ECHO MASTERCLASS
THE RIGHT HEART

HANDBOOK

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Abbreviation list

2D	2-dimensional
3D	3-dimensional
CW	continuous wave
ECG	electrocardiogram
EndoGLS	global endocardial strain
FAC	fractional area change
FreeWallSt	free wall strain
IVC	inferior vena cava
LA	left atrium
LV	left ventricle
LVOT	left ventricular outflow tract
PA	pulmonary artery
PADP	pulmonary artery diastolic pressure
PASP	pulmonary artery systolic pressure
PFO	patent foramen ovale
PLAX	parasternal long-axis view
PSAX	parasternal short-axis view
PW	pulsed-wave
RA	right atrium
RV	right ventricle
RVOT	right ventricular outflow tract
SVC	superior vena cava
TAPSE	tricuspid annular plane systolic excursion
TDI	tissue Doppler imaging
TTE	transthoracic echocardiography

Chapter 1

RIGHT-HEART BASICS

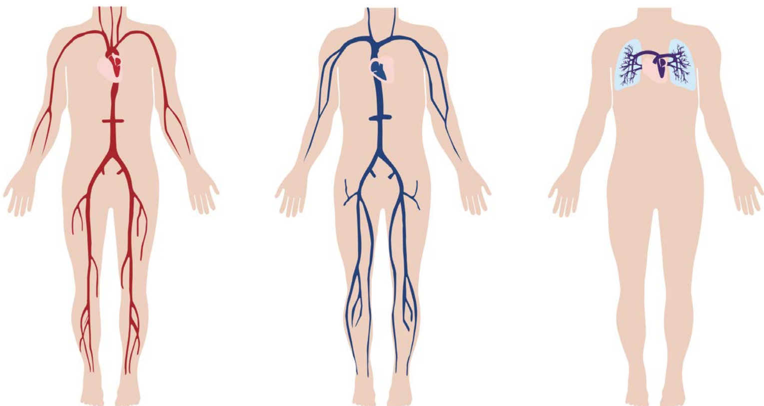
Reviewing the role of the right heart

The cardiovascular system is made up of two subsystems:

1. Arterial circulation (also known as systemic circulation)
2. Pulmonary circulation

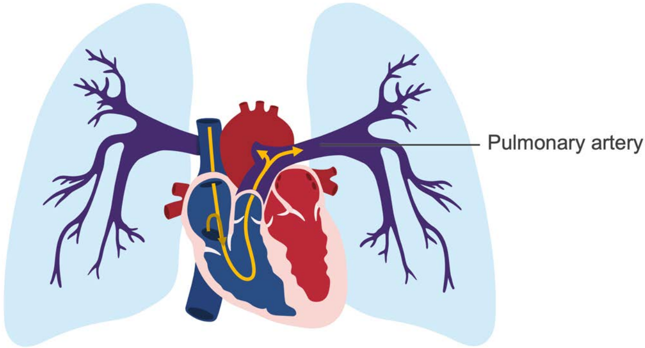
As blood leaves the left heart, it enters arterial circulation, which is responsible for delivering oxygenated blood to the organs and tissues of the body. Deoxygenated blood returning from the organs and tissues of the body (i.e., venous return) moves through the right heart and then on to the lungs.

As the blood leaves the right heart, it enters pulmonary circulation. Pulmonary circulation is responsible for reoxygenating the blood and subsequently delivering it to the left heart for distribution by arterial circulation, which starts the cycle again.



Arterial circulation Pulmonary circulation

The right heart is connected to blood vessels of the lung through the pulmonary artery (PA). Venous blood returning from the body into the right heart is directed to the lungs this way.



Flow of blood through the heart

We can break up the flow of blood through the right heart into a series of steps.

Step 1

Venous return from the body enters the right atrium (RA) during diastole via the inferior vena cava and the superior vena cava. From the RA, blood flows through the tricuspid valve and into the right ventricle (RV).

Step 2

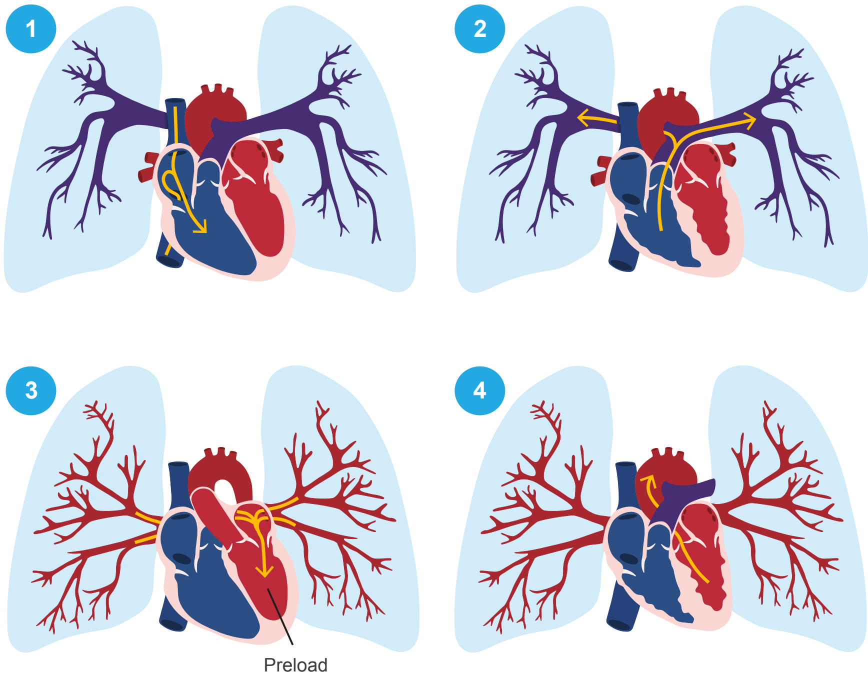
The blood is then pushed through the pulmonary valve, into the pulmonary artery, and to the lungs when the RV contracts during systole.

Step 3

Once at the lungs, the blood is reoxygenated. Next, the blood reenters the heart during diastole, first into the left atrium (LA) via the pulmonary veins and then through the mitral valve into the left ventricle (LV) in preparation for systole.

Step 4

The volume of blood in the LV at the end of diastole, immediately after it has left pulmonary circulation, is called preload. This blood will be pushed through the aortic valve and into the aorta and arterial circulation when the LV contracts during systole.



So, that's it! We have reviewed pulmonary circulation and the path blood takes as it moves toward becoming preload.

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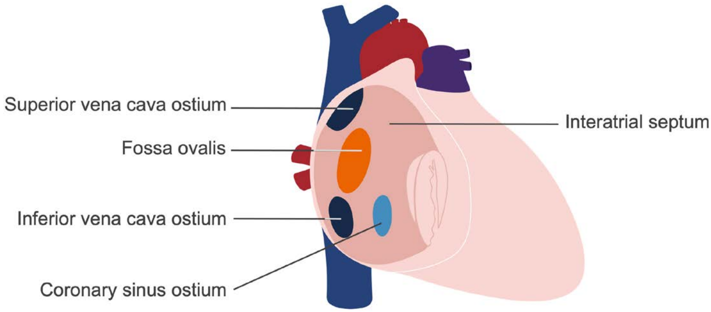
Reviewing the structures of the right atrium

Next, let's take a look at the anatomical structures within the RA so we can understand their basic function.

Side view of the RA

We'll start by looking inside the RA from the side. In this view, we can see all of the structures on and around the interatrial septum (i.e., the wall between the left and right atria).



Superior vena cava ostium

At the top of the RA, you will find the opening (i.e., ostium) of the superior vena cava. The superior vena cava channels blood returning from the upper venous circulation, such as the brain and the arms, into the right atrium.

Inferior vena cava ostium

At the bottom of the RA, you can see the ostium of the inferior vena cava. The inferior vena cava channels venous return from the lower half of the body, such as the abdomen and legs, into the RA.

Interatrial septum and fossa ovalis

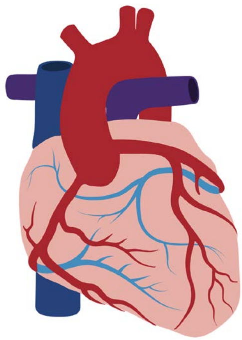
Straight ahead in this view, you are looking at the interatrial septum. This division between the left and right atria is characterized by the fossa ovalis, which is a remnant of the fetal circulation where the RV is bypassed. In a patient, you shouldn't see a hole. However, you will notice that the tissue of the fossa ovalis is a lot thinner than the interatrial septum itself.

Coronary sinus ostium

Below the fossa ovalis at the back of the RA, you will see the ostium of the coronary sinus.

Coronary circulation

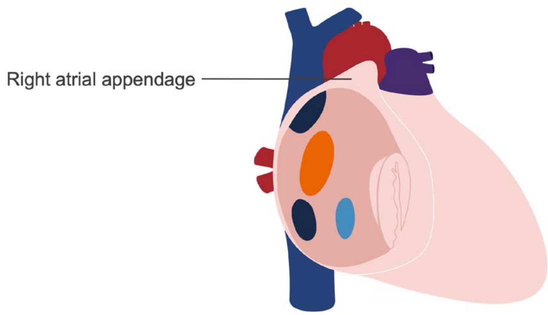
As a muscle, the heart requires blood to circulate and deliver oxygen. The blood vessels supplying the heart muscle with oxygenated blood, and those carrying deoxygenated blood away from the heart muscle, make up the coronary venous circulation.



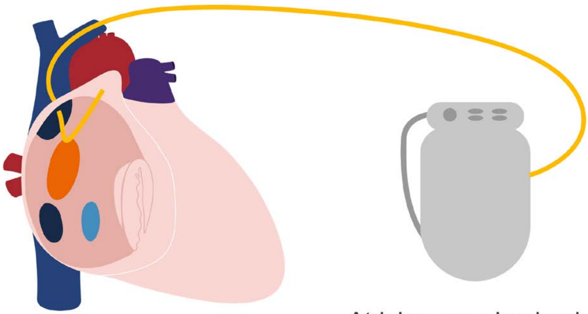
The coronary venous circulation ends with the coronary sinus, where blood returning from the heart muscle enters the RA.

Right atrial appendage

Our last structure to cover is one that is rarely talked about—the right atrial appendage. This structure allows for pressure relief within the atrium. The right atrial appendage can expand to increase the size of the atrium—a bit like building an annex or addition on the back of your house when you need more space.



Something to note is that atrial pacemaker leads are attached to the right atrial appendage. Most of the time we cannot see these leads on an echocardiogram, but in the event that you do, there's no need to be alarmed!



Now you can identify the structures within the RA and state their roles.

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Reviewing the structures of the right ventricle

Let's identify the anatomical structures of the RV and discuss their basic function.

Trabeculae carneae

The right ventricular endocardium is not as smooth as that of the LV. It is highly trabeculated, which means it has a lot of muscular ridges called the trabeculae carneae. For this reason, the inner lining of the RV sometimes seems slightly irregular and bumpy when visualized on echo. This is totally normal.

Chordae tendineae

The chordae tendineae are tendon-like cords of connective tissue that attach the tricuspid valve to the papillary muscles found at the bottom of the RV, securing it in place.

Papillary muscles

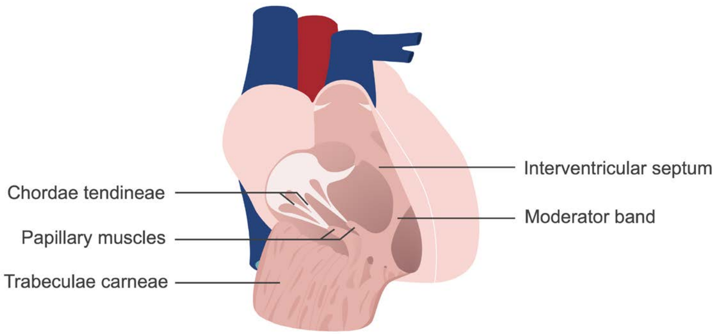
The papillary muscles are located at the bottom of the RV between the chordae tendineae and the wall of the ventricle. There are three papillary muscles associated with the tricuspid valve and, as alluded to earlier, their function is to anchor the tricuspid valve to the muscle of the RV.

Interventricular septum

The interventricular septum is a portion of muscle separating the RV from the LV. We will look at this structure in more detail in a moment.

Moderator band

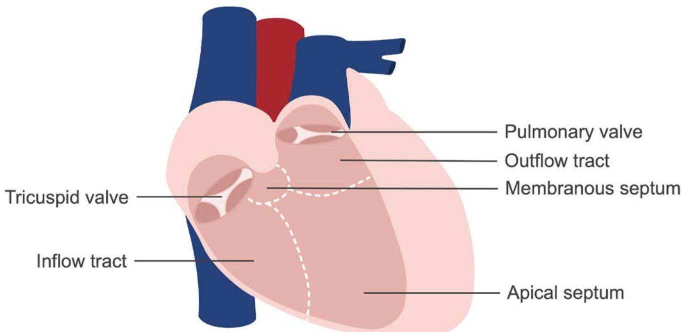
Connecting the papillary muscles and the interventricular septum, near the apex of the heart, is the moderator band. This band of muscle contains the right bundle branch, which is part of the electrical conduction system in the heart.



Interventricular septum

Let's take a look at the interventricular septum in more detail. The interventricular septum can be divided into four regions. For orientation, we have the tricuspid valve on the top left and the pulmonary valve on the top right.

1. **Inflow tract**
   Below the tricuspid valve is the inflow tract.
2. **Outflow tract (i.e., infundibulum)**
   Below the pulmonary valve is the outflow tract.
3. **Apical septum**
   The medial and largest part of the interventricular septum is called the apical septum.
4. **Membranous septum**
   The very small portion above the apical septum is called the membranous septum.



Although these regions all have the same function—to separate the right and left ventricles—it is important to know what they are called, as these regions can act as landmarks to help locate abnormalities identified on an echocardiogram.

Great job. Now you understand right ventricular anatomy and physiology in more detail.

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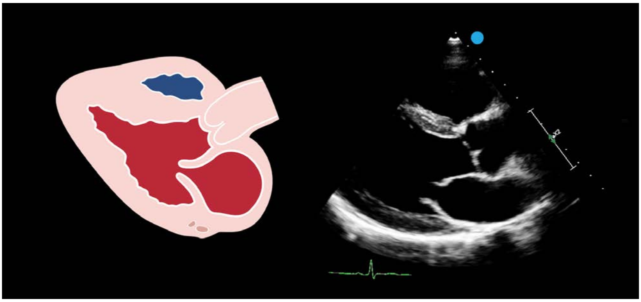
Reviewing the best echocardiography views

Next, let's go through the best echocardiogram (echo) views used to assess the right heart. This includes long- and short-axis views as well as the apical view and subcostal window.

Long-axis views

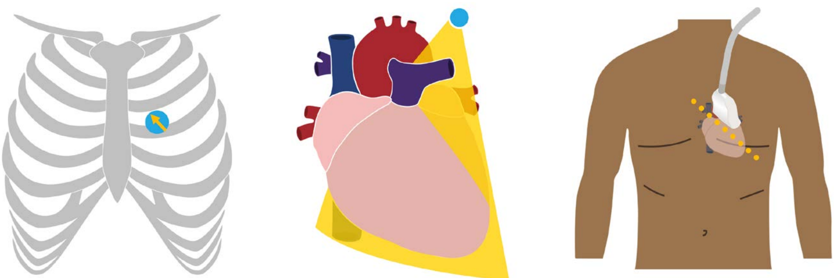
Parasternal long-axis view

First, let's look at the standard parasternal long-axis (PLAX) view.



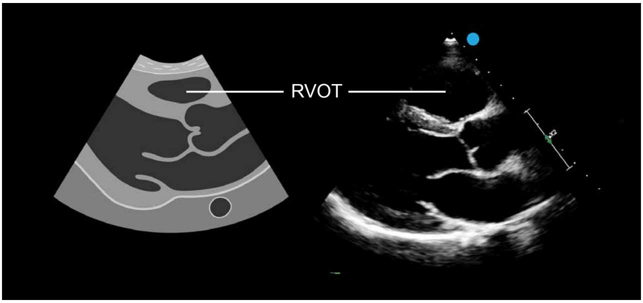
Parasternal long-axis (PLAX) view

In order to obtain this view, place the probe perpendicular to the chest on the third or fourth left intercostal space. The mark of the probe should be facing the right shoulder and the opposite side should face the left hip. The probe should sit diagonally on the chest to account for the heart's angled position in the body.



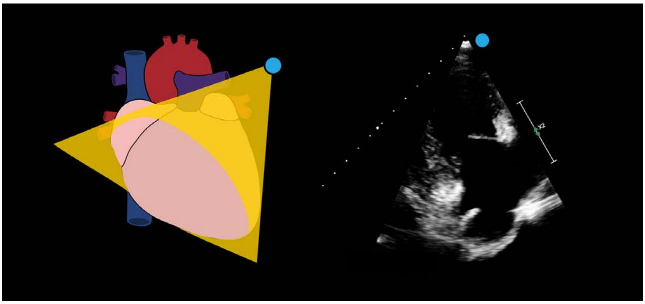
PLAX probe angle and placement

The PLAX view is useful when assessing and measuring the size of the right ventricular outflow tract (RVOT) which, in turn, helps us understand if the RV is dilated or normal size. We cannot see many more structures of the right heart in this view as they are all in front of the ultrasound beam.

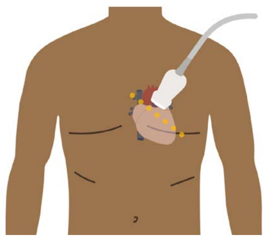


Right ventricular inflow view

If you tilt the probe anteriorly from the parasternal long-axis view, you will be looking at the right ventricular inflow tract.



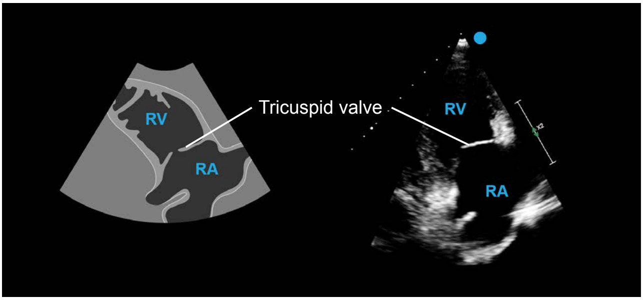
Right ventricular inflow view



Right ventricular inflow view probe angle and placement

To obtain this view, establish the parasternal long-axis view and tilt the probe towards the left shoulder such that the head of the probe is directed at the patient's right hip.

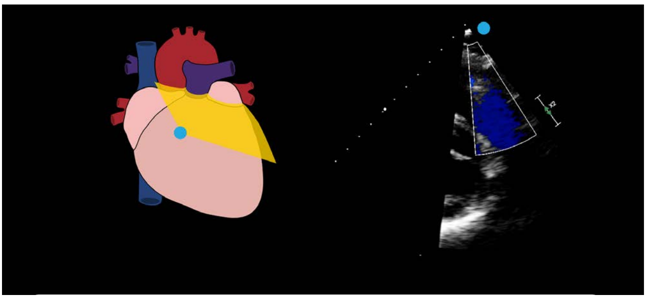
Using this view, the tricuspid valve sits in the middle of the screen, with the RV above and to the left and the RA below and to the right. This view is useful when assessing the tricuspid valve and any potential regurgitation jets.



For more information on how to master the PLAX inflow view, check out the Mastering the PLAX inflow view video from Medmastery's Echocardiography Essentials course.

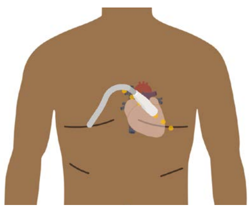
Right ventricular outflow view

Again, from the parasternal long-axis view, if you tilt the probe posteriorly, you will be looking at the right ventricular outflow tract.



Right ventricular outflow view

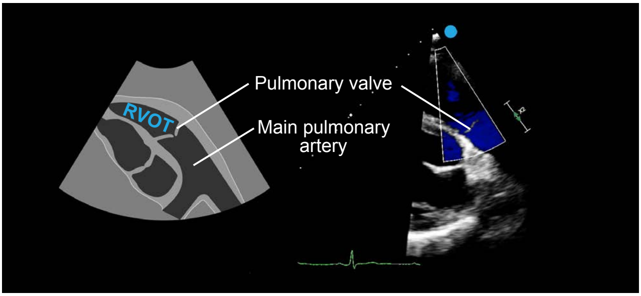
To obtain this view, establish the parasternal long-axis view, and this time tilt the probe toward the right hip such that the head of the probe is directed toward the patient's left shoulder.



Right ventricular outflow view probe angle and placement

This view is useful when assessing the pulmonary valve, as you can see in the highlighted region of the echocardiogram below. The blue flow is moving away from the probe, from the right ventricular outflow tract into the main pulmonary artery. Sometimes, if you get a patient with really good echo windows, you may be able to see the right and left pulmonary artery branches in this view.

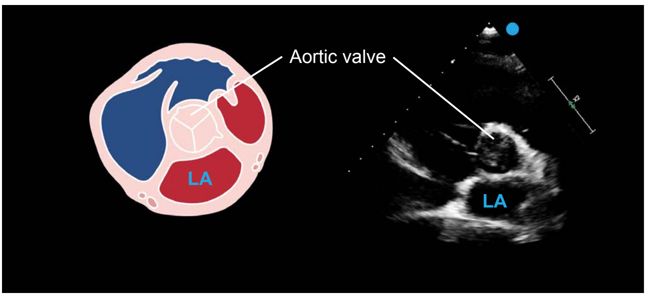
In this lesson's video, the red flow was just minor interference from other structures nearby.



For more information on how to master the PLAX outflow view, check out the Mastering the PLAX outflow view video from Medmastery's Echocardiography Essentials course.

Parasternal short-axis view

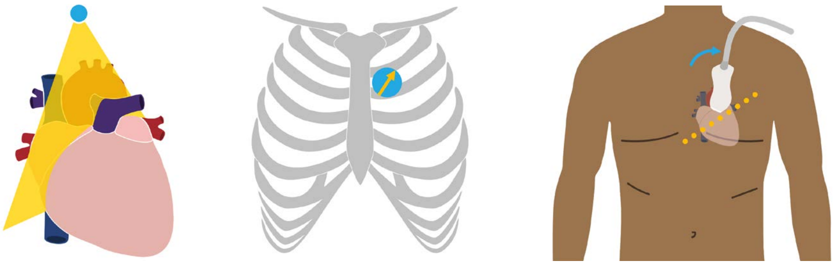
Next, let's move on to the parasternal short-axis view for a look at the vessel level. At the bottom of the image, we get a glimpse of the LA. Right in the middle, you will see the aortic valve.



Parasternal short-axis (PSAX) view

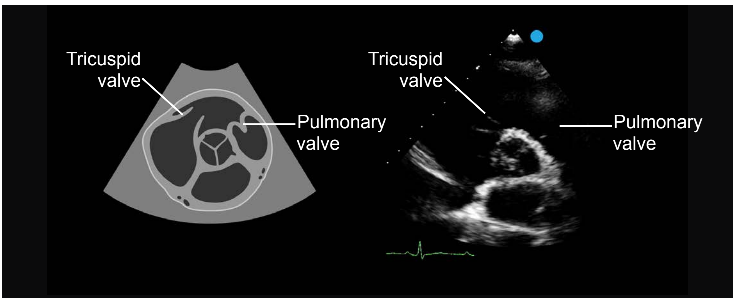
This view is extremely useful to evaluate both right-sided valves: the tricuspid and pulmonary valves.

The parasternal short-axis view bisects the heart along the short plane, between the base and the axis. To obtain this image, go back to a standard parasternal long-axis view, then rotate the probe clockwise until the heart assumes a circular shape on the screen. Sometimes this happens when the mark of the probe is pointing up to the left collarbone or even to the left shoulder.

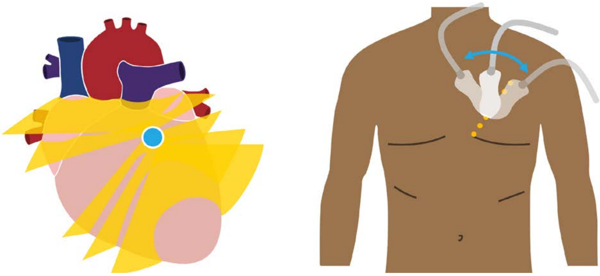


Parasternal short axis view probe angle and placement

Moving clockwise in this view, on the left you will see the RA followed by the tricuspid valve, the right ventricular outflow tract, the pulmonary valve, and finally, the pulmonary artery (PA).

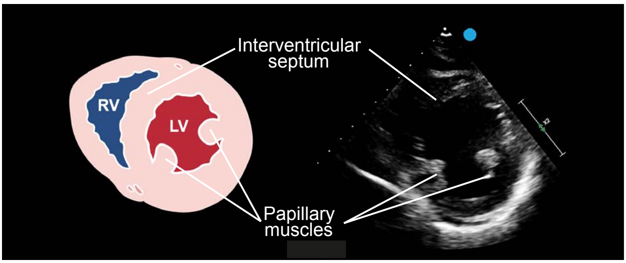


There are multiple scan planes while in the parasternal short-axis view. With the probe in place, you can adjust the scan plane by simply tilting the probe. As you move through the different scan planes, you will be able to visualize the size and motion of the RV from the base of the heart to the apex.



Multiple scan planes

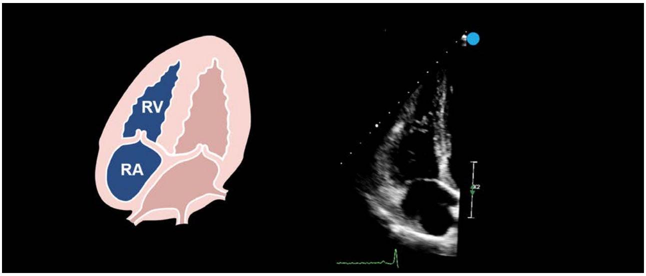
In the image below, we are looking at the papillary muscle level. The two small circular shapes inside the LV are the papillary muscles. Above them, near the top of the screen, you can see the interventricular septum. To the left of the interventricular septum, you can see the RV wrapping around the LV.



