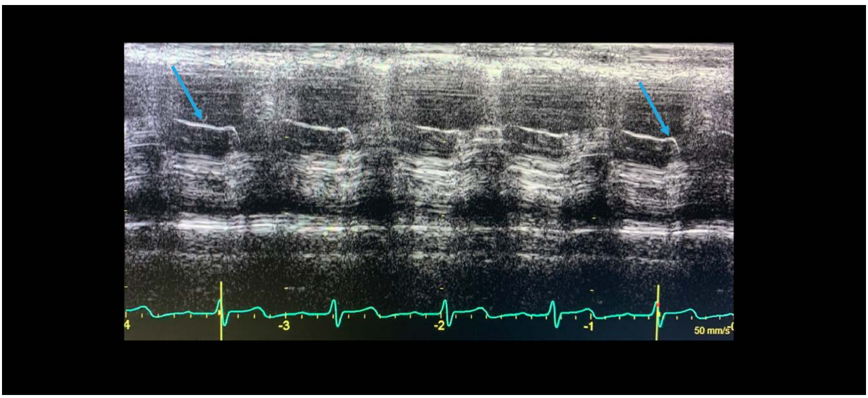

As a semilunar valve, the pulmonary valve is composed of three leaflets, similar to the aortic valve.



Generally, the valve leaflets are thinner than the aortic valve due to the lower pressures in the right side of the heart. Unlike the aortic valve, visualizing of the pulmonary valve is difficult due to lung tissue obstructing the view, and the standard transthoracic echocardiography views only ever show two leaflets at best. Consequently, it is virtually impossible to be certain which leaflets are being seen at any one time. Visual assessment cannot be relied upon because of the challenges in viewing the pulmonary valve.

Occasionally, thickened cusps might be observed, suggesting the presence of valve stenosis.

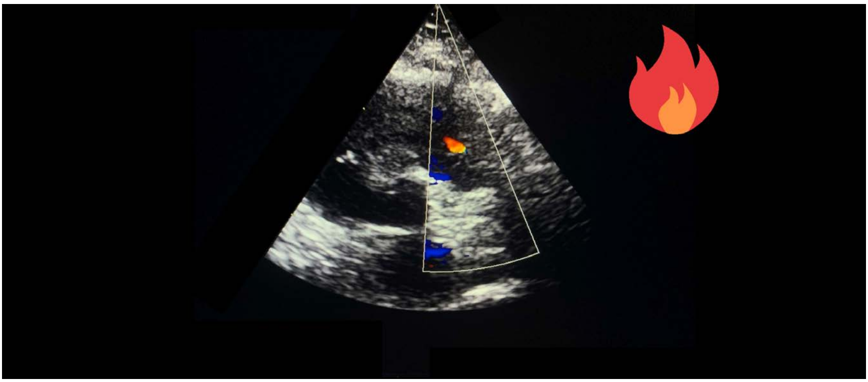
An M-mode recording, with the cursor aligned through the pulmonary valve in the right ventricular outflow tract, might give an indication of pulmonary valve stenosis. The signal detected from the leaflets may be thicker and brighter than usual. Close inspection might even reveal an increased a wave, as shown by a distinctive notch occurring in the valve M-mode profile, just prior to the QRS signal on the ECG monitor lead. This notching is caused by the increased force of the right atrial contraction pushing against the stenotic valve.



# Grading pulmonary regurgitation

Doppler interrogation of the valve from as many of the three windows as possible, using both color flow mapping and spectral Doppler, is important.

When color Doppler is used to assess the pulmonary valve in normal subjects, it will almost always show a very narrow, short (< 10 mm), red *flame* of pulmonary regurgitation, directed from the pulmonary valve towards the right ventricle during diastole.



