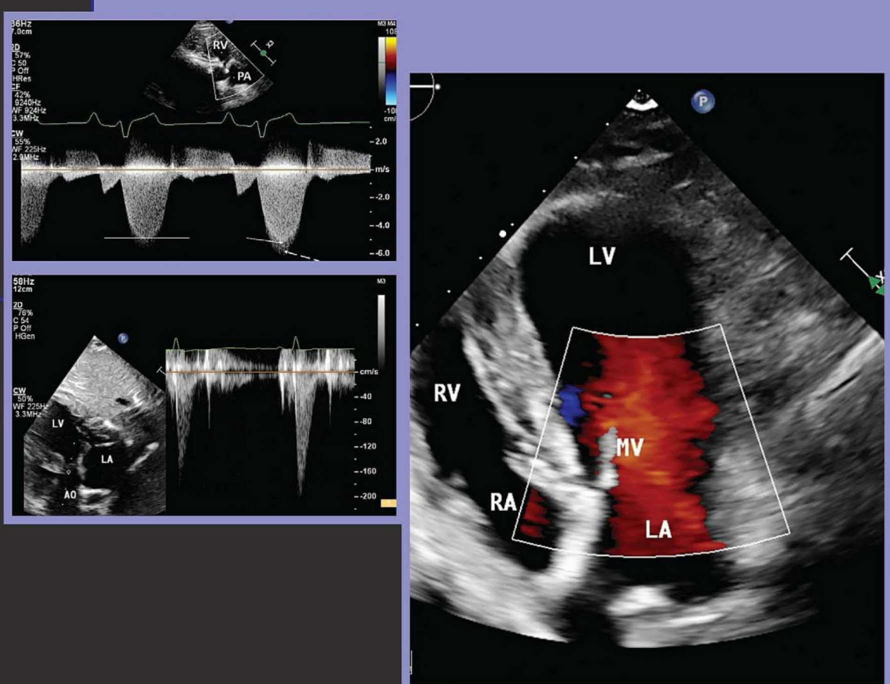
RAPID REFERENCE

Doppler Echocardiography for the Small Animal Practitioner

June A. Boon



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Doppler Echocardiography for the Small Animal Practitioner

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To Dave – my biggest supporter.
Thanks for always believing I can do anything.

Contents

Preface

Two-Dimensional and M-Mode Echocardiography for the Small Animal Practitioner, 2nd edition, published by Wiley in 2017, provides information about how to obtain echocardiographic imaging planes, subjective and quantitative evaluation of size and function, and the 2D and M-mode features of common acquired cardiac diseases in the dog and cat.

This handbook is intended as the next step for the general practitioner and the non-cardiac specialist who have learned to acquire diagnostic 2D and M-mode echocardiographic studies. Here you will learn to apply and use color flow and spectral Doppler. The topics covered include:

- Doppler principles as they apply to accuracy and evaluation of the color flow and spectral Doppler examination
- Imaging planes required for accurate evaluation of flows in the heart
- Explanation of and application of Doppler pressure gradients
- Interpretation of color flow signals
- Common Doppler features of the most frequent acquired heart diseases in dogs and cats
- Online access to videos of technique and evaluation to enhance the principles and topics listed above.

This handbook is not intended as a comprehensive explanation of the echocardiographic features associated with heart disease in animals. *Veterinary Echocardiography,* 2nd edition – a Wiley publication – provides in-depth coverage of echocardiography in animals. It is my hope that *Doppler Echocardiography for the Small Animal Practitioner* will provide some good background knowledge of technical factors affecting diagnostic color and spectral Doppler and will serve as a quick checklist for the Doppler features of common acquired cardiac diseases in the dog and cat.

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/boon/doppler

The website includes:

- Supplementary videos clips.
- A play icon ▷ appears in the margin whenever a relevant video clip is available on the website.
- The password for the site is the last word in the caption for Figure 3.1.

Section 1 The Basics: What You need to know

DOPPLER PRINCIPLES AS THEY APPLY TO ACCURACY AND QUALITY OF THE EXAM

- Doppler shift
  - Johann Christian Doppler
    - Discovered that sound waves change frequency (frequency shift) when there is a change in position between the source of the sound waves and the receiver of the reflected sound waves (Figure 1.1 and Video 1.1)
  - What is a Doppler shift
    - We hear a Doppler shift when we hear a siren
      - As the pitch (frequency) increases we know the vehicle is coming toward us
      - As the pitch (frequency) decreases we know the vehicle is moving away from us
    - The Doppler shift in diagnostic ultrasound (Figure 1.2)
      - When Doppler sound is sent into the heart
        - Blood cells moving away from the transducer send back lower-frequency sound, creating a negative frequency shift (i.e., out with 5 MHz – back with 3.5 MHz)
          - The sound wave is trying to catch the cells – so it interacts with the cells less frequently
        - Blood cells moving toward the transducer send back higher-frequency sound, creating a positive frequency shift (i.e., out with 5 MHz – back with 7.0 MHz)
          - The sound wave is running into the cells – so it interacts with the cells more frequently

Doppler Echocardiography for the Small Animal Practitioner, First Edition. June A. Boon.

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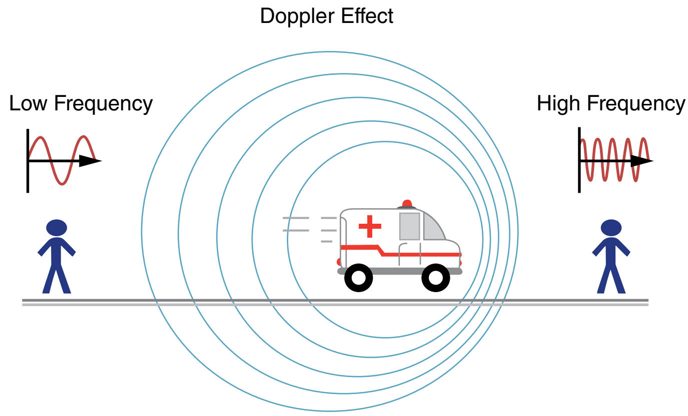


Video 1.1

Figure 1.1 As this ambulance drives toward the person on the right it encounters the wave front and wavelength frequency increases. As it moves away from the person on the left, it encounters the wave front less frequently so the wavelength frequency decreases.

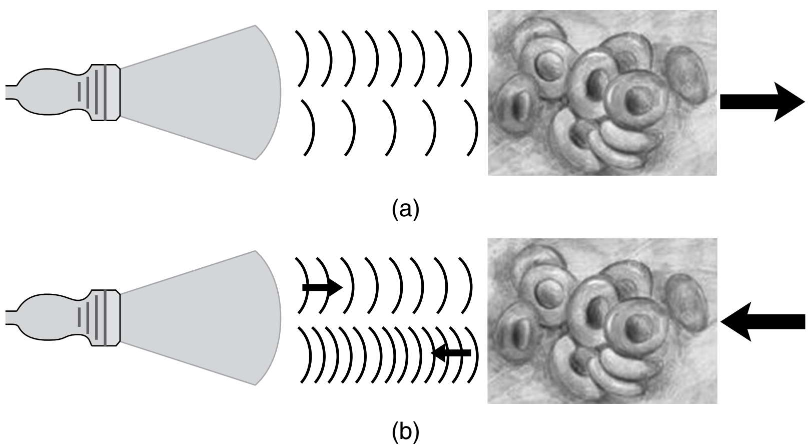
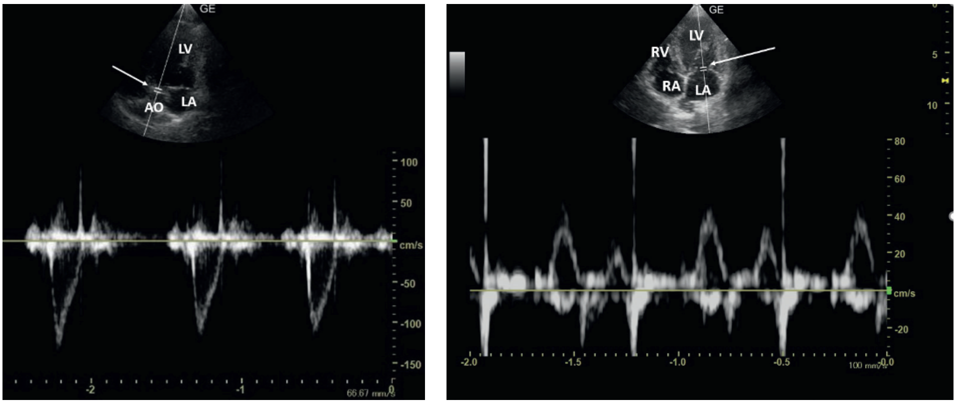


Figure 1.2 (a) As sound waves encounter blood cells moving away from the transducer the reflected sound is at a lower frequency, and the machine processes this negative frequency shift as blood cells moving away from the transducer. (b) As sound waves encounter blood cells moving toward the transducer the reflected sound is at a higher frequency, and the machine processes this positive frequency shift as blood cells moving toward the transducer.

- Types of Doppler
  - Pulsed wave (PW)
    - PW Doppler sends out pulses of sound to a specific location in the heart (Figures 1.3a and b)
    - Reflected sound from the red blood cells at that specific location needs to return to the transducer and be processed (frequency shift calculated) before the next pulse is transmitted



(a) (b)

Figure 1.3 (a) A Doppler cursor placed in the aorta on an apical 5 chamber plane records blood flow moving away from the transducer, and the spectral waveform is displayed below the baseline which represents zero velocity. The pulsed wave (PW) gate here (small equal sign) is placed at the aortic valve, and the spectral flow profile is very specific for that location. (b) A Doppler cursor placed at the mitral leaflets on an apical 4 chamber plane records blood flow moving toward the transducer, and the spectral waveform will be displayed above the baseline which represents zero velocity. The PW gate here (small equal sign) is placed at the tips of the mitral valve leaflets, and the flow is very specific for that location.

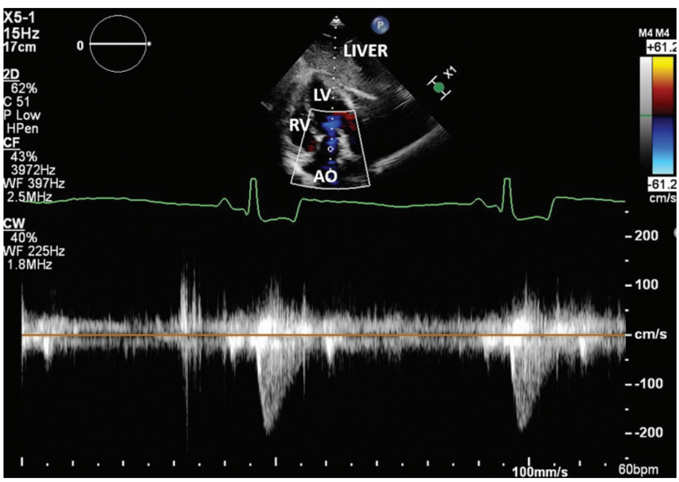


Figure 1.4 The Doppler cursor is aligned with aortic flow leaving the left ventricle on this subcostal 5 chamber view. Using continuous wave (CW) Doppler, flow is recorded all along the Doppler cursor with no site specificity. Flow along this cursor varies dependent on location, and so the flow profile shows all of these velocities. The flow profile is filled in because of these various velocities, but the highest flow is what is seen at the peak of the flow profile.

- Continuous wave (CW)
  - CW Doppler sends sound out continuously along a line through the valves or vessels in the heart. There is no site specificity with CW Doppler
  - Reflected sound is processed continuously (frequency shifts are constantly calculated as blood cells all along the line send reflected sound back to the transducer) (Figure 1.4)

  - Color flow
    - Color flow Doppler is a form of PW Doppler
    - The color box has multiple Doppler lines with multiple gates along each line
    - Each gate sends flow information back to the transducer, which is assigned a color depending on which direction the blood is flowing
    - Flow toward the transducer is typically coded in red (Figure 1.5a and Video 1.5a)
    - Flow away from the transducer is typically coded in blue (Figure 1.5b and Video 1.5b)
    - Green variance maps are available to highlight a lot of variance in the flow being investigated
      - Variance is seen in turbulent flow
      - Not all green represents turbulence, however
- Advantages and disadvantages of each type of Doppler
  - PW
    - Advantages
      - Site specific – velocity only recorded at the gate (Figure 1.3)
    - Disadvantages
      - Cannot record high-velocity flow
  - CW
    - Advantages
      - Able to record high-velocity flow
    - Disadvantages
      - No site specificity – records velocities all along the Doppler line (Figure 1.4)
  - Color flow
    - Advantages
      - Potential abnormal flow is readily identified
    - Disadvantages
      - There is minimal quantitative information associated with color flow Doppler (Figure 1.6 and Video 1.6)
- The spectral display
  - Baseline
    - The baseline is moved up or down as necessary to display either upward or downward flow or both (Figures 1.7a–c)
    - When both upward and downward flows are being investigated and CW is used, the baseline is positioned and scale adjusted so that each flow profile is seen in its entirety
    - When there is upward and downward flow but PW is used, only one or the other can be recorded accurately since the gate is very site specific
    - The baseline is positioned to the top or bottom of the display and scale is adjusted to ideally display the full PW flow profile
  - Velocity scale
    - Velocity scales are seen both above and below the baseline
    - This scale is adjusted lower or higher by a velocity, PRF, or scale knob
    - As the baseline moves up or down the scale changes on each side of the baseline

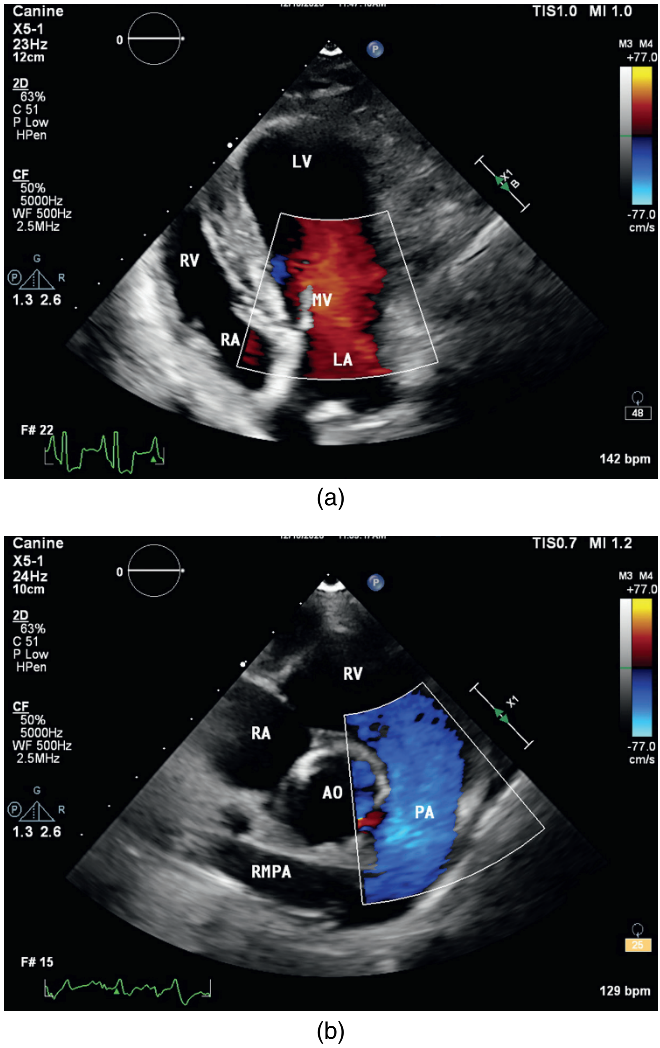
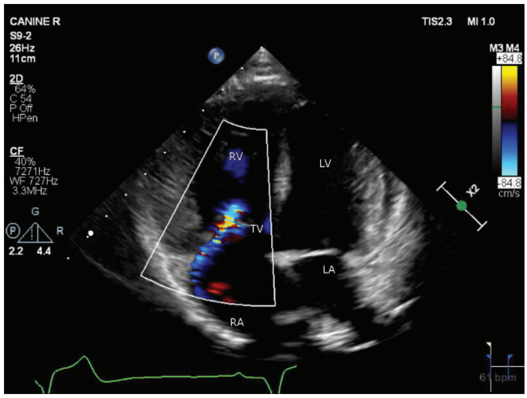


Figure 1.5 The multiple lines of Doppler sound in a color flow sector are filled with PW gates. Each gate records a positive or negative frequency shift that is displayed as a specific color. (a) When reflected sound sends back a positive frequency shift from a PW gate, meaning blood cells are moving toward the transducer, the flow at that gate is color coded in red. Here blood flow is moving up through the mitral valve on this apical 4 chamber view, and the image shows red flow moving through the mitral valve into the left ventricle. (b) When reflected sound sends back a negative frequency shift from a PW gate, meaning blood cells are moving away from the transducer, the flow at that gate is color coded in blue. Here blood flow is moving down into the pulmonary artery on this right transverse view, and the image shows blue flow moving from the right ventricle into the pulmonary artery.

Video 1.5

- If the velocity scale is not adjusted while the baseline is moved, the total velocity remains the same; it is just redistributed above or below the baseline
- Velocity and baseline are adjusted to show a complete spectral flow profile and to eliminate aliasing if possible (Figures 1.7b and c)



Video 1.6

Figure 1.6 While color flow Doppler locates possible areas of abnormal flow rapidly, it provides minimal quantitative information. Tricuspid regurgitation (TR) in this foreshortened apical 4 chamber view is considered mild based upon the size of the color jet, but no hemodynamic information is provided.

- Information obtained from spectral display
  - Velocity (Figures 1.7b and c)
    - Velocity in m/sec or cm/sec is displayed above and below the baseline
  - Direction (Figures 1.7a–c)
    - Blood cells moving toward the transducer are displayed above the baseline
    - Blood cells moving away from the transducer are displayed below the baseline
  - Timing (Figures 1.7a–c)
    - The horizontal axis of a spectral display represents time
    - Blood flow during diastole and systole are displayed at their respective times on the horizontal axis
    - An ECG may make identification of event timing more accurate
  - Intensity (Figure 1.7b)
    - The density of a spectral display is related to the number of blood cells involved in the flow
    - A small volume of blood cells would have less density than a large volume
    - This is accurate when the spectral displays are created with the same Doppler settings and alignment is parallel with both flows

- The color display
  - Direction (Figure 1.5)
    - Blood cells moving toward the transducer are coded in red
      - As velocity increases the color becomes brighter and moves into the yellows
    - Blood cells moving away from the transducer are coded in blue
      - As velocity increases the color becomes brighter and whiter
  - Velocity (Figure 1.5)
    - The scale on each side of the color bar shows the maximum velocity that is encoded in the specific color

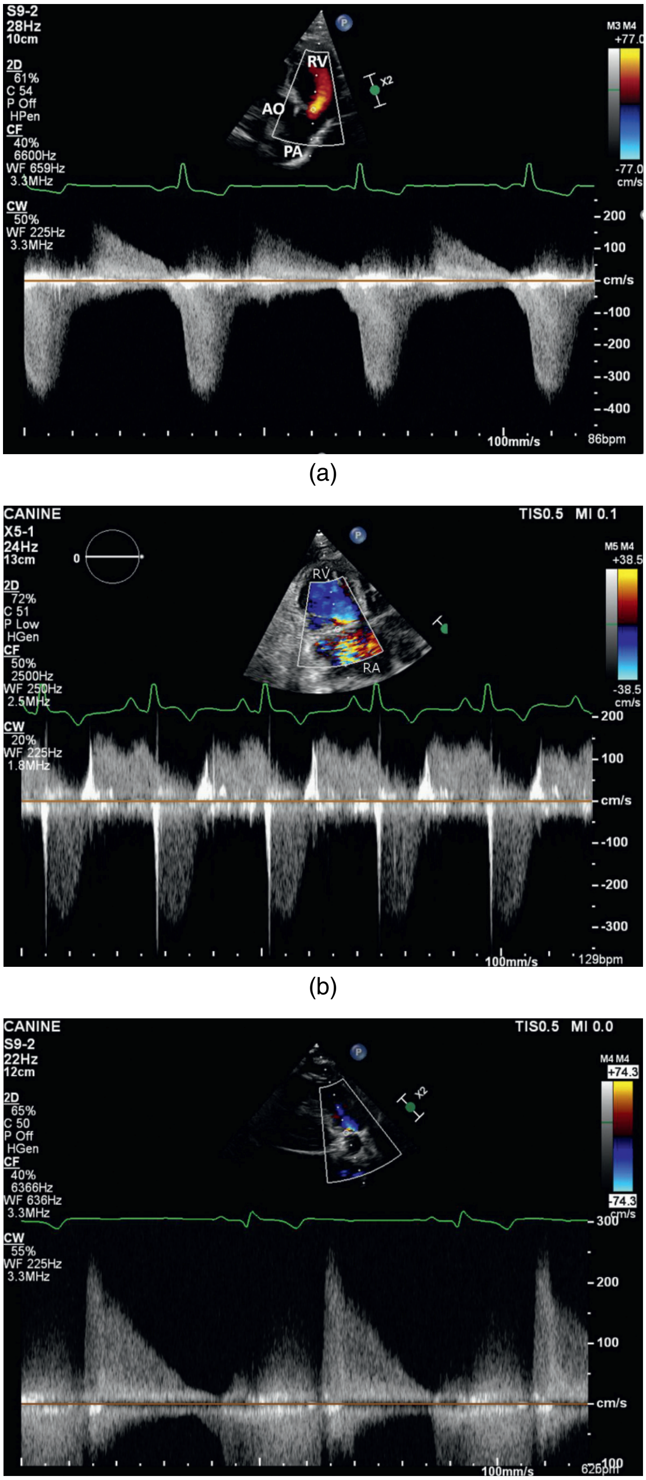
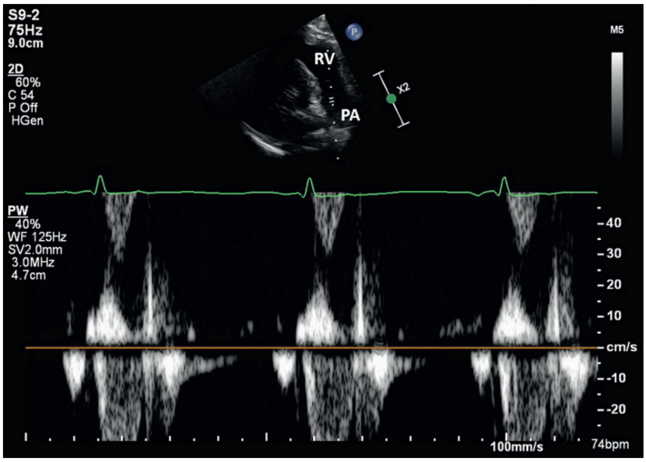


Figure 1.7 The spectral display baseline is moved up or down as needed to accommodate the direction and velocity of flow evaluated. Time is shown on the horizontal axis; the large ticks represent 1 second intervals. An ECG shows systole and diastole, but direction is intuitive based on the color display and location interrogated. (a) This CW display shows upward low-velocity flow (pulmonary insufficiency shown in red) and downward higher-velocity flow (PA systolic flow). The baseline and scale are adjusted accordingly. (b) This spectral display is focused on the high-velocity downward flow, so the baseline is moved to the top of the display and scale is adjusted to fill the spectrum. Downward flow density is less than upward flow intensity and represents fewer blood cells moving down than moving up. (c) This spectral signal is focused on upward flow, so the baseline is moved downward and the scale is adjusted to fill the spectrum.