This view is useful to better understand if both ventricles are contracting well in systole. You can also assess the septum to see if it is behaving normally or if there are any holes or defects.

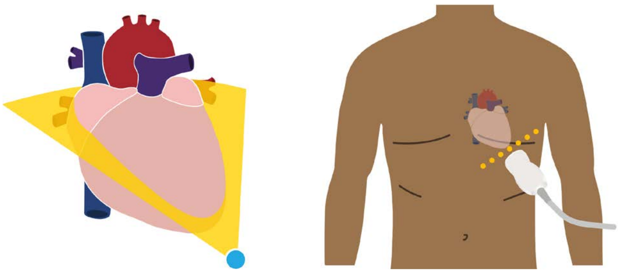
Apical four-chamber view

The apical four-chamber view is the view where we take the most measurements, including the basal dimension of the RV, and we perform tissue Doppler traces of the right ventricular muscle.



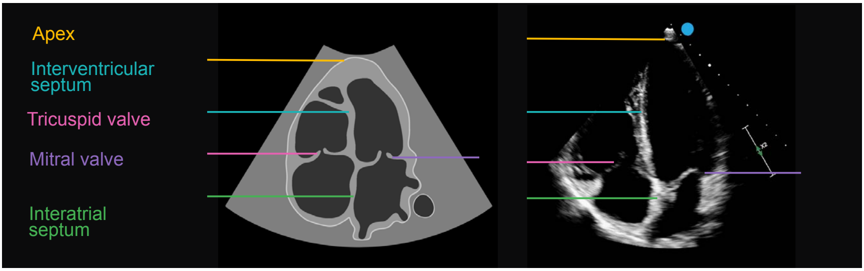
Apical four-chamber view

To acquire the apical four-chamber view, place the head of the probe on the fifth or sixth left intercostal space below the axilla with the mark of the probe facing the left torso. The ultrasound beam should be pointing towards the right shoulder.

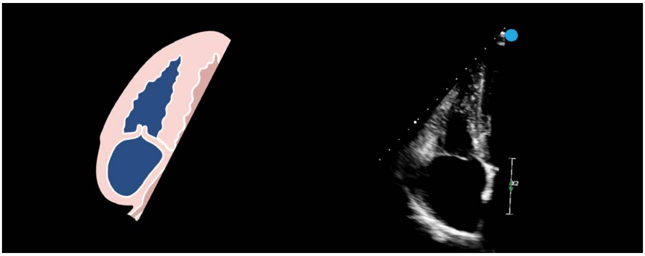


Apical four-chamber view probe angle and placement

Basically, the heart is upside down in this view. The apex is at the top of the screen, and as you move down you will see the mirrored right and left ventricles, tricuspid and mitral valves, and right and left atria at the bottom. We can see the interventricular septum between the ventricles. Similarly, we can see the interatrial septum between the atria.



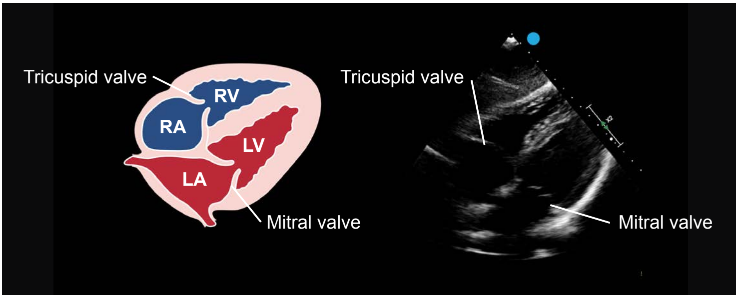
However, when assessing the right heart, we do not want to be distracted by nearby structures, so we tend to make the screen small enough so only the right heart is visible, as shown in the echocardiogram below.



Subcostal view

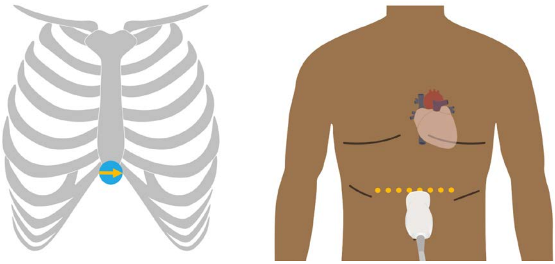
Last but not least, let's take a look at the subcostal view. Using this view, we are viewing the heart from below.

The right heart becomes the most anterior structure and the one closest to the top of the sector. You will see the RA, tricuspid valve, and RV from left to right. Underneath, you can see the matching left-sided structures: the RA, mitral valve, and LV. If you rotate the probe 90° counterclockwise while in the subcostal view, you will get a clear view of the inferior vena cava.



Subcostal view

To obtain the subcostal view, place the probe on the top of the patient's stomach, just below the tip of the sternum. The mark of the probe should be facing the left torso, and the probe should be placed almost horizontally on the belly with the ultrasound beam pointing toward the patient's head.



Subcostal view probe angle and placement

There we have it. You now know the four best echo views to assess the right heart:

1. Parasternal long-axis view
2. Parasternal short-axis view
3. Apical four-chamber view
4. Subcostal view

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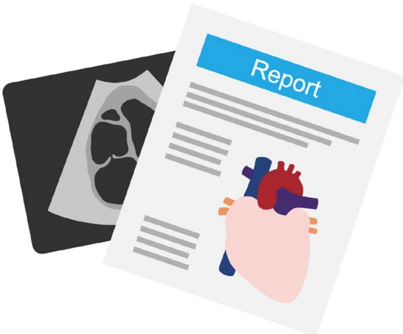
Writing a focused report

Now let's learn how to write a report focused on the right heart. We will cover what to mention, how to structure the report, and which measurements to include.



When writing your report, I recommend taking a step-by-step approach. You will want to mention each major component of the right heart individually.

Be sure to specifically mention the following:

1. RA: size and inner structures
2. RV: shape and function
3. Tricuspid valve: anatomical and functional changes

You may also need to mention the inferior vena cava and the hepatic vein.

Organizing your report

I like to write and organize my reports according to the importance and relevance of changes or abnormalities I observed during the echocardiogram.

Primary changes

I start by reporting the structure that is most affected by the change observed. Was it the atrium? Or was it the ventricle or tricuspid valve?

For example, did you observe a significantly dilated RV? If so, mention this first. How else was the heart affected? Was function diminished? Record all of the important aspects of this structure.

Secondary changes

The second step is to mention structures that were secondarily affected by the primary change. In other words, did the primary change have an effect on another structure?

For example, if we observed a dilated RV, it is likely that the tricuspid valve annulus might be dilated too, leading to significant regurgitation. Though not the primary change, it should be reported at this point.

Remaining structures

The final step is to report on the remaining structures. In this example, we reported changes observed in the RV, and then the effect this primary change had on the tricuspid valve. It is now time to mention the RA and the inferior vena cava, even if they're normal.

Measurements

It is a good idea to include the relevant measurements in the text body of your report as a guide to your assessment.

Right ventricle

There are three measurements you will want to include when reporting on the RV:

1. Tricuspid annular plane systolic excursion (TAPSE)
2. S wave
3. Fractional area change (FAC)

Right atrium

When reporting on the RA, you will want to include the area of this chamber.

Tricuspid valve

When reporting on the tricuspid valve, you will want to include any measurements related to tricuspid regurgitation or stenosis. We will learn how to take these measurements later in this course.

Fantastic job! You now know how to structure and organize a focused echo report.

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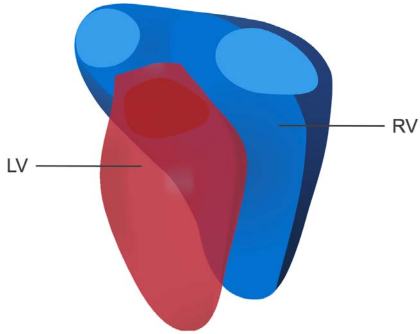
Chapter 2

THE RIGHT VENTRICLE

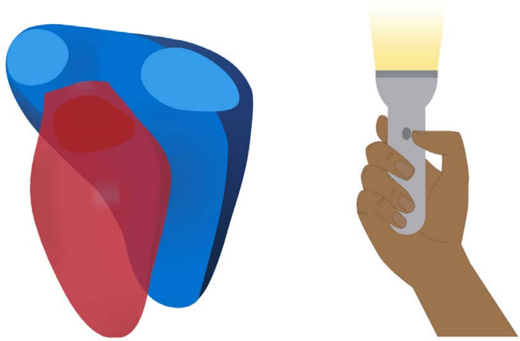
Viewing a healthy right ventricle

Let's take a look at how to recognize a physiologically normal right ventricle on a transthoracic echocardiogram.

To begin, the right ventricle (RV) is a complex structure with a very different shape than that of the left ventricle (LV). You can see that clearly in the image below. The LV, shown in red, looks almost as if it is being embraced by the RV, shown in blue.

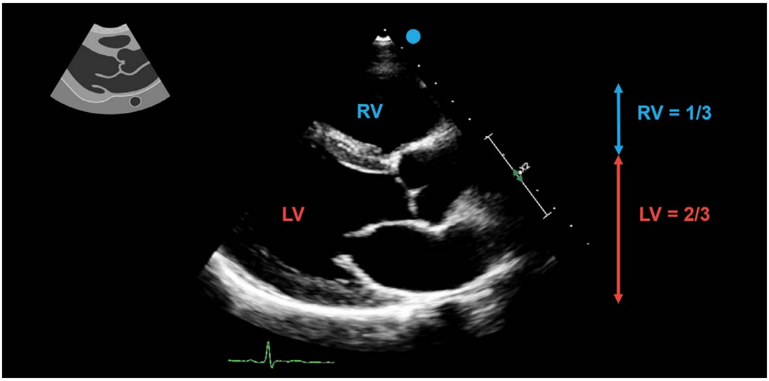


For this analogy, imagine you are holding a flashlight. The flashlight is the LV and your hand is the RV. Your hand isn't symmetrical and doesn't hold the flashlight the same way on all sides; the area under the thumb is much smaller than the area under the remaining fingers. The same happens with the RV. Because of its irregular shape, we need to see and measure it from many different perspectives.



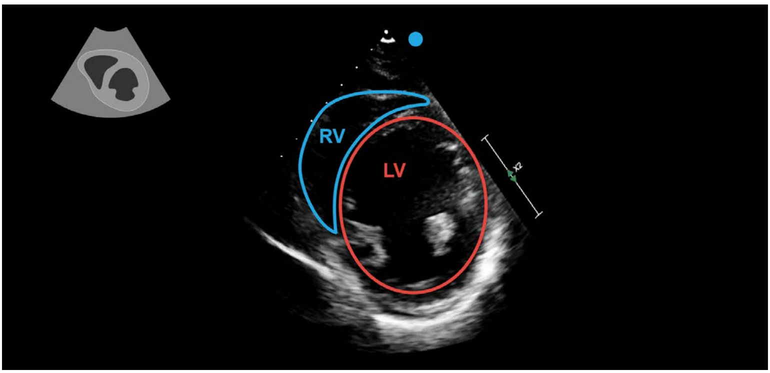
Parasternal long-axis view

A measure of right ventricular size can be attained using the parasternal long-axis (PLAX) view, as seen in the image below. Visually, the RV should take up one-third of the cardiac space, while the LV should take up the remaining two-thirds.



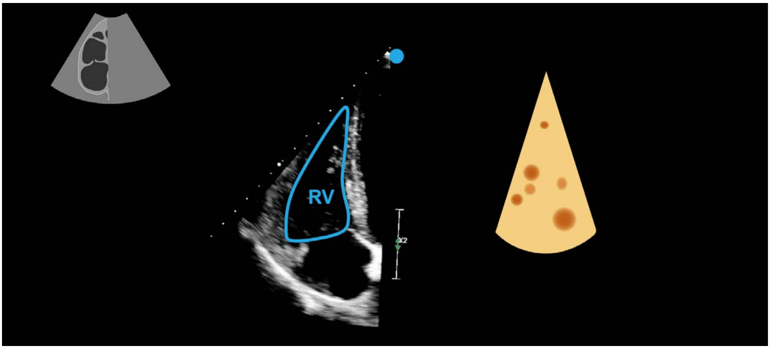
Parasternal short-axis view

The parasternal short-axis view displays the position and shape of the RV very well. The LV has a circular appearance, while the RV looks like a crescent moon that is wrapping around the LV in a friendly hug.



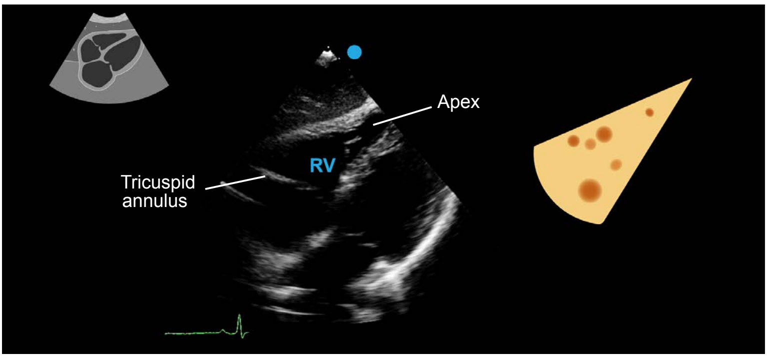
Apical four-chamber view

In the apical four-chamber view, the RV has a completely different shape, more like an upright wedge of cheese. Here, the walls of the ventricle create a triangle with a base formed by the tricuspid valve annulus.



Subcostal view

Lastly, in the subcostal view, we can still see the triangular cheese wedge-shape of the RV. Instead of imaging the RV from the apex down, we are now looking at it horizontally. Here, the tricuspid annulus, which is at the base of the triangle, is on the left of the screen, while the apex is on the right.



Depending on the position of the probe, the RV can appear to be different sizes in the subcostal view. This is because the ultrasound beam may be crossing the

RV at any level, such as at its center or toward one end (i.e., at one of the hands in the hug).

An important tip!

Do not measure the RV while in the subcostal view. It will not be a consistent measurement and may suggest abnormalities that do not really exist.

Great job! You now know that the RV looks very different in each echo view and what shape to expect.

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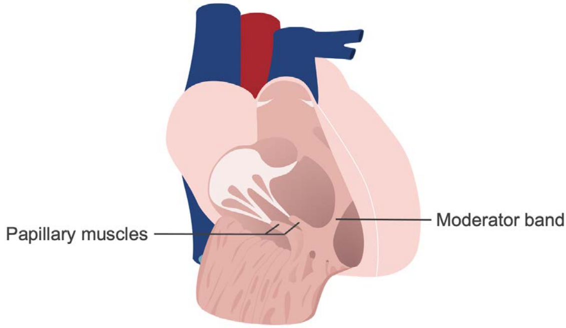
Viewing distinctive structures in the right ventricle

At the end of this lesson, you will be able to recognize two distinctive structures found in the right ventricle on a transthoracic echocardiogram:

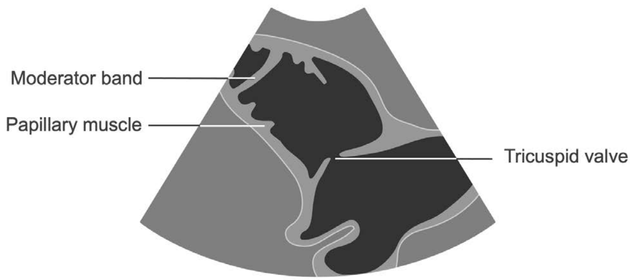
1. Moderator band
2. Papillary muscles



The moderator band and papillary muscles are found in the RV. To better understand the location of these structures, let's look at the PLAX view of the right ventricular inflow tract.

PLAX view

In the PLAX view, if you look beyond the tricuspid valve, you should see two white and bright, or echogenic, structures on the left side of the ventricle. First, near the apex of the heart, you will see the moderator band, and on one of the right ventricular walls, you will see papillary muscles.

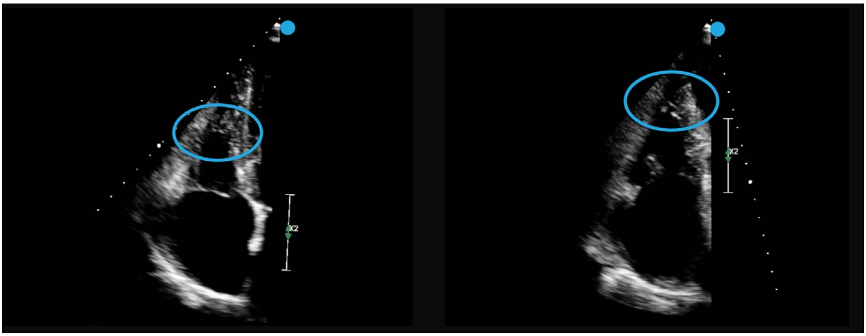


Now let's take a look at these structures in echocardiogram images.

Moderator band

The moderator band is a near-horizontal echogenic band, measuring about one-half of a centimeter in thickness on your echo screen. It is a normal and vital structure, as it carries the right bundle branch from the septum to the right ventricular free wall, as part of the heart's electrical conduction system. The moderator band is often only visible during systole.

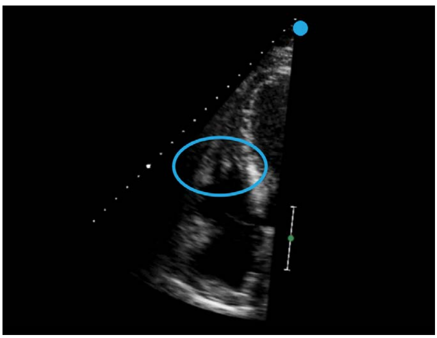
To find the moderator band, we want to look at the RV during systole when it is fully contracted and small in size. You will see a structure with echogenicity similar to the ventricular walls crossing the ventricle near the apex. This is the moderator band.



Moderator band

Papillary muscles

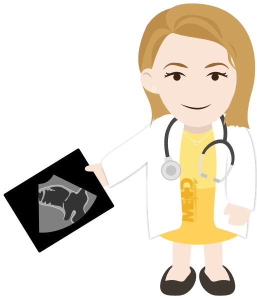
When performing a transthoracic echocardiogram, you may or may not see the papillary muscles. There are three papillary muscles in the RV, but it is hard to distinguish between them on an echocardiogram. Similarly, they lie close to the moderator band, so it may be challenging to differentiate between the different structures.



Papillary muscles

However, rest assured this is a normal structure to which the tricuspid valve leaflets are attached through the chordae tendineae.

Great! Now you know what these two distinctive structures—the moderator band and papillary muscles—look like on an echocardiogram of the right heart.



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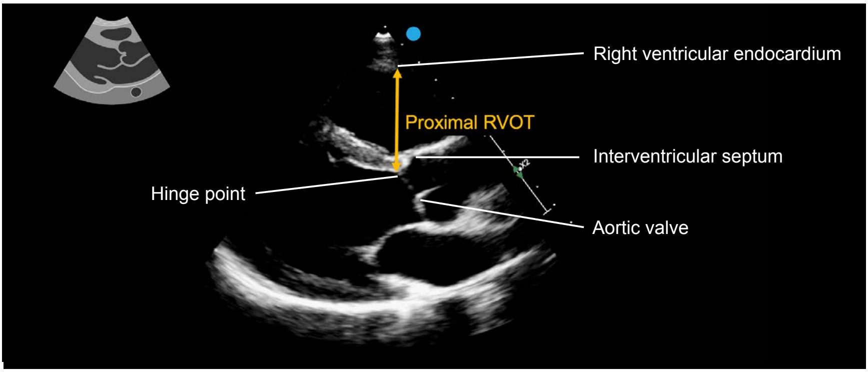
Measuring the right ventricle

Next, we will cover how to measure the structures of the RV using transthoracic echocardiography in a precise and reproducible way.

Right ventricular outflow tract

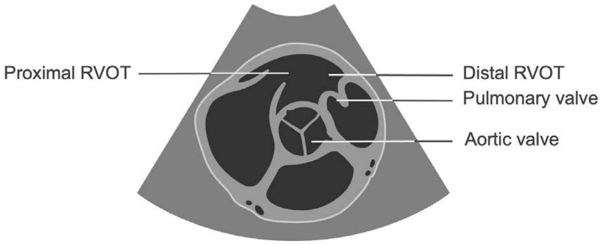
Measuring the right ventricular outflow tract (RVOT) is one of the methods used to establish whether the RV is dilated or normal in size. It is best done using the PLAX view as seen below.

The RVOT measurement can be obtained by starting at the hinge point between the aortic valve and the interventricular septum. Then, measure vertically from the right ventricular side of the interventricular septum up toward the right ventricular endocardium.



PLAX view

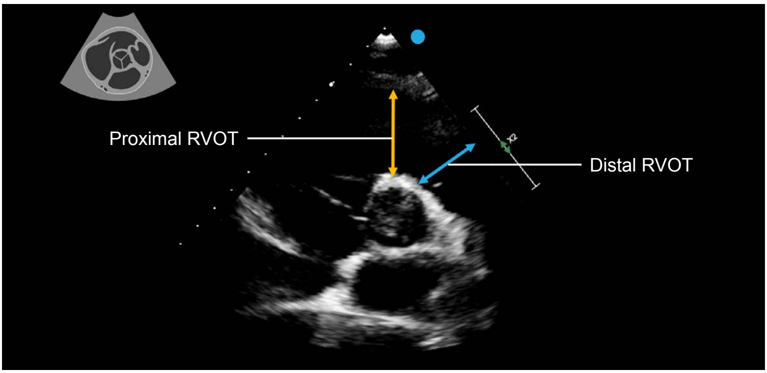
Looking at the parasternal short-axis view, we are now at the vessel level where the pulmonary and aortic valves are both visible. In this view, the RVOT tract is seen at the top of the screen and can be measured at two levels, the proximal and distal levels. Both measurements help us understand if the RV is dilated or normal in size.



Parasternal short-axis view

When measuring the proximal RVOT, place the echo cursor just outside the aorta at its center and within the RVOT. From here, draw a vertical line up to the right ventricular endocardium.

The distal RVOT can be found just above the pulmonary valve. Similarly, it can be measured by placing the echo cursor just outside the aorta, this time above the pulmonary valve at about 2 o'clock, stretching to the endocardium.



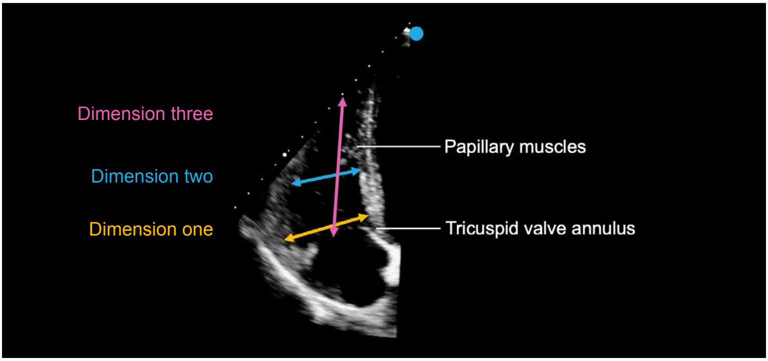
Parasternal short-axis view

Dimensions

Now let's look at the apical view. The RV in this view resembles a triangular wedge of cheese. Here we can take three measurements referred to as dimensions:

1. **Dimension one**
   Dimension one, the base or basal diameter, is taken just above the tricuspid valve annulus where the RV is at its widest.

2. **Dimension two**
   Dimension two, the mid diameter, is taken across the middle of the chamber, just below the papillary muscles. Both dimension one and two measurements are taken from the interventricular septum to the right ventricular endocardium on the left of the screen.
3. **Dimension three**
   Lastly, dimension three measures the length of the RV from the middle of the tricuspid annulus to the apex.



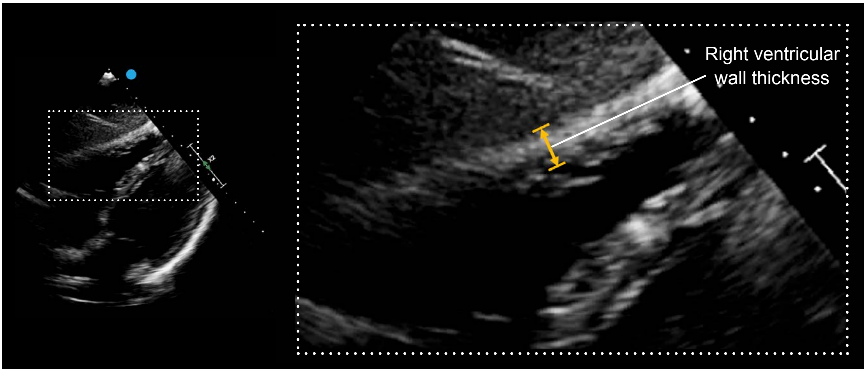
Apical view

Recommendations and guidelines for how to use these measurements differ between countries and even continents. Be sure to find the guidelines for your region of practice, which should provide measurements to define a normal-sized or dilated RV.

Right ventricular wall thickness

The subcostal view is excellent for measuring the thickness of the ventricular muscle. In order to obtain this measurement, zoom in and measure the thickness of the right ventricular wall.

This measurement is helpful to understand if the RV is hypertrophied, meaning the muscle has overgrown. This often happens in response to high pressures in the lungs and the RV itself.



Subcostal view

Always measure in end-diastole

Now that you know how to measure aspects of the RV, be sure you always take these measurements in end-diastole. This ensures you are measuring the ventricle at its largest dimension and it also guarantees consistency between scans and operators.

Great job! You now know how to measure the dimensions of the RV.