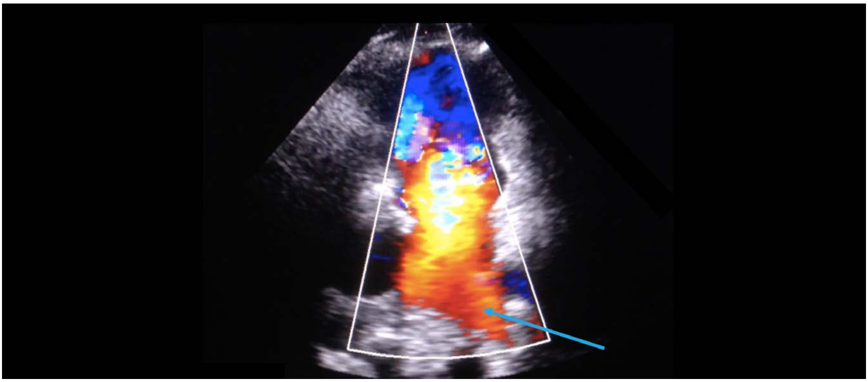
This is usually referred to as either functional regurgitation, physiological regurgitation or a trace of pulmonary regurgitation.

Pathologic pulmonary regurgitation is often found in the setting of pulmonary hypertension.

Color jets that appear wide at the origin, just below the pulmonary valve, suggest more significant regurgitation. However, care needs to be taken to ensure that a broad jet is not simply being seen due to the angle at which the valve is being viewed.

Measurement of the maximum color jet width at its point of origin can be used to suggest how severe the regurgitation might be. A jet width that covers more than at least 60% of the outflow tract suggests the presence of severe pulmonary regurgitation.

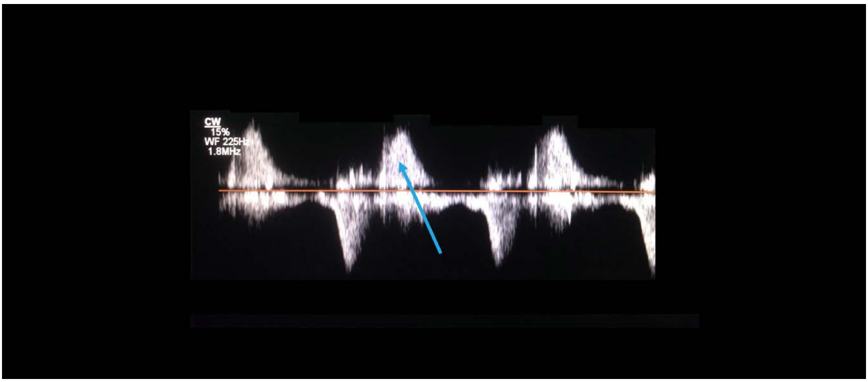
Color flow reversal in the pulmonary arteries often indicates severe pulmonary regurgitation.



It is important to note that in severe pulmonary regurgitation, the color jet may be brief in duration due to the rapid equalization of pressures between the pulmonary artery and the right ventricle.

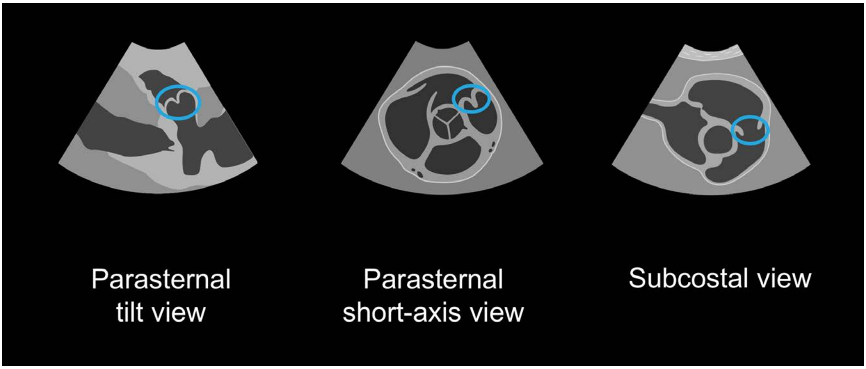
Quantitative assessment, such as vena contract and flow convergence assessment, has not been validated for use during pulmonary valve assessment.

Continuous wave Doppler can usually be aligned well with the flow through the valve in the parasternal short-axis view. Qualitative information derived from the Doppler signal is used to assess severity. A weak, light Doppler signal—with a long pressure half-time—is consistent with mild pulmonary regurgitation. Converesely, a dense Doppler waveform, with a steep deceleration slope, suggests more significant regurgitation. In patients with known congenital heart disease, a pressure half-time of < 100 ms strongly indicates severe pulmonary regurgitation.