- Nyquist limit and aliasing
  - PW (Figures 1.8a–f)
    - PW has a maximum velocity it can record
    - This maximum velocity is called the Nyquist limit
      - Flows that exceed this Nyquist limit will alias
      - An aliased flow signal will not show the complete flow profile
      - Maximum velocity cannot be determined
      - Moving the baseline up or down to maximize velocity either up or down can resolve mild aliasing but not significant aliasing
      - It is difficult to discern the direction of flow
        - Even though intuitively you may know the direction based upon location of the gate and using color flow Doppler
        - A streak from the top of the spectral display to the bottom representing flow is seen
    - CW Doppler is needed to show the peak velocity (Figure 1.8f)
      - There is no Nyquist limit with CW Doppler
  - Color flow (Figures 1.9a–c and Videos 1.9a and c)
    - Color flow has a maximum velocity it can record in pure color (red or blue)
    - This maximum velocity seen on the color bar is called the Nyquist limit
    - Flows that exceed this Nyquist limit will alias
    - An aliased flow signal has mixed colors of red and blue
      - Maximum velocity cannot be determined
      - Moving the baseline up or down to maximize color velocity either up or down may resolve the aliasing since maximum velocity in each direction is increased
      - It can be difficult to discern the direction of flow
        - Even though intuitively you may know the direction based upon location of the color sector
        - A mosaic color flow signal or a layered color flow signal is seen
  - Factors affecting Nyquist limit
    - Transducer frequency
      - Higher-frequency transducers result in lower PW Nyquist limits at any given depth (Figure 1.10a)
      - Lower-frequency transducers allow higher PW velocity to be recorded before aliasing occurs at any given depth (Figure 1.10b)
      - Higher-frequency transducers result in lower color flow Nyquist limits before aliasing occurs at any given depth (Figure 1.10c)
      - Lower-frequency transducers allow higher color flow velocity to be recorded before aliasing occurs at any given depth (Figure 1.10d)
    - Depth of interrogation
      - Increased gate depth at the same transducer frequency decreases the PW Nyquist limit (Figures 1.11a and b)
      - Therefore, higher velocity can be reached before aliasing occurs if PW gate depth is minimized



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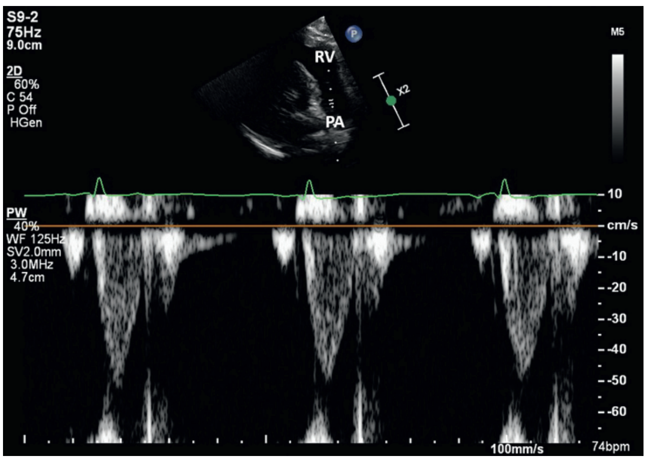

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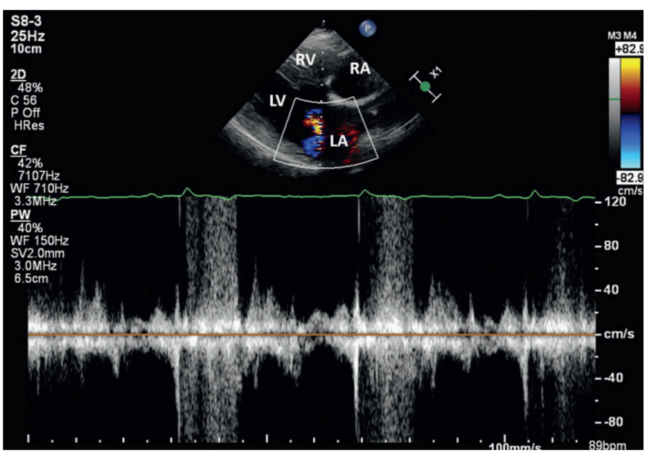
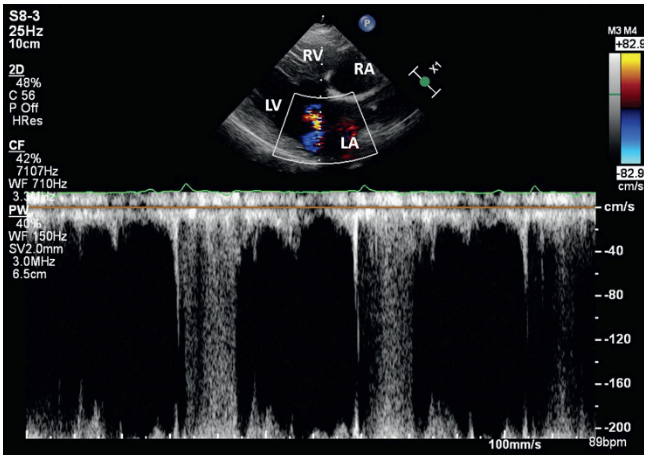
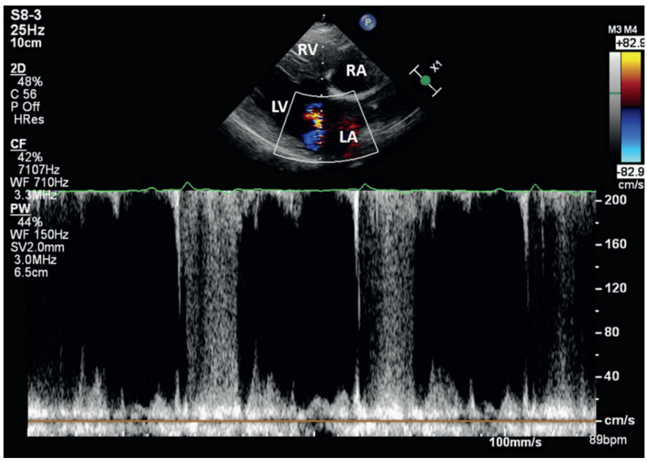


(c)

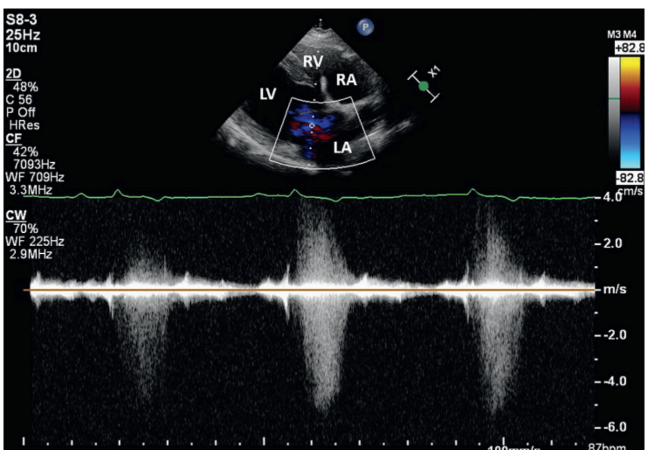
Figure 1.8 (a) The downward flow is not fully displayed and wraps to the top of the spectral display. (b) Moving the baseline up allows the entire display to be seen without aliasing. (c) The baseline is in the middle of this spectral display. The Nyquist limit in each direction is 120 cm/s. Adjusting the scale (velocity or PRF) knob does not increase this velocity. The Nyquist limit has been reached. There is no discernable direction of flow, and peak velocity cannot be determined. (*Continued*)



(d)



(e)



(f)

Figure 1.8 (*Continued*) (d) Moving the baseline up to maximize velocity in the downward direction to over 200 cm/s does not resolve the problem. This is aliased flow, exceeding the Nyquist limit with no discernable direction of flow or peak velocity. (e) Moving the baseline down does not remedy the situation. There is still no discernable direction or peak velocity. (f) Changing to CW Doppler allows higher velocity to be recorded. Peak velocity in a downward direction can now be determined.

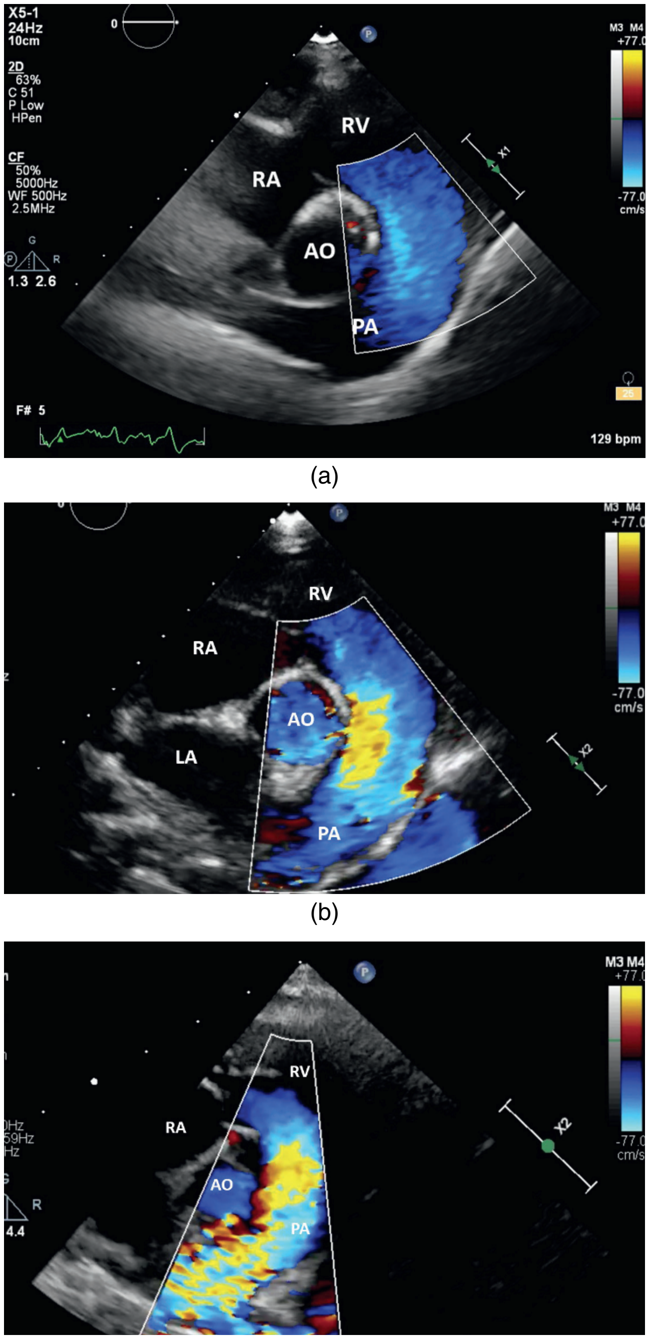


Figure 1.9 (a) Pulmonary artery systolic flow in this image does not exceed the Nyquist limit of 77 cm/s, so color is seen as pure blues with no aliasing. (b) The colors are layered in this pulmonary artery systolic flow image. Normal pulmonary artery systolic flow may be nearly 2m/s, and this flow exceeds the 77 cm/s, which results in an aliased signal, wrapping and layering the colors. (c) The color bar shows a Nyquist limit of 77 cm/s. Flow exceeding this velocity will start mixing colors. Here the pulmonary artery shows a mosaic of color representing the high-velocity turbulent flow associated with pulmonary stenosis.

Video 1.9

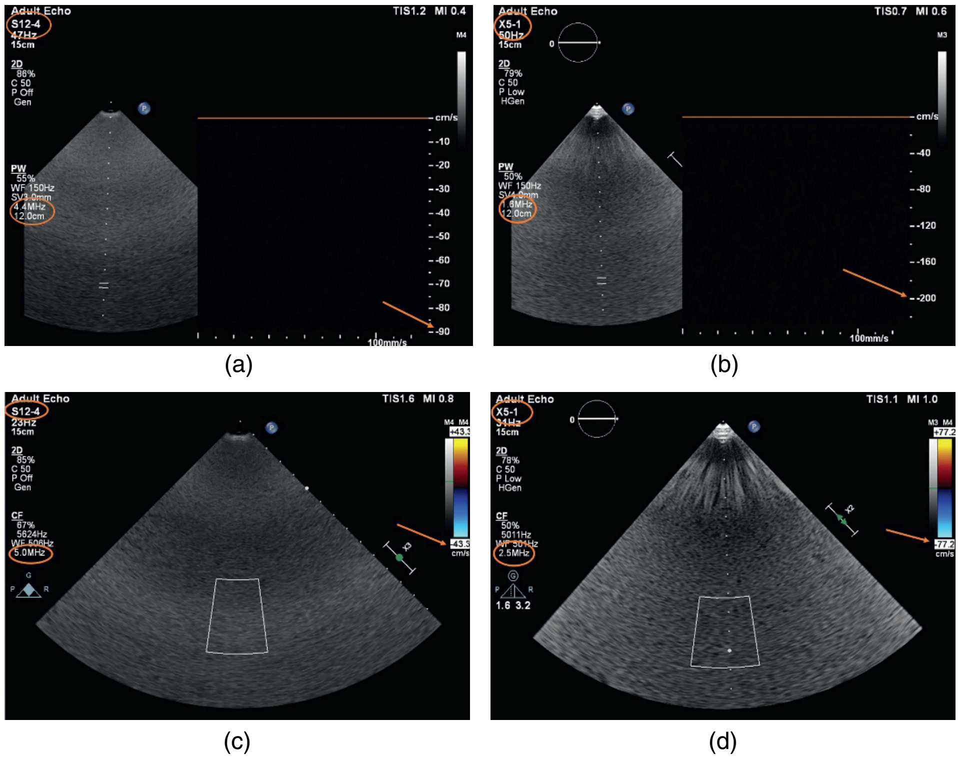
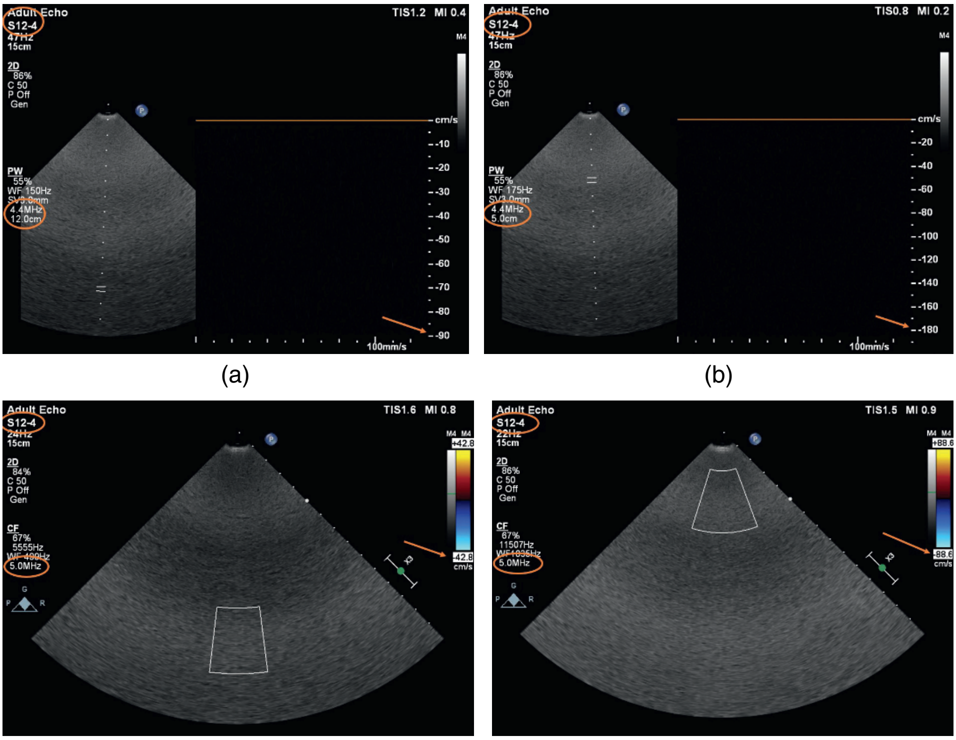


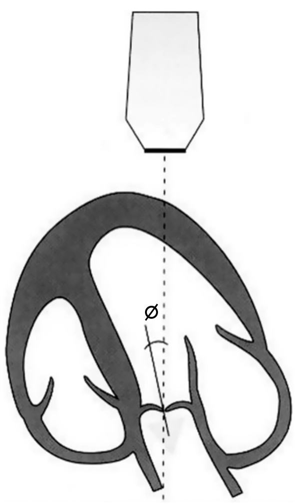
Figure 1.10 (a) This high-frequency transducer has a PW frequency of 4.4 MHz (orange circle) and an aliasing velocity (Nyquist limit) of 90 cm/s (arrow). (b) Lower transducer frequencies allow higher aliasing velocity (Nyquist limits). This PW frequency is 1.6 MHz (orange circle), which allows the maximum velocity to reach just over 200 cm/s (arrow) before aliasing occurs. (c) Using color flow Doppler, the transmitting frequency of 5 MHz (orange circle) in this image allows the Nyquist limit to reach 43.3 cm/s (arrow) before color starts aliasing. (d) A lower transmitting frequency of 2.5 MHz (orange circle) in this color flow Doppler image allows the aliasing velocity to increase to 77.2 cm/s (arrow) before the color signal aliases.

      - Increased depth of the color flow box at the same transducer frequency decreases the Nyquist limit (Figures 1.11c and d)
      - Therefore, higher velocity can be reached before aliasing occurs if color box depth is minimized
- Accuracy of spectral flow information
  - Angle of incidence (Figures 1.12a–c)
    - A Doppler beam aligned perfectly parallel with the flow of interest provides an accurate flow velocity
    - An angle away from parallel to flow of any degree in any direction will underestimate flow velocity
  - Measuring the peak velocity – no fuzz
    - Measure peak velocity at the dense envelope (modal velocity) – not the fuzz below or above (Figures 1.13a and b)



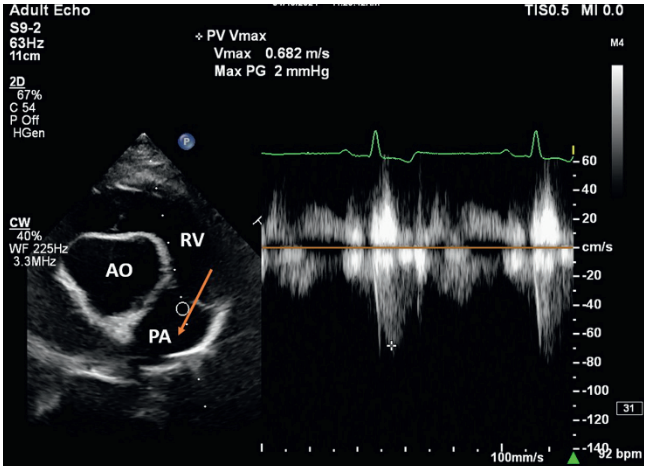
(a) (b) (c) (d)

Figure 1.11 Increasing depth of a PW gate decreases the Nyquist limit, resulting in lower aliasing velocities, and decreased depth allows for higher aliasing velocities. (a) At a Doppler frequency of 4.4 MHz and gate depth of 12 cm (circle) the aliasing velocity is 90 cm/s (arrow). (b) At a Doppler frequency of 4.4 MHz and gate depth of 5 cm (circle) the aliasing velocity is 180 cm/s (arrow). (c) At a Doppler frequency of 5 MHz (circle) and a deep color box the aliasing velocity is 42.8 cm/s (arrow). (d) At a Doppler frequency of 5 MHz (circle) and a shallow color box the aliasing velocity is 88.6 cm/s (arrow).



(a)

Figure 1.12 Any deviation from parallel to flow will underestimate the true velocity. (a) Here the actual direction of flow into the aorta is the solid line and the Doppler cursor (dashed line) is not parallel to the flow. Flow velocity will be underestimated. (*Continued*)



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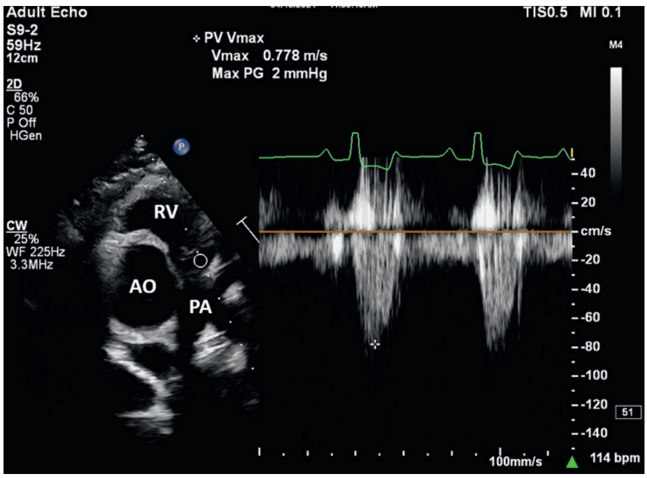
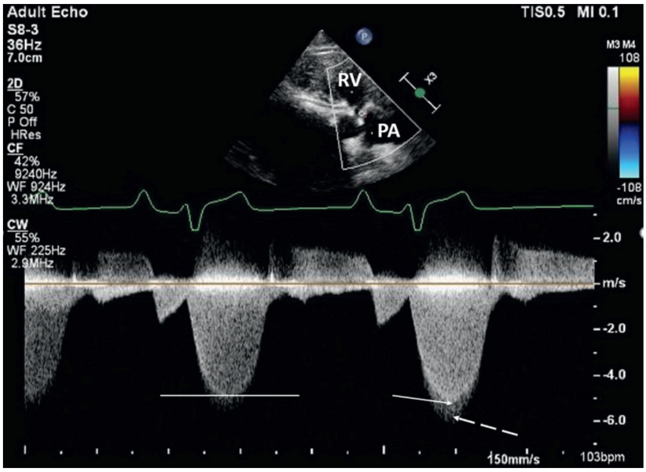


(c)

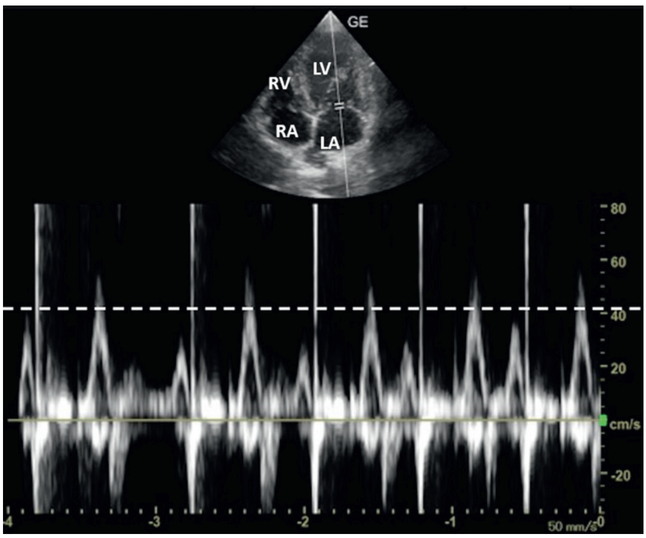
Figure 1.12 (*Continued*) (b) The direction of flow on this right parasternal transverse view of the pulmonary artery is represented by the orange line. The dotted line representing the Doppler cursor is not parallel to flow. The recorded flow velocity is .68 m/s. (c) On this left cranial transverse view of the pulmonary artery in the same dog, the dotted Doppler cursor is lined up more parallel to flow resulting in a higher flow velocity of .78 m/s.