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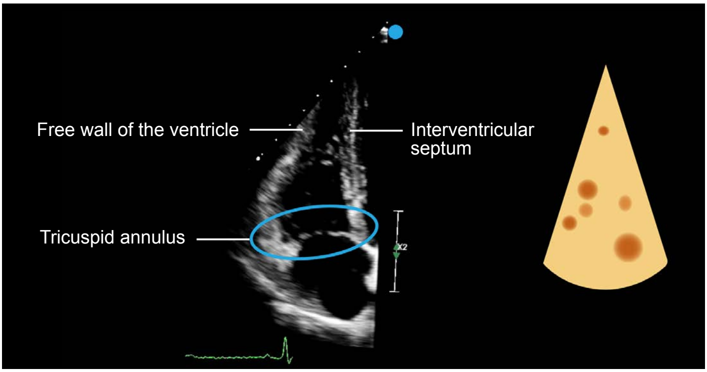
Recognizing poor systolic function

Our next task is to learn how to quickly recognize a failing RV on an echocardiogram.

Up until this point, we have discussed the normal right heart. In review, the size and shape of the RV should be triangular like a wedge of cheese, as seen below. The tricuspid annulus, where the tricuspid valve sits securely, should move up toward the apex during systole and move back down during diastole.

The free wall of the ventricle should contract toward the interventricular septum during systole, making the chamber of the RV smallest at the end of systole. Then move away from the septum during diastole, making the chamber largest at the end of diastole.



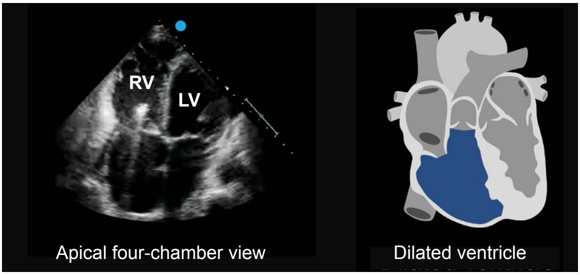
Healthy RV

Identifying ventricular dysfunction

In this [lesson's video](), we compared a healthy pumping ventricle to an extreme case of ventricular dysfunction. You may remember that the RV looked and moved very differently in each example.

Let's take a look at this diseased ventricle in a little more detail using a step-by-step approach.

Size
The RV in this heart was very dilated. In fact, it was the same size or even slightly larger, than the left ventricle.

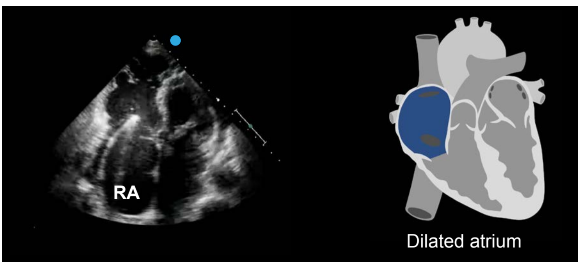


Work
As you may remember, the muscle was not moving as much as it should. In a normal RV, we would see the muscle move toward the interventricular septum during systole when it contracts. In this case, the motion of the free wall of the RV was barely visible and it was the interventricular septum that appeared to be moving.

This was an extreme case of right ventricular failure. Right ventricular failure may happen as a consequence of any of the following:

- Left ventricular failure
- Heart attack
- Inherited diseases affecting primarily the right heart

Other structures
After assessing the size of the RV and how it's working, you can assess the other structures. For instance, in the image below, we can see that the right atrium is significantly dilated as well.

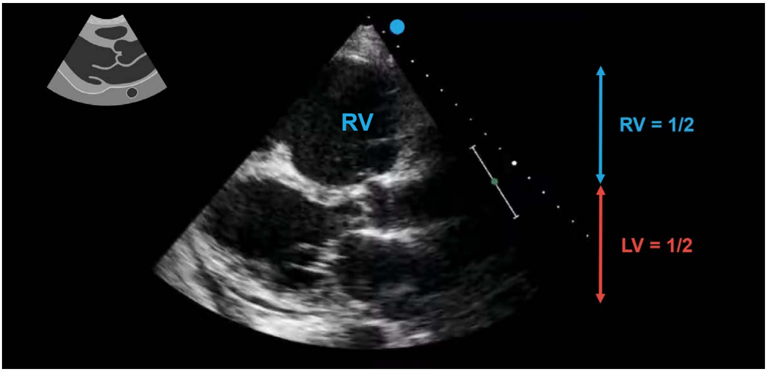


Systematic assessment of the RV

Now that we know what to look for, let's apply it systematically to assess the function of the RV using echocardiography.

Parasternal long-axis view

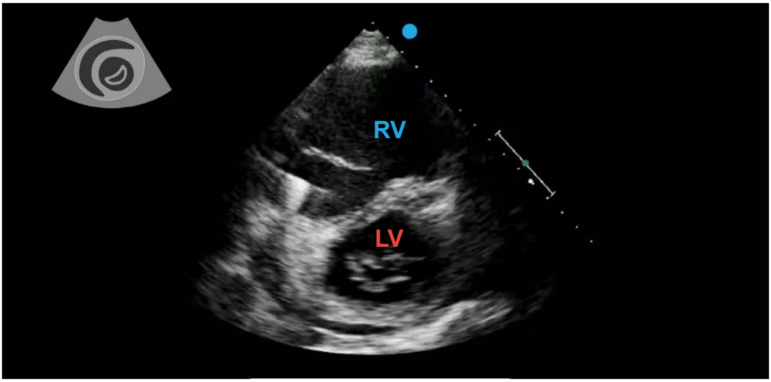
In the PLAX view shown below, the RV easily takes up half of the cardiac size instead of the expected one-third. It is significantly dilated, meaning it has more blood volume than it should and the muscle is overstretched. The cardiac muscle does not like extremes and this excessive stretch will affect how it works, making it less effective.



PLAX view

Parasternal short-axis view

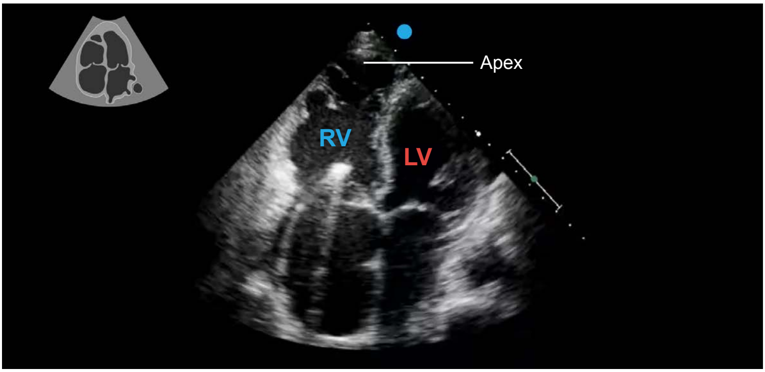
The same is true in the parasternal short-axis view. Again, the RV looks larger than the left. In addition, there was hardly any motion during systole when you would expect to see the ventricle contract.



Parasternal short-axis view

Apical four-chamber view

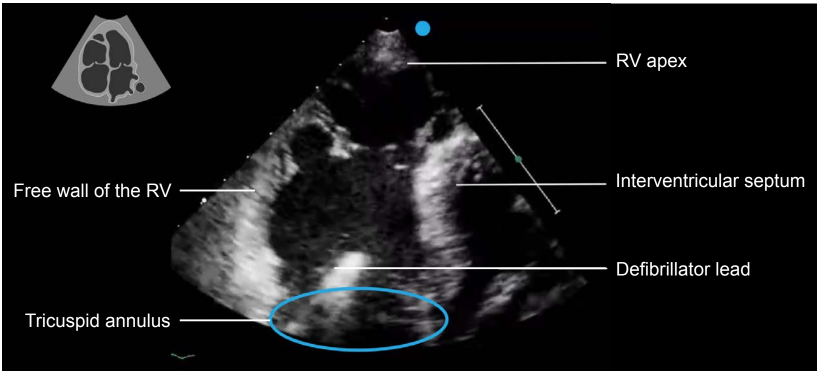
In the apical four-chamber view, the dysfunctional RV appears to be larger than the left ventricle. It has also lost its triangular shape. In addition, the apex is irregularly shaped with a really bulgy appearance.



Apical four-chamber view

When we zoomed in on the RV in the apical four-chamber view, we could see that the tricuspid valve annulus was not moving toward the apex at all. Similarly, the free wall of the RV was not moving toward the interventricular septum during systole. This means that blood ejection was not as effective as it should be.

As a result of this ineffective blood ejection, blood would pool in the RV, the inferior and superior vena cava, and all the veins around the body. This leads to significant swelling of the legs, abdomen, and other areas of the body.



Apical four-chamber view

Well done! After reviewing this extreme case of RV dysfunction, you now know how to visually assess right ventricular function using echocardiography.

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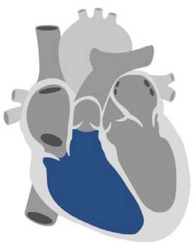
Measuring function with 2D echocardiography

Next, let's learn how to use 2-dimensional (2D) echocardiography to measure right ventricular systolic function. 2-dimensional echocardiography is what we use in daily practice and how we visualize the heart using standard echocardiography.

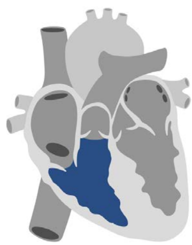
We are going to start by discussing the concept of fractional area change (FAC).

What is the fractional area change?

FAC is a comparison of the area of the RV after diastole when the ventricle is at its largest, and the area of the RV after systole when the ventricle is at its smallest.



End-diastolic area



End-systolic area

In order to perform this comparison, you need to calculate the percentage of change in the right ventricular area between diastole and systole. This will give you an idea of how effective the RV is during systole. By understanding how much the RV changes in size during a full cardiac cycle, you can infer if it is ejecting the appropriate amount of blood into the pulmonary circulation with every heartbeat.

Calculating the FAC (normal RV)

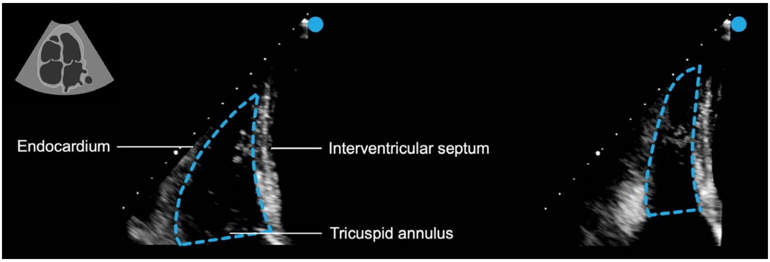
Let's look at an example, starting with a normal RV.

1. **Obtain an apical four-chamber view and zoom in on the RV.**
2. **Freeze the image when the RV is in the end-diastolic frame and take measurements.**

Use your calliper (or the available measurement package on your echo machine) to draw the area defined by the RV endocardium, interventricular septum, and the tricuspid annulus.

3. **Freeze the image when the RV is in the end-systolic frame and measure again.**

   Draw the area of the RV defined by the endocardium, interventricular septum, and tricuspid annulus once again.



End-diastole RV area   End-systole RV area

4. **Calculate the FAC.**

   First, subtract the smaller (systolic) RV area from the larger (diastolic) area. Divide the difference by the larger (diastolic) area and then multiply this value by 100.

$$FAC = \left(\frac{\text{diastolic RV area} - \text{systolic RV area}}{\text{diastolic RV area}} \right) \times 100$$

   Let's do an example calculation with a diastolic area of 13 cm^2 and a systolic area of 7 cm^2.

$$FAC = \left(\frac{13 - 7}{13} \right) \times 100 = 46\%$$

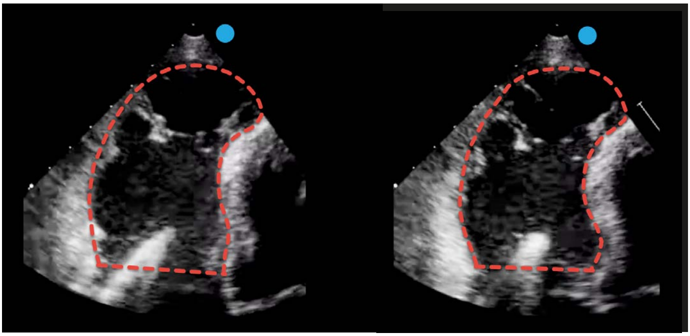
   In this example, the fractional area of change is 46%. Don't worry about the math though; your echo machine or analysis software will calculate this automatically for you.

A normal fractional area change is equal to or greater than 35%. Essentially this means that a normal RV becomes at least 35% smaller during systole.

Normal fractional area change

Calculating the FAC (impaired RV)

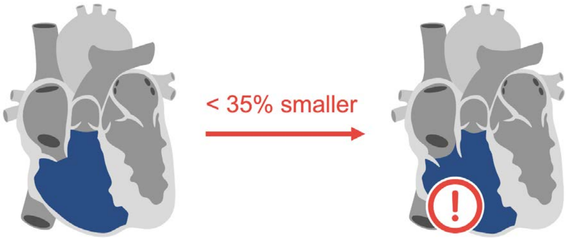
Now, let's look at an impaired RV. Using the same method, freeze the video when the RV is in the end-diastolic frame and draw the area defined by the endocardium, interventricular septum, and tricuspid annulus. Next, repeat this process for end-systole.


End-diastole RV area   End-systole RV area

Once both measures have been taken, calculate the percentage of change in area as we did in the previous example. In this example of the impaired heart, the diastolic area measures 53 cm^2 , and the systolic area measures 46 cm^2 . Again, subtract the smaller area from the larger area and divide by the largest number. Then multiply this value by 100.

$$FAC = \left(\frac{53 - 46}{53}\right) x\ 100 = 13\%$$

The fractional area change is 13%. An abnormal fractional area change is less than 35%, which signifies right ventricular systolic dysfunction.



Abnormal fractional area change

Brilliant! You now know how to measure the functional area of change of the RV using 2D echocardiography. Using this method, you can now assess right ventricular systolic function.

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Measuring function with additional tools

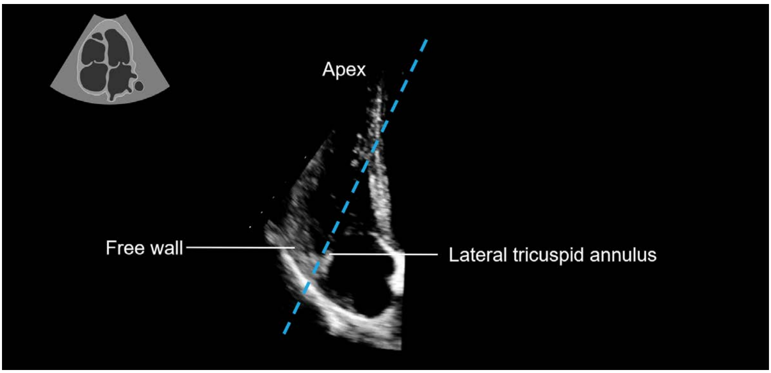
Next, we will discover how to use two additional methods to measure right ventricular function: M-mode and tissue Doppler imaging (TDI). We will also cover how to compile all of the RV measurements we've learned about so far in order to grade right ventricular systolic function.

M-mode

Simply put, the *M* in M-mode stands for motion. With this tool you can assess how far the tricuspid annulus moves up toward the apex during systole on an echocardiogram. It is a quick and simple way to get a screenshot of right ventricular systolic function.

Let's go over the steps to obtaining this measure:

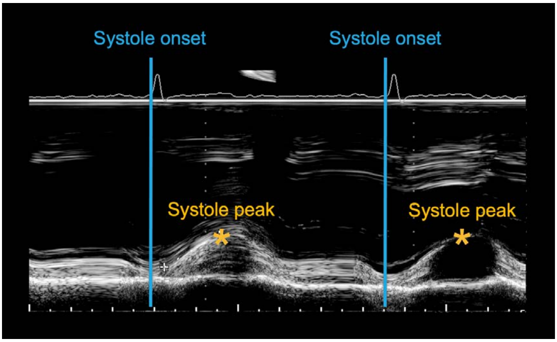
1. **Obtain a four-chamber apical view.**
   This will give you a good look at the RV and tricuspid valve.
2. **Place the ultrasound cursor on the lateral tricuspid annulus.**
   The cursor shows on the screen as a dashed straight line.



3. **Press the M-mode button.**
   M-mode will depict an undulating pattern like a wave at the bottom of the screen.

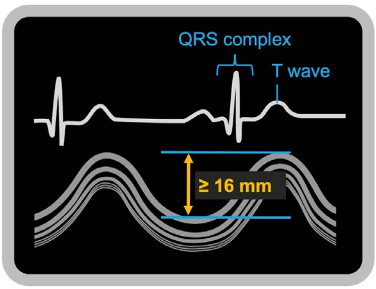
Interpreting M-mode results

When interpreting the results of an M-mode echocardiogram, you want to measure the distance between the onset of systole and the upward movement of the tricuspid annulus, to the maximum motion point achieved.



On the electrocardiogram, this undulating pattern more or less matches the onset of the QRS complex and peak of the T wave. This measure is called the tricuspid annular plane systolic excursion (TAPSE), and it should be greater than or equal to 16 mm. Anything less than this suggests there is a degree of impairment in the systolic function of the RV.

In the illustration below, the blue lines demonstrate the trough and the peak of the undulation. The distance between them, or TAPSE, is marked by the yellow arrow.



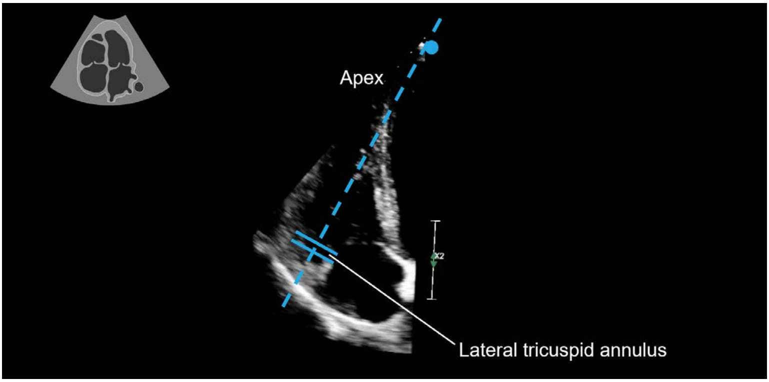
TAPSE

Tissue Doppler imaging

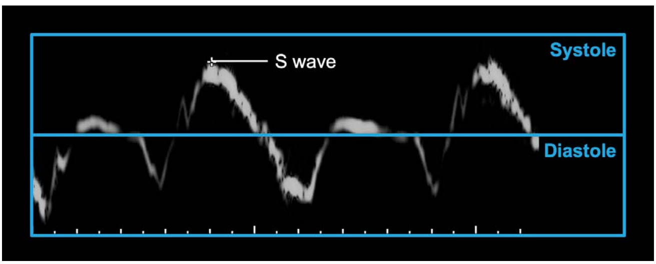
You can use TDI to measure how fast the base of the RV moves toward the apex in systole. The speed of this movement is another measurement that gives us a very good estimate of right ventricular systolic function.

The practical approach for TDI is the same as for M-mode. Let's go over the steps:

1. **Obtain a four-chamber apical view.**
2. **Place the cursor on the lateral tricuspid annulus.**
   This is the same method as we use to acquire the TAPSE. Ensure the sample volume, represented by two dashes on the cursor line, is right on top of the first bit of the right ventricular muscle.

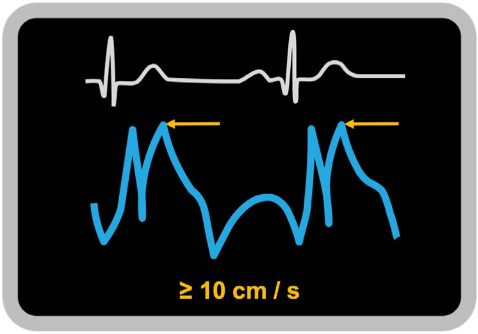


3. **Press the TDI and pulsed wave (PW) buttons.**
   The results are presented in a graph depicting the velocities of the muscle in systole (above the horizontal axis) and in diastole (below the horizontal axis). The S wave (where S stands for systole) is the second peak seen above the horizontal x-axis.



Interpreting TDI results

In order to interpret the results of the TDI graphs, you need to measure the maximum velocity of the right ventricular myocardium during systole. This is represented by the highest peak, the S wave. Click on this point to acquire the measurement. The S wave should measure 10 cm / s or more.



Summary of all measurements of RV systolic function

A normal ventricle will have a TAPSE score greater than or equal to 16 mm, whereas an impaired ventricle will have a TAPSE score of less than 16 mm. A normal ventricle will have an S wave greater than or equal to 10 cm / s, whereas an impaired ventricle will have an S wave of less than 10 cm / s. Lastly, if the fractional area change is greater than or equal to 35%, it is likely you are assessing a normal RV. However, if it is lower than 35%, the ventricle is certainly impaired.

	Normal RV	Impaired RV
TAPSE	≥ 16 mm	< 16 mm
S wave	≥ 10 cm / s	< 10 cm / s
FAC	≥ 35%	< 35%

Fantastic! You now have all of the tools you will need to measure right ventricular systolic function.

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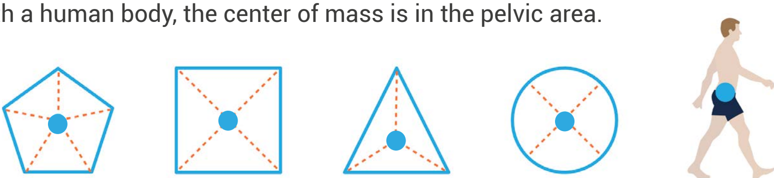
Using septal motion as a guide

Our next task is to learn to recognize patterns of motion in the interventricular septum. These can be used as a guide for assessing overall right ventricular function. We will also cover how to determine if the RV is under a process of volume or pressure overload.

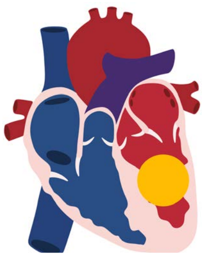
Assessing for center of mass changes

Before we begin, we need to understand the concept of center of mass. The center of mass is a position relative to a system. It can be defined as the average position of all parts of a system, considering their mass.

For example, the geometric shapes below have a very clear center of mass. Because they are symmetrical, the center of mass is their geometrical center. With a human body, the center of mass is in the pelvic area.



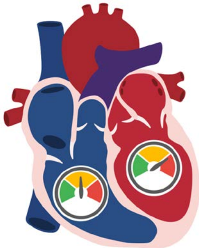
So, what does this mean in terms of the heart? Below, we have a structurally normal heart. Given the distribution of weight of the heart, the center of mass is in the left ventricle.



Normal heart

The left ventricle is the most muscular chamber, therefore the heaviest, and is under the most pressure. All left ventricular motion happens around this center of mass.

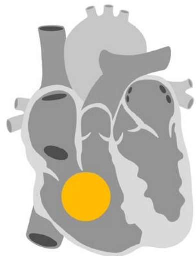
As the left ventricle gets bigger during diastole, the interventricular septum moves toward the RV, as the pressure in the RV is lower than the left ventricle. This relationship changes if the mass or the pressures in either of the ventricles change significantly.



Diastole

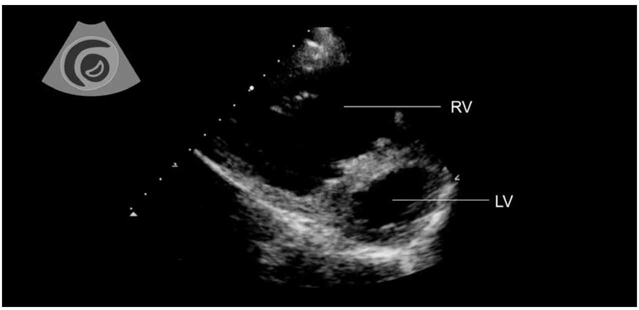
Shifting center of mass in a diseased right heart

Let's look at an example of such a change. On the right, you can see a diseased right heart. The center of mass has shifted to the RV because the RV either has more blood volume than normal, increasing its mass, or it is under excessive pressure due to its reduced function. As a result, the surrounding structures will move around the RV.



Diseased right heart

In the parasternal short-axis view shown below, the RV, found at the top of the screen, is dilated. There are a few indicators to confirm this. First, the RV is larger than the left ventricle. Also, instead of wrapping around the left ventricle, the RV no longer looks like a crescent, but now has a shape similar to an apple slice.



Diseased right heart

As we could see in the lesson video, the RV in this heart moves differently than usual. Because the blood volume is higher than normal in the RV, both the mass and pressure have increased, which causes the interventricular septum to move toward the left ventricle, the chamber with lower pressure.

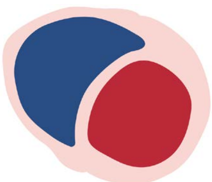
Identifying volume or pressure overload

Let's focus on the interventricular septum in the parasternal short-axis view. In a normal RV, diastole is the moment where the ventricle has the largest volume of blood and the interventricular septum is curved.

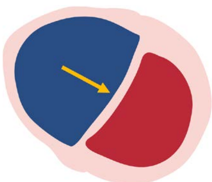
In an abnormal ventricle, the largest volume of blood is even larger. During diastole, this excess blood, or volume overload, pushes the interventricular septum toward the left ventricle, flattening it. This flattened shape is a tell-tale sign that the septum is being pushed in the wrong direction, indicating decreased ventricular function.

As with volume overload, the shape of the interventricular septum can indicate pressure overload. In a normal RV, systole is the moment where the ventricle is under the highest possible pressure.

In an abnormal ventricle, this still happens, but the highest possible pressure is even higher. During systole, this excess pressure, or pressure overload, pushes the interventricular septum toward the left ventricle and the septum becomes flat, again, indicating decreased ventricular function.



Normal heart during diastole



Pressure overload during diastole

Amazing work! You now understand why the septum flattens in cases of right ventricular pressure and volume overload, and you can now recognize this on echocardiography as a guide to overall right ventricular function.