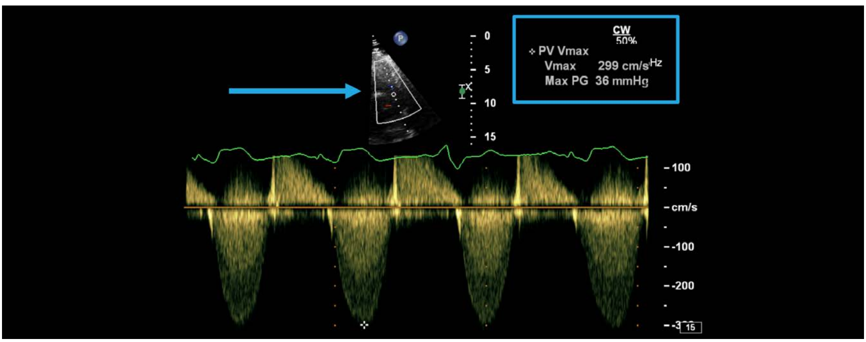


# Assessing pulmonary valve stenosis

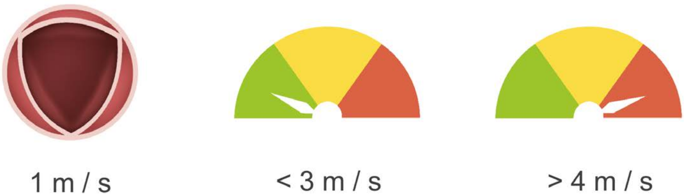
All potential views should be used when assessing flow through the pulmonary valve with spectral Doppler.




Continuous wave Doppler measurement of blood flow velocity within the right ventricular outflow tract usually gives the first indication that pulmonary stenosis may be present. The forward flow, or antegrade velocity, will be increased. A maximum velocity should be detected, from which a pressure gradient can be derived, using the Bernoulli equation.



- A normal velocity across the pulmonary valve will be in the region of 1 m / s.
- Mild pulmonary stenosis is defined as a peak velocity of < 3 m / s.
- Severe stenosis is defined as a peak velocity > 4 m / s.

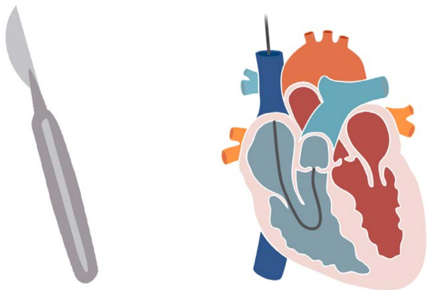



Keep in mind that an increased velocity detected by the use of continuous wave Doppler might be caused by narrowing elsewhere in the right ventricular outflow tract, rather than being due to pulmonary valve stenosis.

Obstructions can develop below the valve (subvalvular), or above the valve (supravalvular). Pulsed wave Doppler should be used to seek the point at which the velocity increases; this step-up will reflect the site of the narrowing. Color flow Doppler may also be useful in locating any narrowing.

# Managing a patient with pulmonary valve disease

Both surgical and catheter-based interventions are available as treatments for pulmonary stenosis.



The method used depends on the degree of obstruction, right ventricular pressure, right ventricular function, and other associated symptoms (e.g., reduced exercise capacity).

For most patients with moderate or severe isolated pulmonary valve stenosis, pulmonary balloon valvuloplasty is both safe and effective in reducing the pulmonary valve gradient and improving symptoms.

Surgical valvotomy is another form of treatment that can be performed in the absence of malformation of the pulmonary annulus. If there is significant malformation of either the valve or annulus, pulmonary valve replacement may be required.

Patients who have mild native pulmonary valve stenosis do not usually require intervention but should be followed up. Patients with a history of pulmonary stenosis who have undergone some form of interventional treatment require ongoing follow up. In particular, monitoring of pulmonary regurgitation by echocardiography is required, along with an assessment of right ventricular size and function.

Pulmonary regurgitation in adults is rarely severe, and is usually insignificant.

However, it is important to be aware that pulmonary regurgitation, following congenital heart disease repair (usually tetralogy of Fallot), is a common late complication with important clinical implications.