OPTIMIZING DOPPLER DISPLAYS

- Color flow
  - Factors affecting color image quality
    - Color gain (Figures 1.14a–c and Video 1.14)
      - Often gain appears to be adequate when color is activated, but always check the color gain
      - Increasing gain until speckling occurs over the color and 2D image, then turn down again until speckling just disappears



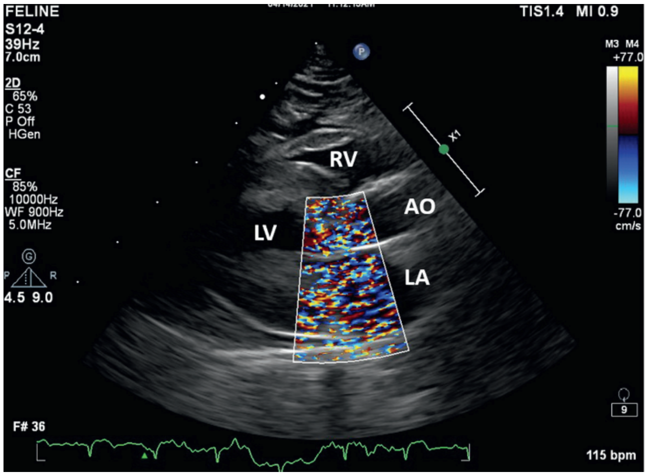
(a)



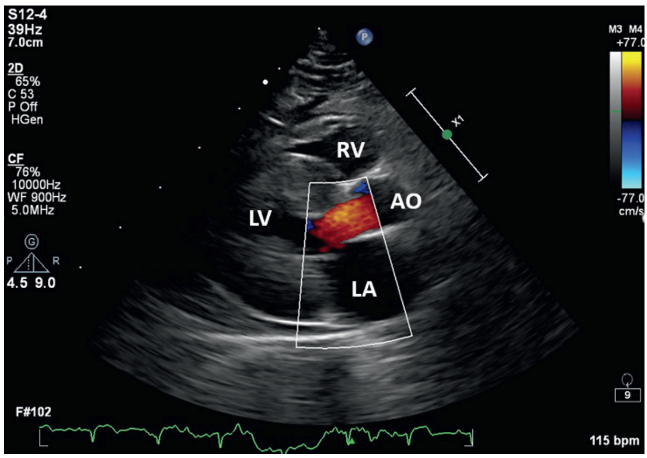
(b)

Figure 1.13 Peak flow should be measured at the modal velocity. This is the bright border of the spectral flow profile. (a) The modal velocity is measured (solid line and arrow) and the gray fuzzy density below it (dashed line) is ignored. (b) The spikes and fuzzy areas above the mitral spectral flow profiles are ignored when measuring peak velocity. Peak velocity measurements of the trans mitral valve E wave are at the dotted line.

- 2D gain (Figures 1.15a and b and Videos 1.15a and b)
  - Turn 2D gain down until chambers and vessels are mostly black
  - Too high of a 2D gain setting prevents good color filling of the area being evaluated
- Image orientation (Figures 1.16a and b and Videos 1.16a and b)
  - Although color flow Doppler is not as angle dependent as spectral Doppler, aligning the 2D image a bit more parallel with the direction of flow helps with color quality
  - Angled and apical views provide the best color filling if the appropriate transducer is used



(a)



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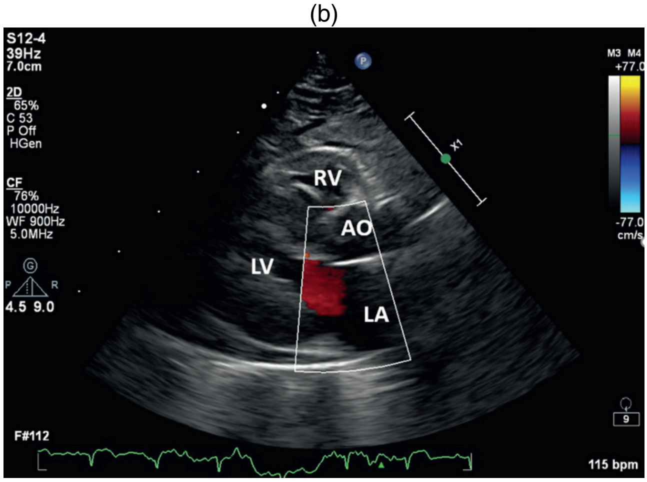
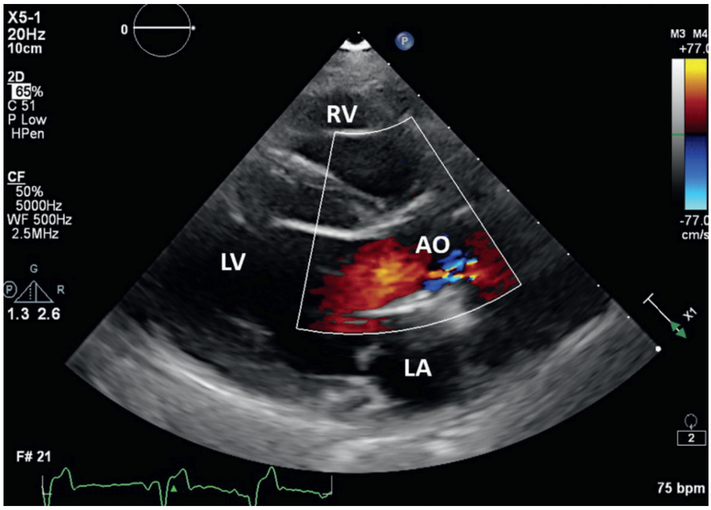


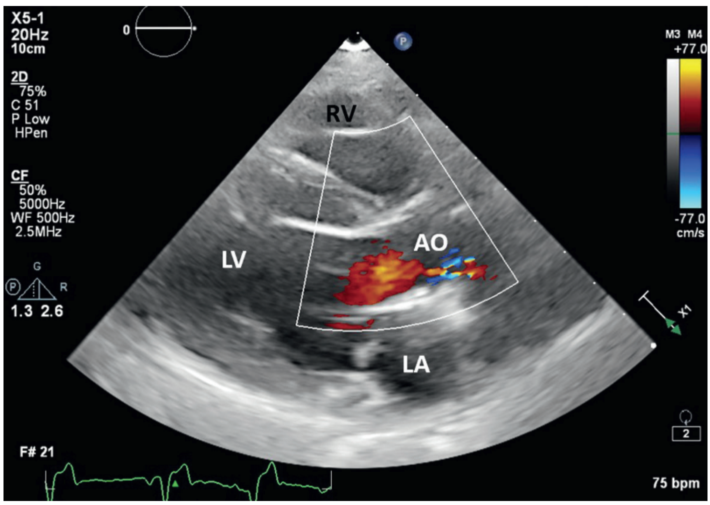
(c)

Video 1.14

Figure 1.14 (a) Adjust color gain until speckling occurs over the color and 2D image. (b) Turn the gain down slowly until the speckling disappears. Here good red flow is seen entering the aorta. (c) And correct color gain setting over the mitral valve shows red flow filling the left ventricular inflow pathway without speckles.



(a)

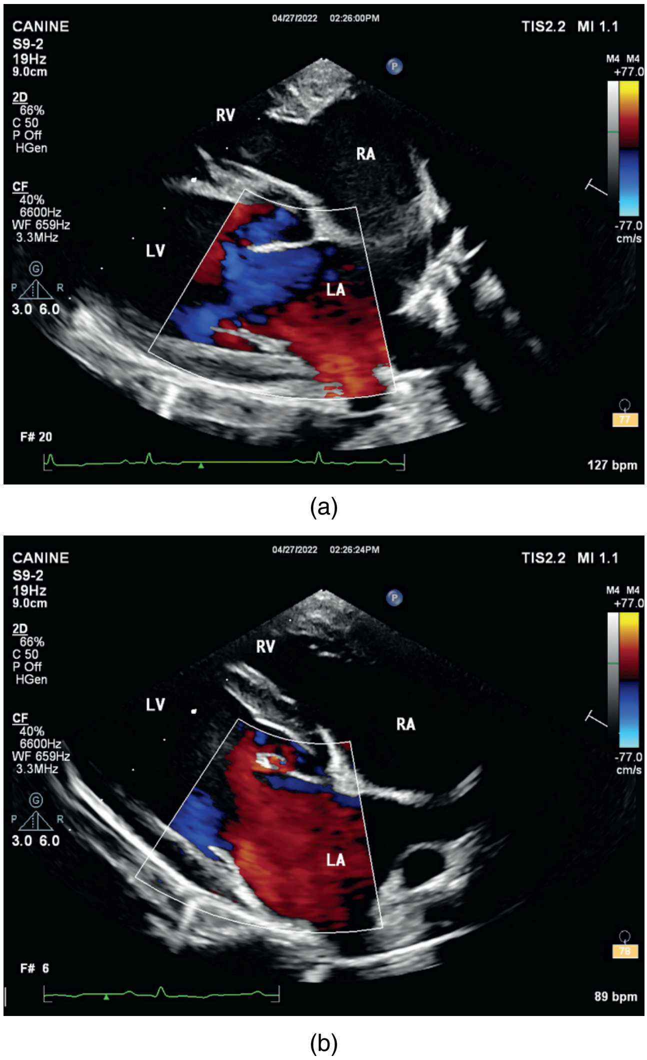


(b)

Figure 1.15 Two-dimensional gain that is set too high can prevent color Doppler from filling the areas of interest. (a) Good color gain and appropriate 2D gain setting, where the fluid-filled chambers and vessels are black, allow the left ventricular outflow tract to fill well with red color. (b) High 2D gain where chambers and vessels are filled with noise prevents color from filling the left ventricular outflow tract to the same degree as in Figure 1.15a.

Video 1.15

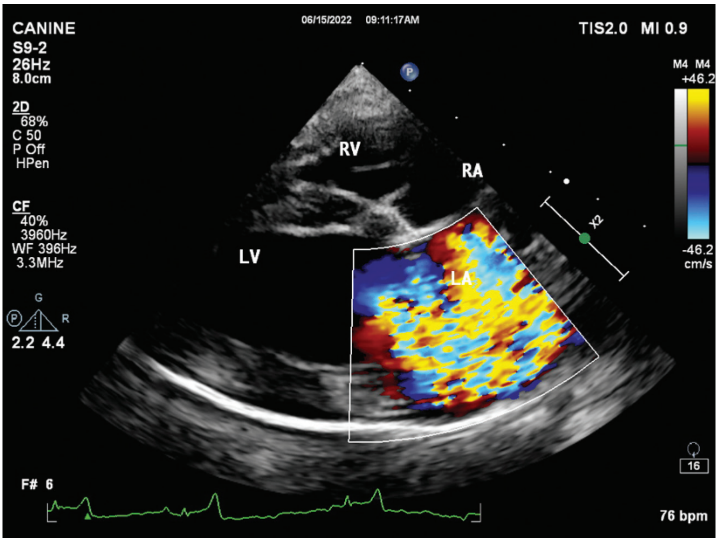
- Nyquist limit (Figures 1.17a and b and Videos 1.17a and b)
  - Decreasing Nyquist limits will create aliasing at lower velocity
    - This can overestimate the significance of a regurgitant jet
  - Increasing Nyquist limits will cause aliasing to develop at higher-flow velocities
    - This can limit the visibility of low-velocity flow like pulmonary veins
  - An optimal Nyquist limit for most purposes in about 70–90 cm/s



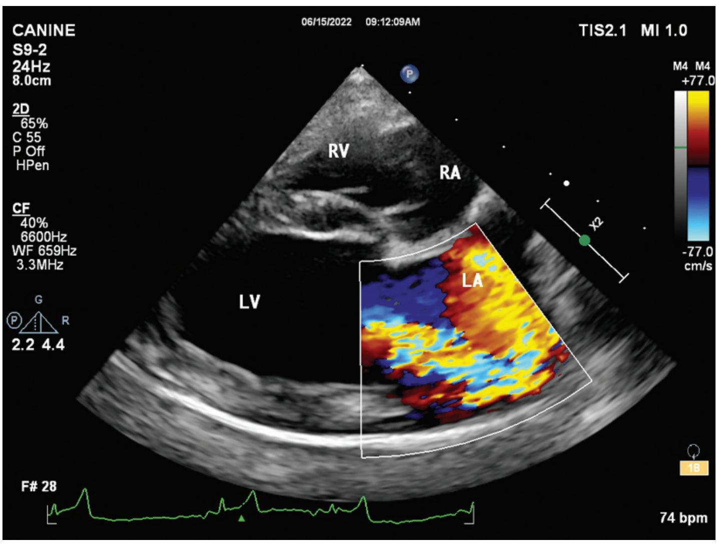
Video 1.16

Figure 1.16 Although color flow Doppler is forgiving of angles, images that line up the direction of flow more parallel to the Doppler beams allow for better color flow processing, and flow is more filled in and diagnostic. (a) This horizontal 2D image shows color with poor diagnostic value because the color is blotchy, without good representation of flow into the LV chamber. (b) This angled view shows more diagnostic color with distinct red flow moving into the LV chamber.

- Frame rates
  - Frame averaging
    - As more frames are averaged the color from different frames will overlap
    - This creates a well-filled-in color image, but the result of too much frame averaging is a slow-motion blurred image
    - One or maybe two averaged frames are recommended for cardiac studies
- Color sector size (Figures 1.18a and b and Videos 1.18a and b)
  - Increasing color sector box width adds Doppler beams and PW gates
    - This adds processing time and color often lags when the box is too wide
  - This especially matters with fast heart rates
    - Keep color sectors small



(a)

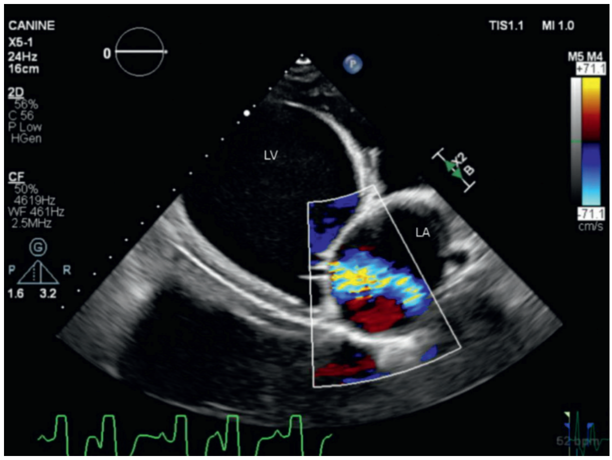


(b)

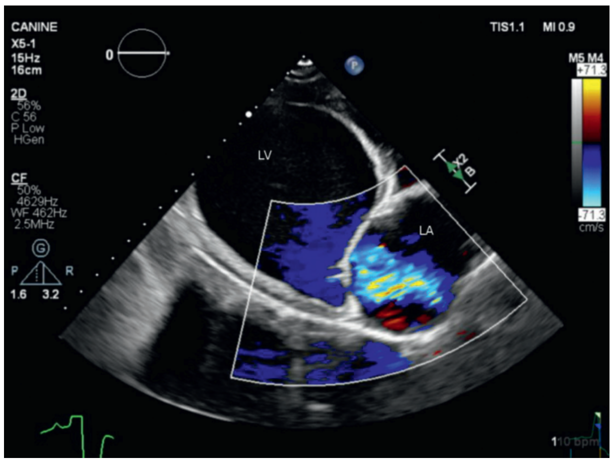
Figure 1.17 Lower Nyquist limits entrain lower flow velocities into the aliased signals. (a) A Nyquist limit of 46.2 cm/s creates a larger regurgitant jet area than a Nyquist limit of (b) 77.0 cm/s, where flow is not aliased until velocities reach 77.0 cm/s. Low Nyquist limits in regurgitant flows can overestimate the significance of the regurgitation.

Video 1.17

- Spectral Doppler
  - Factors affecting image quality
    - Depth of gate (Figure 1.11)
      - Increasing gate depth decreases the Nyquist limit
      - Aliasing will occur at lower velocities than if a shallower gate position is used
      - Decreasing gate depth is not always possible and is dependent upon the valve or vessel being evaluated



(a)



(b)

Video 1.18

Figure 1.18 Larger color sector boxes slow down frame rate, resulting in slow motion or late color mapping. (a) A smaller color box size allows frame rates to be high and color processing to map color accurately. The mitral regurgitation jet in this image is clearly defined. (b) This large color sector makes processing time longer, and color is less clearly defined. The mitral regurgitation in this image of the same dog as in Figure 1.18a is poorly defined because of this low frame rate. These differences are more visible in the associated videos.

- Interrogation angle (Figure 1.12a)
  - Aligning the Doppler beam parallel to flow results in the most accurate assessment of velocity
- Gate size
  - Gate size is typically set at 2–3 mm
  - Increasing gate size can help record very small flows
- Baseline (Figure 1.7)
  - Move the baseline up or down as necessary to see the entire spectral envelope

- Scale (Figure 1.7)
  - Adjust scale as necessary to optimize the display
  - If aliasing occurs when scale is at its maximum, switch to CW if possible
- Frequency (Figure 1.10)
  - Higher transducer frequencies decrease the maximum velocity of the spectral display
  - Lower transducer frequencies increase the possible velocity before aliasing occurs

LAMINAR AND TURBULENT FLOW

- Normal laminar flow (Figure 1.19, Figure 1.3)
  - Normal blood flow travels in a linear path at similar velocities
  - As a result, normal blood flow has hollow PW envelopes (Figure 1.20)
- Turbulent flow
  - When flow becomes turbulent it is no longer laminar and multiple velocities are recorded (Figure 1.21)
    - This results in a filled-in PW flow profile (Figure 1.22)
    - This is referred to as spectral broadening
  - CW Doppler envelopes are always filled in since flow velocities are recorded all along the Doppler line (Figure 1.4)

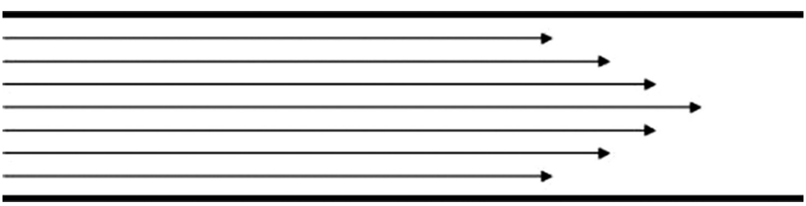


Figure 1.19 Normal blood flow through the heart is laminar. Blood travels in a linear path at similar velocities.

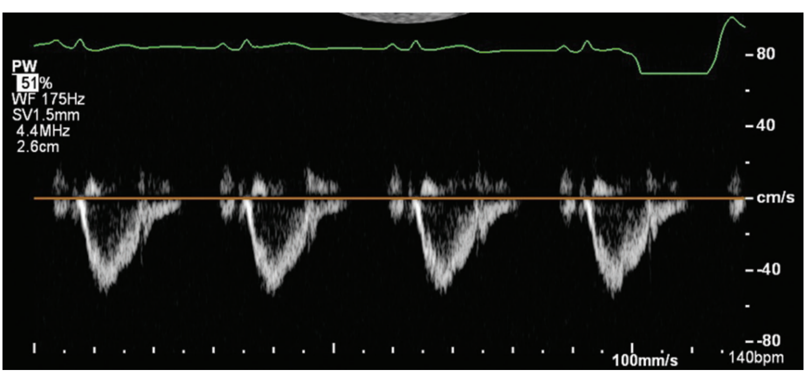


Figure 1.20 Normal laminar blood flow has hollow PW envelopes since there is no great spread in velocity.

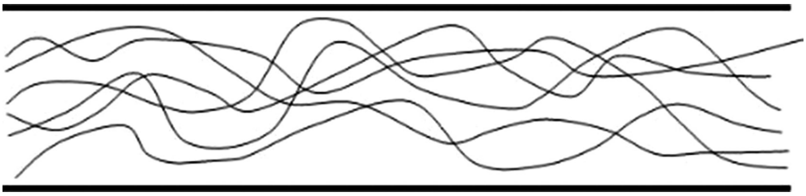


Figure 1.21 When flow becomes turbulent it is no longer laminar, and multiple velocities and directions are present.

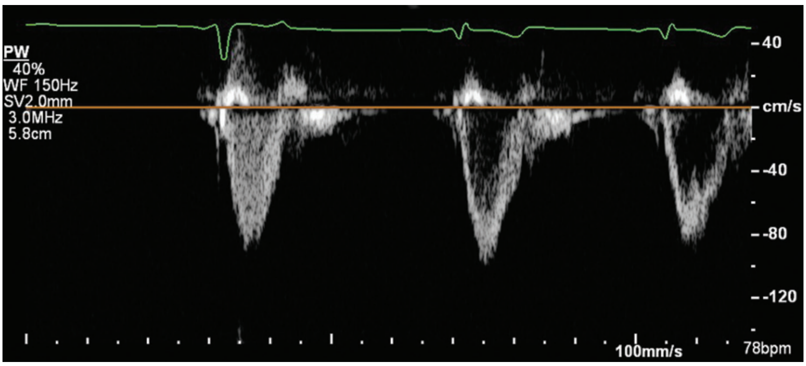


Figure 1.22 Non-laminar flow causes filled-in PW flow profiles. This is called spectral broadening. However spectral broadening can occur secondary to technical error. Flow here shows spectral broadening in the first flow profile and laminar flow in the latter profiles at the same gate location. The laminar flow is correct. Flow does not change from turbulent to laminar in the same location.

- Causes of spectral broadening
  - High gain settings
  - Poor angle of incidence relative to flow
  - Turbulence
  - Always seen in CW

Section 2 The Doppler Examination

- Spectral Doppler
  - Normal spectral flows in the heart
    - Mitral valve
      - Imaging plane used
        - Spectral Doppler of the mitral valve can be obtained from the apical 4 chamber view (Figures 2.1a and b and Video 2.1)
      - Technique
        - This is a PW flow analysis only
        - Place the gate at the tips of the MV leaflets when open
      - Appearance
        - There are two phases to LV filling through the mitral valve
        - Just before the MV opens LA pressure is at its highest
        - This creates a rapid inflow of blood into the LV chamber early in diastole – the first phase (Figure 2.2a)
          - This first peak is called the E peak (for early diastolic flow)
        - Pressure between the LV and LA equilibrate and the MV closes partially (Figure 2.2a)
          - Little to no flow occurs at this time
        - With atrial contraction toward the end of diastole, LA pressure increases and the MV opens again secondary to this active push of blood into the LV – the second phase of ventricular filling (Figure 2.2a)
          - This is referred to as the A peak (for atrial contraction)
        - Slower heart rates (longer diastolic time periods) will separate the two phases (Figure 2.2b)
        - Faster heart rates (shorter diastolic time periods) will result in closer E and A peaks (Figure 2.2b)
          - There will be complete summation of E and A waves when heart rates become very rapid (Figure 2.2c)
        - E velocities are normally higher than A velocities

Doppler Echocardiography for the Small Animal Practitioner, First Edition. June A. Boon.

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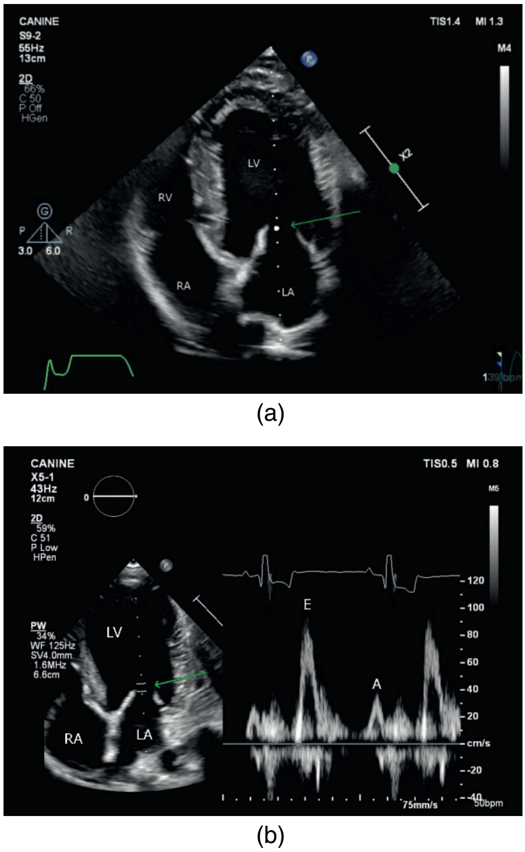


Video 2.1

Figure 2.1 (a) Spectral Doppler of the mitral valve can be obtained from the apical 4 chamber view. The arrow shows where the PW gate is placed. (b) Trans mitral valve flow is recorded with PW Doppler. The gate is placed at the tip of the mitral valve when it is open (arrow). The spectral display to the right shows upward flow above the baseline. E represents early diastolic filling of the left ventricle, and A represents antegrade flow secondary to the atrial contraction at the end of diastole.