Chapter 3

THE RIGHT ATRIUM

Recognizing a healthy right atrium

In this lesson we will discuss all things right atrium (RA) and, by the end, you will be able to recognize a normal RA and its associated structures using echocardiography.

A normal RA is supposed to be smaller than the right ventricle (RV). However, when you are performing a full assessment of the RA, you might also notice a few distinct structures.

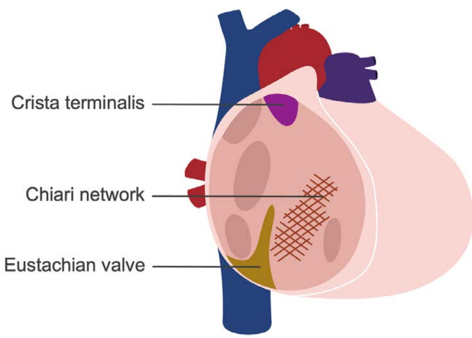
You might even start to wonder, *Are these supposed to be here? Are these abnormalities I should report?* Don't worry. In most cases, these structures are normal and are remnants of life in the womb.

The fetal heart

During fetal life, circulation in the heart is not split into right and left as it is after birth. The fetal lungs are collapsed in utero, and the pressures in the lungs are too high for the RV to overcome. Instead, all gas exchange happens at the placenta.

Another interesting feature of the fetal heart is that blood returning from the placenta moves through the RA into the left atrium through a series of holes and with the help of three unique structures within the RA:

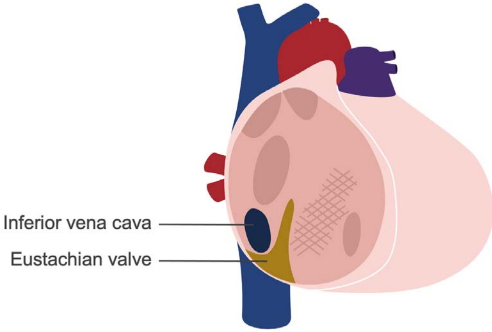
1. Eustachian valve
2. Chiari network
3. Crista terminalis



Let's discuss each one of these structures in a bit more detail.

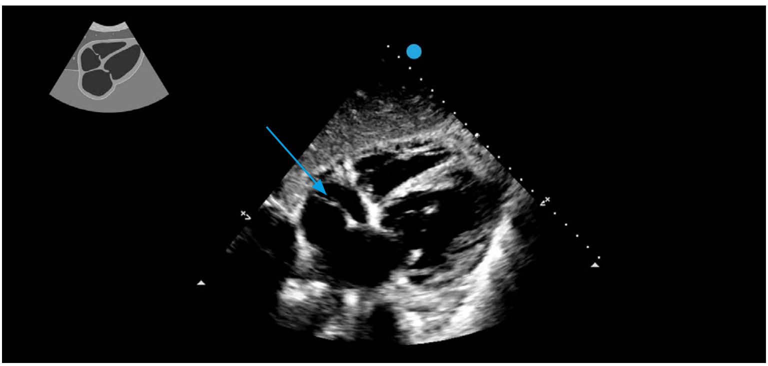
Eustachian valve

The eustachian valve is found near the ostium of the inferior vena cava.



You will probably see the eustachian valve in most of your adult patients, though not all of them because it is quite a small structure. It is a filamentous structure and, as mentioned, is found at the bottom of the RA next to the opening of the inferior vena cava.

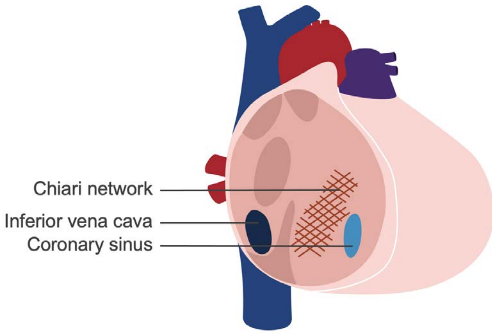
The eustachian valve has a really important role in the fetal heart, diverting blood flow from the inferior vena cava directly to the left atrium through the foramen ovale. A remnant structure, it can be easily viewed in a subcostal image as shown below.



Eustachian valve

Chiari network

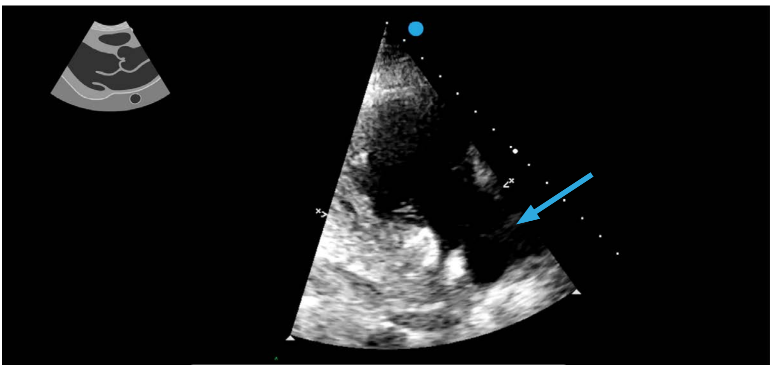
The net-like Chiari network stretches across the middle of the RA near the ostia of the inferior vena cava and coronary sinus.



The Chiari network is another remnant structure from the fetal heart. It has no significant role in the adult heart.

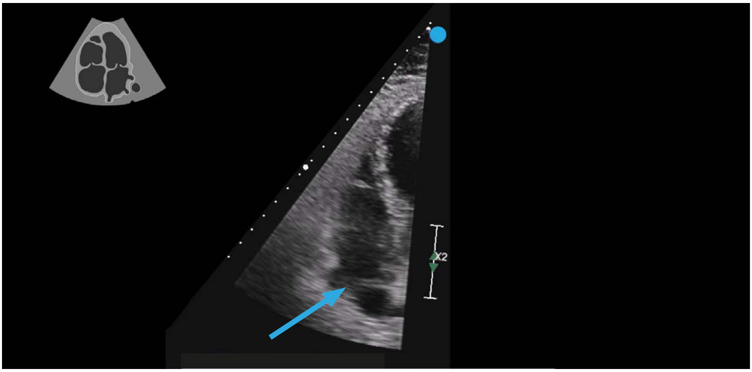
The Chiari network has a web-like appearance and arises from the inferior portion of the RA between the inferior vena cava and the coronary sinus.

Below we have the parasternal right ventricular inflow view. If you look closely, you might be able to identify the Chiari network as really thin filaments crossing the atrium at the bottom right of the screen.



Chiari network

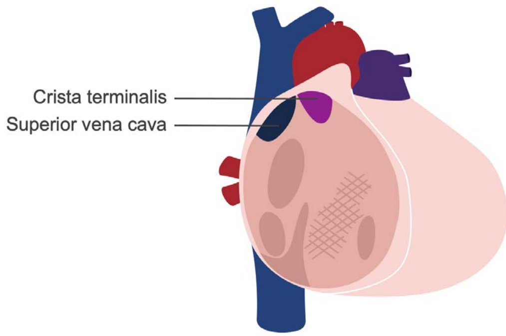
In our next image, we can see an apical four-chamber view focused on the right heart. Again, we can see the thin filaments of the Chiari network crossing the atrium.



Chiari network

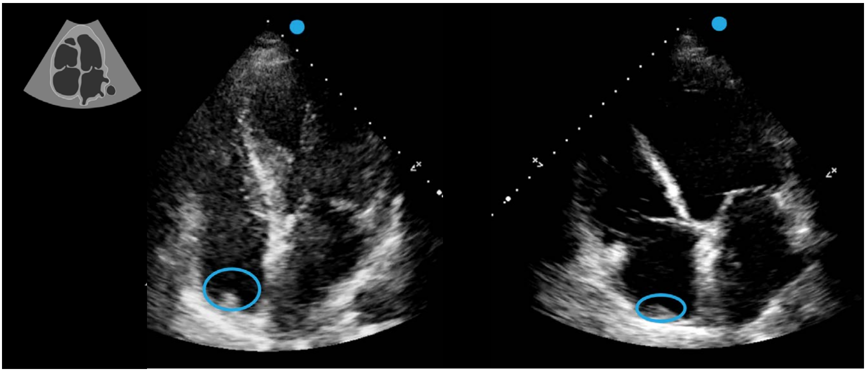
Crista terminalis

The crista terminalis is found on the roof of the RA next to the ostium of the superior vena cava.



The crista terminalis is not a remnant of the fetal heart. It is a very small structure that acts as a protective barrier to the sinoatrial node.

The crista terminalis is a ridge of smooth muscle on the roof of the RA, just next to the ostium of the superior vena cava, and it is best seen in the apical four-chamber view. But be aware, it is easy to mistake the crista terminalis for a thrombus or a clot.



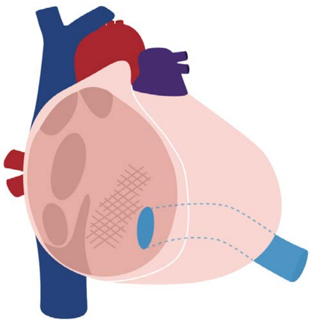
Crista terminalis

Other structures to identify

Next, let's take a look at a few other structures you should recognize in the RA.

Coronary sinus

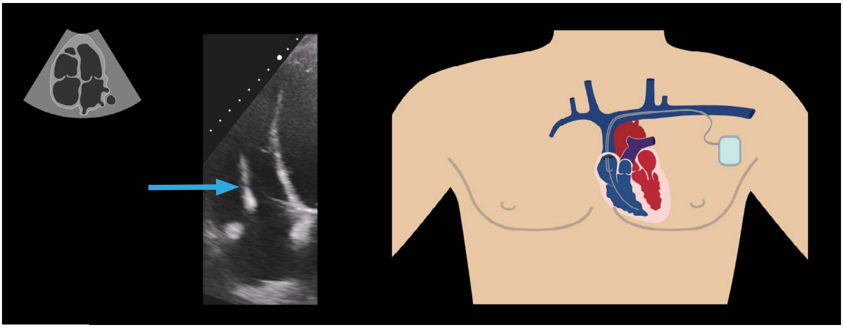
The coronary sinus is an important tube-like structure that enters the RA from the back of the heart. It is part of the coronary circulation system returning deoxygenated blood from the myocardium to the RA.



Coronary sinus

Pacemaker

The RA in many of your patients, particularly your older patients, may have something that looks like the image below. This is a pacemaker or an implantable cardioverter-defibrillator lead. On your echocardiogram, it appears as an almost vertical line crossing the whole right heart, as you can see on this apical four-chamber view.



Pacemaker

Although it would be hard to mistake a lead for a blood clot, it is really important to find out whether your patient has a pacemaker or defibrillator before you start your echocardiogram, as they may have an ongoing infection that could lead to abnormal attachments to it.

Great job! Now you know what a normal RA looks like. You also know that despite their appearance, the eustachian valve, crista terminalis, and Chiari network are normal structures, and there is no need to worry when you see them.

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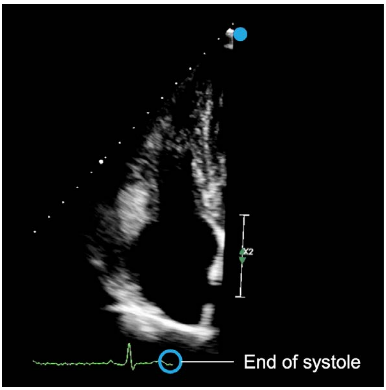
Measuring the right atrium

Let's discuss how to measure the RA according to the guidance from different international echocardiography societies.

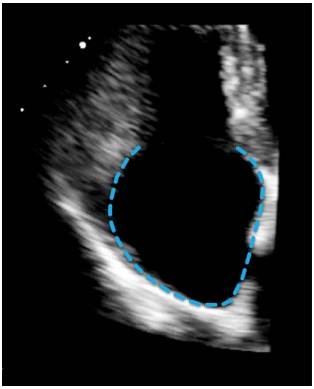
Measuring RA area, length, and volume

First, we'll go over the steps you can use to measure the right atrial area, length, and volume:

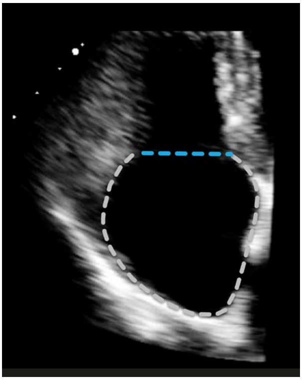
1. **Obtain an apical four-chamber loop.**
   In preparing to measure the RA, the first thing you want to do is to obtain an apical four-chamber loop. You don't have to, but if you want to reduce your margin of error, feel free to zoom in on the RA.
2. **Freeze the loop on the end-systolic frame.**
   This is when the RA will be at its fullest. By capturing the loop at the end of systole, you will avoid underestimating its true size.



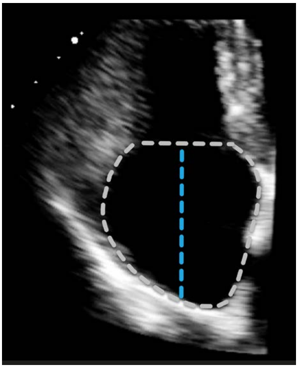
3. **Trace around the right atrial endocardium.**
   When zoomed in, using the caliper, trace around the right atrial endocardium.



4. **Close the circumference with a straight line at the tricuspid annulus.**
   This will give you the right atrial area.



5. **Measure the length of the atrium.**
   You can do this by drawing the longest axis from the middle of the tricuspid annulus to the roof of the atrium.

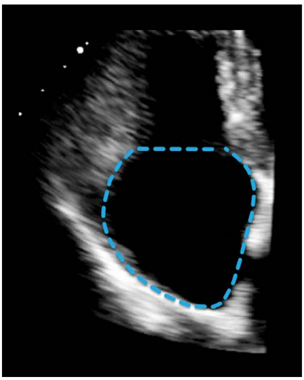


6. **Let the machine calculate the volume.**
   Once outlined, the echo machine will automatically calculate the volume of the RA using the measured right atrial area and length.

Using the method of disks

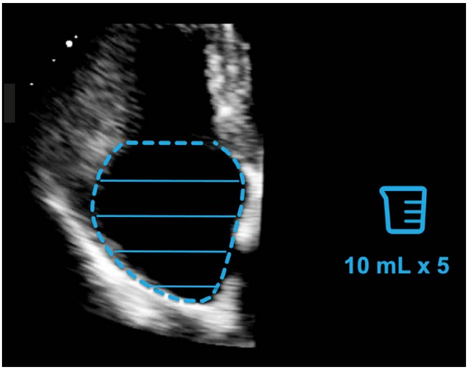
The method of disks is another way to measure the right atrial volume. To use the method of disks, you only have to select the right measurement package on your echo machine or the reporting system.

Again, start by tracing the right atrial endocardium.



Next, the echo machine will take care of the calculus for you. The machine will divide the space into a series of disks of the same volume. The software will then multiply this volume by the number of disks used in order to calculate the volume of the entire RA.

For example, imagine each of the disks in the echocardiogram below measure 10 mL. Since there are five of them, this would infer that the RA has a 50 mL capacity.



Great work! You are now able to measure the right atrial area, length, and volume using echocardiography.

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Seeing holes in the interatrial septum

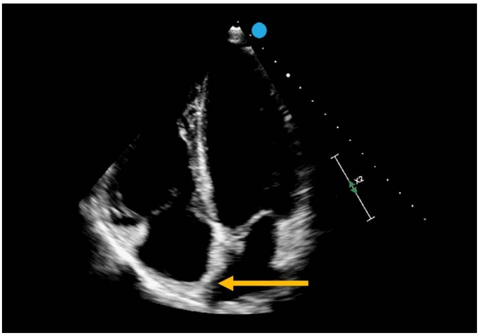
Let's learn to recognize and classify three abnormalities in the interatrial septum:

1. Secundum atrial septal defect
2. Primum atrial septal defect
3. Patent foramen ovale

We'll take a look at how to recognize these three in a moment, but first, let's start with learning to recognize the signs of an atrial septal defect.

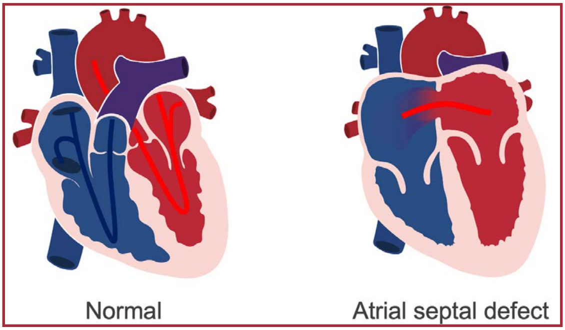
Signs of an atrial septal defect

Many physicians may be confused by an apical four-chamber image that looks like the one featured below. It's an echocardiogram of the RA with a dark area in the interatrial septum. Is that a defect?

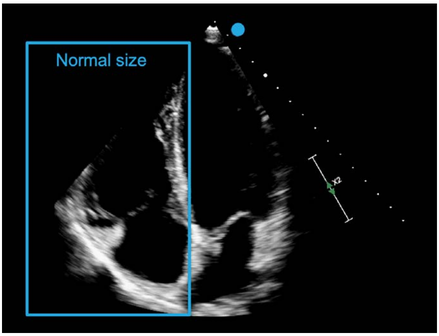


Enlarged right heart

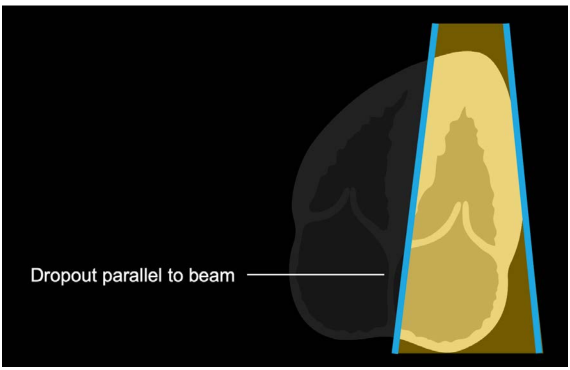
The first thing you should do if you encounter something like this is to look at the right heart and ask yourself, *Is it normal-sized?* If there were an atrial septal defect, the right heart would very likely be enlarged.



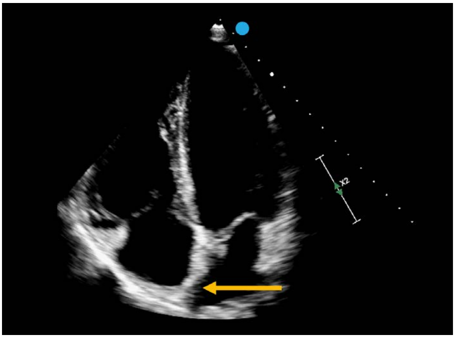
In our example echocardiogram, we can see that the right heart is a normal size. The dark area in the interatrial septum is actually due to ultrasound drop-out.



Ultrasound drop-out occurs when the ultrasound beam is parallel to the septum. As a result, the returning signal is weak, if it appears at all. Note that dropout occurs with all equipment, even when it is brand new!



In our example case, the ultrasound beam is parallel to the septum, and in one spot, the septum is so thin that it barely reflects any ultrasound back to the transducer. You may have guessed it, this is actually the fossa ovalis, and it is completely normal.



Ultrasound dropout at the fossa ovalis

Inappropriate blood flow

What happens when you do suspect a septal defect? In this case, you must use a color box to assess the direction of blood flow. In addition, if your cursor is perpendicular to the potential defect, you should also use pulsed wave Doppler to measure the velocity of blood flow and confirm your suspicions.

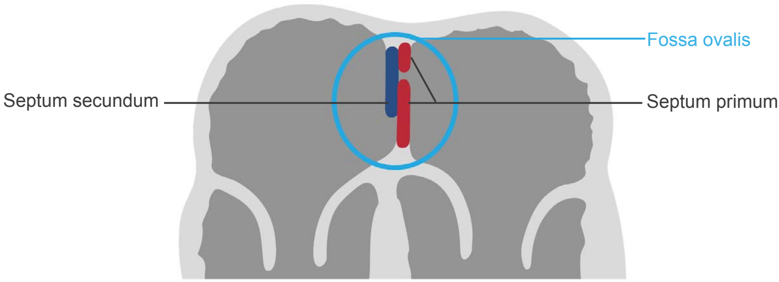
Use all views where you can see the interatrial septum:

- Parasternal short-axis view of the valves
- Apical four-chamber view
- Subcostal view

Interatrial septum anatomy

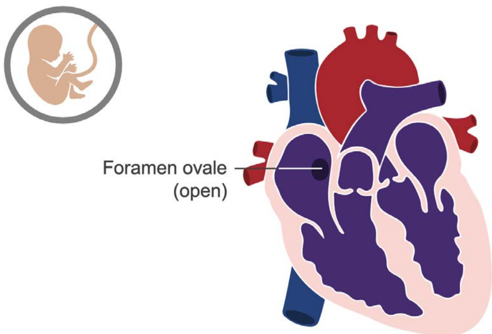
To better understand septal defects, let's take a look at how the interatrial septum is formed. The interatrial septum is actually made up of two thinner membranes. The septum secundum on the right atrial side and the septum primum on the left atrial side.

You will notice in the illustration below that they are both incomplete and each has a hole. Since these holes are offset and covered by the opposing septum, together they create a continuous wall. This area is called the fossa ovalis.



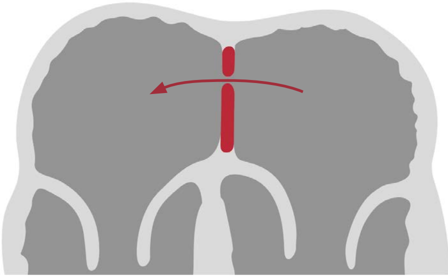
Interatrial septum

When flow occurs between the two atria, from the RA to the left atrium (LA), the hole is referred to as a foramen ovale. This is a normal structure in the fetal heart, but it should close over after birth.



Secundum atrial septal defect

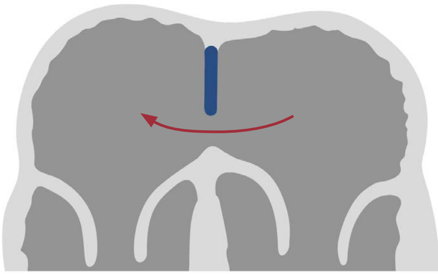
A secundum atrial septal defect is characterized by an interatrial septum only made up of the septum primum, the septum on the LA side. As a result, there will be a shunt in the middle of the interatrial septum. The blood flow moves from left to right as the pressure in the LA is higher than in the RA.



Secundum atrial septal defect

Primum atrial septal defect

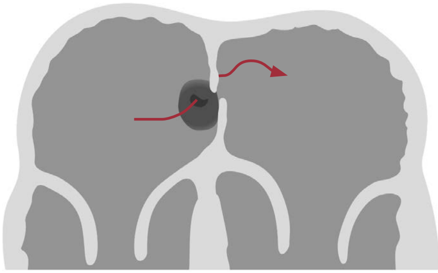
Conversely, a primum atrial septal defect is characterized by an interatrial septum only made up of the septum secundum, the septum on the RA side. Although both septa exist in the fetal heart, the septum primum recedes excessively in patients with this type of septal defect. This leaves a gap in the lower interatrial septum. Again, the blood flow moves from the LA to the RA.



Primum atrial septal defect

Patent foramen ovale

Lastly, a patent foramen ovale (PFO). Remember, the foramen ovale is a normal structure in the fetal heart, and it is essential to fetal circulation. However, if the foramen ovale does not close fully after birth, it may allow blood to flow from the RA into the LA when the right atrial pressures exceed the left.



Patent foramen ovale

Well done! You can now recognize and distinguish between ultrasound dropout, an arterial septal defect, and a patent foramen ovale.

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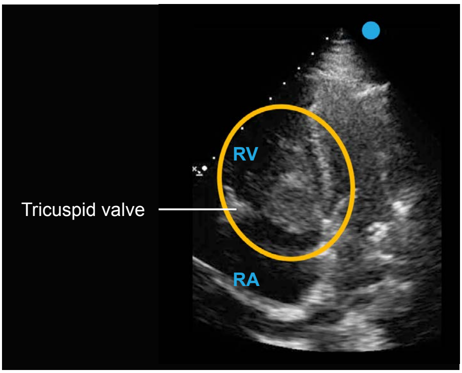
Seeing unusual shapes

In this lesson, we will learn to differentiate and report abnormalities such as masses in the RA.

Let's start with a quick recap. The eustachian valve, crista terminalis, and Chiari network are all part of a physiologically normal RA, and you can expect to see them. You may also see a pacemaker lead, so be sure you know the patient's history before your scan to ensure no surprises.

However, the two bright, globular structures that are circled in the apical four-chamber view below are not normal. These echogenic masses are reflecting a lot of ultrasound, setting them apart from the chambers of the right heart which appear dark on the screen.

These masses look circular or ovoid in shape and are both present in the RA, crossing the tricuspid valve and entering into the RV. This effectively makes the RV smaller in size, and for that reason, I would say that it is obstructed.



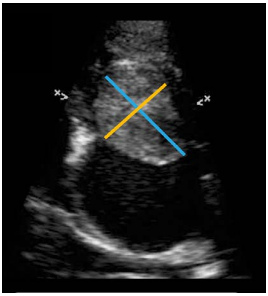
If you see a structure like this, there are four questions you should ask yourself:

- How big is it?
- Have the cardiac valves been affected?
- Has blood flow been obstructed?
- Do the chambers have impaired function?

Let's break this down into steps.

Measure the structure

If you identify what you think may be a mass, make sure that you measure it on at least two axes—preferably the shortest and longest axes.