Patients with a previous tetralogy repair should be considered for surgery when moderate or severe pulmonary regurgitation is detected in association with symptoms such as reduced exercise capacity. In addition, severe pulmonary regurgitation with concomitant right ventricular dilation, impaired right ventricular function, arrhythmias or significant tricuspid regurgitation requires surgical intervention.

Patients with significant pulmonary regurgitation may show signs of decreased right ventricular function. Follow-up enables appropriate timing of pulmonary valve replacement. Although specific data is lacking to indicate exactly when valve replacement should be undertaken in the presence of right ventricular dysfunction, it is likely that function will improve or remain stable when the volume overloading (due to pulmonary regurgitation) is prevented by replacing the valve.

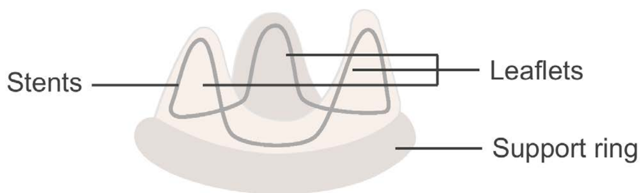
Chapter 6

# PROSTHETIC VALVES

# Recognizing the variety of prosthetic valves

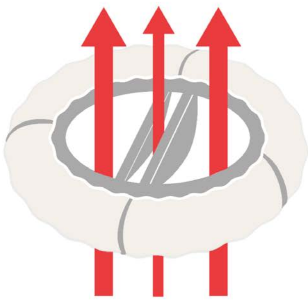
There are a range of options available for the replacement of damaged heart valves, both in terms of procedures and types of valves. There are three main valve types, based on the construction of the valve: bioprosthetic, mechanical, and homograft replacements.


Bioprosthetic valves are made from animal tissue, known as xenografts, and are the most commonly used replacement valves. Porcine valves or bovine pericardial tissue are often used to make these valves. Bioprosthetic valves are designed to resemble the anatomical structure of a native valve. The leaflets are usually shaped to match normal leaflets and are attached to a support ring. Raised structures, known as stents, are usually present at each of the commissures. Stentless versions do exist but they are more complex to implant and are generally less frequently used.



Mechanical valves with a variety of designs have existed for many years. Currently, the most commonly implanted mechanical valve is the bileaflet model. The long-lasting nature of mechanical valves means that it is not unusual to see patients with older versions of mechanical valves (e.g., tilting disc or ball and cage designs). A bileaflet valve is comprised of two hinged semicircular discs that open within the valve ring to reveal three routes for blood flow: two large outer orifices and a smaller central opening.

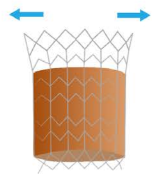
Bileaflet mechanical valve | Tilting disc valve | Ball and cage valve



Homografts, made from cryopreserved native human tissue valves (taken post-mortem from donors) are also used. These are usually used as semilunar valve replacements.

Open-heart surgery used to be the only approach for replacement valve implantation. However, there have been rapid developments in transcatheter technology, transcatheter aortic valve implantation or replacement (TAVI) is now a standard approach for suitable patients. Transcatheter valves come in two varieties: balloon-expandable valves comprised of bovine tissue on a cobalt-chromium metal frame, and self-expanding valves constructed from pig or bovine pericardial tissue within a nitinol, flexible wire framework.

Balloon-expandable valve

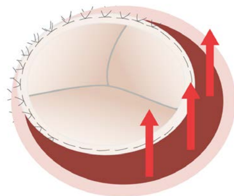


Self-expandable valve

# Discovering what can go wrong with prosthetic valves

Mechanical failure of structures within a replacement mechanical valve is rare. Modern bioprosthetic valves are becoming increasingly durable, though the leaflet tissue can gradually degenerate, resulting in reduced pliability and subsequent stenosis or regurgitation.

Issues related to the sewing ring of the replaced valve can develop due to changes occurring in the valve annulus. Loss of sutures can lead to regurgitation from around the sewing ring.