- The deceleration slope of the E peak is related to how quickly LA and LV pressures equilibrate
  - A steeper slope means they equilibrate quickly
  - A slower descent means it take longer for LV and LA pressures to equilibrate
- Measurements (Figure 2.3)
  - E wave velocity
    - Place a caliper at the peak E wave
  - Deceleration slope and time
    - From peak E wave follow the slope during deceleration to baseline
  - A wave velocity
    - Place a caliper at peak A wave

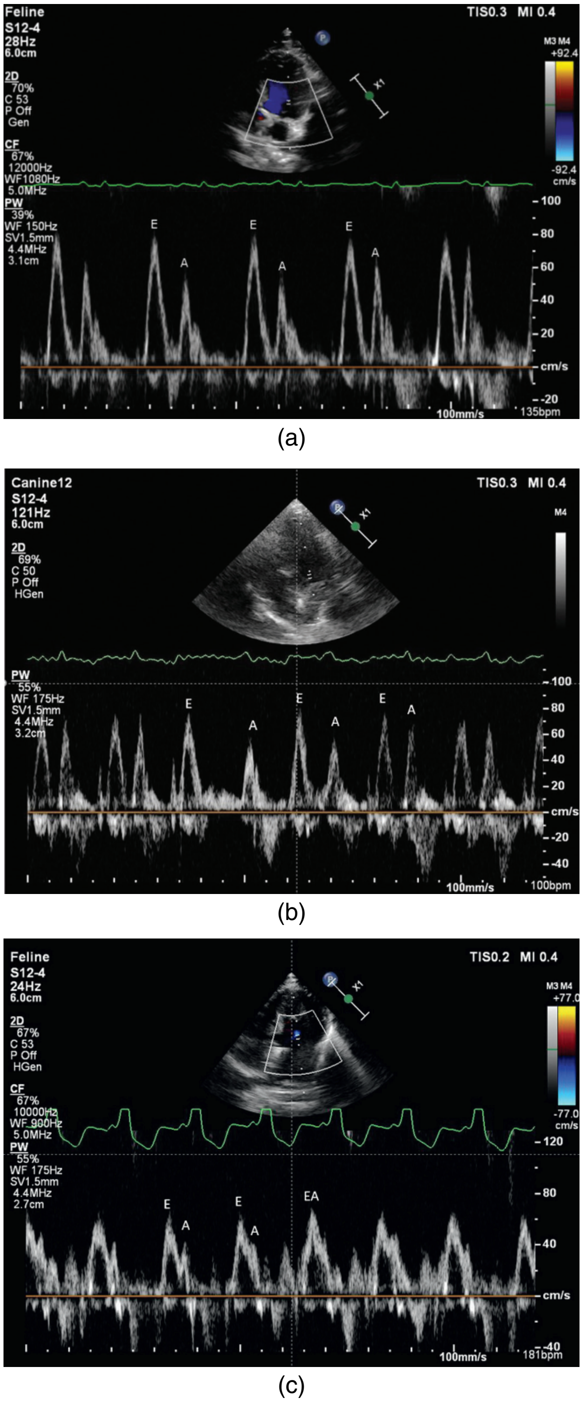


Figure 2.2 (a) Trans mitral valve flow shows the two phases of diastolic left ventricular filling. E represents early diastolic filling while A represents filling of the left ventricle secondary to the atrial contraction. (b) Diastolic time periods vary as heart rate changes. Slower heart rates with longer diastolic time periods have E and A waves that are farther apart. Shorter diastolic time periods with faster heart rates have E and A waves that are closer together. (c) Fast heart rates can have E and A waves that start to superimpose upon themselves, and when the heart rate is fast enough E and A waves can completely summate.

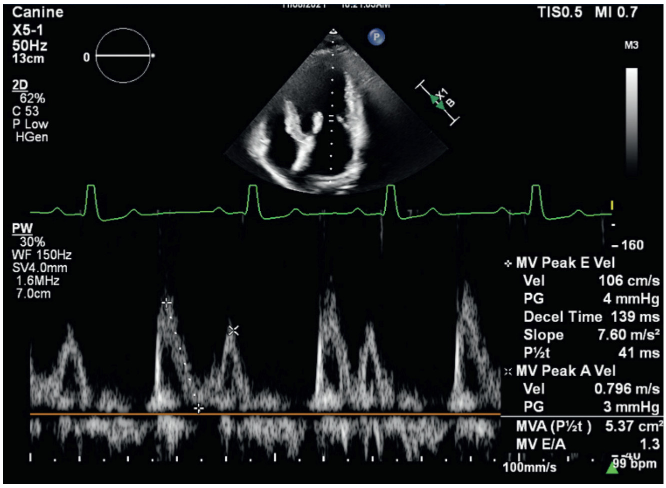


Figure 2.3 Measuring trans mitral flow involves measuring peak E wave velocity, a deceleration time for the E wave, and peak A wave velocity.

- Aorta and LVOT
  - Imaging planes used (Figures 2.4a–d and Videos 2.4a and c)
    - Apical 5 chamber or subcostal views are necessary to align the Doppler cursor with the LVOT and aorta
      - The longest apical LV chamber possible truly aligns the outflow tract
      - Therefore, subcostal views often have an aorta whose flow is more aligned with a cursor
      - A foreshortened LV chamber may appear to align the cursor with the aorta, but it is an oblique alignment
  - Technique
    - Using PW Doppler in the aorta, the gate should be placed in the aorta just distal to the aortic valve (Figure 2.4b)
    - Using PW Doppler of the left ventricular outflow tract, the gate should be placed in the outflow tract just proximal to the aortic valve (Figure 2.4a)
    - Using PW for stroke volume requires gate placement at the valve
    - With CW Doppler align the Doppler cursor parallel to the walls of the aorta or outflow tract (Figures 2.4a and b)
    - CW of the LVOT should be done only after PW has documented an abnormal aliased signal and maximum velocity is desired
  - Appearance and measurement (Figure 2.5)
    - Aortic flow is rapidly accelerating with slower deceleration
    - Peak velocity is reached within the first third of systole
    - Normal flow velocity is typically less than 2 m/s
    - Flows more than 2.5 m/s are typically considered abnormal

    - Flow velocity between 2 and 2.5 m/s is equivocal and is evaluated situationally
    - Measure peak velocity
- Pulmonary artery and RVOT
  - Imaging planes used
    - Right parasternal transverse AO with PA (Figure 2.6a and Video 2.6a)
      - This should be used for RVOT and not PA flow unless the PA is aligned with the cursor as it sometimes is in the cat
    - Right parasternal oblique long axis (Figure 2.6b and Video 2.6b)

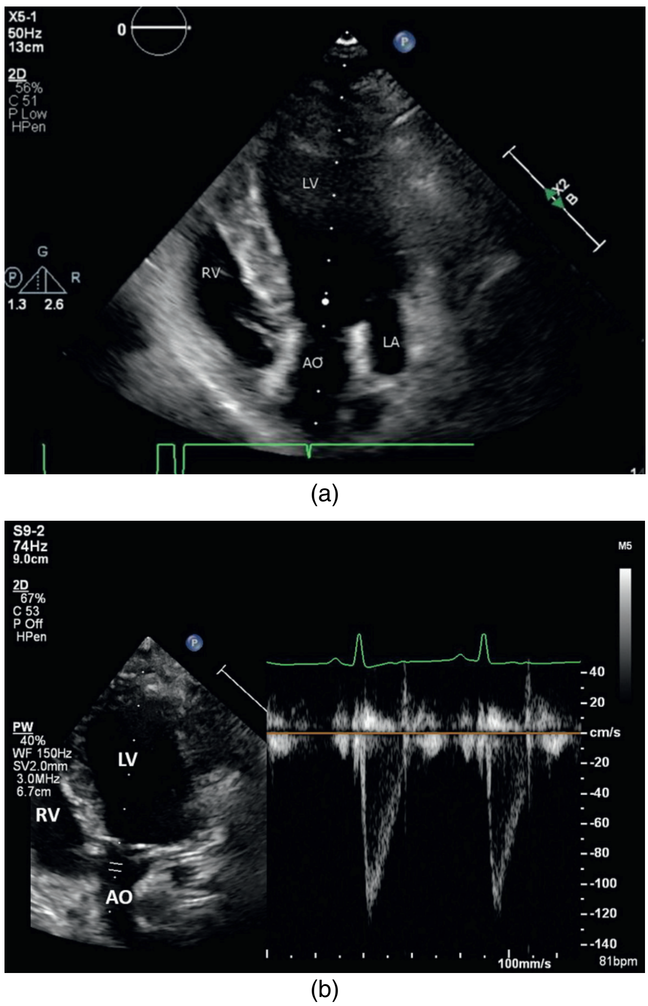
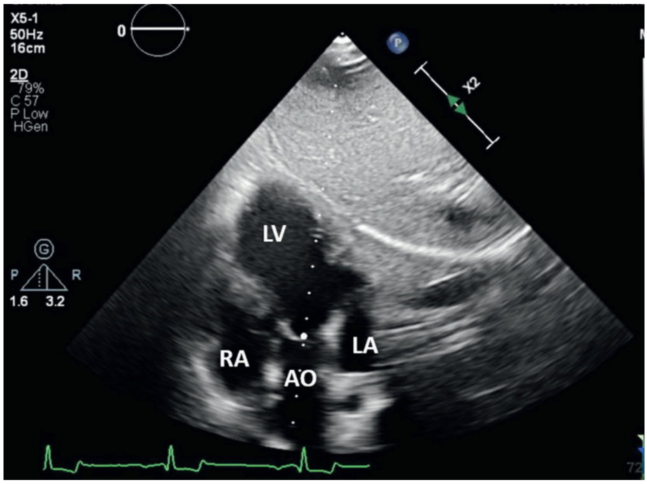
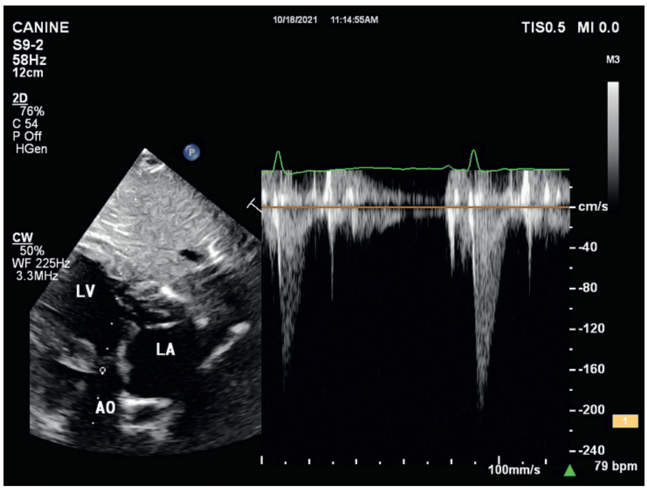


Figure 2.4 (a) Spectral Doppler of the aorta and outflow tract can be obtained from the apical 5 chamber view, lining the Doppler cursor up parallel to the left ventricular outflow tract and aorta. The gate (large dot) is placed proximal to the aortic valve for outflow tract velocity. (b) Aortic flow is recorded with PW or CW Doppler. With PW, the gate is placed in the aorta just distal to the aortic valve. The spectral display to the right shows downward flow below the baseline as blood exits the left ventricle. (*Continued*)

Video 2.4



(c)



(d)

Figure 2.4 (*Continued*) (c) Spectral Doppler of the aorta can also be obtained from the subcostal view, lining the Doppler cursor up parallel to the left ventricular outflow tract and aorta. (d) Aortic flow is recorded with PW or CW Doppler. With PW, the gate is placed in the aorta just distal to the aortic valve. The spectral display to the right shows downward flow below the baseline as blood exits the left ventricle.

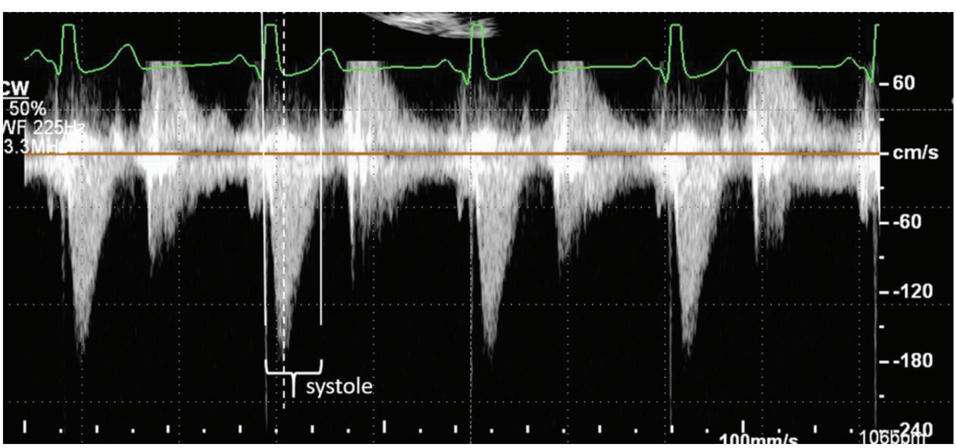


Figure 2.5 The aortic spectral envelope is always downward and rapidly accelerating with peak velocity (dotted line) occurring during the first third of the ejection phase (bracket). Peak aortic flow velocity is typically 200 cm/s or less. Peak flow velocity here is about 140 cm/s.

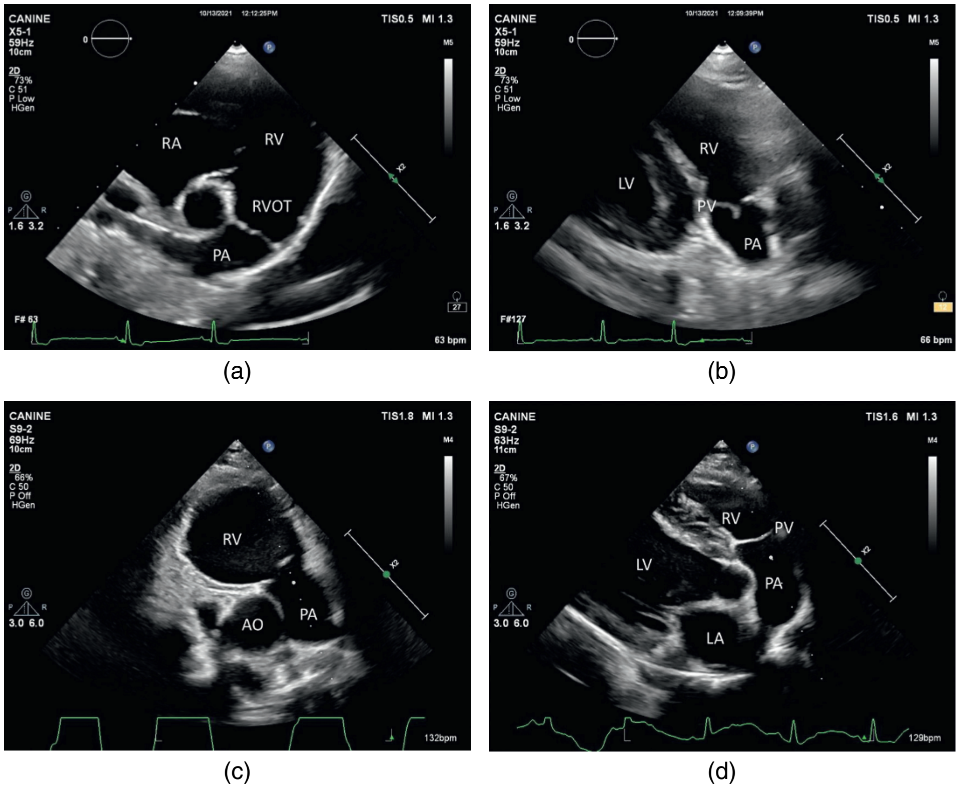


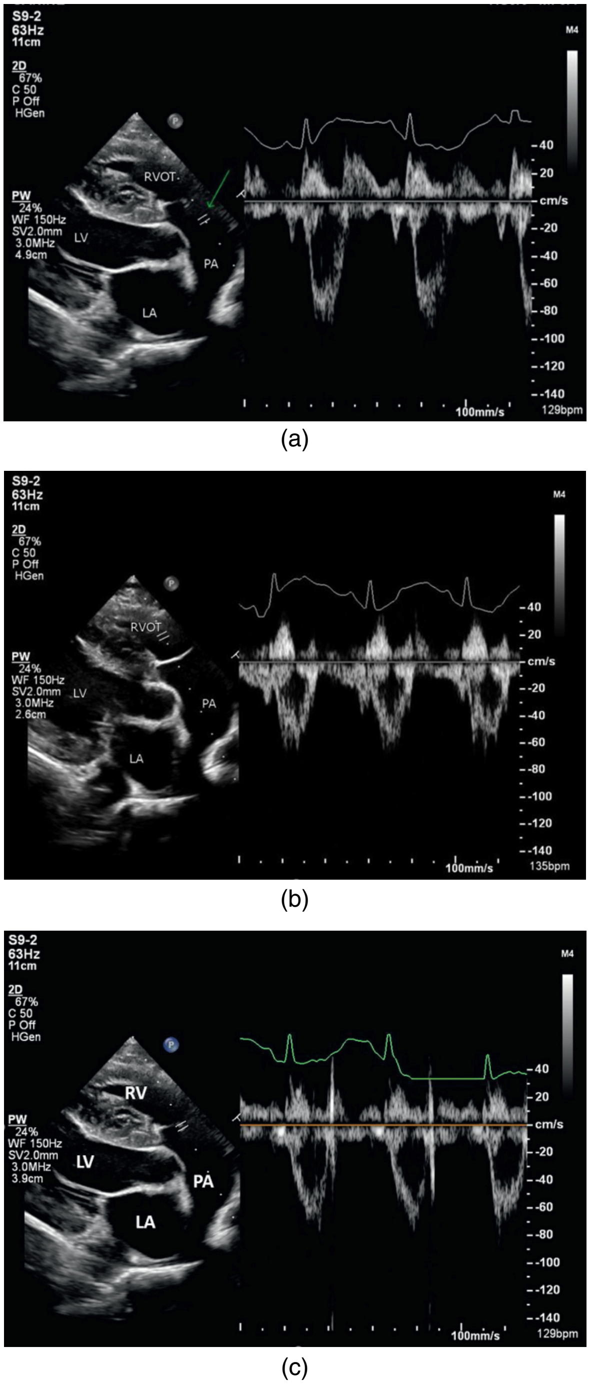
Figure 2.6 (a) Right ventricular outflow tract flow can be obtained from the right parasternal transverse view of the heart base. This view should be used for the outflow tract only as the PA does not usually align parallel to flow. (b) The right parasternal oblique long axis view of the pulmonary artery often lines the Doppler cursor up parallel to right ventricular outflow tract and pulmonary artery flow. (c) The left cranial short axis view is often used to align a Doppler cursor parallel to pulmonary artery flow. If using PW Doppler, the gate should be placed just distal to the pulmonary valve (large dot). (d) The left cranial long axis view also often aligns a cursor parallel to pulmonary artery flow. If using PW, the gate should be placed just distal to the pulmonary valve (large dot).

Video 2.6

- Left cranial short axis (Figure 2.6c and Video 2.6c)
- Left cranial long axis (Figure 2.6d and Video 2.6d)

▫ Technique

- PW Doppler of systolic pulmonary artery flow has the gate placed in the pulmonary artery just distal to the valve (Figures 2.6c and d, Figure 2.7a, and Videos 2.6c and d)
- PW Doppler of the right ventricular outflow tract has the gate placed in the outflow tract proximal to the pulmonary valve (Figure 2.7b and Video 2.7b)
- PW for stroke volume requires gate placement at the valve itself (Figure 2.7c and Video 2.7c)
- With CW Doppler align the Doppler cursor parallel to the walls of the pulmonary artery or outflow tract (Figures 2.7a–c)



Video 2.7

Figure 2.7 (a) A gate placed just distal to the pulmonary valve (arrow) records downward systolic pulmonary artery flow. If using CW, the gate placement is not critical. Normal PA flow is typically less than 1.6 m/s. (b) A gate placed in the right ventricular outflow tract records downward systolic flow with velocities less than that in the pulmonary artery itself. CW Doppler should not be used for RVOT flow unless aliasing occurs. (c) Using PW Doppler to calculate stroke volume leaving the right ventricle, the gate should be placed right at the pulmonary valve. CW Doppler is not used for stroke volume calculation.

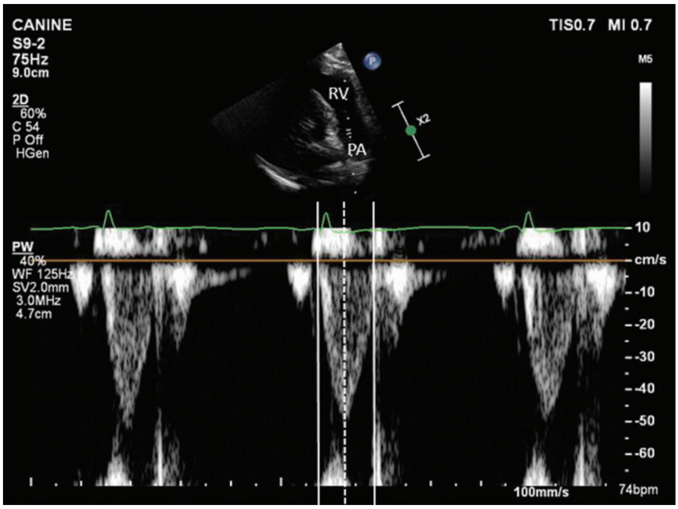
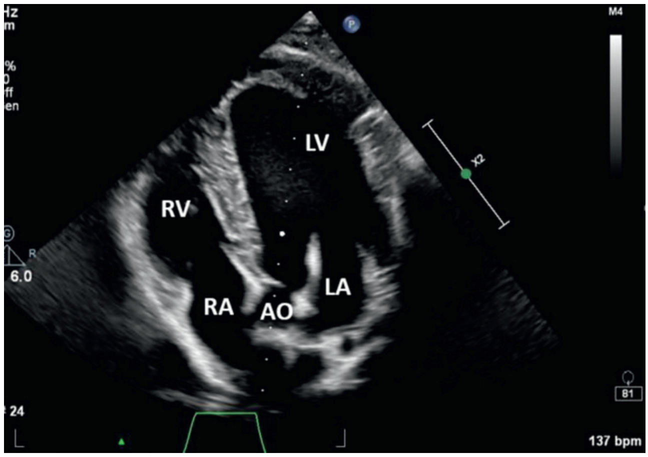


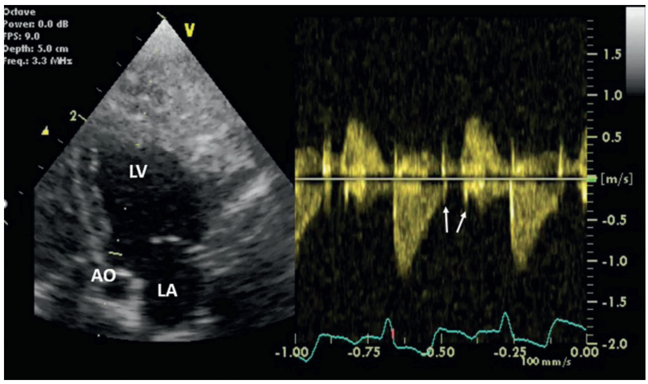
Figure 2.8 Pulmonary artery flow profiles are symmetrical with peak velocity (dotted line) occurring during the middle third of ejection (between solid lines). Peak velocity is typically less than 1.6 m/s. Acceleration time is measured from the start of flow to peak velocity (from first solid line to dotted line) and ranges from about 50 ms to 120 ms. Right ventricular ejection time (between solid lines) is measured from the start of systolic flow to the end. A ratio of acceleration time to ejection time should be greater than .32, consistent with the fact that peak velocity occurs during the middle third of ejection time.