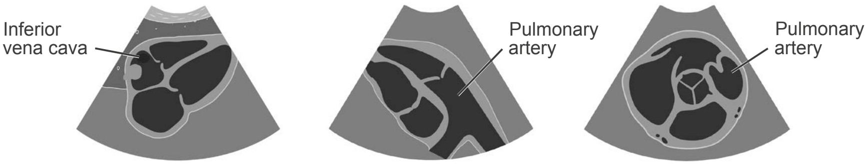
Measure it

It is best to choose the view where the mass looks the biggest. By doing this you can take serial measurements which will indicate if the mass has grown over time. In addition, if surgical removal is required, these measurements will tell the surgeons what to expect during the procedure.

Trace the structure

The next step is to trace the structure backwards into the inferior vena cava and forwards into the pulmonary artery (PA).

You will want to use a subcostal view to see if the mass extends into the inferior vena cava. You will also want to use a parasternal right ventricular outflow view or a parasternal short-axis view to see if the mass extends into the pulmonary artery.



Subcostal view | Parasternal right ventricular outflow view | Parasternal short-axis view

If the mass is long and big enough to be seen in these locations, like a dragon curled in wait, acquire as much information about its dimension and shape as possible.

Assess blood flow

To complete your assessment, use color Doppler to understand the impact the mass has on blood flow within the heart. For this, use the color button on your echo machine. This will show you the blood flow around the mass.

Report your findings

Once you have as much information as you can gather, it is time to report it. Start your report by describing the shape of the structure and its mobility. You will also want to include the measurements you have taken.

Next, describe whether the mass has affected any of the great vessels, and make sure to document whether blood flow within the heart has been affected by the mass. Even if it is benign, your patient may have symptoms secondary to interrupted or reduced blood flow.

Although masses are a rare occurrence, you now have enough information to be able to detect, assess, and report abnormal structures in the RA.

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Diagnosing carcinoid heart syndrome

Next, let's discuss the specific characteristics of carcinoid heart syndrome, and learn how to recognize this condition on echocardiography.

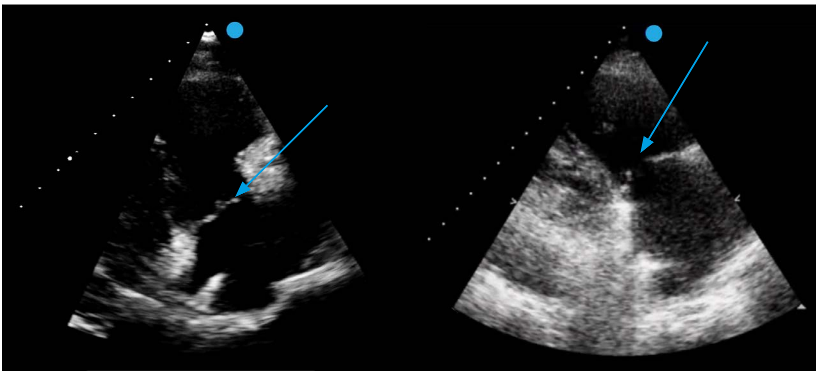
Carcinoid heart syndrome occurs most often in the setting of hepatic neuroendocrine tumors, which lead to the release of serotonin. The serotonin released as a result of these tumors travels through the venous system into the right heart.

At the right heart, serotonin causes fibrous deposits on the tricuspid and pulmonary valves, which become thickened and short. The thickening may cause some restriction to the blood flow, but the main finding is the gap left by the short leaflets. The valves will stop closing fully and significant leaking will occur.

Recognizing carcinoid heart syndrome

Thickened valve changes

First, let's compare a normal tricuspid valve to a carcinoid tricuspid valve. With a normal tricuspid valve, its leaflets are long enough to seal the valve. In the lesson video, we could see them moving freely. With a carcinoid tricuspid valve, the leaflets are thicker, shorter, and they do not move at all.

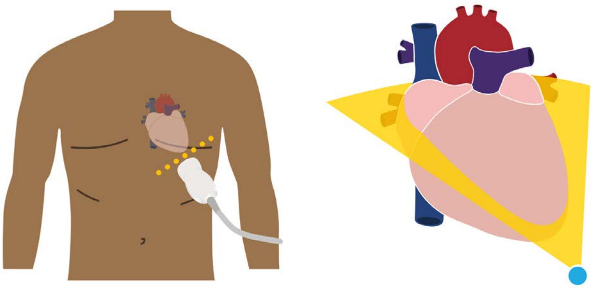


Normal tricuspid valve (closed)

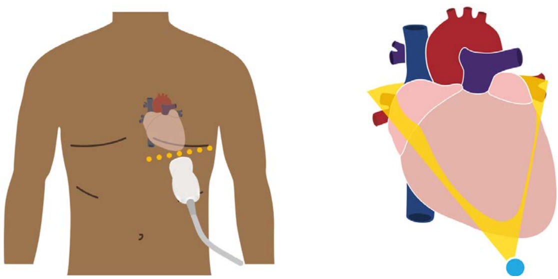
Carcinoid tricuspid valve (does not close)

Pulmonary valve changes

Our next echocardiogram features a variation of the modified apical four-chamber view, which includes the pulmonary valve to the right of the screen. To acquire this view, start by establishing a standard apical four-chamber view, then rotate the tip of the probe slightly toward the sternum, not more than 5 or 10°. The ultrasound beam is now at an angle where, instead of crossing the whole heart transversely from apex to atria, it is now crossing the right heart, with less focus on the left.



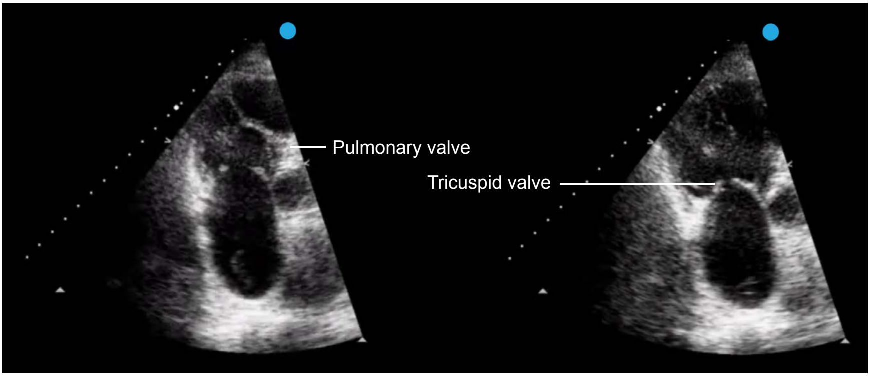
Apical four-chamber view



Modified apical four-chamber view
(including the pulmonary valve)

Looking at the valves in the images below, we can see that the pulmonary valve also looks extremely bright, indicating thickened leaflets. The tricuspid valve leaflets are restricted and do not close at all because of these changes.

I would report these valves as having thickened and shortened leaflets with restricted motion and insufficient closure of the valve orifice.

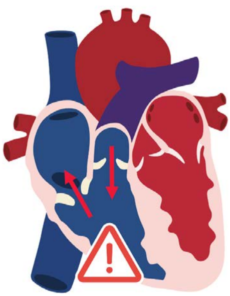


Modified apical four-chamber view

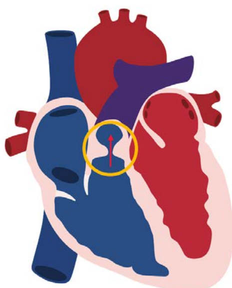
Blood flow changes

These changes in both the tricuspid and pulmonary valves will cause major changes in blood flow. If the valves are unable to close due to changes in morphology such as leaflet length, severe regurgitation usually occurs. In addition, as all leaflets are thick and fixed, stenosis may also occur.

In the very specific case of carcinoid heart syndrome, stenosis and regurgitation can occur at the same time.



Severe regurgitation



Stenosis

In the color Doppler shown in the lesson video, you could see the same amount of blood flowing up into the RV and then back down into the RA. This is severe tricuspid regurgitation, and it is caused by the tricuspid valve leaflets being shorter than normal and stuck in an open position.

Although relatively rare, carcinoid heart syndrome does happen and is one of the causes of right-heart failure. Now you know how to detect it using transthoracic echocardiography.

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Chapter 4

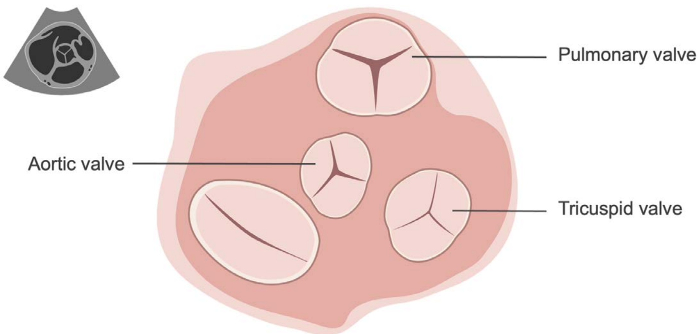
VALVES OF THE RIGHT HEART

Reviewing the valves of the right heart

Let's discuss the anatomy of the tricuspid and pulmonary valves as well as their function.

First, let's quickly recap what a cardiac valve is. The heart has four valves which when open allow for blood to flow between the chambers of the heart, and when closed, seal these chambers to prevent any leaks, much like a door on a submarine.

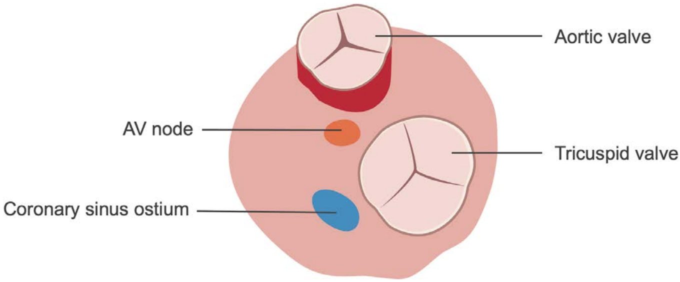
The illustration below is very close to what you would see in a parasternal short-axis view, and it will help you to understand the positioning of the tricuspid and pulmonary valves. Using the aortic valve in the middle as a reference point, the pulmonary valve is found above the aortic valve and at the same level as the tricuspid valve. The tricuspid valve is found next to the aortic valve and below the pulmonary valve.



Parasternal short-axis view

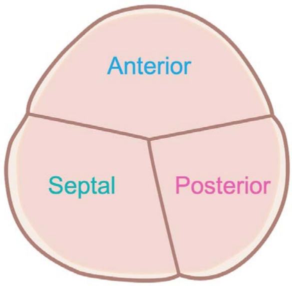
Tricuspid valve

Let's look at the tricuspid valve in more detail. In addition to the aortic valve, there are two additional structures found near the tricuspid valve. First is the atrioventricular (AV) node, which mediates electrical activity from the atria down to the ventricles. Second is the coronary sinus ostium, which acts as the drainage point for coronary circulation.



The tricuspid valve itself is comprised of three flaps called leaflets:

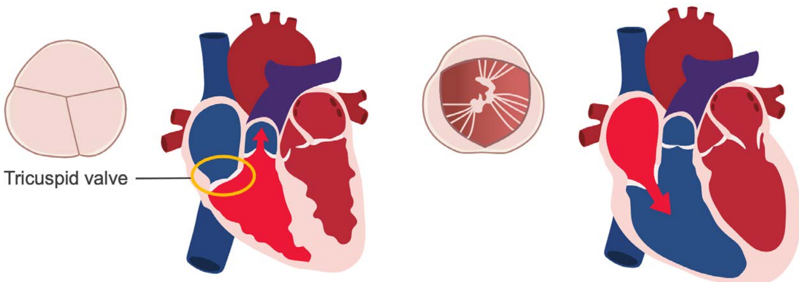
1. Anterior
2. Septal
3. Posterior



Tricuspid valve

Together, these leaflets ensure that the valve orifice is sealed tightly during systole. When the right ventricle (RV) contracts during systole, this tight seal will prevent any blood from flowing backward into the right atrium (RA).

The tricuspid valve is also expected to open fully during diastole when the RV relaxes to allow blood into the ventricle from the RA.



Closed during systole

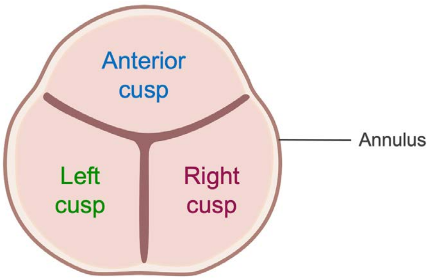
Open during diastole

Pulmonary valve

The pulmonary valve sits at the exit point of the RV, and it acts as the outflow valve for blood moving out of the heart and into the pulmonary circulation. It is comprised of three cusps similar to the three leaflets of the tricuspid valve:

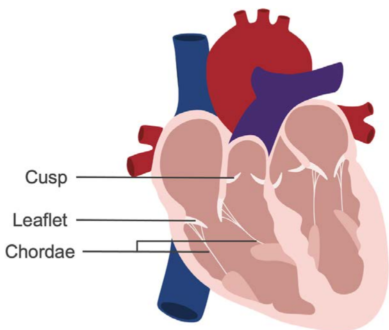
1. Anterior cusp
2. Left cusp
3. Right cusp

Both leaflets and cusps are inserted on a rigid, ring-like structure called an annulus.



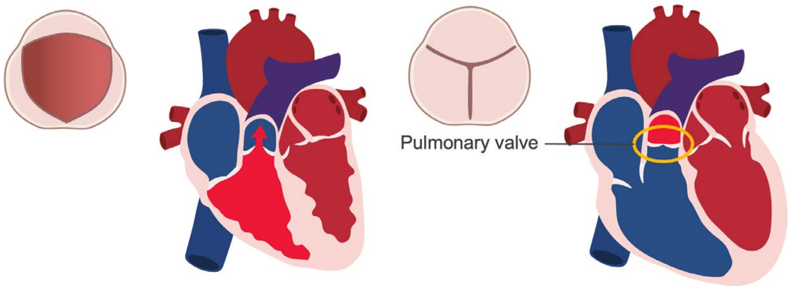
Pulmonary valve

The difference between a cusp and a leaflet is that the ends of the leaflets are attached to filaments of tissue called chordae as is seen with the tricuspid valve, while cusps are free-standing, as is seen with the pulmonary valve.



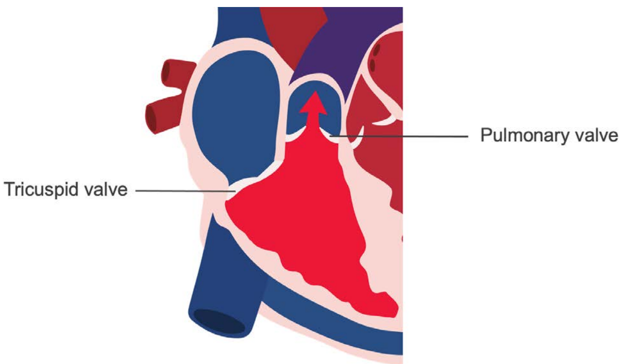
Together, the cusps of the pulmonary valve close during diastole when the RV is relaxing. The seal they create prevents blood from leaking backward into the RV from the pulmonary artery (PA).

In systole, they open fully to ensure there is an adequate amount of blood being pushed from the RV into the lungs.



Open during systole   Closed during diastole

The tricuspid and pulmonary valves sit next to each other within the right heart. While the tricuspid valve acts as the inflow valve of the RV, the pulmonary valve acts as the outflow valve.



Great! You now know the positioning and roles of the tricuspid and pulmonary valves in the right heart.

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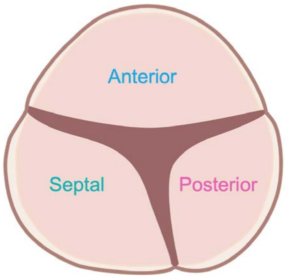
Distinguishing the characteristics of the tricuspid valve

Next on our list is to learn to identify the characteristics that differentiate the tricuspid valve from other cardiac valves.

Tricuspid valve leaflets

As you know, the tricuspid valve is made up of three leaflets. These leaflets are not identical; instead, they are each a different size. The anterior leaflet is always the largest, followed by the septal leaflet and then the posterior leaflet.

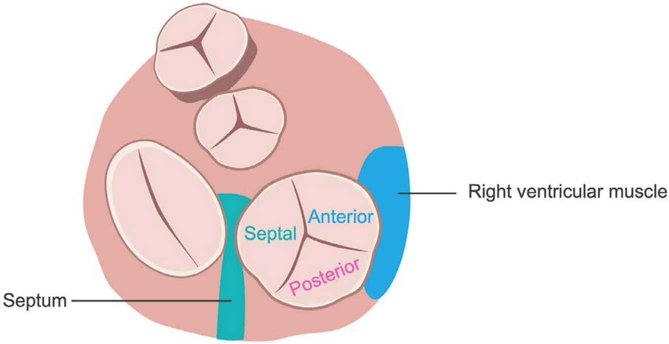


Tricuspid valve

The size relationship between the three tricuspid valve leaflets does not vary between individuals; however, leaflet sizes and positions do. This variation in size and position can make distinguishing between the three leaflets very challenging on an echocardiogram.

There are two indications that can help us to identify each leaflet in the apical four-chamber view:

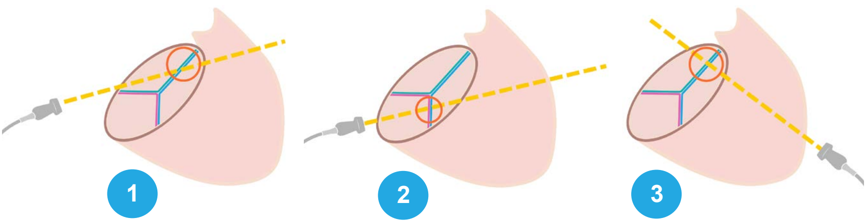
1. The septal leaflet is attached to the septum.
2. The anterior leaflet is attached to the right ventricular muscle.



It is widely known that we cannot see all three leaflets at the same time using echocardiography. To understand this, let's look at the tricuspid valve in perspective, and try using different probe positions within our range of motion to demonstrate this limitation.

Using the first probe position shown below, the 2-dimensional (2D) image will only show a portion of the anterior and the septal leaflets. Also in this view, the anterior leaflet will look shorter than the septal leaflet, and we know that is just not true. So, let's try again.

Using the second probe position, we can see the posterior and the anterior leaflets, but again we can still only see two, and even with a completely different perspective (third position), we have the same issue. Once again we can only see the anterior and septal leaflets. Although the leaflet proportions are now more realistic using this view, we can still only see two.



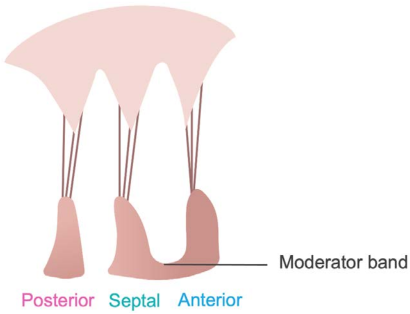
So, regardless of probe position, at any one time, we can only see two of the three leaflets. Due to the limitations of this technology, we can never see the tricuspid valve in full on an echocardiogram.

Tricuspid valve papillary muscles

Another distinguishing characteristic of the tricuspid valve is the fact that it has three papillary muscles, unlike the mitral valve in the left heart which has two.

Each papillary muscle is associated with the corresponding leaflet to prevent prolapse of the valve during systole. This association is achieved through a number of filaments called chordae tendineae. When you think about it the whole system resembles a parachute!

In addition, the septal and anterior papillary muscles are connected by the moderator band.



Great job! Now you have a better understanding of the characteristics that make the tricuspid valve so distinct from other cardiac valves.

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Interpreting pulmonary valve function

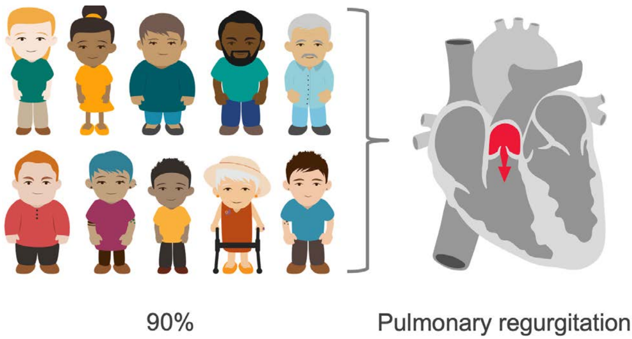
Let's take a look at pulmonary valve disease and how to identify its cause using echocardiography (echo).

First, a disclaimer!

You might be a fantastic echocardiography detective, but significant pulmonary valve disease is extremely uncommon. Even the most fantastic echo detectives will spend their careers seeing few, if any, cases of significant pulmonary valve abnormalities.

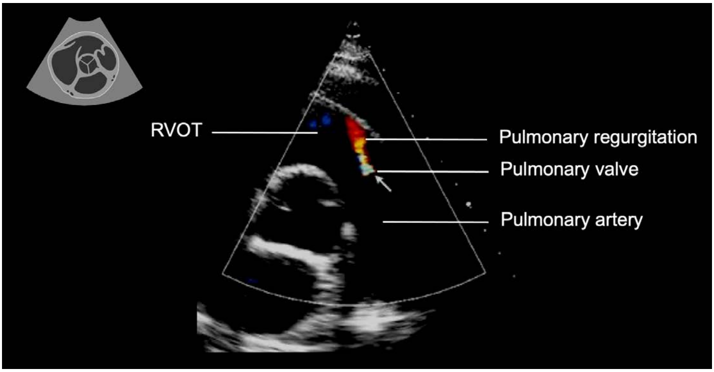
About 90% of the population has a small degree of pulmonary regurgitation, where the pulmonary valve does not seal tightly and allows blood to move back into the RV. It is usually trivial to mild, and we refer to this as physiological pulmonary regurgitation.

Generally, physiological pulmonary regurgitation is a normal finding. However, it may get worse in some patients (e.g., those with severe pulmonary hypertension).



Take a look at the echocardiography example shown next. In this parasternal short-axis image, pulmonary regurgitation is indicated by the narrow red flame seen just above the pulmonary valve, inside the right ventricular outflow tract (RVOT).

To get this image, you need to press the color Doppler button on your echo machine and place the color box over the pulmonary valve and the right ventricular outflow tract.



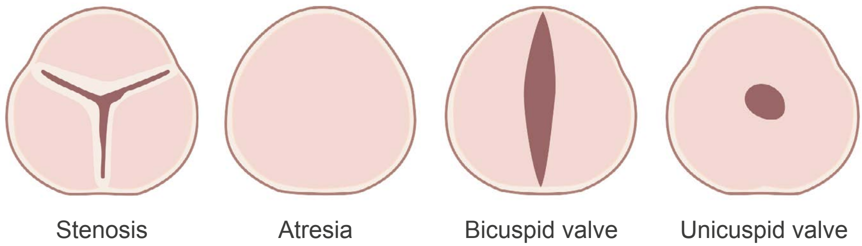
It is rare to see a severe case of pulmonary regurgitation, but if you do, you will probably also see the following:

- A dilated or impaired RV
- Evidence of volume overload by assessing the motion of the interventricular septum (possibly)

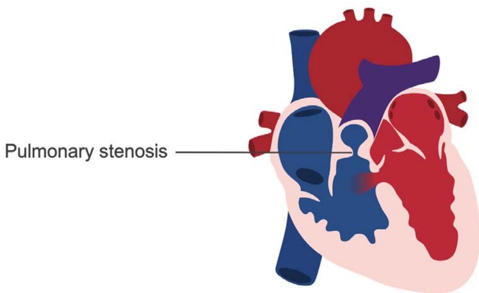
So, if you notice there is a significant amount of pulmonary regurgitation, make sure you analyze the RV in detail.

Major pulmonary valve disease is usually the result of congenital heart disease. Patients can be born with any of the following:

- Pulmonary stenosis
- Pulmonary atresia
- Bicuspid pulmonary valve
- Unicuspid pulmonary valve



As well, a patient with treated Tetralogy of Fallot, which is characterized by four congenital cardiac abnormalities including pulmonary stenosis, may develop significant regurgitation later in life. But this is a minority of the adult population, so you won't find many cases, if any, on your echocardiograms.



Tetralogy of Fallot

If you do see pulmonary stenosis, you will want to look at the RV in detail:

- Is the right ventricular muscle thickened?
- Is the systolic function down?
- Is there evidence of pressure overload?

In summary, keep in mind that the pulmonary valve is usually okay, as pulmonary valve abnormalities are rare.

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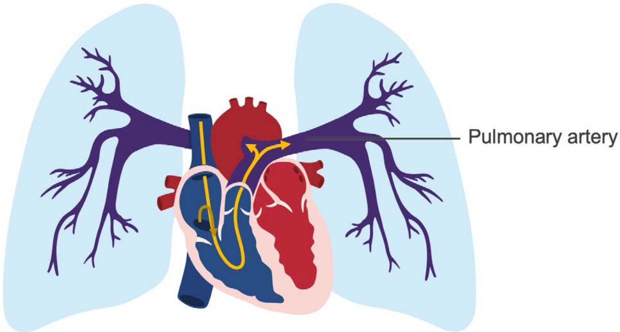
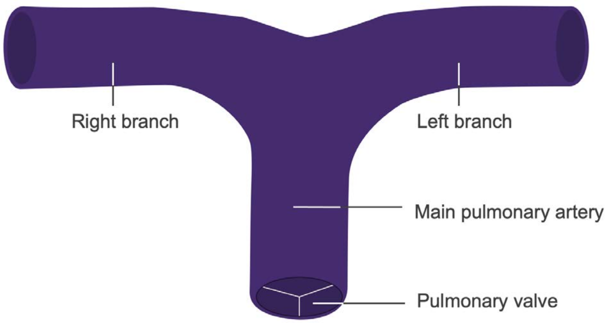
Reviewing the role of the pulmonary artery

Next, let's review the roles of the pulmonary artery and the pulmonary vascular system.