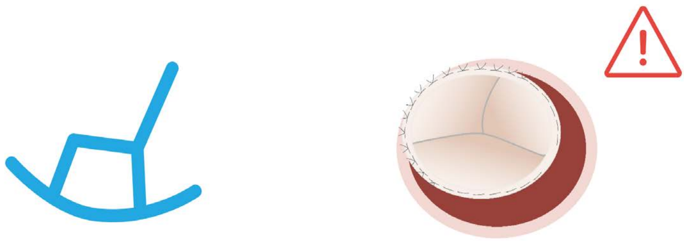


Mechanical replacement valves increase the risk of thrombus formation. Thrombi can result in embolic events or valve dysfunction. Recently it has been recognized that thrombus formation might also be a significant issue for biological valves too.

Infection associated with replacement values is a serious clinical issue. Endocarditis may give rise to vegetations similar to those found on native valves; however, if the infection is only in the sewing ring, vegetations may not be visible. In such cases, observation of how well the valve structure appears to be fixed in position, and the presence of paravalvular regurgitation, might be the only signs of the issue.

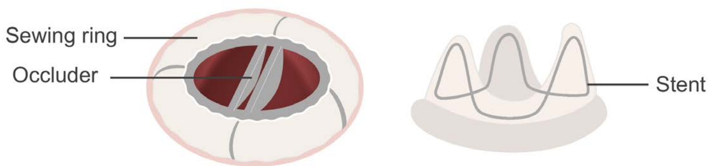
A replacement valve that appears loose, typically described as *rocking*, strongly suggests that there is a serious problem within the sewing ring.

This is often due to a loss of suture material resulting in valve dehiscence.



An overgrowth of endothelial and fibrous tissue around and within the valve, known as pannus, can affect prosthetic valve function in a similar manner to thrombus formation.

Replacement valves that are too small for the patient can lead to problems even if the prosthetic valve itself is functioning normally. When this occurs, it is known as patient-prosthetic mismatch. By definition, mechanical and xenograft replacement valves will always cause an element of patient-prosthetic mismatch because the presence of additional structures (e.g., sewing ring, occluders, and stents) take up space that would normally be available for blood flow.

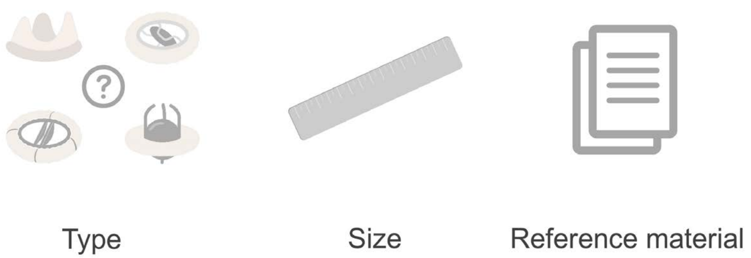



However, significant problems don't usually arise unless the mismatch is severe.

# Assessing the function of prosthetic valves

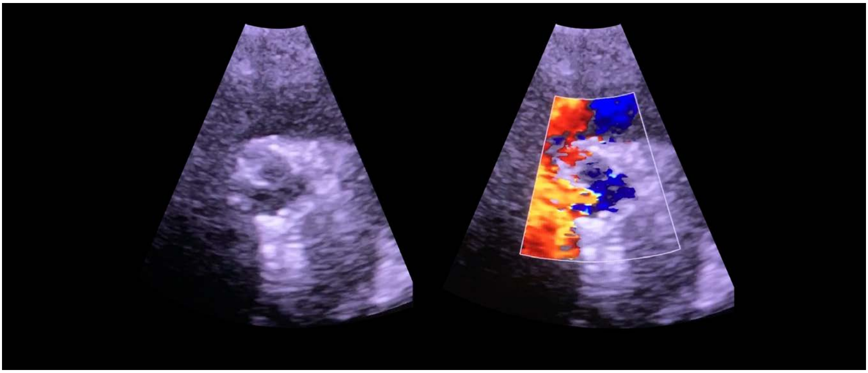
Echocardiographic assessment is key to the assessment of replacement valve function, yet it is often a very difficult task to perform and is fraught with pitfalls.