    - CW of the RVOT should be done only after PW has documented an abnormal aliased signal and maximum velocity is desired
  - Appearance and measurement
    - Normal pulmonary artery flow profiles are symmetrical with acceleration and deceleration similar and peak flow velocity in mid-systole (Figure 2.8)
    - Peak flow velocity is measured
      - Peak velocity is typically less than 1.6 m/s
    - Acceleration time can be measured (Figure 2.8)
      - Normal acceleration time is approximately 50–120 ms
      - Acceleration time is measured from the onset of downward systolic flow to peak velocity
    - RV ejection time can be measured (Figure 2.8)
      - Ejection time is measured from the onset of systolic flow to the end of systolic flow
    - A ratio of pulmonary artery acceleration time to ejection time is calculated
      - A normal ratio is greater than .32
- Left ventricular isovolumic relaxation time (IVRT)
  - Isovolumic relaxation time is the period from aortic valve closure to mitral valve opening
    - All valves are closed
    - The ventricle relaxes until its pressure drops below left atrial pressure
    - This provides the pressure gradient, allowing the mitral valve to open, and blood flows into the ventricular chamber

- Imaging planes used
  - This time period can be recorded from apical or subcostal 5 chamber views (Figures 2.9a and b and Videos 2.9a and b)
    - Technique
      - A CW cursor often records IVRT while recording aortic systolic flow, but a PW gate placed in the left ventricular outflow tract does as well
      - Color flow Doppler can be used to identify the junction of blue downward aortic flow and red upward trans mitral flow (Figure 2.9c and Video 2.9c)
      - A PW gate or a CW line is placed at this junction
    - Appearance and measurement (Figures 2.10a and b)
      - A click identifies closure of the aortic valve, and the next click identifies opening of the mitral valve
      - Measure the time interval between the two clicks
      - Either measure from before the first line to before the second line or right on the line to right on the line
  - Pulmonary venous flow
    - Pulmonary venous flow into the left atrium is continuous and phasic (Figure 2.11)
    - During systole while the mitral valve is closed, most of left atrial filling occurs
      - This is pulmonary vein S flow
    - During diastole when the mitral valve is open, blood moves through the pulmonary vein and like a conduit moves with mitral flow into the left ventricle
      - This is pulmonary vein D flow
    - When the left atrium contracts, blood not only moves forward through the mitral valve but also flows backward into the pulmonary vein
      - This occurs at the onset of the P wave and ends with the onset of systole and is pulmonary venous atrial reverse flow, Ar
    - Imaging planes necessary and technique
      - Imaging planes used are
        - Right parasternal transverse left atrium aorta view (Figure 2.12a and Video 2.12a)
        - Right parasternal long axis view (Figure 2.12b and Video 2.12b)
        - Left foreshortened apical 4 chamber (Figure 2.12c and Video 2.12c)
        - Left cranial left auricle view (Figure 2.12d and Video 2.12d)
      - This is a PW recording with the gate placed entirely into the pulmonary vein (Figure 2.13)
    - Appearance and measurement (Figure 2.14)
      - Normal pulmonary venous flow has S and D waves that are similar in velocity, with S usually being slightly higher
      - The S wave can be biphasic in slower heart rates
      - Measure peak S, D, Ar velocities and Ar duration
  - Left auricular flow
    - Imaging planes used
      - Left parasternal cranial transverse left auricle (Figure 2.15a and Video 2.15a)
      - Left parasternal cranial long left auricle (Figure 2.15b and Video 2.15b)



(a)



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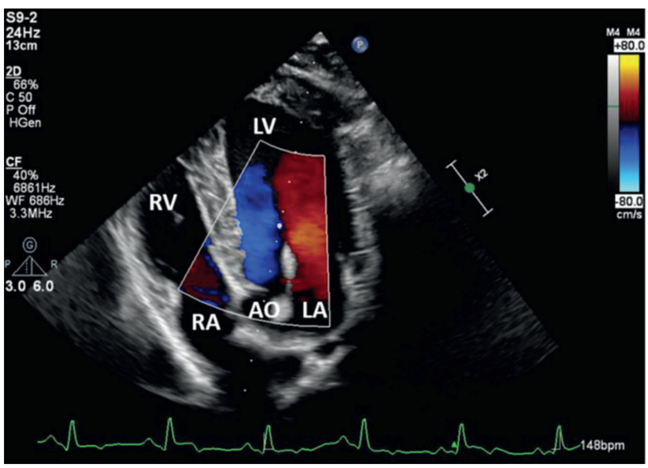
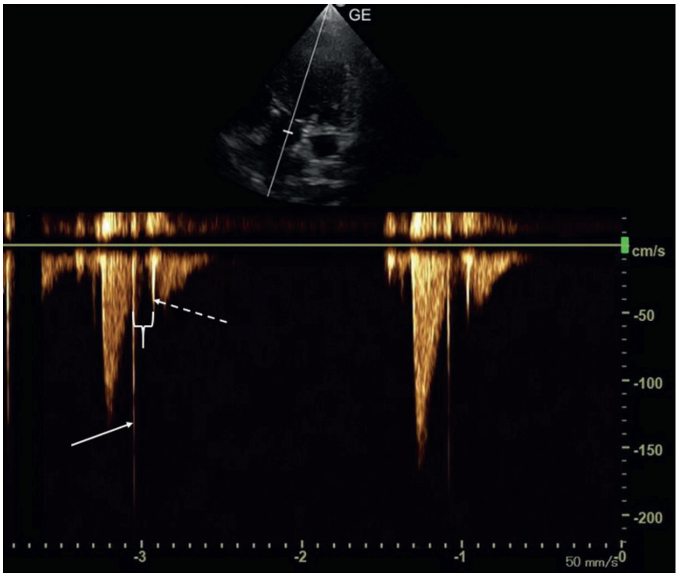


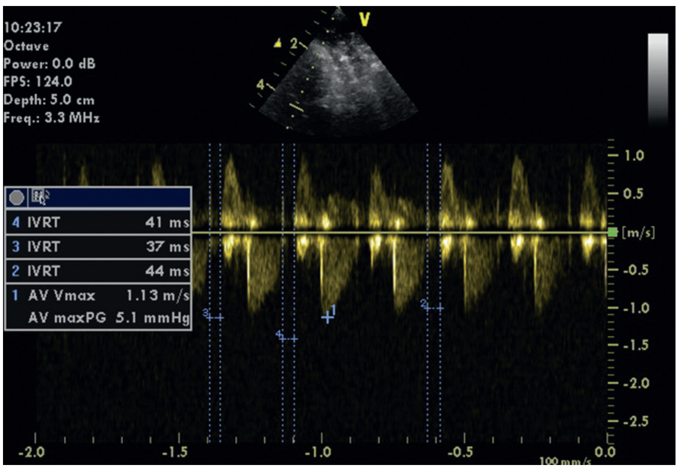
(c)

Figure 2.9 (a) Isovolumic relaxation time can be measured from apical 5 chamber views while recording aortic flow with CW Doppler. The spectral display often shows IVRT as well. If PW is used, a gate (large dot) is placed in the outflow tract between the mitral valve and interventricular septum. This will not record accurate aortic flow, of course. (b) Subcostal views can also be used. Often CW Doppler of aortic flow in this view shows IVRT on the spectral display. The time period is from the click that represents aortic valve closure to the beginning of mitral flow into the left ventricular chamber (between arrows). (c) Color flow Doppler can define the junction of red flow into the left ventricular chamber and blue flow down into the aorta. A CW Doppler cursor placed along this junction can record IVRT. If using PW, place a gate at the junction of these two flows (large dot).

Video 2.9



(a)



(b)

Figure 2.10 (a) IVRT is the time period between end of ejection to start of diastolic flow into the LV chamber (bracket). Measure IVRT from the click that represents aortic valve closure (solid arrow) to the start of mitral flow into the ventricular chamber. Often a click is seen at the start of mitral valve flow, and using it provides accuracy (dotted arrow). (b) Measurements of IVRT in this image range from 37 to 44 ms. Normal feline IVRT is approximately 38 to 54 ms. It varies slightly with heart rate.

- Technique
  - This is a PW flow recording (Figure 2.16)
  - Place the gate at the perceived junction of auricle and atrium
  - Move the gate farther into the auricle if there is difficulty in recording the flow
  - Gate size can be increased to facilitate detection of auricular flow

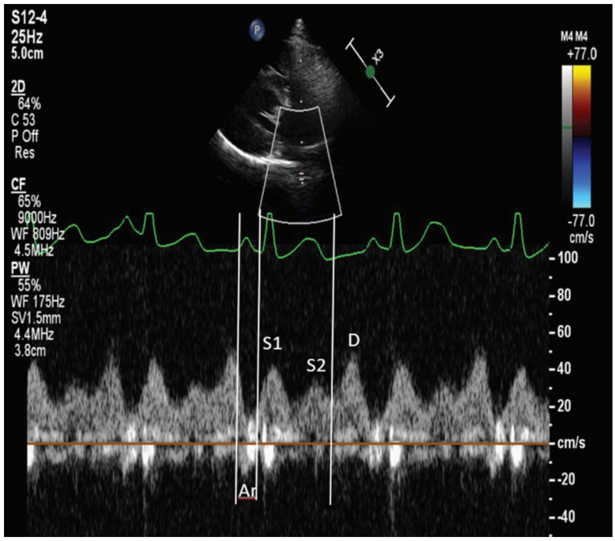


Figure 2.11 Pulmonary venous flow is continuous and phasic. During systole when the MV is closed most of atrial filling occurs; this is pulmonary venous S wave. Systolic flow can be biphasic, and the waves are labelled S1 and S2. Fast heart rates typically will not show both phases of systole. Diastolic flow into the left atrium is the pulmonary vein D wave. The mitral valve is open at this time, and flow moves like a conduit from the vein into the LA and through the MV. During atrial contraction there is reversed flow into the vein, the pulmonary vein Ar wave. The lines indicate the start and end of atrial contraction and the end of ventricular systole.

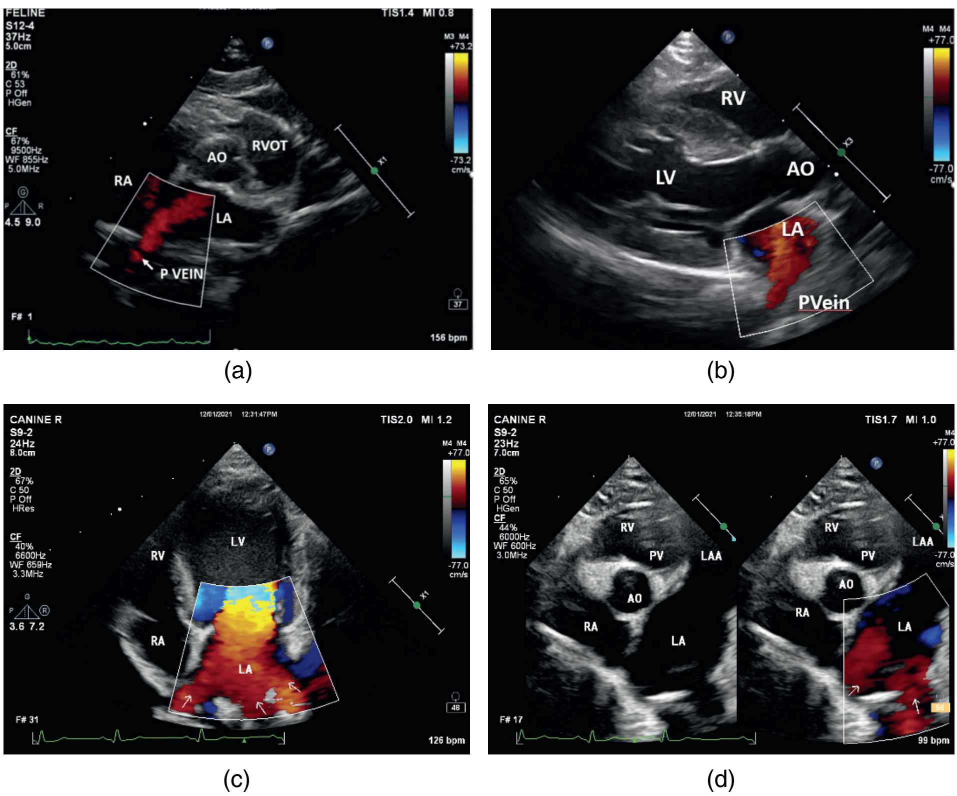


Figure 2.12 Pulmonary venous flow can be obtained from several left atrial views. The veins are identified by looking for red flow into the left atrial chamber. (a) Right parasternal transverse view of the aorta and left atrium. (b) Right parasternal long axis views. (c) Left parasternal foreshortened apical 4 chamber view. (d) Left parasternal transverse view of the left auricle and atrium.

Video 2.12

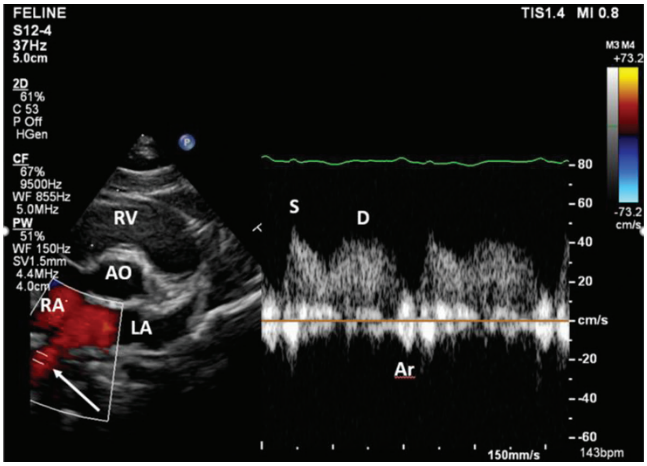


Figure 2.13 Spectral evaluation of pulmonary venous flow uses PW Doppler only. The gate is placed entirely in the vein (arrow). The more parallel to flow the Doppler cursor is, the more accurate the venous flow velocities are. To the right the spectral display shows S, D, and Ar flow.

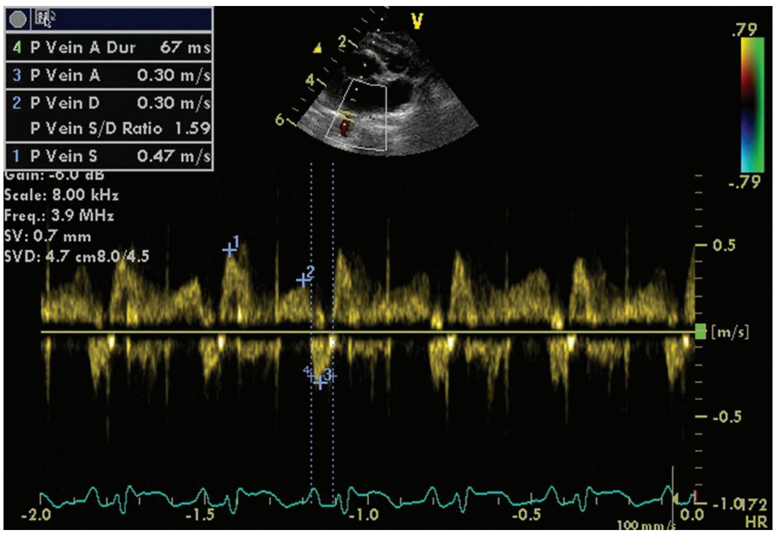
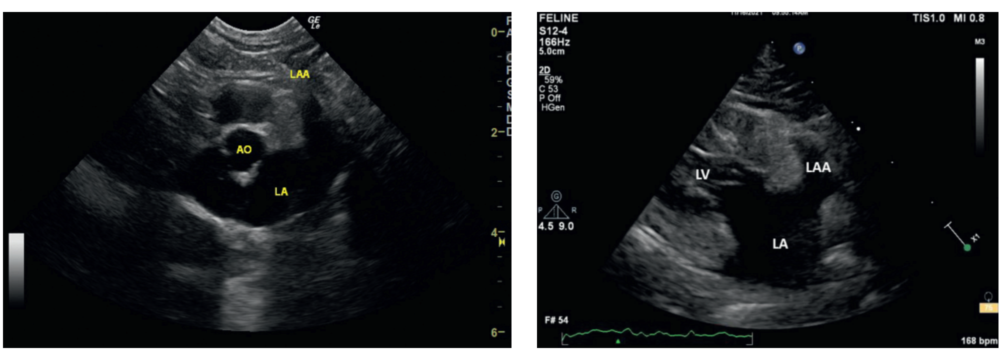


Figure 2.14 Each component of pulmonary venous flow is measured. Peak S, D, and Ar velocities as well as Ar duration are measured. The dotted lines show the beginning and end of Ar flow for the duration measurements. Note that the reversed flow starts with the ECG p wave.



(a) (b)

Video 2.15

Figure 2.15 Left auricular filling and emptying is obtained from either the (a) left cranial transverse view of the auricle or (b) left cranial long axis views of the auricle (arrow in video).

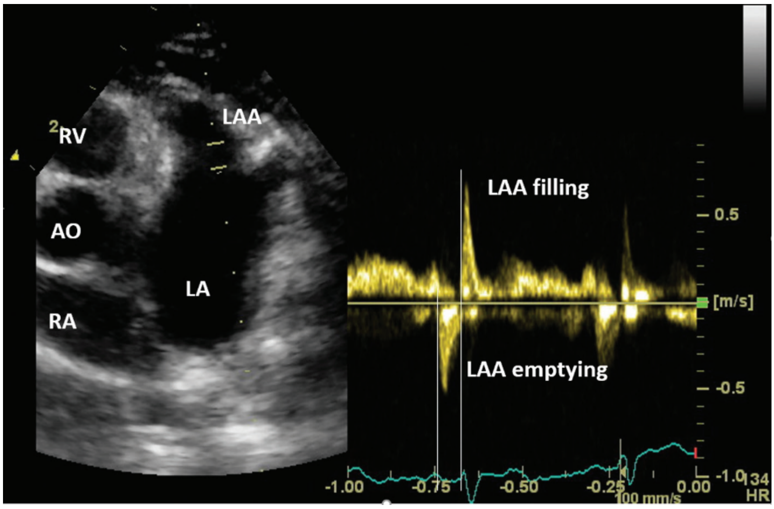
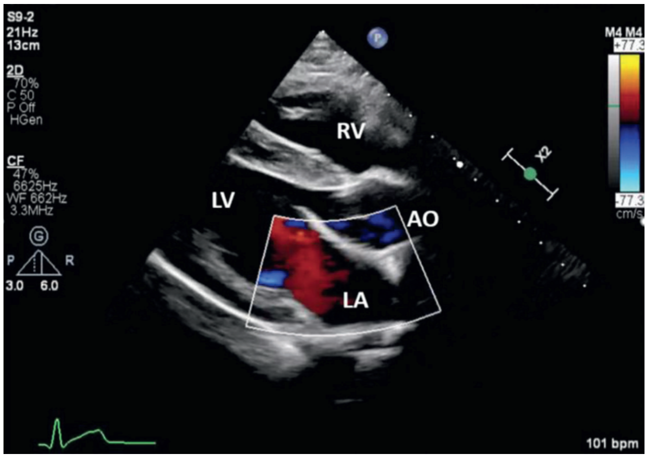


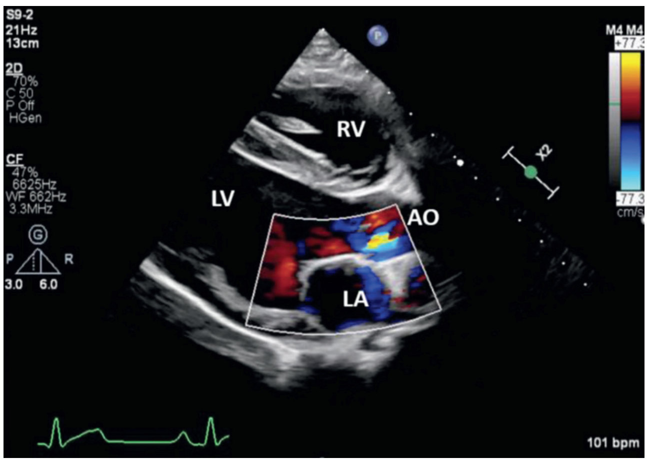
Figure 2.16 Use PW for left auricular flow. The gate is placed at the perceived junction of the auricle and atrium. If there is difficulty in recording flow, move the gate farther into the atrial appendage. Auricular emptying occurs with the atrial contraction, and filling occurs during systole. The lines show how these filling and emptying flows correlate to the atrial contraction and the beginning of ventricular systole on the ECG. Peak emptying and filling velocities are measured. Normal velocities are greater than .24 m/s.

- Appearance and measurement (Figure 2.16)
  - During ventricular systole as the left atrium and auricle fill there is upward flow
  - During atrial systole as the left atrium contracts there is downward flow as blood moves out of the left auricle
  - Measure peak emptying and filling flow velocities

- Color Flow Doppler
  - Normal color flow in the heart
    - Mitral valve
      - Imaging planes used
        - Right parasternal inflow outflow view (Figures 2.17a and b and Video 2.17)
        - Right parasternal 4 chamber view (Figures 2.18a and b and Video 2.18)
        - Left apical 4 chamber view (Figures 2.19a and b and Video 2.19)
        - Left apical 5 chamber view (Figures 2.20a and b and Video 2.20)
      - Technique
        - Imaging planes that are somewhat angled will yield the best color flow information
        - The color sector should be placed so the tips of the mitral valve are included in the box and the bulk of the box is over the left atrium
        - This allows evaluation of normal LV filling during diastole and regurgitant flow during systole



(a)

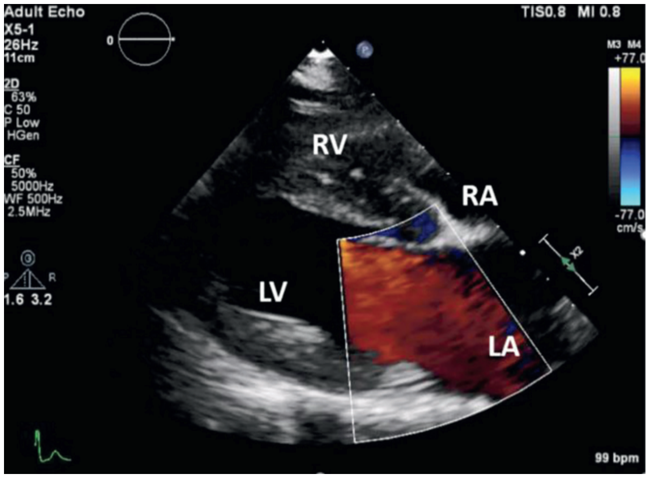


(b)

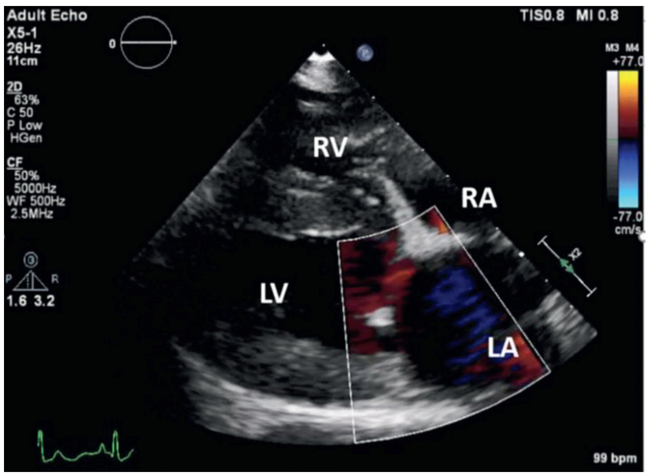
Video 2.17

Figure 2.17 Color flow Doppler of the mitral valve can be obtained from the right parasternal inflow outflow view. (a) During diastole there is typically red flow moving upward into the left ventricular chamber. (b) During systole there should be no color flow recorded on the atrial side of the valve.

  - Appearance
    - Normal flow is upward in all of these imaging planes so color will be red to yellow with some blue if the Nyquist limit is exceeded
    - Normal trans mitral valve flow is typically less than 1 m/s so aliasing if present is minimal and occurs early in diastole
    - During systole there is no aliased flow that starts at the closed mitral leaflets in the left atrium
- Aorta
  - Imaging planes used
    - Right parasternal inflow outflow view (Figures 2.21a–c and Video 2.21)
    - Left cranial long axis of the aorta (Figures 2.22a and b and Video 2.22)



(a)



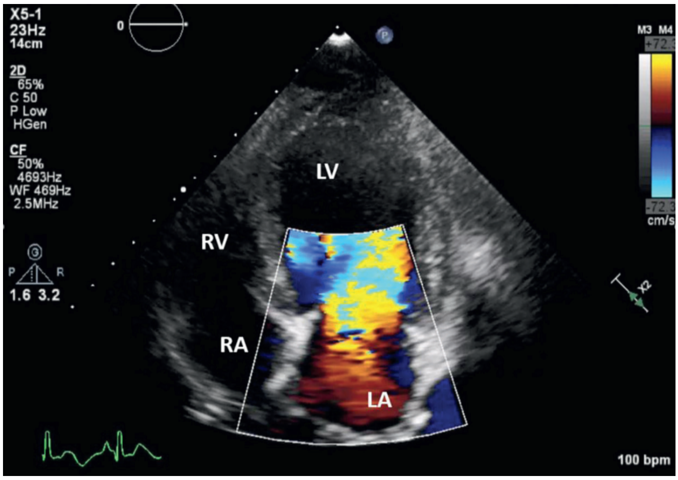
(b)

Figure 2.18 The right parasternal 4 chamber view can be used to evaluate MV flow. (a) During diastole there is typically red flow moving into the left ventricle. (b) During systole there should be no color flow signals on the atrial side of the closed valve.