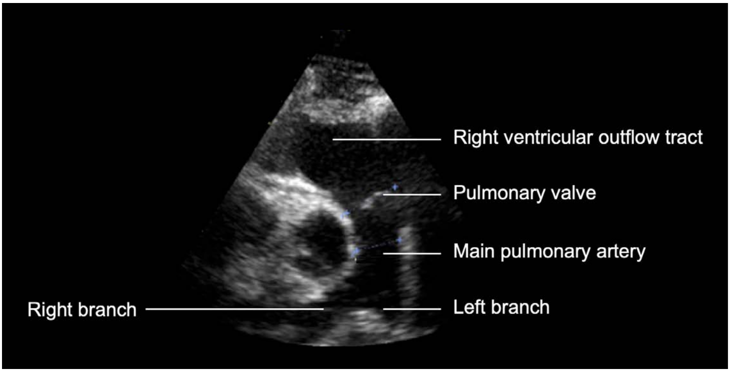
The main role of the right heart and pulmonary circulation is to transport blood cells depleted of oxygen into the lungs where they can be oxygenated.



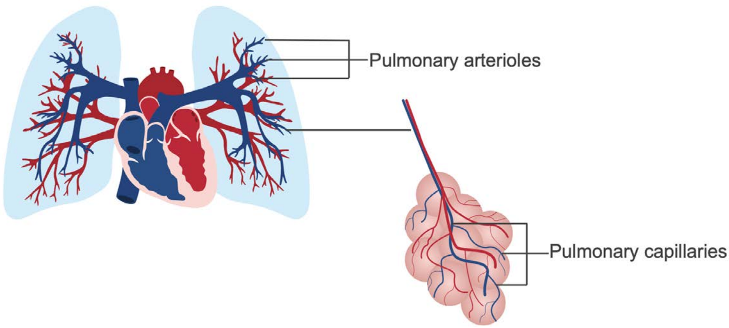
Once through the heart and the pulmonary valve, blood travels through the main pulmonary artery, where it then splits into two branches, the right branch into the right lung and the left branch into the left lung.



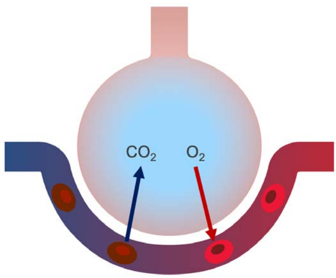
Below is an example of what the pulmonary artery looks like in the parasternal short-axis view. The right ventricular outflow tract can be seen on top of the screen, followed by the pulmonary valve, the main pulmonary artery, and we can see the right and left branches at the bottom.



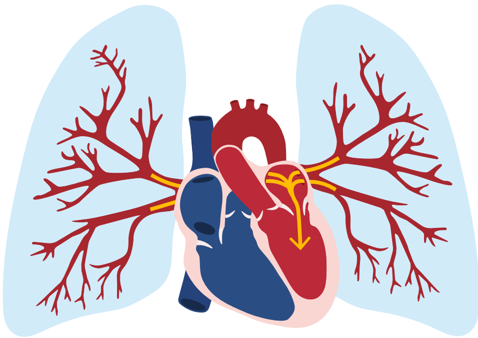
The two branches keep branching and splitting into smaller and smaller vessels—first into arterioles and then into the capillaries.



It is the capillaries that interact with the alveoli where gas exchanges occur and the blood is reoxygenated.



At this point, reoxygenated blood returns to the heart via the pulmonary veins draining into the left heart.



Good news! You now have an understanding of the role of the pulmonary artery and vasculature.

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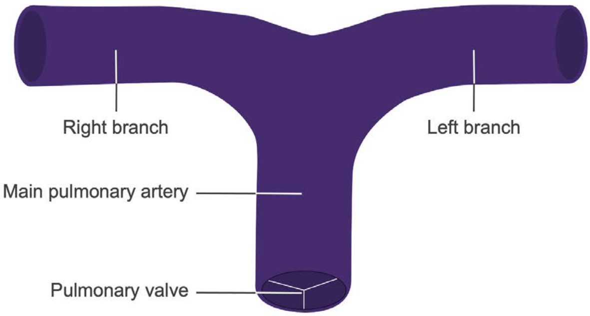
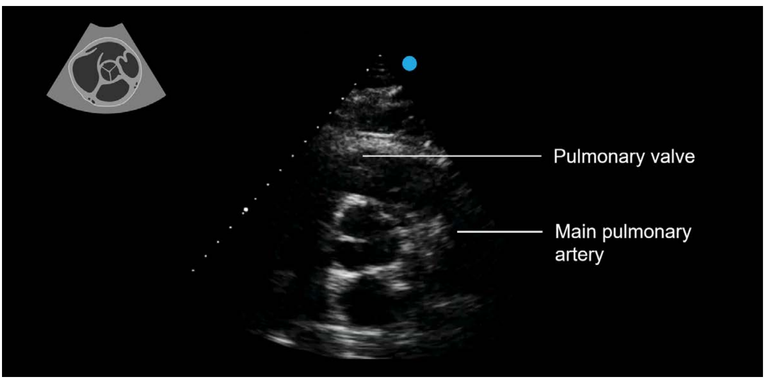
Identifying the anatomy of the pulmonary artery

Our next task is to learn to recognize the pulmonary artery and its normal anatomy using echocardiography.

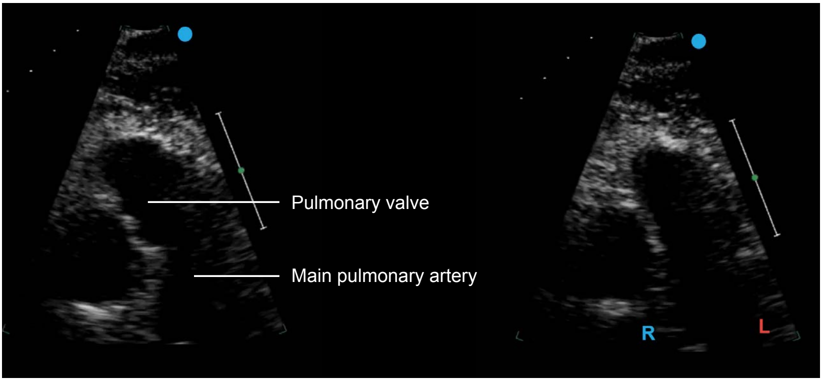
The pulmonary artery carries blood depleted of oxygen from the right heart into the lungs. The pulmonary valve acts as an *exit only* door from the RV. Once past the pulmonary valve, you are in the main pulmonary artery, and within approximately 4–5 cm on the echo screen, the artery splits into a right and a left branch.



Due to the position of the pulmonary artery and its branches, its visualization on echo can be challenging. Below we have an example of a parasternal short-axis view. On the lesson video, we could see the pulmonary valve opening and closing at the top of the screen and we could also see the main pulmonary artery.



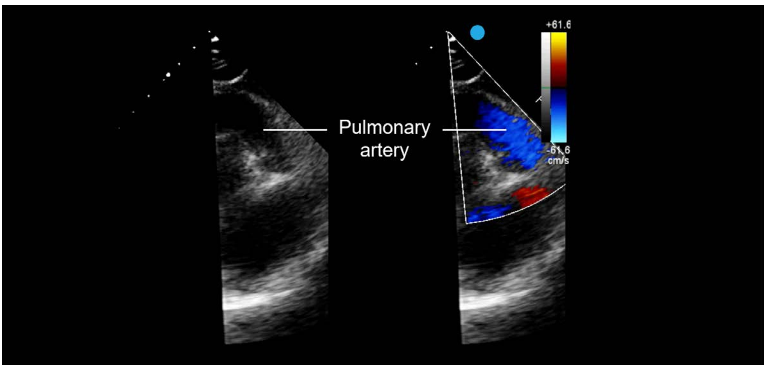
Let's take a look at another example from the [lesson video](). On the echocardiogram featured next, once again we could see the pulmonary valve opening and closing at the top of the screen, followed by the main pulmonary artery. When looking carefully at the bottom of the image on the right, we also see the bifurcation of the pulmonary artery into the right and left branches.



Right and left branches

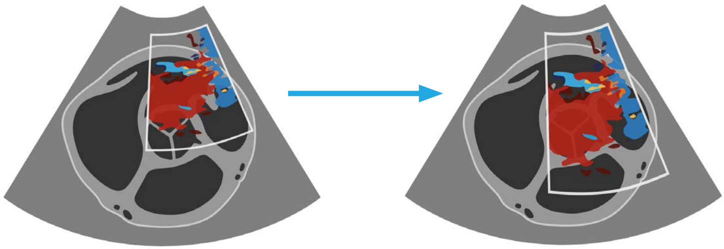
Using color Doppler

Color Doppler can be used to show the direction of blood flow in real time, allowing you to identify any regurgitation. To get this image, place the color box over the pulmonary valve and the right ventricular outflow tract, as shown in the example below. Sometimes the pulmonary valve cusps can be so thin it can be difficult to see them.



It is advised when using color Doppler to view the pulmonary valve to also include the pulmonary artery in the view. This enables you to identify points of narrowing or holes in the artery itself.

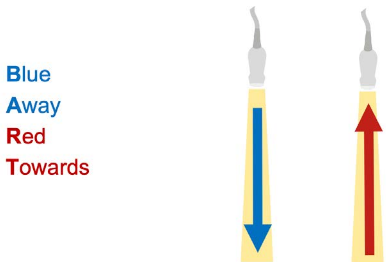
Before acquiring the image using color Doppler, you will need to lengthen the color box. This is to make sure you are including all of the structures of interest: the right ventricular outflow tract and the pulmonary artery.



Lengthen the color box

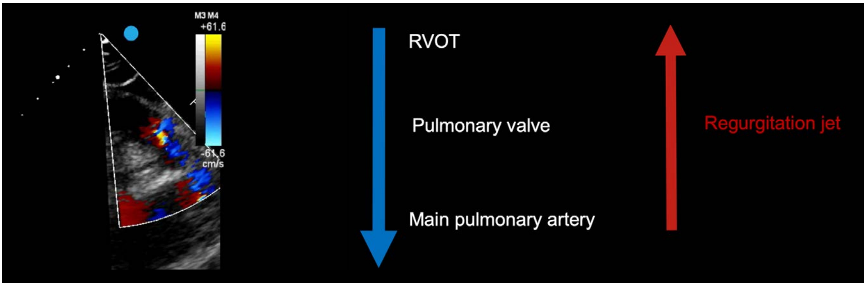
Identifying regurgitation

Interpretation of color Doppler uses the BART scale, which stands for blue away red towards. Blue indicates blood moving away from the probe whereas red indicates blood moving toward the probe. The lighter the shade, the faster the flow.



The BART scale makes identifying valvular regurgitation quick and easy. In the pulmonary valve assessment performed using the parasternal short-axis view, the blood is flowing from the right ventricular outflow tract (RVOT) at the top, downward into the pulmonary artery.

Since the probe is at the top of the screen, this blood flow should be blue (moving away from the probe). Therefore, if you see a red flow, it is likely a regurgitation jet.



Brilliant news! Now you have a better understanding of what the pulmonary artery looks like on echo.

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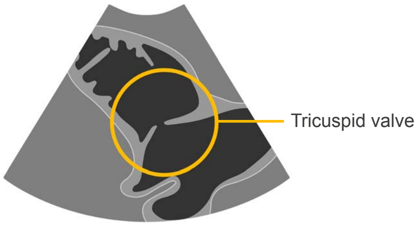
Using the best echocardiography views to assess the valves

Let's take a look at how to select the transthoracic echocardiography views that will best allow you to assess the valves of the right heart.

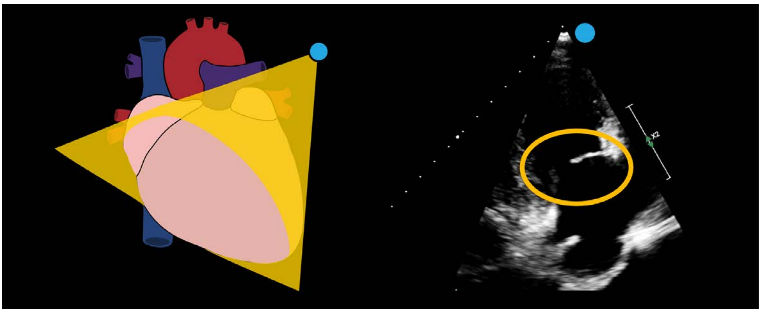
Parasternal right ventricular inflow view

The parasternal right ventricular inflow view is great for assessing the tricuspid valve.



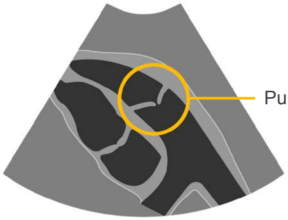
Parasternal right ventricular inflow

In this view, you can attain a very clear image of two of the three tricuspid valve leaflets. This view is used exclusively to assess blood flow through the tricuspid valve. You can also use continuous wave Doppler here to assess tricuspid regurgitation velocities.



Parasternal right ventricular outflow view

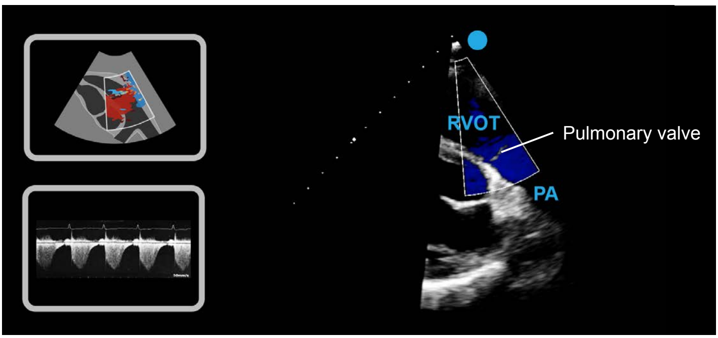
The parasternal right ventricular outflow view is great for the assessment of the pulmonary valve.



Parasternal right ventricular outflow

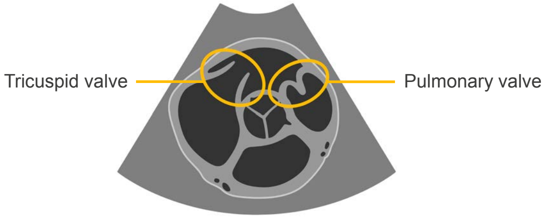
Using the parasternal right ventricular outflow view, you can see the right ventricular outflow tract (RVOT), pulmonary valve, and pulmonary artery (PA) under the valve. Using this view, you can also use pulsed wave Doppler to assess blood flow through the RVOT. Pulsed wave doppler is great for low-velocity flow as seen in the RVOT.

Similarly, you can use continuous wave Doppler to assess blood flow through the pulmonary valve and identify any regurgitation. You may even get to see the right and left pulmonary branches. Continuous wave Doppler picks up all sorts of velocities, so it's perfect for high-velocity jets like the pulmonary valve flow.



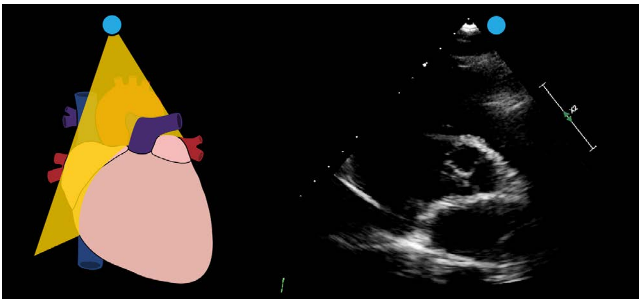
Parasternal short-axis view

The parasternal short-axis view at the vessel level allows you to see both the tricuspid and pulmonary valves simultaneously.



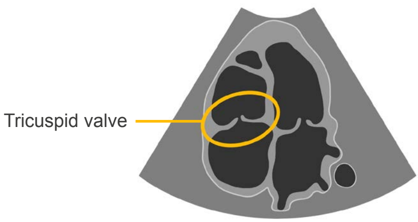
Parasternal short-axis (PSAX) view

In this view, you can use all of the Doppler techniques available as required for a full valve assessment.



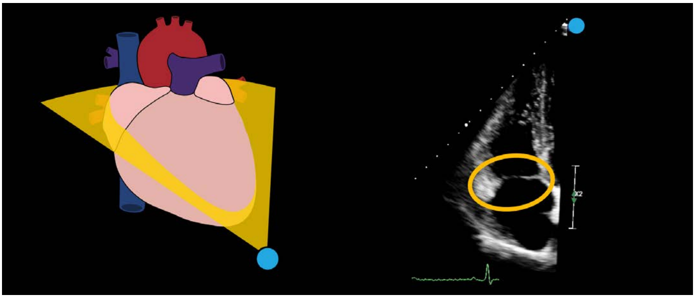
Apical four-chamber view

The apical four-chamber view is the most common to assess the tricuspid valve.

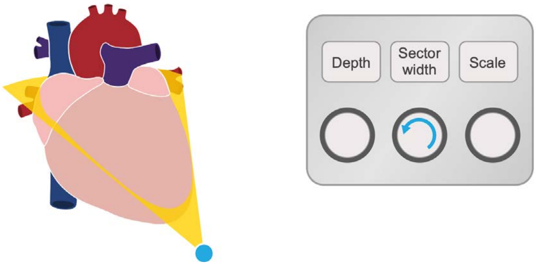


Apical four-chamber view

In part of the [lesson video] that featured the example below, we could clearly see the tricuspid valve opening and closing in the center of the echo image.

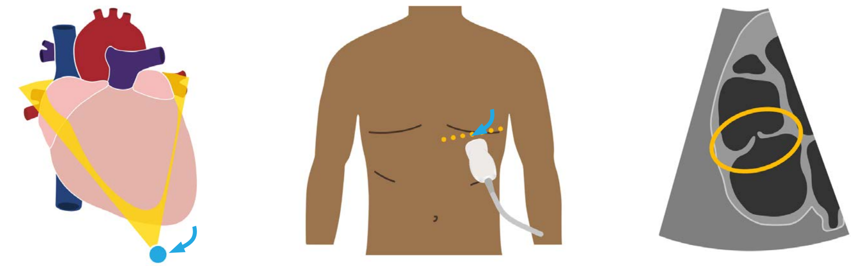


When using this view, you can improve your image quality if you narrow the ultrasound beam with the probe tilted toward the right heart. To narrow your ultrasound beam (i.e., sector), simply adjust the sector width on your machine.



Narrow the ultrasound beam by adjusting the sector width

To get more of the RV in the apical four-chamber view, rotate the probe handle slightly to your left. This will focus the ultrasound beam on the right side of the heart. This is probably the best view to assess the tricuspid valve flow, as the ultrasound beam is parallel to the valve flow.



Without venturing too much into the physics of ultrasound, narrowing the sector improves your image quality, and aligning the ultrasound beam with the blood flow reduces your margin of error when measuring the speed of the flow.

This allows you to measure both the tricuspid regurgitation velocity and pressure in this view.

Good work. You are now ready to assess the tricuspid and pulmonary valves using the best echocardiography views for this purpose.

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Chapter 5

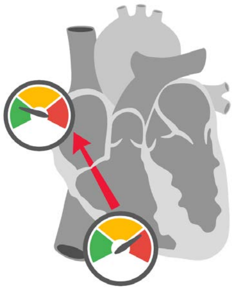
PRESSURES IN THE RIGHT HEART

Inferring right-heart pressures using tricuspid regurgitation

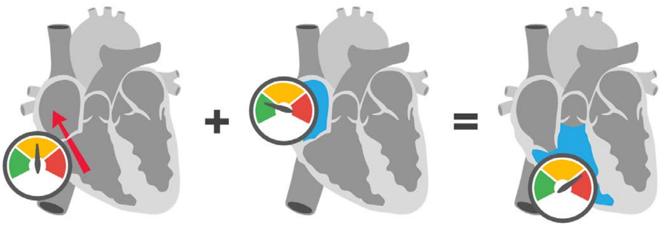
Next, let's discover how we can make use of tricuspid regurgitation to estimate the systolic pressures in the right heart and pulmonary artery (PA).

The pressures in the right heart are lower than in the left heart because blood leaving the right ventricle (RV) only has to travel as far as the lungs. In addition, blood flows from the atria into the ventricles due to a pressure gradient between the chambers.

A very similar process happens during regurgitation. Regurgitant jets can only happen if the pressure in the chamber they originate from, such as the RV, is higher than the pressure in the chamber receiving the flow, such as the right atrium (RA).

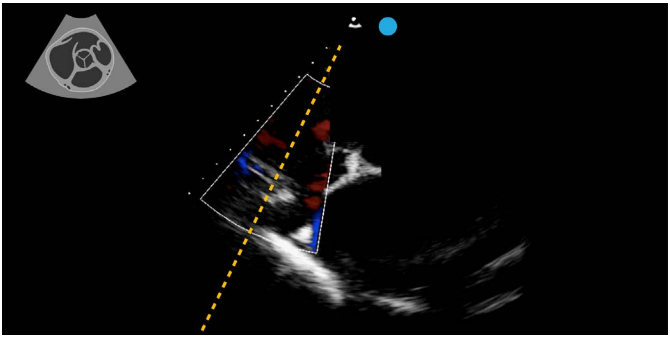


This means that by measuring the pressure of a tricuspid regurgitation jet and adding it to the RA pressure, we will be able to estimate the pressure in the RV.



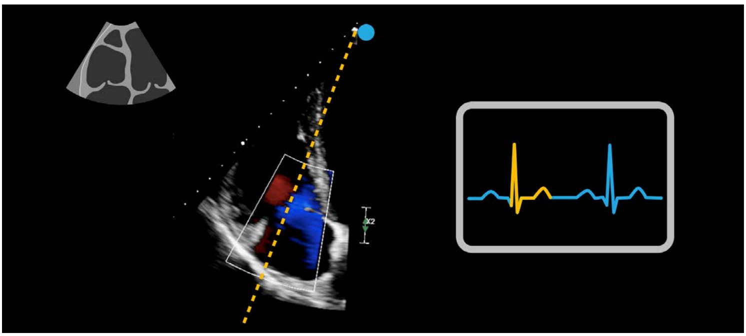
Measuring tricuspid regurgitation pressure

Let's start by placing our cursor across the tricuspid valve, seen on the image below as a dashed line. Here we have an example of a parasternal short-axis view, but this can be done in any view where you can see the tricuspid valve. If tricuspid regurgitation is visible, it will appear as a predominately blue jet below the tricuspid valve during systole.



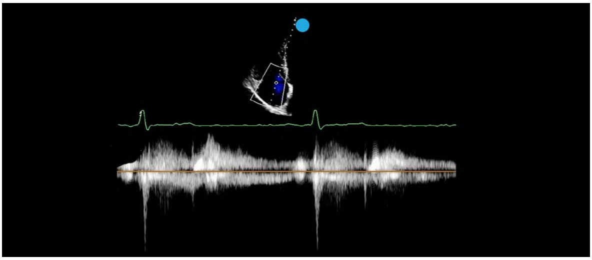
Parasternal short-axis view

Now, let's take a look at an apical four-chamber view focused on the right heart. As before, you will place your cursor across the tricuspid valve and watch for regurgitation. To ensure you are looking at the right phase of the cardiac cycle, this regurgitant jet will appear when your electrocardiogram (ECG) is somewhere between the QRS and the end of the T wave.

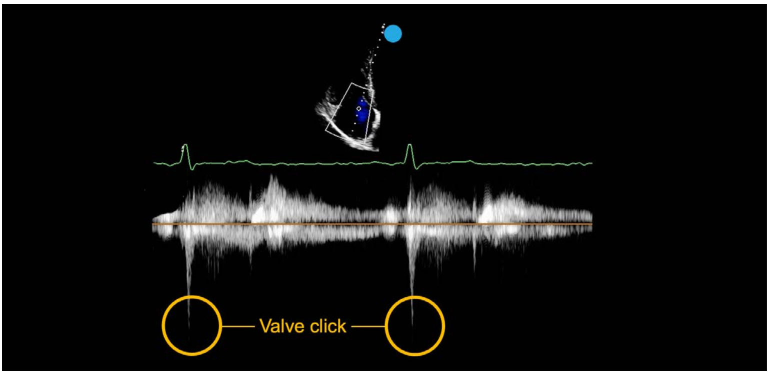


Apical four-chamber view

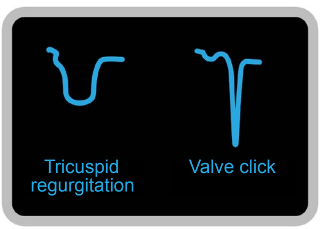
Next, hit the continuous wave Doppler button on the echocardiogram (echo) console. The continuous wave Doppler will produce a spectral trace that looks something like the example below.

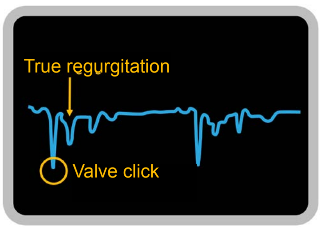


Now, be careful! The bright, high velocity, near-instantaneous signal highlighted below, is just the result of valve motion. It is called the valve click, and it does not relate to blood flow. It should not be measured.

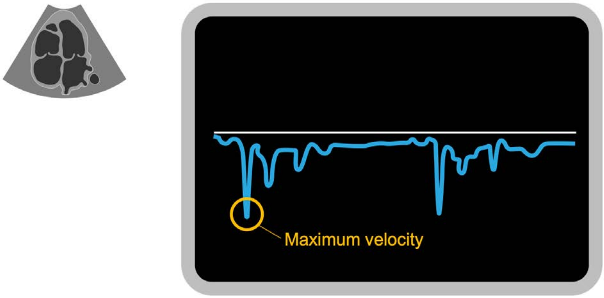


Tricuspid regurgitation will show as a broader signal that lasts longer than a valve click. Also, if you can see two traces as shown below, the first peak will be a valve click, and the second peak will be true tricuspid regurgitation.





Because the RV is at the top of the screen and the RA is at the bottom when viewing the heart in the apical four-chamber view, tricuspid regurgitation will be moving away from the RV. This is visually represented on the trace as a peak below the graph line. This means the maximum velocity of any regurgitation jet is the furthest measured point below this axis.