Each type of replacement valve has its own unique flow pattern and velocity. Imaging of the valve is often limited due to the effect of artifact and acoustic shadowing. Knowledge of the type and size of valve being assessed, as well as access to appropriate reference material, is essential in order to perform a comprehensive study of a patient with a replacement heart valve.




A postoperative echo is important in order to demonstrate normal valve function and record a set of baseline measurements that will be helpful for comparative purposes in subsequent studies.

Replacement valves in the aortic position should appear stable. The cusps of a bioprosthetic valve and the occluders of mechanical valves should be seen to open fully. This can often be demonstrated well by using color flow mapping to demonstrate that color fully occupies the orifice during systole.



Thickened cusps, immobile leaflets or occluders in the case of a mechanical valve, are signs of prosthetic valve obstruction. However, limited echo views might mean that it's not possible to easily spot these abnormalities. Doppler interrogation is often the key to highlighting an issue when measuring values outside the expected normal range for the valve.

General rules for an aortic valve replacement

- Suspect severe obstruction if the peak velocity is ≥ 4 m / s.
- Suspect severe obstruction if there is a mean pressure gradient of ≥ 35 mmHg.

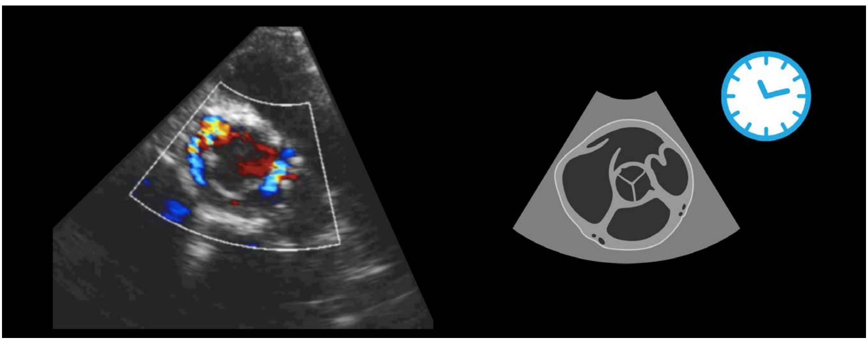
For a prosthetic mitral valve, a peak velocity > 2.5 m / s should make you suspicious of valve obstruction.

Although pressure half-time measurement for a prosthetic valve cannot be used to derive an orifice area, this measurement can prove useful, as the pressure half-time will lengthen dramatically when valves become obstructed. Hence, a pressure half-time of > 200 ms should be considered suspicious for a prosthetic valve obstruction.

On the right side of the heart, cutoff values are lower. A peak velocity of > 1.6 m / s for a prosthetic tricuspid valve and > 3.2 m / s for a prosthetic pulmonary valve are strongly suggestive of a prosthetic valve abnormality.

Regurgitation is usually visible in all mechanical valves, with a distinctive pattern depending on the valve type. For example, when the commonly used bileaflet valve closes, it is possible to see multiple small jets of regurgitation.

Trivial regurgitation might be present in normal bioprosthetic valves, but anything more than trivial is considered to be suspicious. Care should be taken to establish whether the cusps appear normal or not as well as specifically where the regurgitation is coming from. Check carefully to see whether the source is from within the valve or from around the sewing ring, indicating that it is paraprosthetic in origin. The short-axis view is useful for this purpose because it is possible to describe the location of paraprosthetic regurgitation using a clock face analogy.



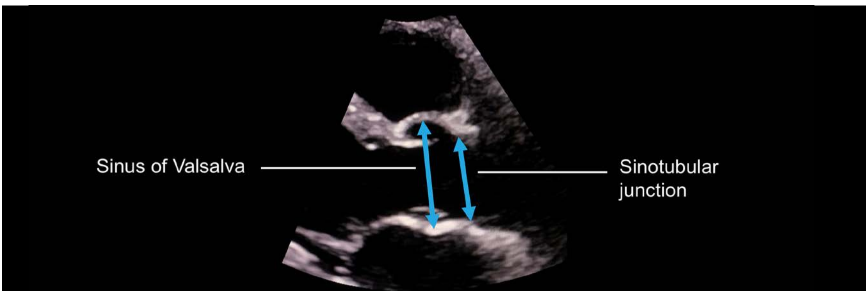
# Examining transcatheter valves

Symptomatic patients with aortic stenosis who are deemed unsuitable for surgical intervention may instead be suitable for a transcatheter aortic valve replacement (TAVR), also known as TAVI.