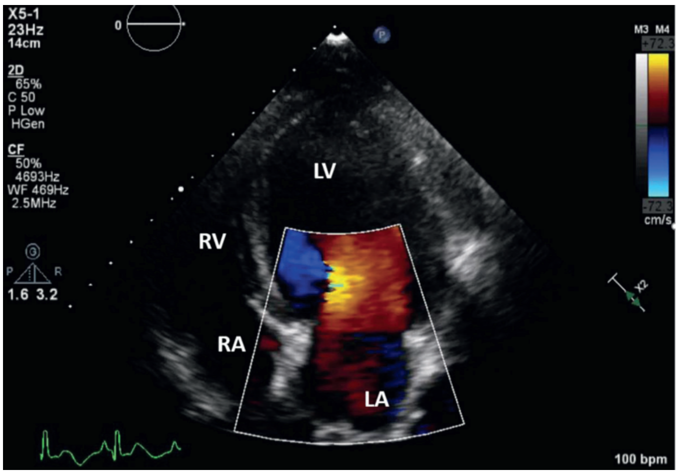
Video 2.18

- Left apical 5 chamber view (Figures 2.23a and b and Video 2.23)
- Subcostal view of the aorta (Figures 2.24a and b and Video 2.24)

- Technique
  - The color sector should be placed so the aortic valve and part of the aorta are included in the box, with the bulk of the box over the left ventricular outflow tract
    - This allows evaluation of normal LV ejection during systole and abnormal regurgitant flow into the outflow tract during diastole



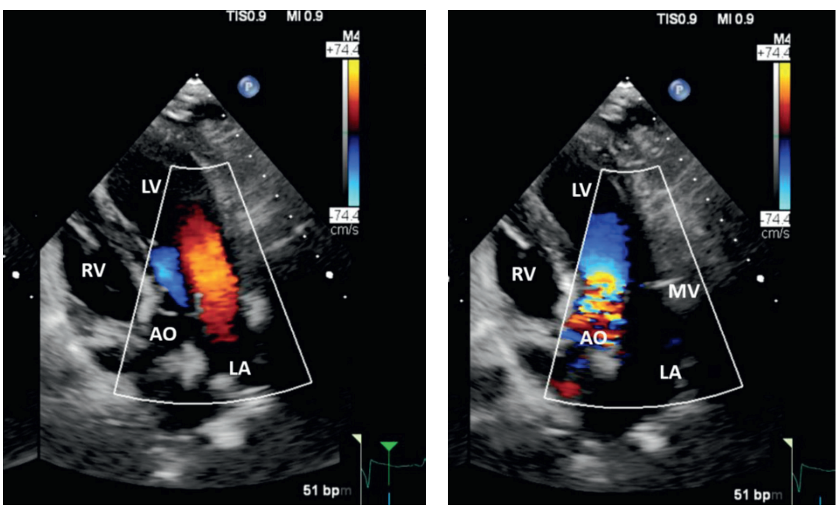
(a)



(b)

Video 2.19

Figure 2.19 Apical 4 chamber views provide excellent color flow information as flow is more parallel to the Doppler cursor. (a) During early diastole in this patient there is aliased upward flow moving into the left ventricle. (b) During late diastole flow velocity is lower and non-aliased flow moves into the left ventricle.



(a) (b)

Video 2.20

Figure 2.20 Apical 5 chamber views are used to evaluate mitral valve color. (a) During diastole there is upward red flow moving into the left ventricle. (b) During systole there should be no color flow signals on the atrial side of the closed mitral valve.

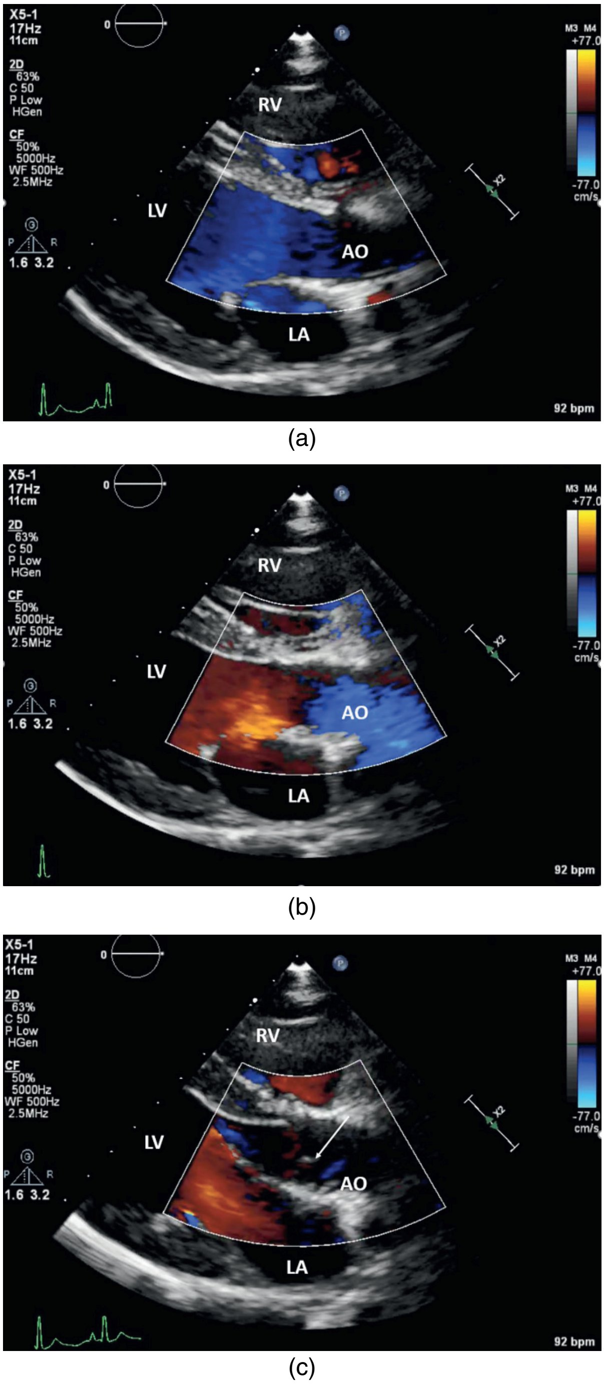
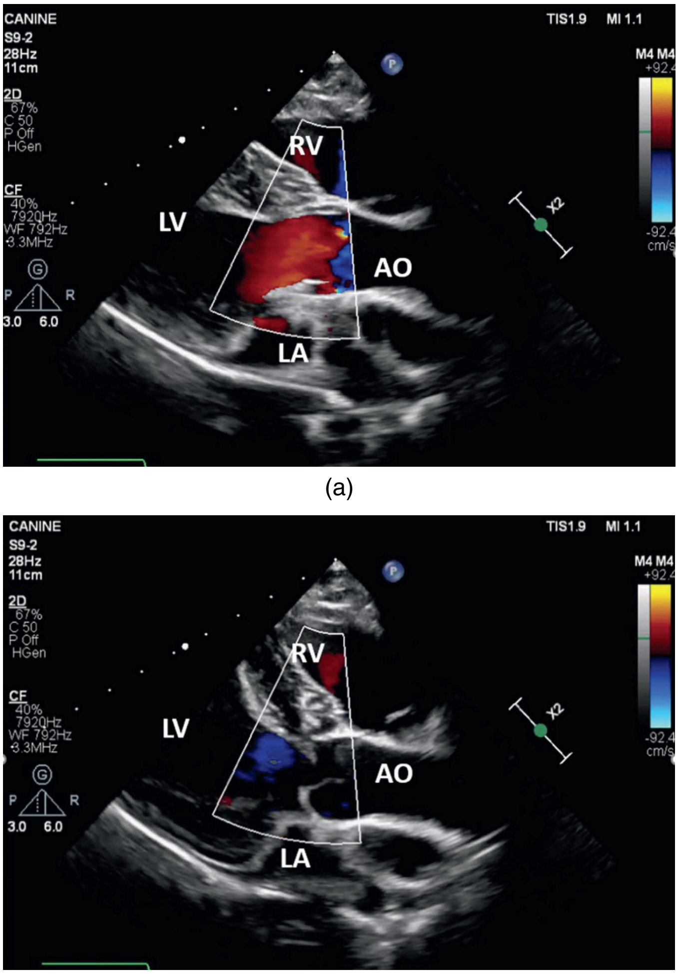


Figure 2.21 The right parasternal inflow outflow view is used to evaluate aortic and left ventricular outflow color. (a) During early systole flow into the aorta and through the outflow tract may be red as flow moves toward the aorta in the left ventricular outflow tract. Aliased flow is common and normal since the Nyquist limit is often exceeded. (b) Systolic flow may also be blue if the image orientation has the aorta slightly lower than the left ventricle. (c) During diastole the dash of the closed aortic valve (arrow) should be seen, and there should be no flow into the left ventricular outflow tract above the open MV.

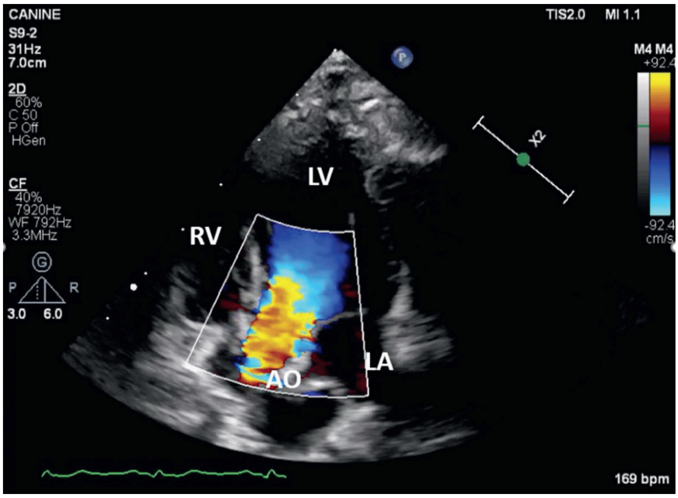
Video 2.21



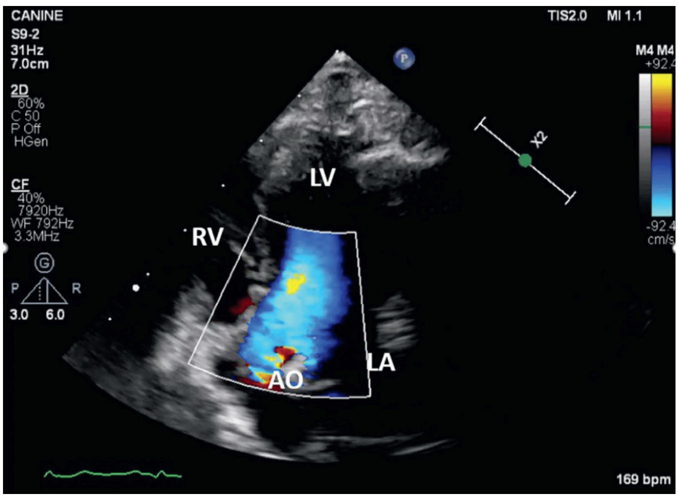
Video 2.22

Figure 2.22 Left cranial long axis inflow outflow views are used to evaluate left ventricular outflow tract and aortic flow. (a) During systole flow is either red (as it is here) or blue depending on the orientation of the aorta and outflow tract on the sector. Aliased flow is common and normal since the Nyquist limit is often exceeded. (b) During diastole there should be no color flow signals starting at the closed aortic valve moving into the left ventricular outflow tract.

- Appearance
  - Normal flow is downward in the apical view so color will be blue to white, but often the Nyquist limit is exceeded since normal aortic flow velocities may be up to 2 m/s and aliasing will occur
  - Normal flow may be upward to downward depending upon which way the aorta is directed on the right parasternal inflow outflow view and on the left cranial long axis view
  - During diastole there should be no flow extending from the aortic valve into the left ventricular outflow tract



(a)



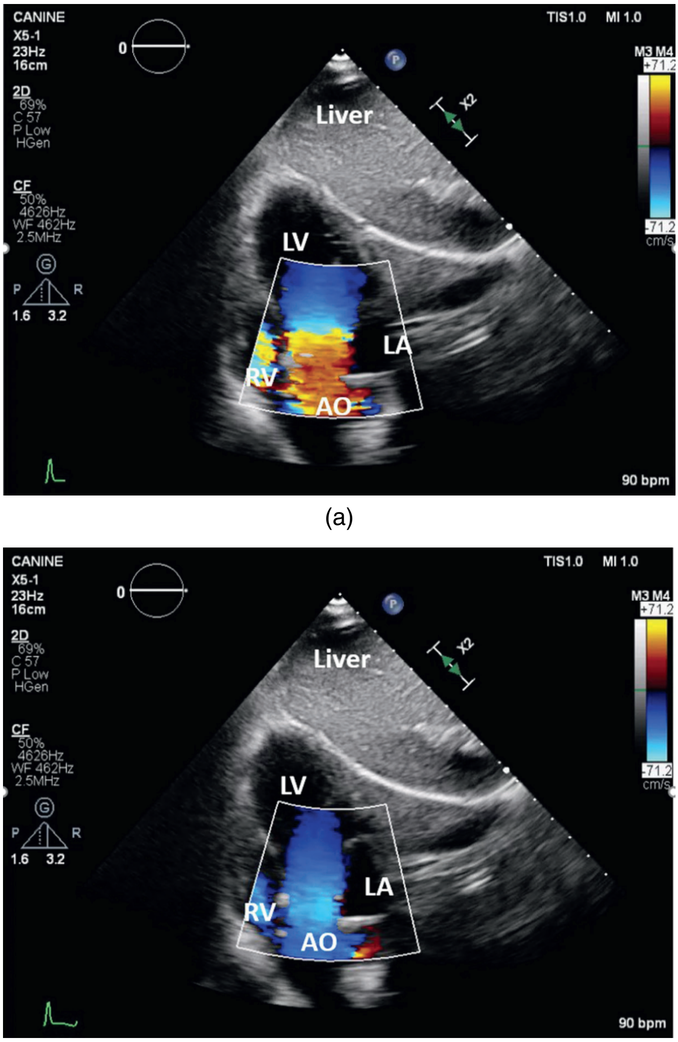
(b)

Figure 2.23 Apical 5 chamber views are used to evaluate color flow of the aorta and left ventricular outflow tract. (a) During early systole color may alias since Nyquist limits are typically lower than the maximum normal aortic flow velocity of about 2 m/s. (b) During late systole flow will be less aliased, if at all, as flow decelerates.

Video 2.23

- ◇ This aortic regurgitant flow may be blue or red depending upon the direction of the jet
- ◇ Aortic insufficiency is usually abnormal

- Pulmonary artery
  - Imaging planes used
    - Right parasternal transverse heart base (Figures 2.25a–c and Video 2.25)
    - Right parasternal modified long axis (Figures 2.26a and b and Video 2.26)
    - Left cranial long axis view (Figures 2.27a and b and Video 2.27)
    - Left cranial transverse view (Figures 2.28a–c and Video 2.28)



(a)

(b)

Video 2.24

Figure 2.24 The subcostal view of the aorta often shows good color flow but may be too deep in some animals for diagnostic color if a high-frequency transducer is used. (a) During early systole flow is blue as blood flows into the aorta but may be aliased as the Nyquist limit is usually exceeded. (b) Late systole shows blue downward flow as deceleration occurs.

- Technique
  - The color sector should be placed so the pulmonary valve and right ventricular outflow tract are included in the box and the box extends over the main pulmonary artery to the bifurcation
  - This allows evaluation of normal RV ejection during systole and regurgitant flow into the outflow tract during diastole

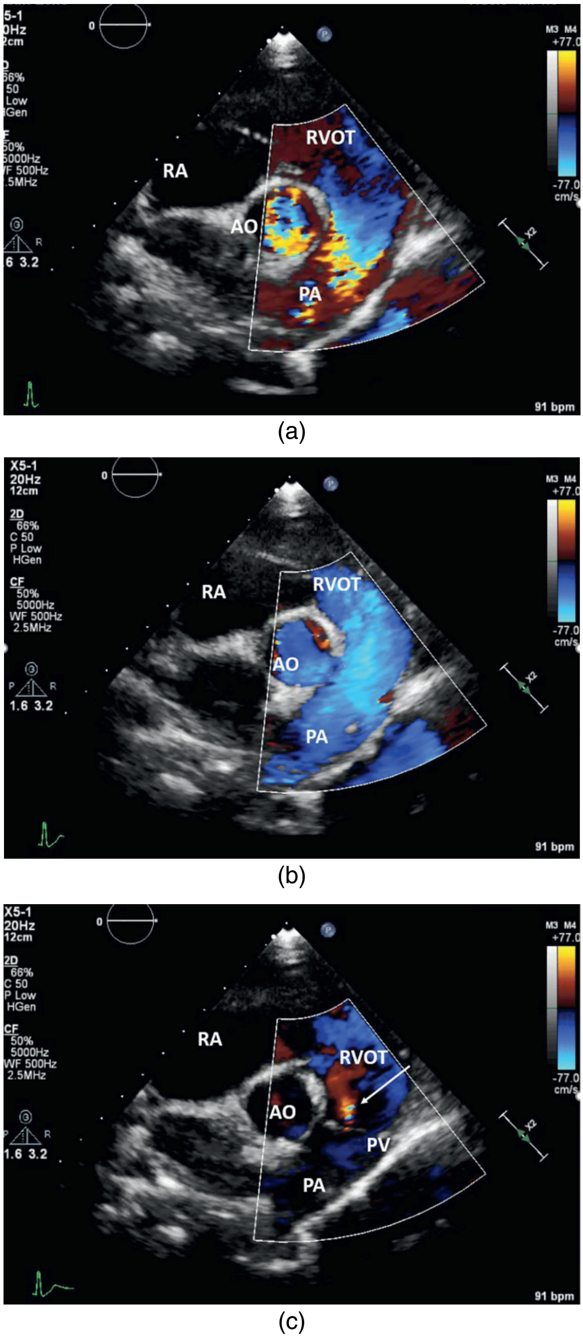
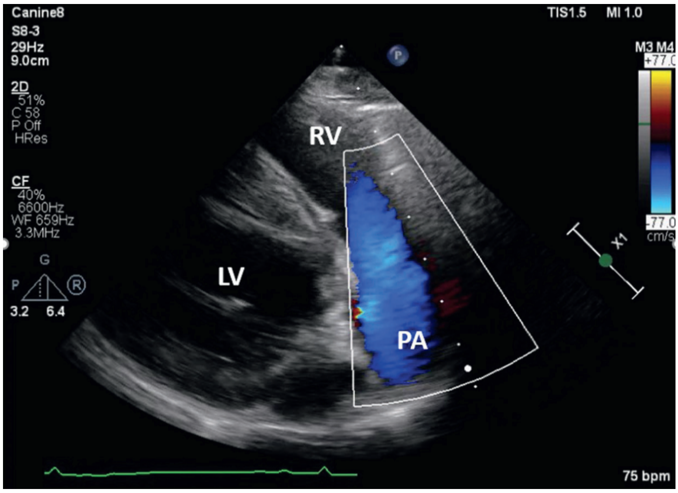
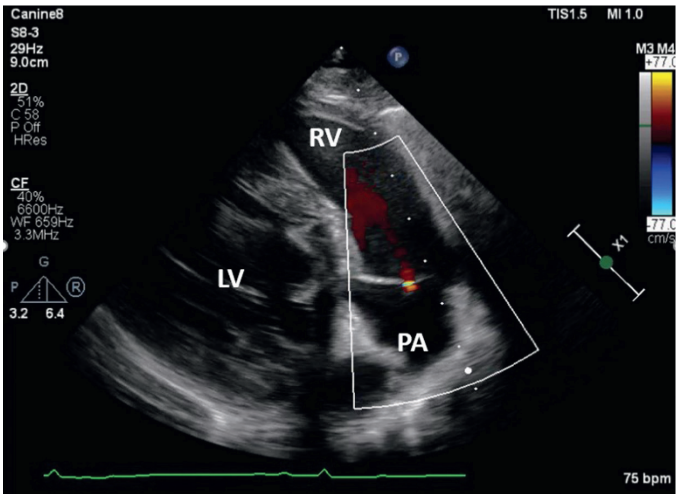


Figure 2.25 The right parasternal transverse view at the heart base of the pulmonary artery shows excellent color flow Doppler since flow is somewhat parallel to the direction of flow. (a) Early systole often shows normal aliased downward flow if the Nyquist limit is exceeded. (b) Late systole typically shows non-aliased blue colors as blood flow decelerates. (c) There is often trace to mild pulmonary insufficiency (arrow) during diastole in normal hearts. This insufficiency is always red and typically has minimal if any aliasing.

Video 2.25



(a)

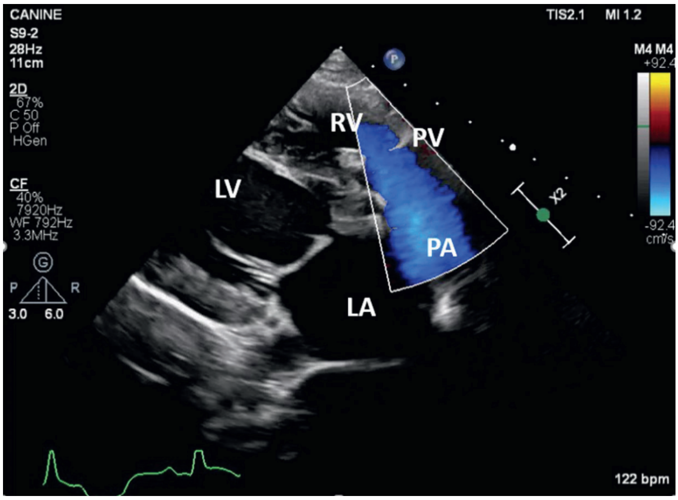


(b)

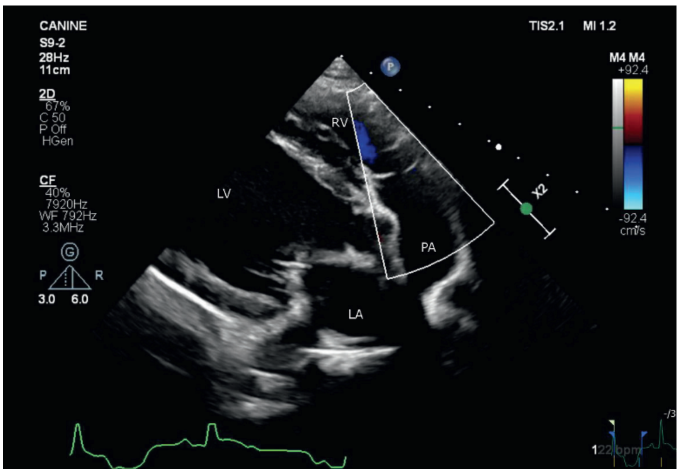
Video 2.26

Figure 2.26 The oblique (modified) long axis view of the pulmonary artery typically has good diagnostic color despite not showing as much of the main PA. (a) Color is blue as blood flows down from the right ventricle. It may alias in some cases if the Nyquist limit is low. (b) There is often trace to mild pulmonary insufficiency during diastole. This flow is always red.