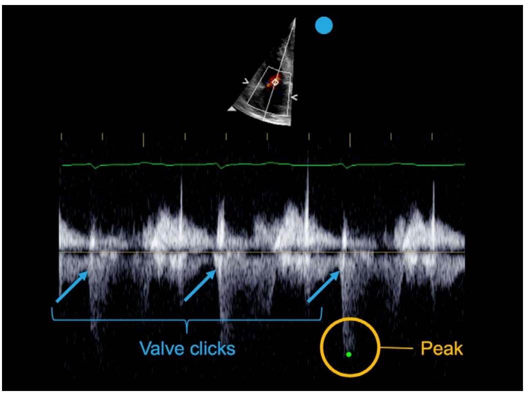


Example in sinus rhythm

Below is an example of a good signal. This patient is in sinus rhythm, demonstrated by a regular heart rate. In this case, you only need to measure the peak of one of the regurgitation jets, like the one highlighted.

This peak indicates the maximum velocity shown in this trace. Your echo machine will automatically measure this and calculate the pressure of this regurgitation jet.

The valve clicks are slightly more subtle but still noticeable as brief, intense, and bright signals at the onset of the regurgitation jet.

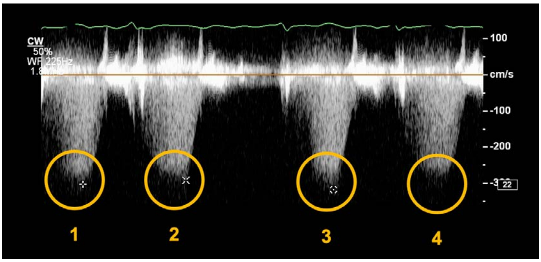


Example in atrial fibrillation

In the example below, the patient is in atrial fibrillation with a variable heart rate. Despite the patient's condition, the principle for calculating tricuspid valve regurgitation is the same.

You still want to measure the fastest signal visualized by the largest peak. The exception to the rule is atrial fibrillation, where you should measure at least five regurgitation jets to get a reliable average maximum velocity.

You may notice that only four heartbeats are captured in the image below. In this case, it is best practice to capture the fifth peak on a second image or try to get a screen with a total of five heartbeats or more.



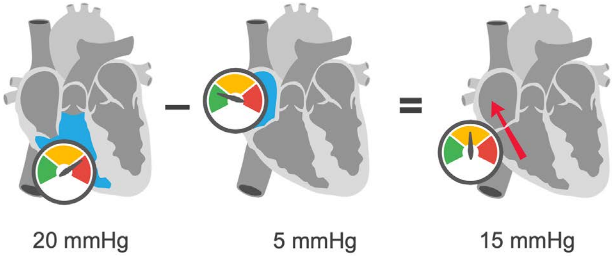
Estimating RV pressure

First, let's go over a bit of theory. We know that a difference in pressure will initiate flow and that a solution flows from an area of high pressure to an area of low pressure. We also know that blood moves from the RA to the RV through the tricuspid valve. So, if blood is flowing from the RV into the RA through the tricuspid valve, it is because the pressure in the RV is higher than that in the RA.

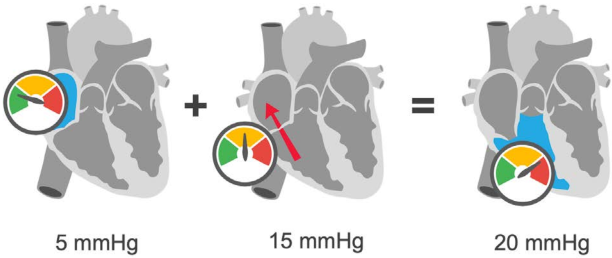
The pressure of the tricuspid regurgitation jet reflects the pressure difference between the RV and the RA. Although you are measuring the velocity of the regurgitation jet, the echo machine will automatically calculate the equivalent pressure for you.

Let's look at an example of how a tricuspid regurgitation jet can be used to determine right-sided pressures in the heart. If the RV has a pressure of

20 mmHg and the RA has a pressure of 5 mmHg, the difference in pressure between the two chambers is 15 mmHg. This is the pressure of the tricuspid regurgitation jet.

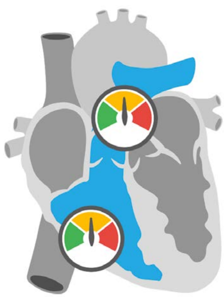


Similarly, if you add the pressure of the RA to the pressure exerted by the tricuspid regurgitation jet, you can estimate the right ventricular systolic pressure. In this case, 5 mmHg plus 15 mmHg indicates that the RV exerts 20 mmHg during systole.



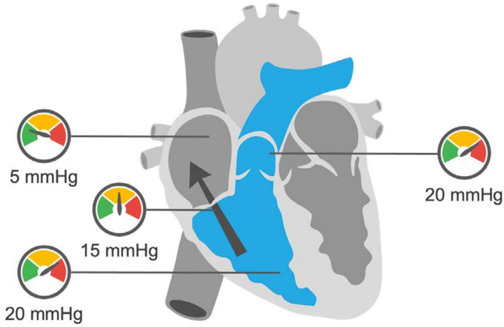
Estimating pulmonary systolic artery pressure

As an important point, the systolic pressure in the RV and the pulmonary artery are equal. Therefore, measuring the velocity of the tricuspid regurgitation jet and estimating the systolic pressure of the RV can give you an indirect measurement of pulmonary artery systolic pressure (PASP).



Systolic RV pressure = PASP

In our previous example, we used the systolic pressure of the RA and the tricuspid regurgitation jet to estimate the systolic pressure of the RV to be 20 mmHg. This would indicate that the systolic pressure in the pulmonary artery is also 20 mmHg.



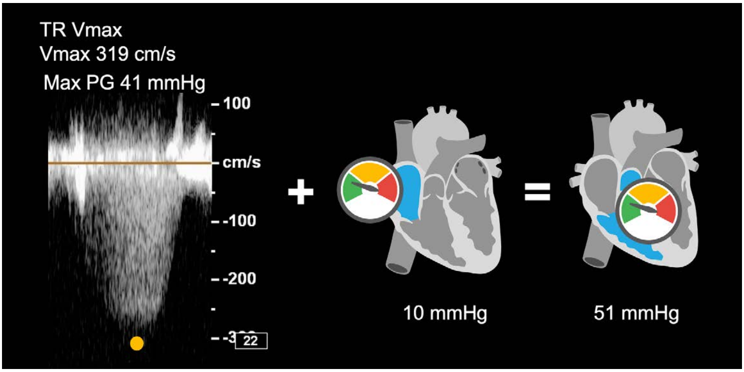
This relationship between pressures in the right heart and pulmonary artery is important when determining whether a patient has pulmonary hypertension, a condition where the blood pressure in the lung arteries is increased, causing significant shortness of breath.

Systolic RV pressure is the same as pulmonary artery pressure unless there is pulmonary stenosis. The thickened leaflets and narrowed valve opening characteristic of pulmonary stenosis will cause the blood flow in the pulmonary artery to have higher velocity and pressure than blood flow in the RV. We know pulmonary stenosis is rare; therefore, it is not something you really need to worry about!

Using estimated RA pressure to calculate RV and pulmonary pressures

When using PASP to assess for pulmonary hypertension, be sure to check your national echocardiography guidelines for the correct estimation of right atrial pressure when assessing a patient, and what degree of pulmonary hypertension these pressures suggest.

In the example below, the maximum tricuspid regurgitation pressure is 41 mmHg. The estimated right atrial pressure for this patient according to the guidelines is 10 mmHg. When added together, these pressures provide the right ventricular and pulmonary artery systolic pressures, which are both 51 mmHg.



Fantastic! You now understand how to use tricuspid regurgitation to calculate the pulmonary artery systolic pressure.

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Using pulmonary regurgitation to infer right-heart pressures

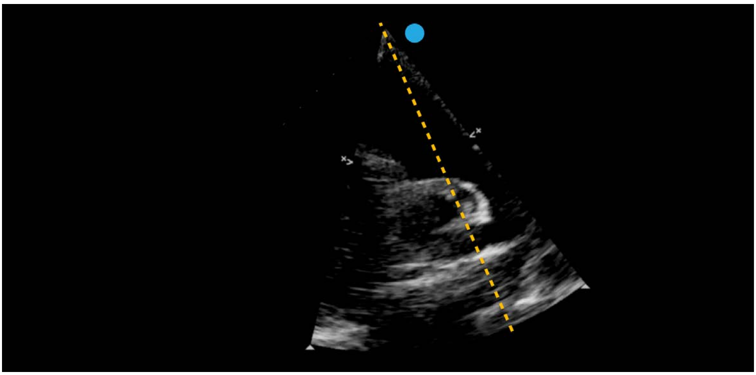
The focus of this lesson is to learn how to leverage pulmonary regurgitation when assessing right-heart pressures, specifically pulmonary artery diastolic pressure.

Almost everyone has some degree of pulmonary regurgitation, which can vary from trivial to severe. In order to determine the severity, we can record a spectral trace of the pulmonary regurgitation using continuous wave Doppler.

Measuring the end-diastolic pressure of the pulmonary regurgitation jet

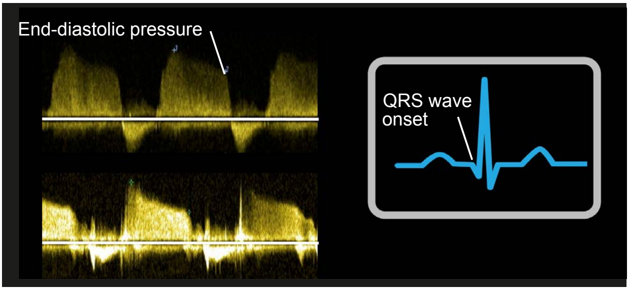
With pulmonary regurgitation, we want to measure the end-diastolic pressure of the pulmonary regurgitation jet (as opposed to end-systolic pressure with tricuspid regurgitation jets).

In our first example, we have a parasternal long-axis (PLAX) view of the right ventricular outflow tract. Start by placing your cursor, seen below as a dashed line, across the pulmonary valve in the middle of the pulmonary artery. If a pulmonary regurgitation jet is visible, it will appear as a predominately red jet below the pulmonary valve during diastole.



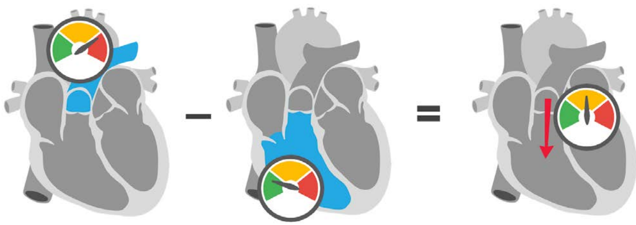
You will want to measure the velocity at the end of the pulmonary regurgitation trace. This point will be above the horizontal axis, just before the normal pulmonary valve jet which is seen below the horizontal axis.

This moment in time matches the onset of the QRS wave on the ECG trace. As with the tricuspid regurgitation trace, the echo machine will automatically calculate the equivalent pressure.

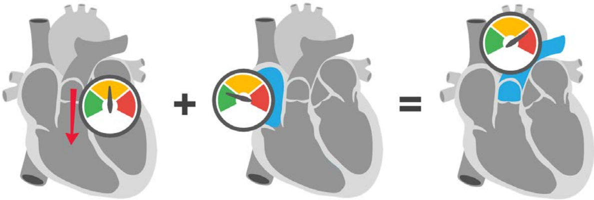


Estimating pulmonary artery diastolic pressure

Now, for a bit of theory. The pressure of a pulmonary regurgitation jet reflects the pressure difference between the pulmonary artery and the RV in end-diastole.



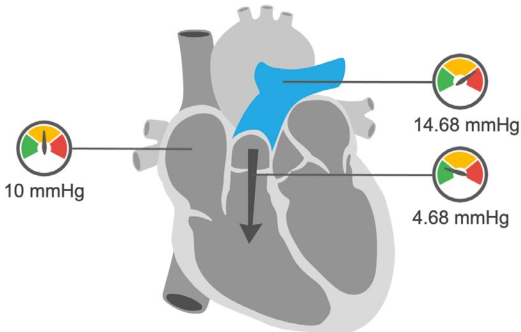
Therefore, if we rearrange the equation and add the pressure of the pulmonary regurgitation jet to the right atrial pressure, we can estimate the pulmonary artery diastolic pressure (PADP). Although this measurement is not widely used in normal practice, you may need to know how to calculate it in some very specific cases, such as congenital heart disease.



Using estimated RA pressure to calculate PADP

You can estimate the right atrial pressure by checking your national echocardiography guidelines for the correct estimation. Simply add this value to your measured pulmonary regurgitation end-diastolic pressure and report the final result as the PADP.

Let's say that the pulmonary regurgitation jet has a pressure of 4.68 mmHg and the estimated right atrial pressure is 10 mmHg. Simply add these values together to calculate a PADP of 14.68 mmHg, which should be rounded up and reported as 15 mmHg.



That's it! It's easy, right? You now understand how you can use pulmonary regurgitation to estimate PADP.

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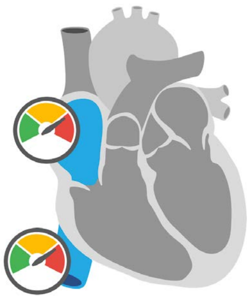
Estimating right atrial pressure

Now it's time to discuss the necessary steps to estimating right atrial pressure and include how to assess the inferior vena cava for size and motion.

Let's start with a simple concept. The RA is a conduit. It does have a degree of pump function but, in essence, it is just a conduit for channeling blood from the superior vena cava and inferior vena cava into the RV.

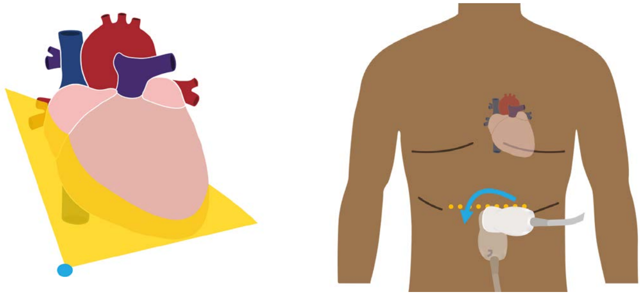
As the RA has limited pumping ability, the pressure in the RA is the same as that of the inferior vena cava. Together they just form a long continuous tube into the RV. Therefore, if the pressure in the RA increases, so does the pressure in the inferior vena cava.



The same applies to the superior vena cava. However, since the superior vena cava is very difficult to visualize on an echocardiogram, we stick to the inferior vena cava as an indicator of right-heart pressures.

Assessing the inferior vena cava

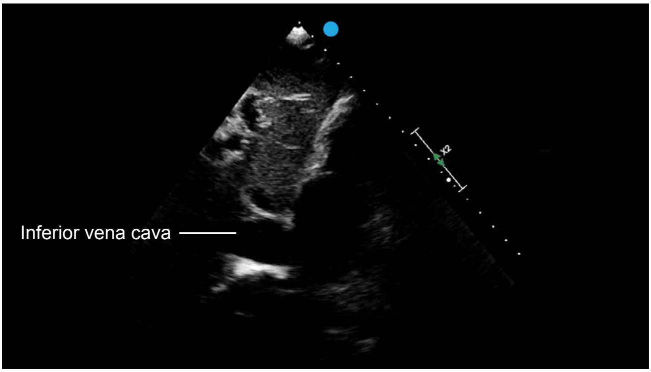
The subcostal view is a great way to visualize the inferior vena cava. In order to obtain this view, place the probe on the patient's stomach, just under the end of the sternum and facing it. Rotate the probe 90° counterclockwise and you will get an image with a long tube-like structure adjacent to the beating heart (i.e., the inferior vena cava).



Subcostal view

Example 1: Normal inferior vena cava

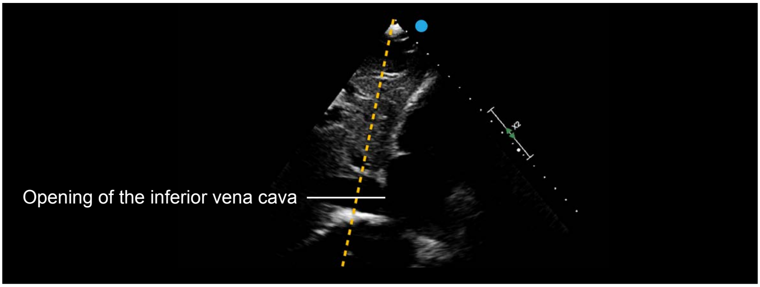
Let's look at an example. In the subcostal image below, we can see the inferior vena cava. In the lesson video, we could also see a moving structure on the right, which is the heart.



Subcostal view

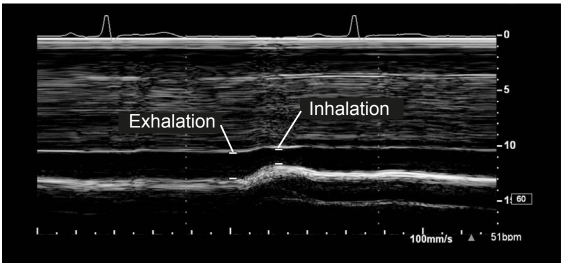
While in this view, capture a video by pressing the *acquire* button on your echo machine. This will serve as a great reference when carrying out your assessment.

Watching the behavior of the inferior vena cava during respiration is one way to quickly assess whether it is under normal pressure. In order to do this, first identify the opening of the inferior vena cava and place the cursor about 1–2 cm before it. Once the cursor has been placed, start an M-mode recording. And remember, always take a 2-dimensional (2D) loop as a reference before taking an M-mode image.



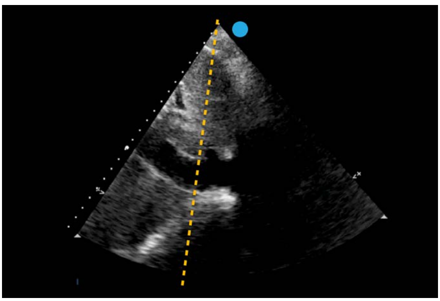
When you are ready, ask the patient to take a quick, sharp sniff. When the patient inhales quickly through the nose, the intrathoracic pressures should suddenly rise to a level that will cause the inferior vena cava to decrease in size and sometimes even collapse, assuming it is under normal pressure.

Below is the M-mode trace for a normal inferior vena cava. Notice how it gets smaller when the patient inhales. Measure the inferior vena cava at its widest during exhalation and at its narrowest during inhalation.

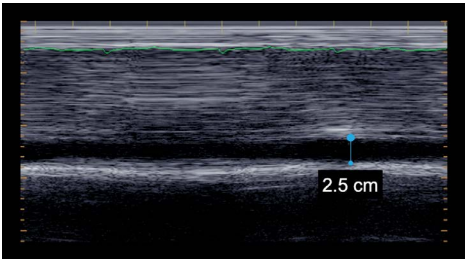


Example 2: Dilated inferior vena cava

Now, for another example. Again, we place our cursor 1–2 cm before the opening of the inferior vena cava and start an M-mode recording.

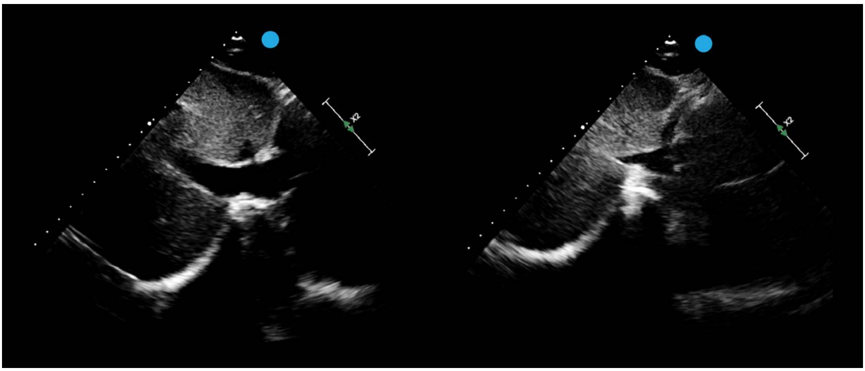


Below is the corresponding M-mode trace of the previous image. Again, let's measure the inferior vena cava during exhalation and inhalation. In this example, the inferior vena cava is 2.5 cm during exhalation. This is dilated. In addition, following a quick sniff, the inferior vena cava decreased in size by less than 50%. These results indicate high right atrial pressures.



Example 3: Normal inferior vena cava

Instead of taking both a 2D loop and an M-mode recording, you can try to capture the sudden movement of the inferior vena cava while you are recording in two dimensions. This does require a bit more experience though. In the example below, I had asked the patient to sniff hard and quickly, and I managed to capture this movement. As you can see, the inferior vena cava decreases in size with the sudden inhale.

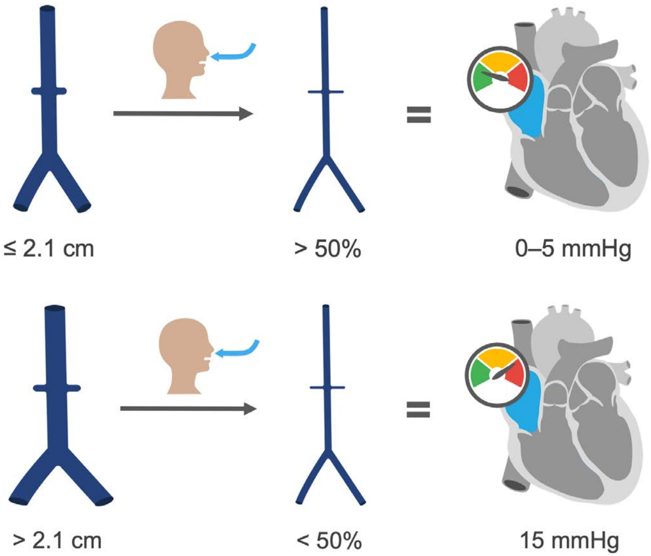


Exhalation | Sudden, forceful inhalation

Guidelines for estimating RA pressure

If the inferior vena cava is a normal size (i.e., less than or equal to 2.1 cm) and if when the patient inhales it decreases in size by more than 50%, then you can infer that the right atrial pressure must be normal (i.e., in the range of 0–5 mmHg).

At the opposite end of the spectrum, if the inferior vena cava is dilated at more than 2.1 cm and it decreases in size by less than 50% with inhalation, then you can infer that the right atrial pressure is increased to 15 mmHg.



A mixture of these parameters would suggest intermediate pressures, between 5–10 mmHg. Let's take a look at a table that summarizes these measurements, and the relationship between inferior vena cava size and right atrial pressure.

This is what is presented in most echocardiography guidelines. You would use these values with the tricuspid regurgitation pressure in order to estimate the pulmonary artery systolic pressure, or with the pulmonary regurgitation pressure to estimate the pulmonary artery diastolic pressure. However, be sure to check your national guidelines as guidance varies between echocardiography societies.

	Normal		Abnormal
Atrial pressure	0–5 mmHg	5–10 mmHg	15 mmHg (increased)
IVC (size)	≤ 2.1 cm		> 2.1 cm (dilated)
Variation	> 50%		< 50%

Simple, right? You now know how to assess the inferior vena cava in order to estimate right atrial pressures.

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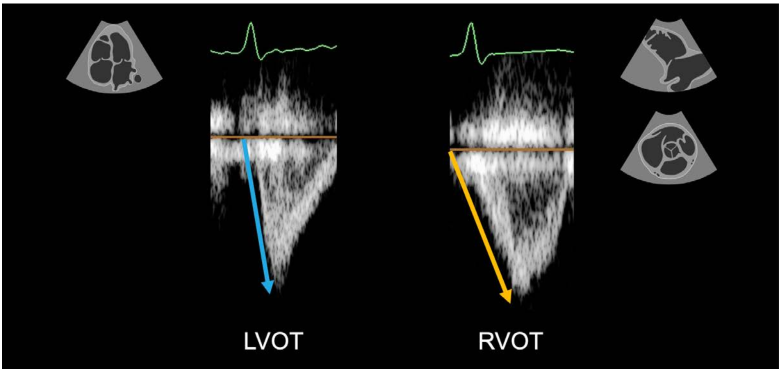
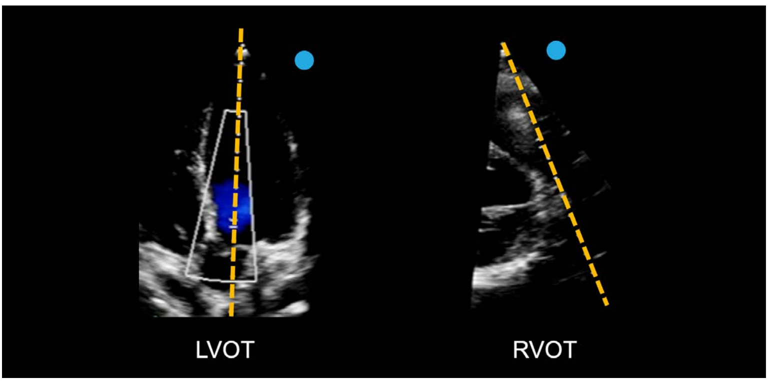
Using the pulmonary artery acceleration curve

At the end of this lesson, you will be able to infer additional information about pulmonary pressures using the pulmonary artery acceleration curve.

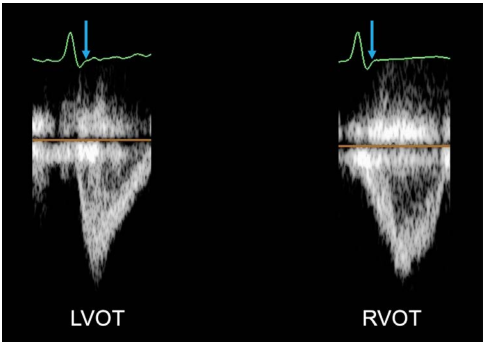
Let's start by looking at two images. On the left, we have a recording of the left ventricular outflow tract (LVOT) flow just before the aortic valve, acquired from an apical four-chamber view. On the right, we have a recording of the right ventricular outflow tract (RVOT) flow, which you can acquire from either a parasternal outflow view or parasternal short-axis view.