Transthoracic echocardiography is the main diagnostic tool to provide baseline information prior to the intervention and for follow-up after the procedure. A pre-procedural echo should provide details regarding the aortic valve and root that might be helpful to the interventional cardiologist performing the TAVR.

A clear indication of whether the valve is bicuspid or tricuspid should be given. TAVR performed in patients with bicuspid valves can result in significant post-procedural aortic regurgitation. Calcification outside of the valve leaflets (e.g., within the left ventricular outflow tract or the proximal aorta) should be highlighted, as this can lead to procedural complications such as aortic dissection.

The sinus of Valsalva and sinotubular junction diameter should be measured in diastole, and these measurements should be included in the report.



In addition to the aortic valve and associated structures, there are other aspects of the pre-procedural echo that should be highlighted. It is important to consider the thickness of the basal septum, as hypertrophy in this region may affect the choice and positioning of the TAVR valve.

Left ventricular function should be reported; however, even severely impaired left ventricular function is not a contraindication for TAVR.

Mitral regurgitation should be quantified. Some studies suggest that significant mitral regurgitation might be reduced following a TAVR. However, in those patients in whom regurgitation is not reduced, there is likely to be increased mortality. Knowledge about the amount of tricuspid regurgitation and right-heart size and function is useful. Studies indicate that tricuspid regurgitation is unlikely to improve following TAVR, and its presence is associated with a significantly increased risk of mortality.

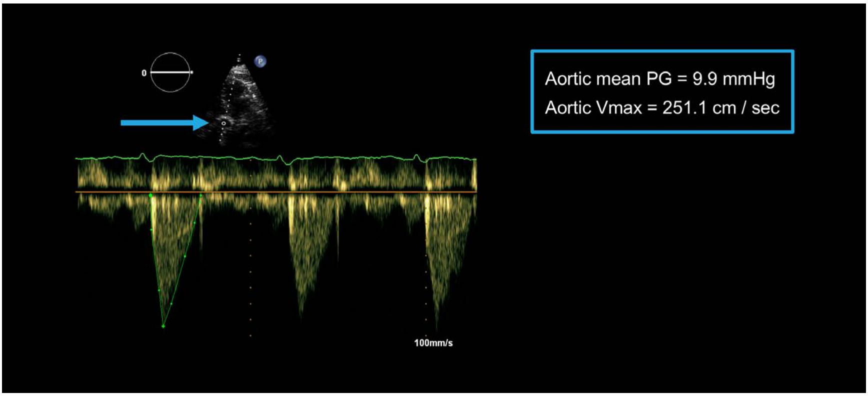
Current opinion indicates that following TAVR, patients should be followed up with a baseline transthoracic echo 30 days post-implant, followed by another scan at one year post-implant, and ongoing annual surveillance thereafter.

These post-procedural echos need to specifically evaluate the following.

- Replaced valve
- Left ventricular function
- Severity of mitral regurgitation

Valve follow-up is similar to that of standard prosthetic valves, with a visual assessment of stability, location, and if possible, leaflet appearance and movement. Device migration is a potential complication, so confirmation that its position is maintained is important. Based on experiences reported to date, structure failure of TAVR valves is rare.

Doppler interrogation should be used to record the maximum velocity and mean gradient. The effective orifice area should be calculated.




When using pulsed wave Doppler, try to ensure that the sample volume is placed before the stent in the LVOT, rather than within the stent itself, as this results in an underestimation of the effective orifice area.

Paravalvular regurgitation is a common finding post-TAVR and is an important predictor of long-term outcomes. It can be difficult to assess and quantify due to the acoustic shielding arising from the valve stent. There are often multiple paraprosthetic regurgitant jets, and there may even be a regurgitant jet through the valve too, making it difficult to assess paravalvular regurgitation. Features such as the number of jets, vena contra, jet width as a percentage of the left ventricular outflow tract, and presence of flow reversal in the aortic arch, can all be used to assist the grading of severity of regurgitation.

# Further reading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