- Appearance
  - Normal systolic flow is downward in all views so color will be blue to white. Often the Nyquist limit is exceeded since normal pulmonary systolic flow velocity may be up to 1.6 m/s and aliasing will occur
  - If there is pulmonary insufficiency there will be upward red flow extending from the pulmonary valve into the right ventricular outflow tract
  - Trace to mild pulmonary insufficiency is considered normal in most animals



(a)

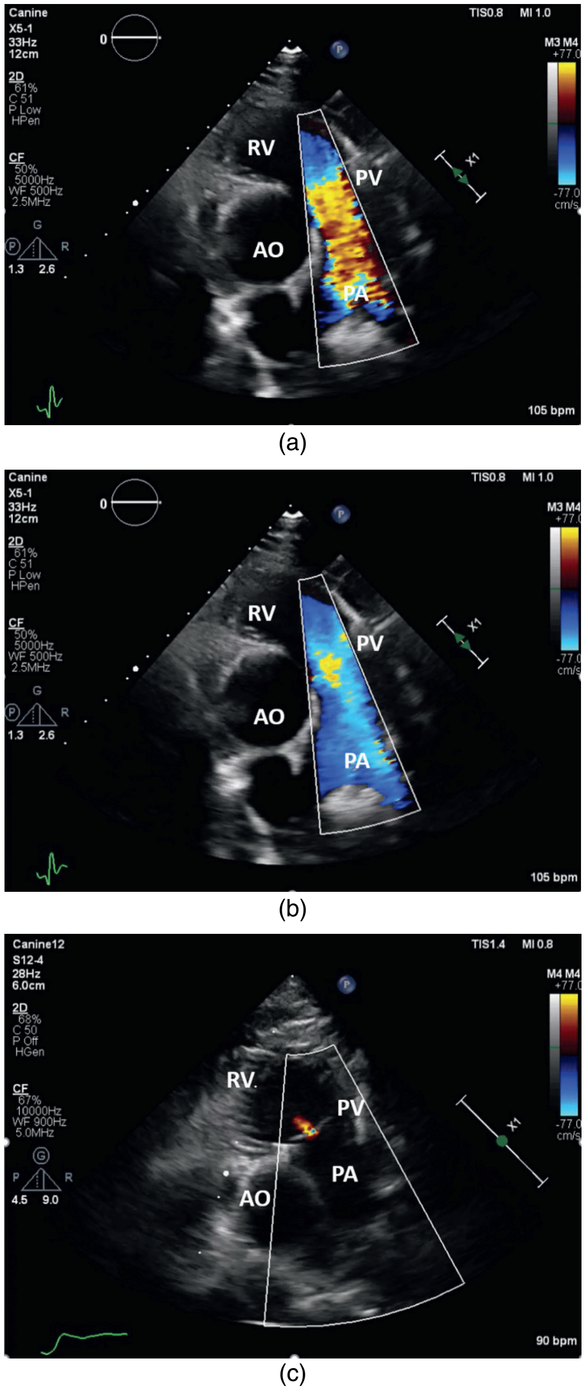


(b)

Figure 2.27 Pulmonary artery images obtained from the left cranial long axis views usually show good diagnostic color. (a) Flow is downward and blue as blood leaves the right ventricle and enters the pulmonary artery. It may alias if the Nyquist limit is lower than the flow velocity. (b) Although pulmonary insufficiency is common in normal hearts, here during diastole when the pulmonary valve is closed, there is no flow moving upward into the right ventricle.

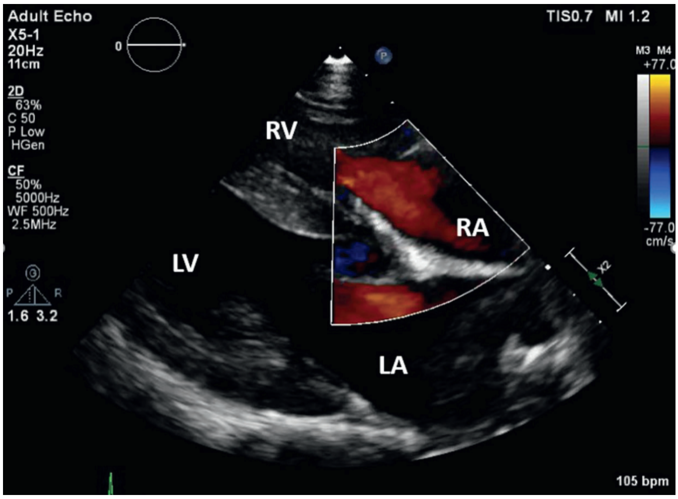
Video 2.27

- ◇ Normal pulmonary insufficiency typically does not alias, extends only a cm or 2 into the right ventricular outflow tract, generates no murmur, and shows no structural abnormalities of the valve
- Tricuspid valve
  - Imaging planes used
    - Right parasternal 4 chamber view (Figures 2.29a and b and Videos 2.29a and b)

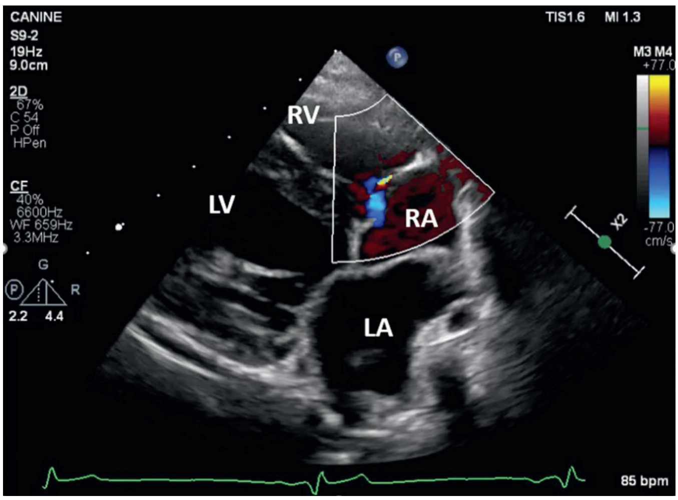


Video 2.28

Figure 2.28 Color on left cranial transverse views of the pulmonary artery is usually diagnostic. (a) Early systole in this dog shows normal aliased downward color as blood velocity exceeds the Nyquist limit. (b) Later in systole as flow decelerates color flow shows a minimally aliased blue color. (c) During diastole a small flame of red is seen extending from the pulmonary valve into the right ventricular outflow tract. This is a normal finding.



(a)



(b)

Figure 2.29 Right parasternal 4 chamber views can be used to evaluate tricuspid valve color. Images should be angled to move the right atrium into the sector and to obtain diagnostic color. (a) Color is red as blood flows from the right atrium through the tricuspid valve into the right ventricle during diastole. (b) During systole there may be trace to mild tricuspid insufficiency in many normal dogs. Here a small blue jet is seen on the atrial side of the tricuspid valve during systole.

Video 2.29

- Right parasternal short axis view at the level of the aorta (Figures 2.30a and b and Video 2.30)
- Left parasternal cranial transverse view (Figures 2.31a–c and Video 2.31)
- Left parasternal apical 4 chamber or foreshortened view (Figures 2.32 and Video 2.32)
- Left parasternal right atrial appendage view (Figures 2.33a and b and Video 2.33)

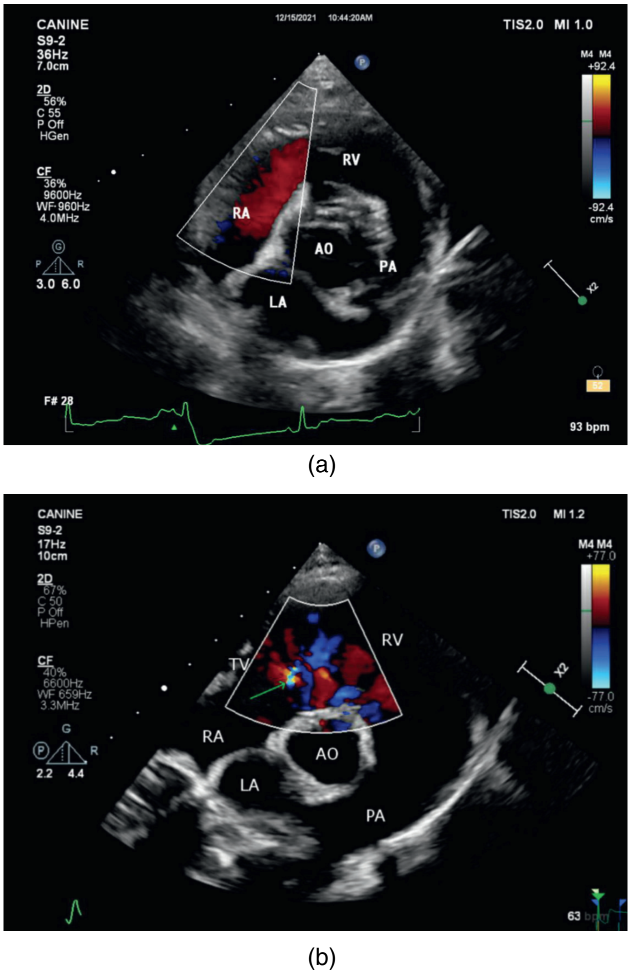


Figure 2.30 Right parasternal transverse heart base views at either the left atrial level or the pulmonary artery level may show diagnostic color, especially if the right side of the heart is enlarged. (a) Flow is red as blood moves upward into the right ventricle through the tricuspid valve. (b) During systole trace to mild tricuspid insufficiency can be seen in normal hearts. Here a trace amount of regurgitant flow is seen on the atrial side of the tricuspid valve.

Video 2.30

- Technique
  - The color sector should be placed so the tips of the tricuspid valve are included in the box and the bulk of the box is over the right atrium
  - This allows evaluation of normal RV filling during diastole and regurgitant flow during systole
- Appearance
  - Normal flow is upward in all of these imaging planes so diastolic color will be red to yellow with some blue if the Nyquist limit is exceeded
  - Normal trans tricuspid valve flow is typically less than 1 m/s so aliasing if present is minimal and occurs early in diastole

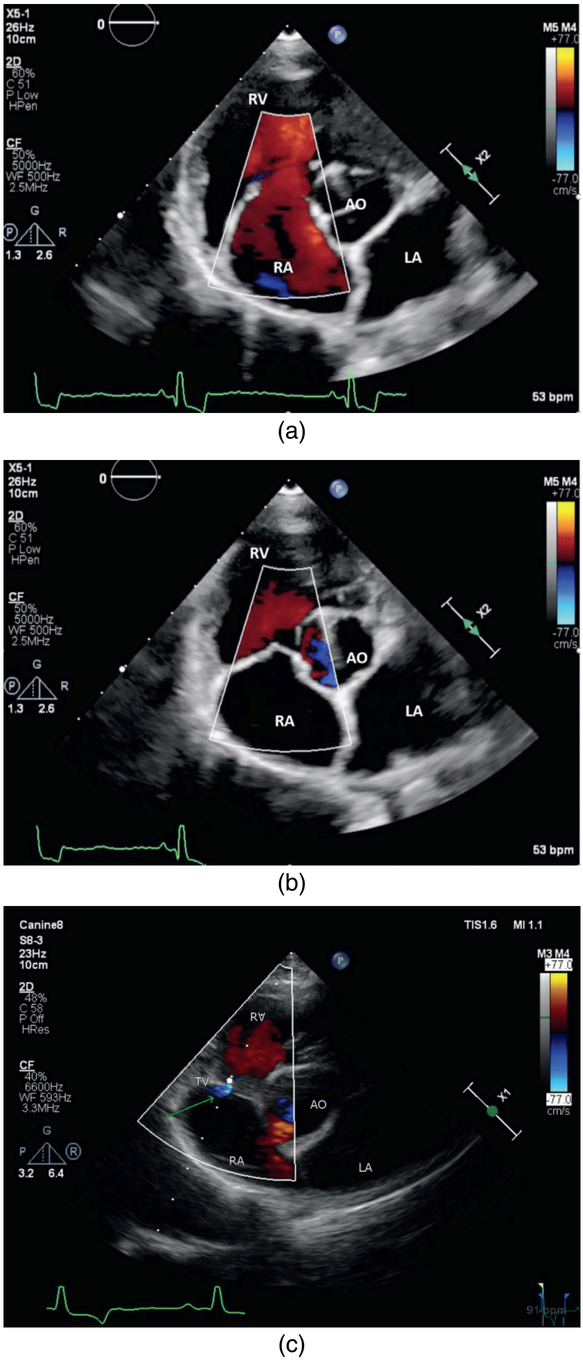
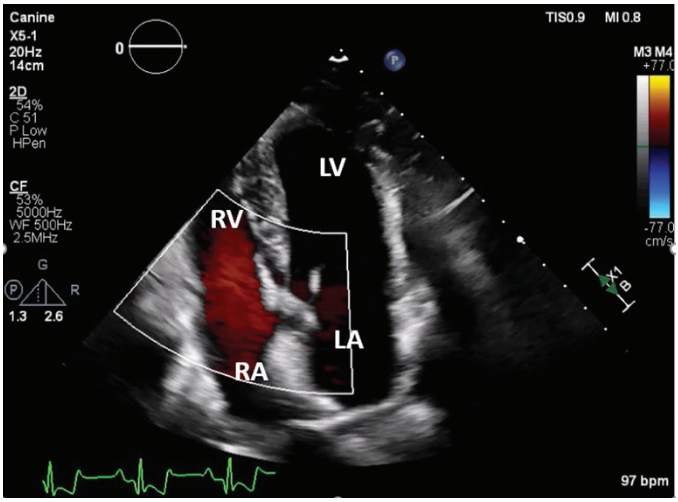


Figure 2.31 The left cranial transverse imaging plane is ideal for recording upward flow through the tricuspid valve into the right ventricle. (a) Color typically shows non-aliased red flow moving up through the tricuspid valve. (b) During systole when the tricuspid valve is closed the lack of color on the atrial side of the valve indicates a competent valve. (c) Trace to mild tricuspid regurgitation is a normal finding, however, and this image shows a small blue regurgitant jet.

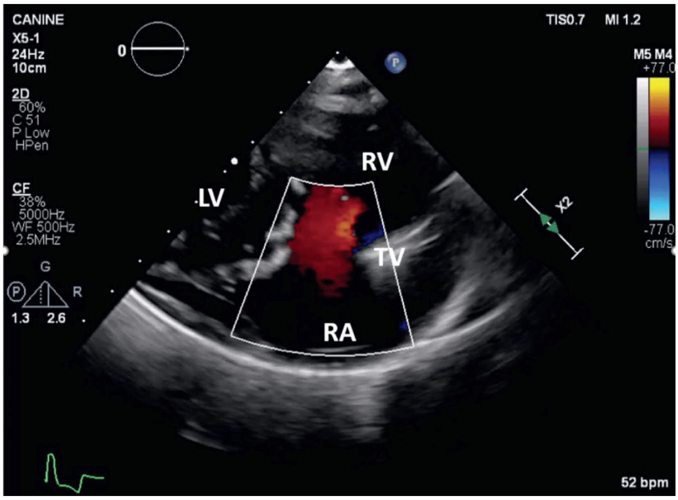
Video 2.31



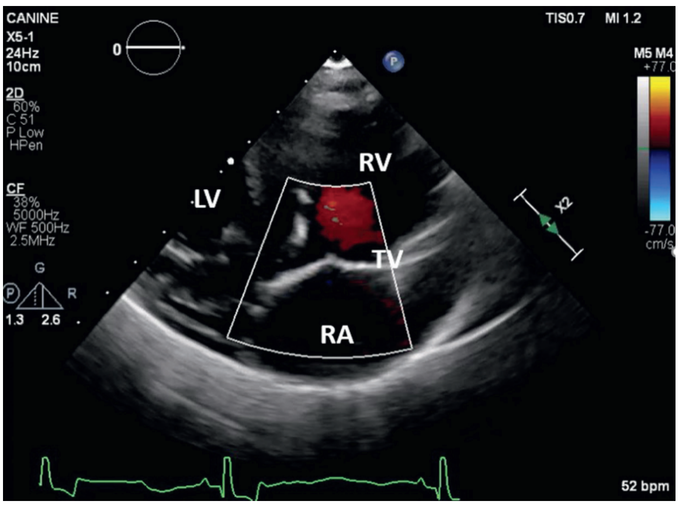
Video 2.32

Figure 2.32 The apical 4 chamber view is sometimes a good plane to record diagnostic color flow through the tricuspid valve. More often, however, a foreshortened 4 chamber view is better. Here diastolic upward flow through the tricuspid valve is red. This flow is typically not aliased since trans tricuspid flow is generally low velocity in the normal heart.

- During systole, regurgitant flow if present will start at the leaflets and extend into the right atrial chamber
  - Regurgitant flow can be red or blue with aliasing depending upon the direction of the jet
  - Trace to mild tricuspid regurgitation may be a normal finding in both dogs and cats
  - Normal tricuspid insufficiency typically does not alias, extends only a cm or 2 into the right ventricular outflow tract, generates no murmur, and there should be no structural abnormalities of the valve



(a)



(b)

Figure 2.33 Images of the right auricle from the left cranial location show tricuspid valve leaflets opening upward into the right ventricle. This is ideal for diagnostic color as it aligns well with Doppler sound beams. (a) Flow through the valve during diastole is red and non-aliased. (b) During systole the lack of blue color on the atrial side of the valve is consistent with the absence of a leak.

Video 2.33

Section 3 Applications

- Pressure Gradients (PGs)
  - PG meaning
    - PG represents the difference in pressure between two places
    - Blood flow always moves from a higher-pressure chamber or vessel to a lower-pressure chamber or vessel
  - Normal pressures in the heart and vessels (Figure 3.1)
    - Peak left ventricular and aorta systolic pressure is whatever systemic pressure is (blood pressure)
    - Peak right ventricular and pulmonary artery systolic pressure is 20–30 mm Hg
    - Diastolic pressure in the aorta is equal to diastolic blood pressure
    - Diastolic pulmonary artery pressure is typically less than 10 mm Hg
    - Diastolic pressures in the chambers of the heart are low at close to zero with a max of about 10 mm Hg
  - Bernoulli equation (Figure 3.2)
    - PG is calculated from flow velocities in the heart by using the Bernoulli equation
      - $PG = 4(V_2^2 - V_1^2) + \int_1^2 (dv/dt \times ds + R(v))$
        - V_2 is the flow velocity at the site being investigated
        - V_1 is the flow velocity just proximal to the site being investigated
        - $\int_1^2 (dv/dt \times ds + R(v))$ are factors affecting flow acceleration and frictional forces
  - Modified equation
    - Proximal flow velocities in a normal heart are usually close to 1 m/s, so in the equation V_1^2 is close to 1
    - Frictional and flow acceleration forces are typically negligible
      - These portions of the equation are dropped, leaving a modified equation
      - $PG = 4(V_2^2)$
        - With V_2 being the highest flow velocity in the area of interest
      - A flow velocity of 2 m/s would result in a PG of 16 mm Hg using the modified equation

Doppler Echocardiography for the Small Animal Practitioner, First Edition. June A. Boon.

Companion website: www.wiley.com/go/boon/doppler

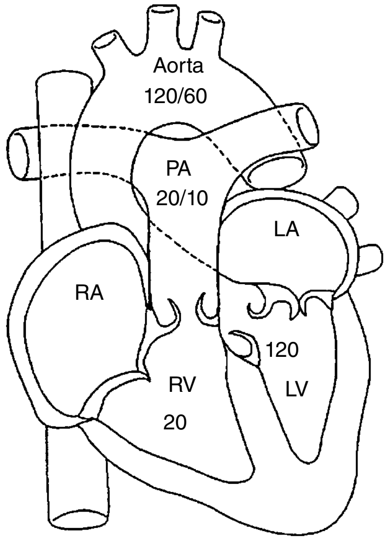


Figure 3.1 Typical normal pressures in the heart and great vessels are shown. Of importance, peak left ventricular systolic pressure is equal to systemic systolic pressure. Right ventricular peak systolic pressure is equal to pulmonary artery systolic pressure. Diastolic pressures in the chambers of the heart are all low, close to 0, always less than 10 mm Hg. These are representative. Of course, systolic blood pressure could be 135 and then LV pressure would be 135. Normal pulmonary artery systolic pressure ranges from 20 to 30 mm Hg and then of course so would right ventricular pressure.

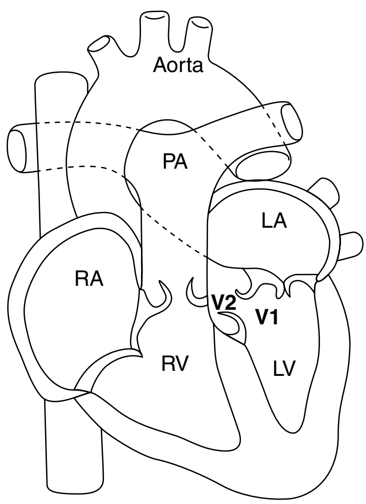


Figure 3.2 The Bernoulli equation used to determine pressure gradients in the heart uses proximal velocity (V_1) and velocity at the site of interest (V_2). Proximal velocity in almost all cases is close to 1, and when this is plugged into the Bernoulli equation, it results in subtracting 1 from V_2, a negligible amount.

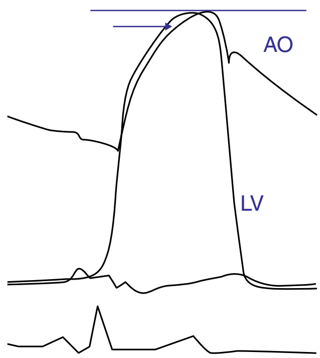


Figure 3.3 Blood always flows from high to low pressure. If peak velocity in the LV and AO are the same (solid line horizontal line), how does blood flow? The answer lies in the fact that LV pressure rises before aortic pressure. This small offset in pressure is what allows blood to flow from the LV to the aorta during systole. If peak aortic flow velocity is 2 m/s, the PG is 16. The small delay in pressure difference of 16 mm HG in this example (arrow) allows blood to be ejected into the aorta.

- How can blood flow when pressures in the ventricles and great vessels are the same? (Figure 3.3)
  - Blood flows with pressure
  - Peak pressures in the aorta and left ventricle and pulmonary artery and right ventricle are the same
  - There is a small offset as ventricular pressure rises before vessel pressure
    - This difference is what keeps blood flowing, and the 2 m/s aortic flow velocity with a 16 mm Hg PG represents that slight offset in rising pressure
- Factors Affecting Flow Velocities
  - Volume
    - Adding volume to blood flow through a vessel or valve elevates velocity if the orifice size does not change
      - This is like turning your faucet on slightly or turning it on a lot; water velocity increases as more water moves out of the same size faucet
    - A ventricular septal defect that shunts volume to the right ventricle will elevate pulmonary artery velocity (Figure 3.4)
  - Narrowed pathway (Figures 3.5a and b)
    - The continuity equation states that volume in equals volume out
    - When a pathway (aorta or pulmonary artery) is narrowed by stenosis, flow velocity must increase for blood to keep moving out of the chamber
      - This is like the narrows in a river, where water velocity becomes rapid and turbulent as the same amount of water must move downstream through the narrow area
  - Pressure
    - A regurgitant jet has a velocity that corresponds to the pressure in the chamber it is coming from
    - Higher pressure in the right ventricle, for instance, would drive a tricuspid regurgitant jet faster than normal right ventricular pressure (Figures 3.6a and b)

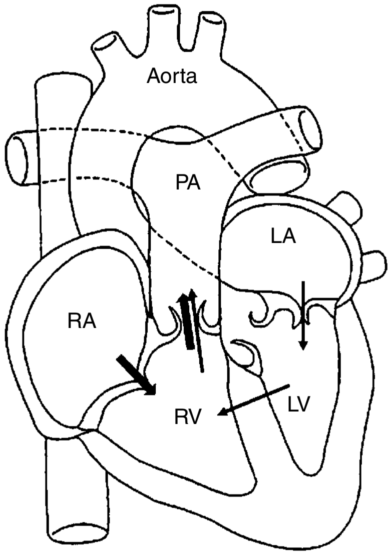
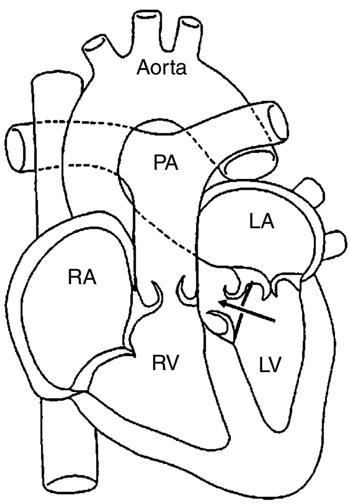


Figure 3.4 Adding volume to blood moving through a valve or vessel will increase flow velocity through that vessel or valve if the valve or vessel size remains unaffected. Here the volume shunting across a ventricular septal defect (thin arrows) is added to normal volume leaving the RV (thick arrows). The result is increased PA flow velocity.