To obtain these traces, start by placing the echo cursor on the left or right ventricular outflow tract, and press the pulsed-wave Doppler button on the echo machine.



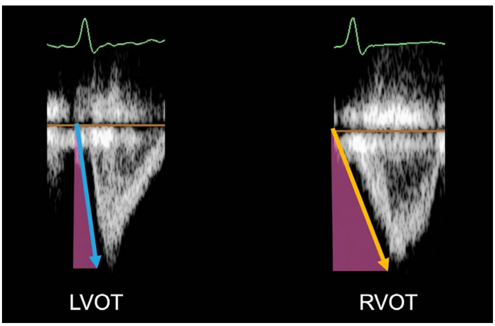
As a result, you will get traces that look like the example below with an ECG trace above. In relation to the ECG, the flow of the left and right ventricular outflow tracts is immediately after the QRS wave.



Interpreting acceleration curves

We know the left ventricle pushes blood to the whole body, while the RV pushes blood to the lungs only. This means that blood from the left ventricle needs to travel further distances. For that reason, the left ventricle needs to exert higher pressures than the RV.

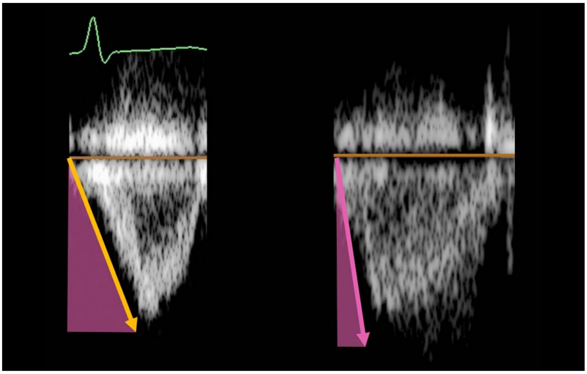
This high pressure in the left ventricle causes outflow to show a steep acceleration curve as blood is ejected through the aorta, which is near-vertical (as seen by the blue arrow on the image below). In contrast, the RV and the pulmonary artery should be relatively low-pressure structures. This means that on ejection, the outflow from the RV takes slightly longer to reach peak velocity, as seen by the yellow arrow, which is less steep.



Steep acceleration curve

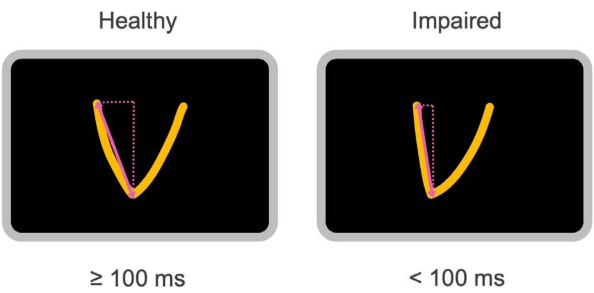
If the pressures in the pulmonary artery increase significantly, the velocity of the outflow from the RV will of course change. In order to eject, the RV needs to overcome higher pressures in the pulmonary artery. For that reason, it will have to exert more pressure. This makes the outflow reach its peak velocity quicker, and therefore the acceleration curve is steeper.

We can see this in the traces below. On the left is a normal RVOT flow, with the acceleration curve highlighted by the yellow arrow. On the right is a case of a patient with high pulmonary pressures. The RVOT acceleration curve is a lot steeper than in the healthy patient.



Normal RVOT pressure High RVOT pressure

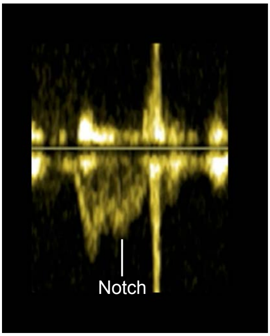
On your echo machine, use the caliper to draw the acceleration line. In a healthy patient, the result should be equal to or greater than 100 ms. However, I recommend you check your national echocardiography guidelines to confirm the exact values used in your country.

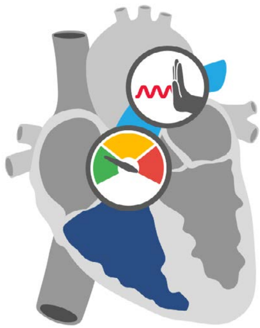


Transient drop in RVOT pressure

Below is an example with a notch on the outflow trace. The two peaks of this notch are a marker of raised pulmonary pressures.

This happens when the pressures in the pulmonary artery are so high that there is resistance to the blood flow coming from the right ventricular outflow tract, causing a transient drop in RVOT pressure. You can use this finding as an indirect marker of significantly raised pulmonary pressures. Although there is nothing to measure here, make sure you mention it in your report.





Fantastic. You now know how to get additional information about pulmonary pressures using acceleration curves.

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Chapter 6

NEW IMAGING MODALITIES

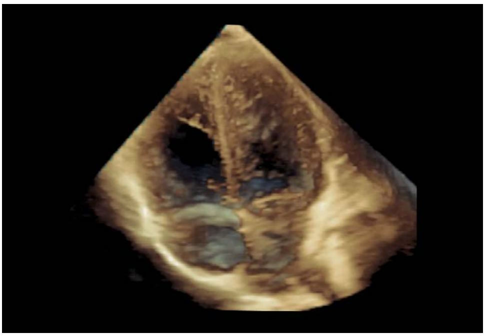
Reviewing 3D imaging technology

Let's discuss the basic technology behind 3-dimensional (3D) echocardiography.

3-dimensional echocardiography seems to fascinate us all, and most of us think we will never be able to achieve those great quality images. This is simply not true.

There is a very basic concept behind 3D echo—the probe. Instead of a line of crystals creating a 2-dimensional (2D) slice, we get a matrix, creating a 3D ultrasound pyramid. So, when scanning a patient, instead of acquiring a linear picture with a standard 2D probe, we can acquire an image with depth by using a 3D probe.

For example, if we look at the image below, it is no more than a simple 2D apical four-chamber view with depth added to it. It shows the same structures and has the same appearance. Just add depth and, magically, it almost feels like you can reach into the heart.

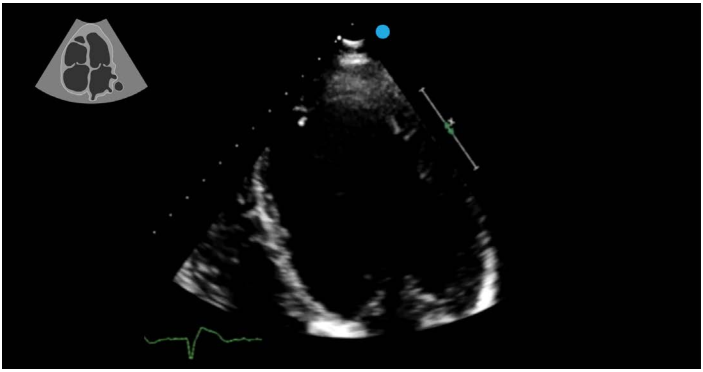


Apical four-chamber view

3-dimensional reconstructions

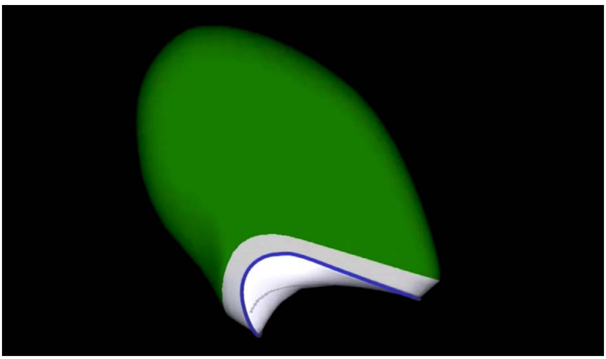
Not only are the images 3D and high quality, but 3D echo allows you to build reconstructions of the heart or different parts of it. Let's look at an example.

Below is a very poor left ventricle (LV), as seen in the apical four-chamber view. You may wonder what it looks like in other echo views. Can we see the whole ventricle in three dimensions at the same time?



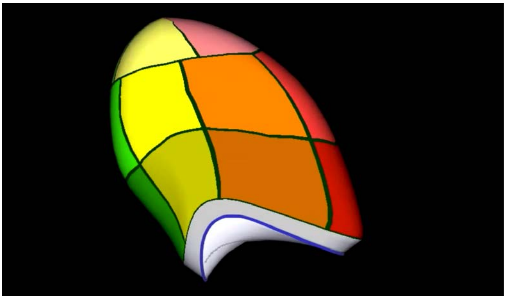
The short answer is yes. You can view the whole ventricle at one time, but by using a 3D model reconstructed using the data collected by the machine. This requires specialized software, a 3D probe, and your standard apical four-chamber view. The probe allows the machine to capture a lot more information, which can later be used to reconstruct the image in 3D.

Below is a snapshot of a 3D reconstruction of the poorly functioning LV we saw in the image above. You can see the mitral valve plane at the bottom of the screen in white. When looking at these reconstructions, you can even rotate the ventricle around its axis to see what is happening on the opposite side.



The next image is another snapshot from the same 3D reconstruction, but the LV has been split into different walls indicated by different colors. These divisions enable you to assess the motion of the ventricular muscle in these different regions using the 3D reconstruction.

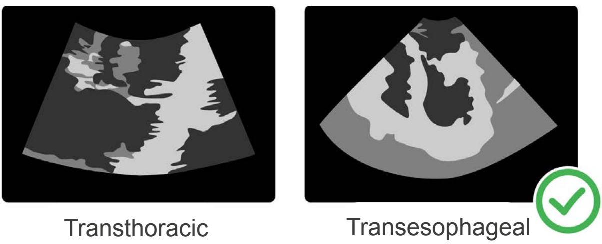
This colored reconstruction is particularly helpful with aneurysms, as they are often missed or only partially seen with 2D imaging. With 3D echocardiography, there are no secrets.



Obtain a high-resolution 2D image first

When performing 3D echo, there's an important consideration to keep in mind. In order to achieve a good 3D image, you first need to achieve a high-resolution 2D image. For a good echo image, you need good ultrasound penetration and the screen must be optimized.

Below is an example—a comparison of transthoracic and transesophageal echocardiography. The transesophageal echo usually has better image quality because the probe is so much closer to the heart, and this improves the ultrasound penetration and image resolution as you can see. This is an example in 2D, but the principles are the same for both 2D and 3D imaging.



Great! You now have a basic understanding of 3D echocardiography.

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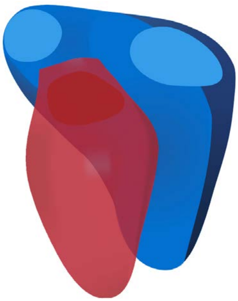
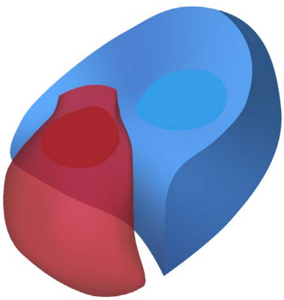
Using 3D imaging to visualize the right heart

Let's take a look at how 3D echocardiography will be able to support the assessment of the right heart in the future.

If you recall, the right ventricle (RV) has a very particular and unusual shape. As it wraps around the LV, you can never see the whole chamber with all dimensions in the same plane. There is always something missing in any view.



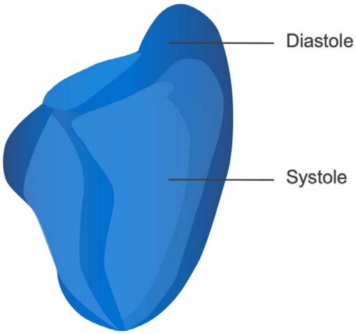
For example, before seeing the image below, would you have said that the RV in the previous image was this wide and deep? From this simple example, you can see the implications this has for 2D echocardiography.



The RV is a challenging structure to assess in two dimensions because of its shape and the fact that it embraces the LV, which is why it require so many different views. We haven't even talked about right ventricular volumes or ejection fraction, which are common measures for the LV, because these measurements are only possible with 3D imaging!

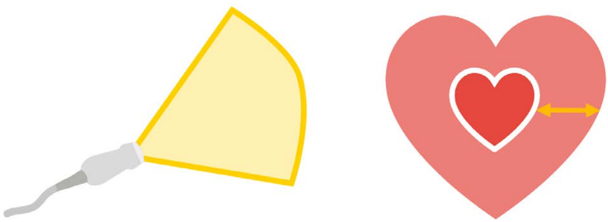
Advantages of 3D imaging

Using a 3D reconstruction, there are several ways to assess the overall fitness of the RV. For instance, you can create a map of the whole chamber portraying the systolic volume and shape of the ventricle, as well as the diastolic volume and ventricular shape, as seen below. All you need is specialized software and a 3D probe.



The 3D image captured by your echo machine will provide a lot more information than a 2D image. This data can later be used to create these maps. Additionally, because this processing happens offline, after you have seen the patient, it does not add any time to your scan. Although it is still in its early stages, transthoracic 3D has a lot to offer in the near future!

Now, let's compare 2D and 3D echocardiography. Although 2D echo only allows us to measure the fractional area change as a surrogate measurement of systolic function, 3D echo can allow us to measure real volumes and calculate an accurate and reproducible right ventricular ejection fraction. Can you imagine the possibilities of this technology in the future?



2D echocardiography: surrogate measurement

3D echocardiography: accurate measurement

Fantastic. Although this is a sneak peek as 3D echo is not being used in the clinical assessment of the right heart at this time, you are now a step ahead for when it does become routine practice!

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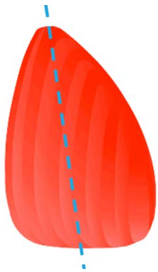
Reviewing strain analysis

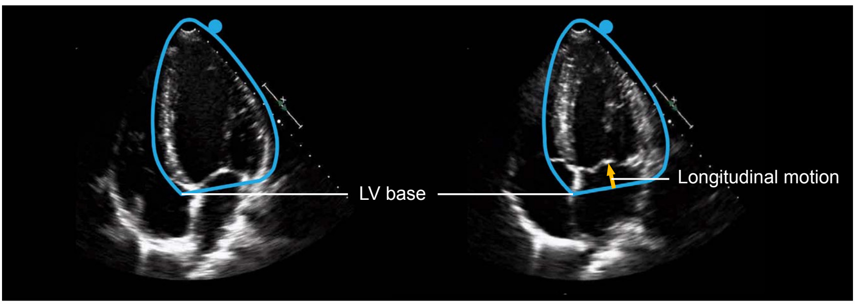
The goal of this lesson is to help you understand the theory behind strain echocardiography.

Assessing longitudinal motion

Let's start with the LV and forget about the right heart for a moment. Imagine a vertical line bisecting the LV as shown in the illustration below. In systole, the LV contracts vertically along this line from the base to the apex.



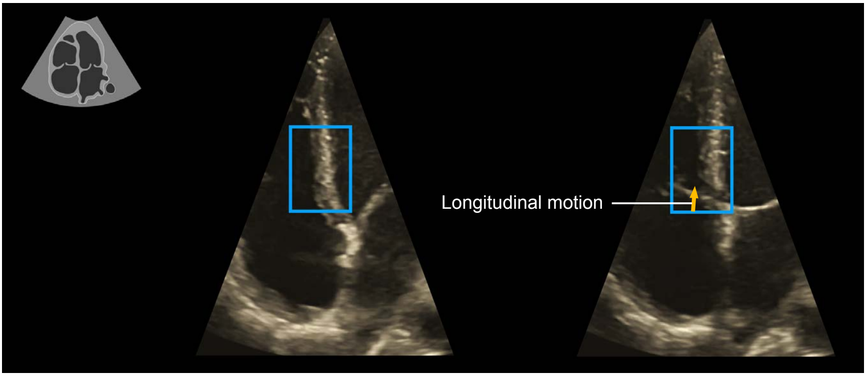
When looking at the first echo loop in this lesson's video, we focused on the LV and the base of the ventricle. As you may recall, we could see how this area moved towards the apex at the top of the echo screen. This vertical motion during ventricular contraction is known as longitudinal motion.



This is how a muscle, any muscle, behaves when it contracts. For example, when the arm curls, the bicep contracts and becomes shorter. Take note that this is the same behavior as the cardiac muscle during systole.

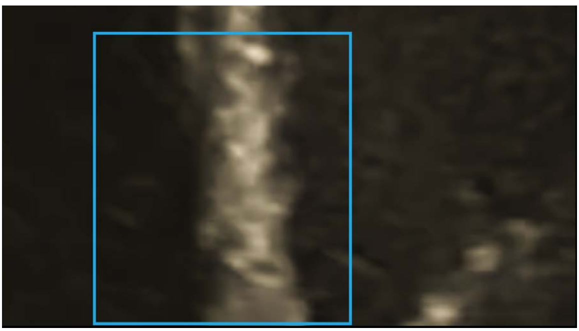
When we looked at the second echo loop featured in this [lesson's video] (an apical four-chamber loop), we focused on the interventricular septum. The septum is an easy anatomical marker for the visualization of longitudinal motion.

We marked the basal septum with a blue box, or kernel. The box focuses on the region of interest, which in this case was the septum closest to the base of the ventricle. Do you remember how the basal septum moved slightly towards the apex during systole? Once again, that is longitudinal motion.



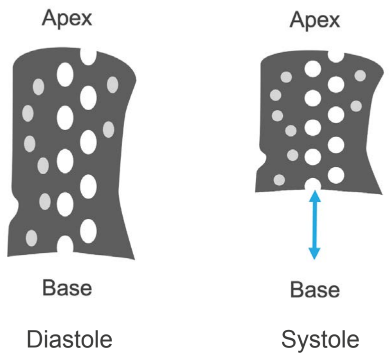
How to measure longitudinal motion

When we zoomed in on our kernel from the previous image, still focusing on the basal septum, we could see different levels of brightness on our 2D image, created by the ultrasound reflection from different cardiac fibers. These varying levels of brightness create a unique pattern of dots, almost like a fingerprint of the patient's myocardium.

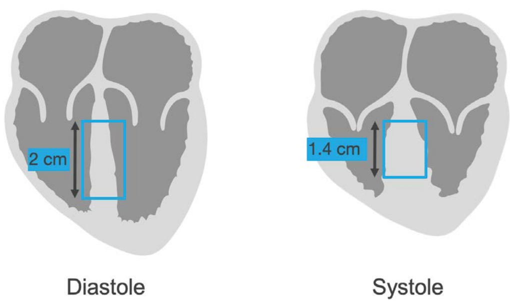


In strain analysis, we track the movement of these dots over time, and they help to visualize the longitudinal motion of the ventricle during systole. We expect the dots to move from the base towards the apex during systole, and we expect the image inside the kernel to become compressed.

In diastole, the muscle of the ventricle is relaxed and the whole muscle is at its longest. Therefore, each one of the kernels is also at its longest.



Below is an example. the kernel you are measuring is 2 cm in length during diastole. As the ventricle contracts, the muscle becomes shorter and so does each kernel, such that at the end of systole the kernel measures 1.4 cm.



What do we do with these measurements?

With these measurements, we can calculate a percentage change in size. From our example, 1.4 cm is 30% shorter than the original 2 cm our kernel measured when the muscle was fully relaxed. As we have lost some dimension during muscular contraction, we refer to strain as a negative number. In this case, -30%.

$$\frac{2\text{ cm} - 1.4\text{ cm}}{2\text{ cm}} \times 100\% = 30\%\text{ shorter}$$

What is strain?

Put simply, strain is just a measure of muscle deformation during the cardiac cycle. As the myocardium contracts during systole, the fibers become shorter. As it relaxes during diastole, the fibers become longer. This difference, or strain, is presented as a negative percentual change.

Global longitudinal strain is an additional measure of systolic function, determined by averaging the strain of every kernel measured during contraction.

Good work! You should now understand the basic theory behind strain echocardiography and analysis.

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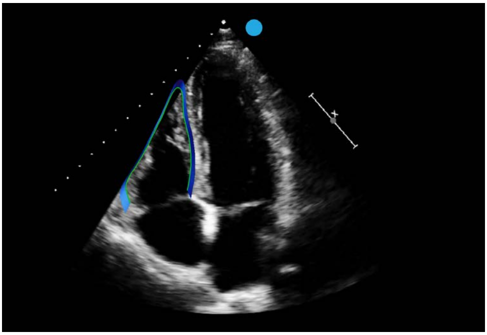
Using strain to study function

Next, let's go through cases of RV strain analysis and see how it applies to a normal ventricle, a dilated ventricle with normal function, and an impaired ventricle.

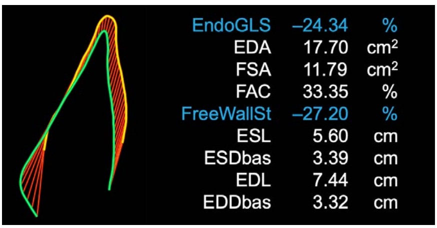
Strain analysis of a normal RV

Below is an example of a healthy, normal heart. In this [lesson's video](), we could see that the RV remained highlighted throughout the cardiac cycle on the 2D loop. This is the strain analysis software tracking the motion of the myocardium. For longitudinal strain, you want to use an apical four-chamber view of the RV.



When we zoomed in on this image, the software has defined the maximum distension of the ventricle during diastole in green and the maximum systolic contraction in yellow. The software also presents this data numerically, reporting global endocardial strain (EndoGLS) and free wall strain (FreeWallSt).

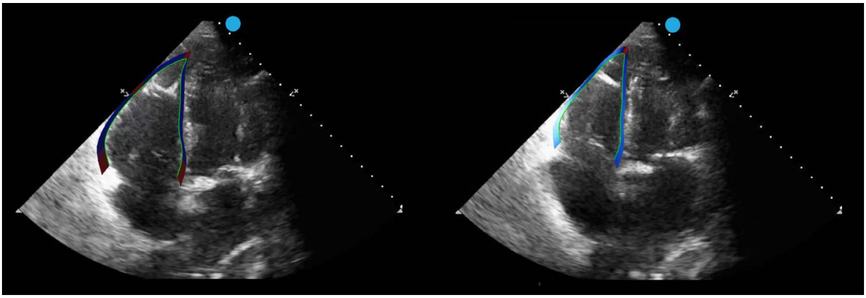
In this example, the right ventricular muscle as a whole shortened by 24% during systole, while the right ventricular free wall shortened by 27%.



Unlike global endocardial strain analysis, free wall strain analysis excludes the septum just in case there is any LV dysfunction that could act as a confounder. It is important to have both measurements to avoid overestimating or underestimating right ventricular function.

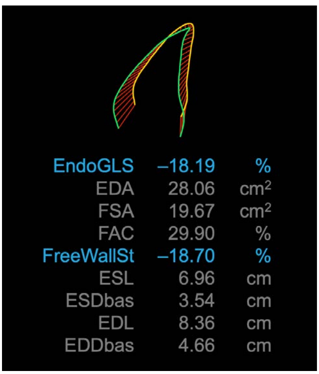
Strain analysis of a dilated RV with normal function

Next, we looked at an example of a severely dilated RV. You could tell it was dilated because it was larger than the LV. In fact, the whole right heart appeared to be enlarged. However, did you notice in the lesson video how the RV still moved well from base to apex? Despite this being an impaired ventricle, longitudinal strain was not affected.



Diastole Systole

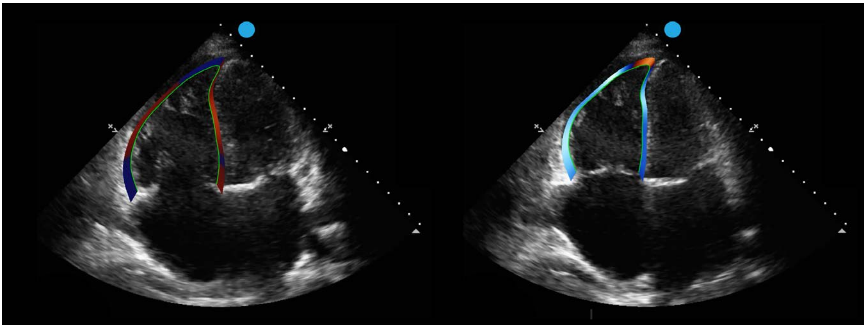
Numerically, right ventricular strain for the whole chamber and that of the free wall alone both measure around –18%. This means that the muscle during systole becomes 18% shorter than what it is in diastole.



Although there are no officially recommended values to distinguish healthy from impaired, it is generally accepted that strain values between −18% and 0% correlate with an impaired RV. So, I would keep an eye on this patient just in case the right ventricular function worsens.

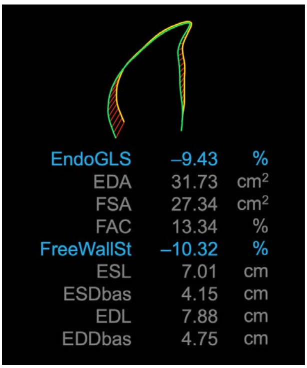
Strain analysis of an impaired RV

In our next example, we saw a ventricle that was significantly dilated. Again, the RV appeared larger than the left, and it was easy to see in the apical four-chamber loop just how poor this ventricle was functioning. As you may recall, it was just not doing much at all.



Diastole Systole

In this case, strain analysis supports this observation. The resulting values of the analysis were seriously low at roughly 9–10% shortening.



Strain analysis is useful when assessing the RV as a means to confirm the assessment you made using standard measurements. It may also be useful in the detection of subclinical dysfunction, where all other measurements are normal but strain is the first indicator that something may be wrong.

If you want to use strain analysis in your routine clinical practice, keep in mind that every echo vendor has created their own software complete with different cutoff values for normalcy. Always double-check that you are using the correct reference values, which you can find out by consulting with the manufacturer representative for your echo machine.

Well done! We have successfully gone through three very different cases of strain assessment of the RV.

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APPENDIX

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