(a)



(b)

Figure 3.5 Blood flow velocity must increase to move through a narrowed area. Volume in equals volume out. This is like the narrows in a river. Water velocity increases and creates rapids as the same volume of water must pass through the narrows as it travels downstream. (a) Pinching off the end of a water hose to narrow the opening increases water velocity. (b) Blood flow velocity must increase across a sub valvular aortic stenosis. The increase in velocity corresponds to the severity of the stenosis.

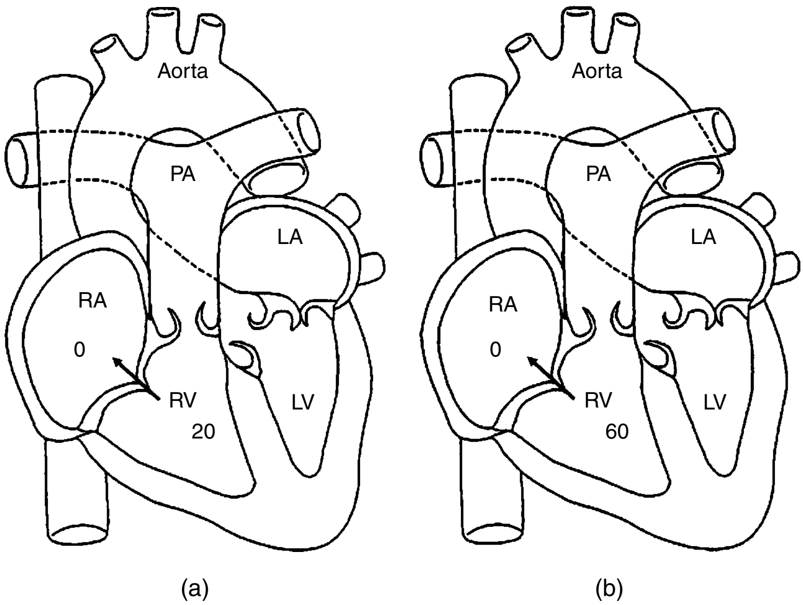
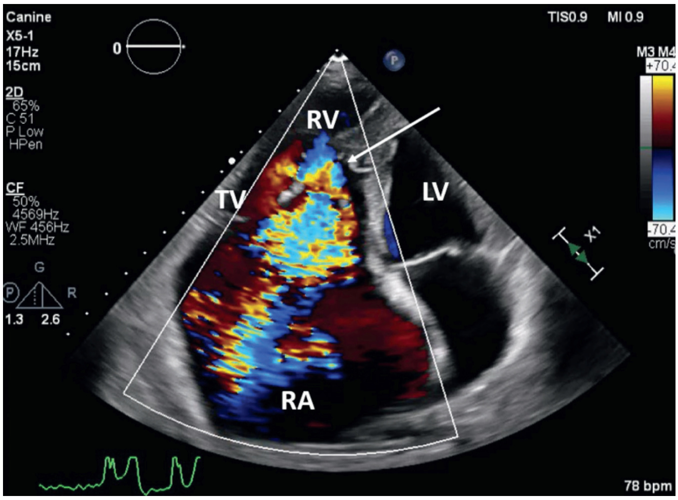


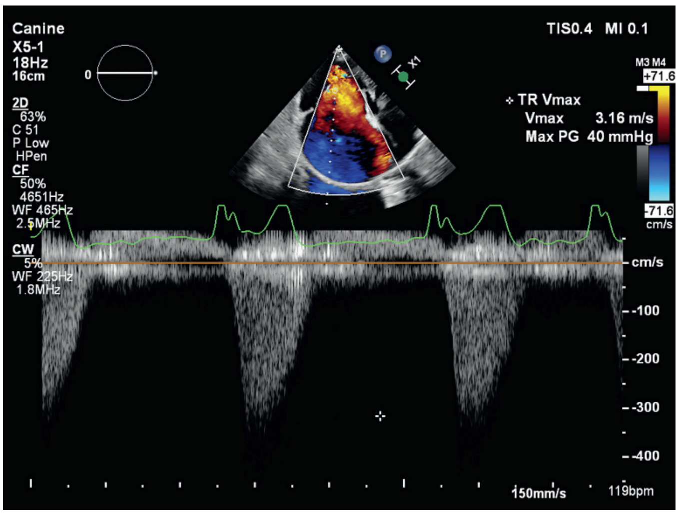
Figure 3.6 Increased pressure driving regurgitant flow elevates flow velocity. It is worth noting that the following pressure gradients and flow velocities have nothing to do with the severity of the insufficiency, just the pressure driving the insufficiency. (a) A normal RV systolic pressure of 20 mm Hg drives a tricuspid regurgitant jet with 20 mm Hg of pressure (a velocity of 2.25 m/s, PG = $4(2.25^2)$). (b) An elevated right ventricular systolic pressure of 60 mm Hg drives a tricuspid regurgitant jet with 60 mm Hg pressure (a velocity of about 3.9 m/s, PG = $4(3.9^2)$).

- Limitations of the simplified Bernoulli equation
  - Doppler derived flow velocity is accurate if the Doppler sound beam is perfectly parallel to the flow being evaluated (Figure 1.12a)
    - Any degree away from parallel in either direction results in underestimation of flow velocity and of course an underestimated PG
    - So, the PG is always at least what is derived from the flow velocity
  - Invalid V_1 (Figures 3.7a and b and Video 3.7)
    - V_1 is not negligible in severely abnormal valves that have a wide-open pathway for regurgitation
    - V_1 is also not negligible when there is a tunnel type of obstruction to flow
      - The PG will be overestimated in both examples since V_1 is not subtracted from V_2
    - These are uncommon instances when PG can be overestimated

- Common Applications of PG in Acquired Heart Disease
  - Using mitral regurgitation
    - Calculation of LA pressure (Figures 3.8a and b)
      - If systolic BP is known, this is what LV systolic pressure is if the left ventricular outflow tract is normal
      - In the presence of mitral regurgitation (MR), LA pressure can be estimated from the PG of the mitral regurgitant jet



(a)



(b)

Video 3.7

Figure 3.7 There are times when the modified Bernoulli equation will overestimate a pressure gradient. One instance is if V_1 is not negligible and becomes much more than 1. In the modified Bernoulli equation, if V_1 was 3 m/s V_1^2 would be 36 and it would not be subtracted from V_2^2 as it should be in the full Bernoulli equation. This is not a common problem in hearts with insufficiency secondary to degenerative valve disease. (a) Severe tricuspid insufficiency where the valves do not come close to touching each other, like that seen in some cases of tricuspid dysplasia, has a V_1 that is not negligible (arrow). (b) The tricuspid regurgitation PG of the image in (a) shows a PG of 40 mm Hg, implying elevated RV pressure when it is normal.

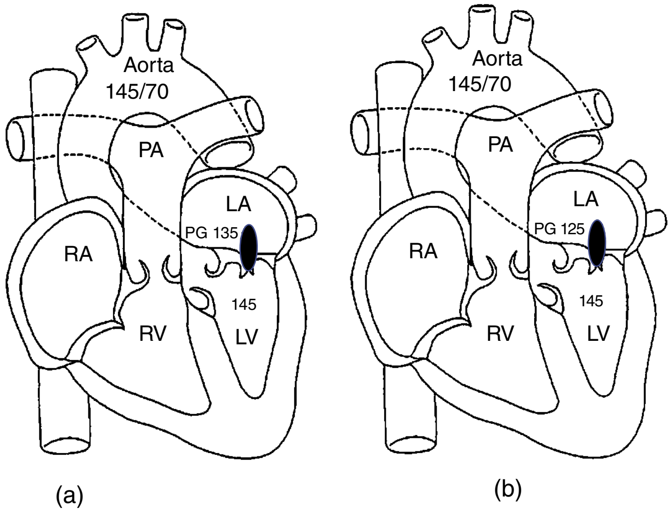


Figure 3.8 Pressure gradients across a mitral regurgitant jet when LV pressure is known can help estimate LA pressure. If the Doppler cursor is not aligned perfectly parallel to the regurgitant jet, the PG will be underestimated and LA pressure will be overestimated. (a) Here there is a left ventricular pressure of 145 mm Hg and a mitral regurgitation jet flow velocity consistent with a PG of 135 mm Hg between the LV and the LA. This difference in pressure suggests that the LA pressure is 10 mm Hg. (Since it is 135 mm Hg higher in the LV than the LA and knowing the LV is 145, the LA must be 10.) (b) If LV pressure is 145 but the mitral regurgitant flow velocity shows a PG of 125 mm Hg, then the LA pressure is estimated at 20 mm Hg. (Since it is 125 mm Hg higher in the LV than the LA and knowing the LV is 145, the LA must be 20.)

- An MR flow velocity of 5.8 m/s has a PG of 135 mm Hg
- This means it is 135 mm Hg higher in the LV than LA
- If BP is 145 mm Hg, then the LV is 145 mm Hg
- For the PG to be 135 higher in the LV than the LA, the LA must be about 10 mm Hg
- This sounds like a great way to estimate LA pressure
  - The only pitfall is if the Doppler cursor is not lined up perfectly parallel with the MR jet, in which case the PG is underestimated
  - An underestimated PG would result in an overestimated LA pressure

- Verification of BP (Figures 3.9a and b)
  - A more common application of PG using MR is to verify a low or high BP
  - If a low BP of 80 is questioned and there is MR, the PG of the MR provides an at least pressure of the LV, and with a normal left ventricular outflow tract (aorta) this should approximate the BP
    - An MR PG of 120 is consistent with LV pressure that is 120 higher than LA pressure
    - Regardless of what LA pressure is, the LV must be at least 120
    - In the presence of a normal outflow tract this is what systemic pressure is close to, making the BP of 80 invalid

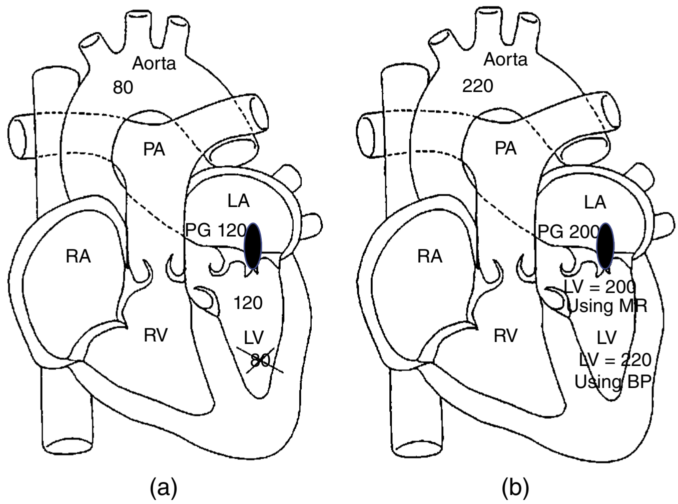


Figure 3.9 (a) A blood pressure of 80 mm Hg is consistent with an LV peak systolic pressure of 80 mm Hg. If a mitral regurgitation jet velocity has a PG of 120 mm Hg, LV pressure must be at least 120 mm Hg. This example proves the BP recording is invalid. (b) A blood pressure of 220 suggests an LV pressure of 220 mm Hg. If a mitral regurgitant jet has a PG of 200, it suggests an LV pressure of at least 200 mm Hg. These are similar enough to validate the systemic hypertension and support a BP of at least 200.

- If a high BP of 220 is questioned and there is MR, the PG of the MR provides an at least pressure of the LV, and with a normal left ventricular outflow tract (aorta) this should approximate the BP
  - In this scenario an MR PG of 200 is consistent with LV pressure that is 200 higher than LA pressure
  - Regardless of what LA pressure is, the LV must be at least 200. This approximates the BP and confirms the systemic hypertension.
- There are other applications of Doppler on MR flow that are beyond the scope of this booklet

- Hypertrophic cardiomyopathy (Figure 3.10)
  - Significance of LVOT obstruction
  - Systolic anterior motion (SAM) of the mitral valve and/or septal hypertrophy in hypertrophic cardiomyopathy creates an obstruction to LV outflow
  - The left ventricle must generate high pressure to eject blood into the aorta through the obstructed outflow pathway
  - Flow velocity increases as a result
  - The narrower the pathway the more the LV pressure must increase and the higher the flow velocity becomes
    - A flow velocity of 3 m/sec has a PG of 36 mm Hg, meaning the LV needs to generate 36 mm Hg more pressure than what is in the system (aorta) to eject the blood
    - The higher the PG the more significant the obstruction

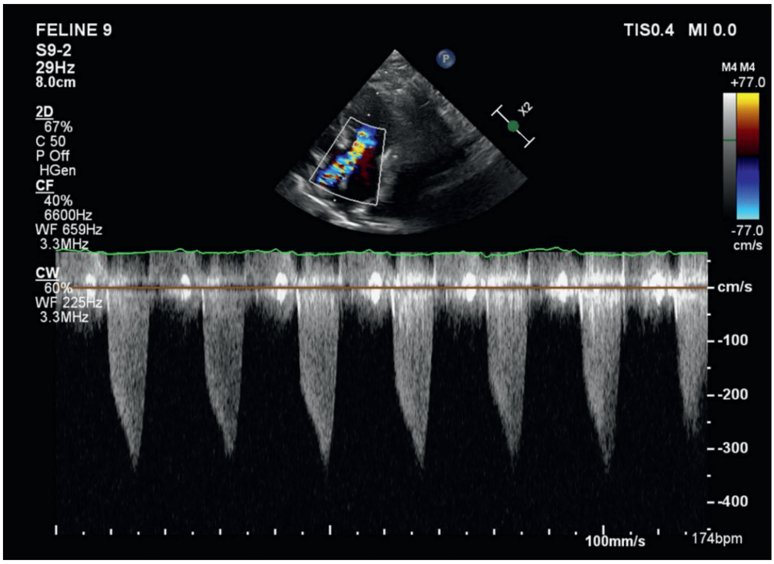


Figure 3.10 Flow velocity across a narrowed pathway is elevated and reflects severity of the narrowed (stenotic) pathway. Here left ventricular outflow tract velocity in a cat with hypertrophic cardiomyopathy has a velocity of about 3 m/s, resulting in a PG of about 36 mm Hg, a mild degree of obstruction. The late peaking shape (dagger) is also consistent with a dynamic obstruction.

- The obstruction in hypertrophic obstructive cardiomyopathy is dynamic
  - Meaning the obstruction changes throughout systole
  - At the beginning of systole flow enters the aorta and as systole proceeds, SAM of the mitral valve and dynamic contraction of the septum progressively narrow the pathway
  - The result is a late peaking flow profile with peak velocity at the end of systole when the pathway is narrowest
  - This is often referred to as a dynamic or "dagger"-shaped flow profile

- Pulmonary hypertension (Figures 3.11a–c)
  - Tricuspid regurgitation PG and RV pressure
    - The systolic pressure in the RV drives the flow velocity of a tricuspid regurgitant jet
    - A calculated PG of 20 mm Hg from a TR jet and an estimated RA pressure of 0 Hg results in RV pressure of 20 mm Hg – normal RV pressure
      - The PG means RV pressure is 20 more than 0
    - A calculated PG of 60 mm Hg from a TR jet and an estimated RA pressure of 0 mm Hg results in RV pressure of 60 mm Hg – elevated RV pressure
      - The PG means RV systolic pressure is 60 more than 0
    - So, the PG reflects the "at least" RV systolic pressure
    - Only 2 things elevate RV systolic pressure: pulmonary hypertension and pulmonary stenosis
      - Pulmonary stenosis (PS) is ruled out by a normal pulmonary artery flow velocity.

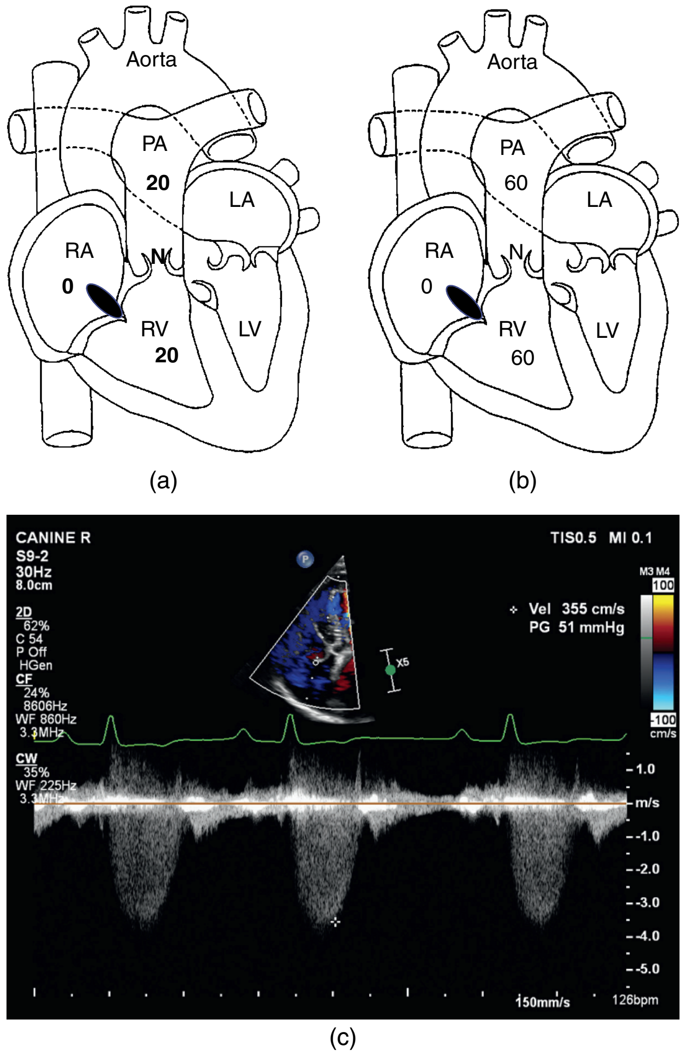


Figure 3.11 (a) When right ventricular pressure is normal the driving pressure of a tricuspid regurgitant jet will reflect that pressure. The TR velocity put into the modified Bernoulli equation results in a PG of 20 mm Hg. This means the RV pressure is 20 higher than RA pressure. If the right atrium appears normal its pressure is estimated at 0 and the RV pressure is 20. (b) If right ventricular pressure is 60, the tricuspid regurgitant velocity put into the modified Bernoulli equation equals a PG of 60 mm Hg. This means right ventricular pressure is 60 higher than right atrial pressure. If the right atrium appears normal the RA pressure is about 0 and right ventricular pressure is 60 mm Hg. This is elevated. Only 2 things elevate right ventricular pressure: pulmonary hypertension and pulmonary stenosis. Flow velocity across the pulmonary valve will differentiate. A normal pulmonary artery flow velocity is consistent with pulmonary hypertension, while an elevated pulmonary artery flow velocity is consistent with pulmonary stenosis. (c) This tricuspid regurgitant flow velocity is 355 cm/s with a calculated pressure gradient of 51 mm Hg (using the modified Bernoulli equation). Right ventricular pressure is at least 51 mm Hg. This is elevated and may represent either pulmonary hypertension or pulmonary stenosis. Differentiate using pulmonary artery flow velocity.

- In the absence of PS, the elevated RV pressure is consistent with elevated PA pressure (equal to the RV pressure) and the presence of pulmonary hypertension
- Generally, PA systolic pressure higher than about 70–80 is considered severe hypertension and pressure lower than 50 is mild hypertension

- When the right atrium is enlarged the pressure is unlikely to be 0
  - If it is 10, for instance, and the TR has a PG of 25, then RV pressure is 25 higher than 10
    - The estimated RV pressure is then 35 – mildly elevated
  - If the RA is 20 and the TR PG is 25, then RV pressure is 25 higher than 20
    - The resulting RV pressure is then 45
  - Used in humans and frequently used in dogs despite not being validated in dogs, an ultrasound way to estimate RA pressure involves imaging the caudal vena cava as it crosses the diaphragm
    - The cava should collapse completely or almost completely with every breath (Figure 3.12 and Video 3.12)
      - This suggests an RA pressure of 0–5 mm Hg
    - A cava that collapses more than 50% but not close to completely
      - Suggests an RA pressure of 5–10 mm Hg
    - A cava that collapses but less than 50%
      - Suggests an RA pressure of 10–15 mm Hg
    - A cava that does not collapse (Figure 3.13 and Video 3.13)
      - Suggests RA pressure of 15–20 mm Hg
    - The presence of ascites secondary to right heart failure
      - Is consistent with RA pressure of 20 mm Hg or greater

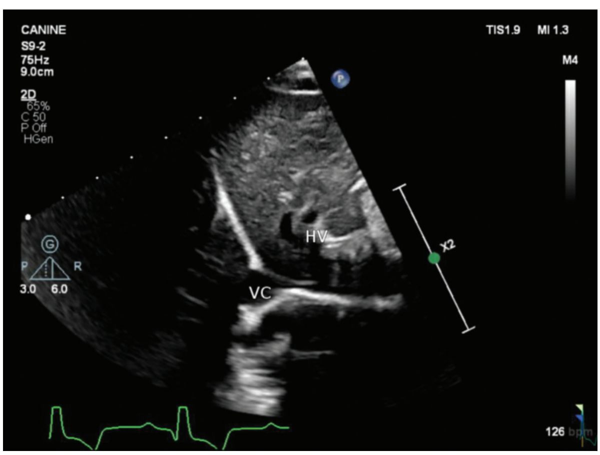
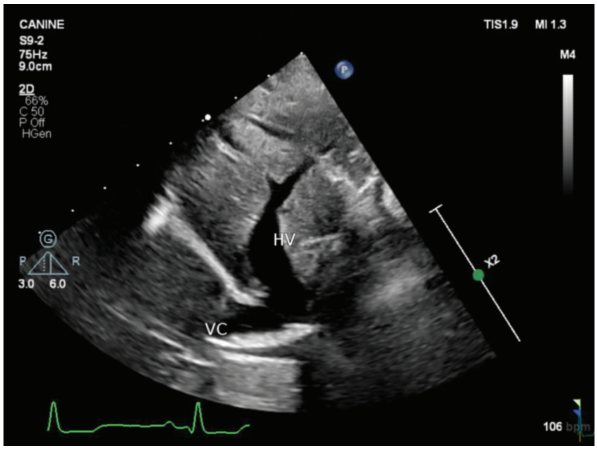


Figure 3.12 The vena cava as it crosses the diaphragm should collapse almost completely if not completely with every breath taken. The cava here collapses normally, and this reflects normal right atrial pressure of 0–5 mm Hg.

Video 3.12



Video 3.13

Figure 3.13 As right atrial pressure increases above normal the pressure backs up into the vena cava and hepatic veins. The vena cava here does not collapse at all, consistent with right atrial pressure of 15–20 mm Hg.

- Pulmonary insufficiency reflects PA diastolic pressure (Figures 3.14a–c)
  - The diastolic pressure in the PA drives the flow velocity of a pulmonary insufficiency (PI) jet
  - A calculated PG of 5 mm Hg from a PI jet and an estimated RV diastolic pressure of 0 mm Hg results in PA diastolic pressure of 5 mm Hg
    - The PA diastolic pressure is 5 more than 0
  - A calculated PG of 30 mm Hg from a PI jet and an estimated RV pressure of 0 mm Hg results in PA diastolic pressure of 30 mm Hg
    - The PA pressure (where the blood is coming from) is 30 more than 0
  - So, the PG reflects the "at least" PA diastolic pressure
  - The flow profile of a PI jet is plateau shaped
    - The early peak PI velocity (which is always higher than the velocity at the end of the flow profile) reflects mean diastolic pressure
    - The end diastolic PI pressure gradient reflects the actual PA diastolic pressure
    - Measure whichever one is the clearest to define
    - Normal mean PA pressure is mid to high teens.
    - Normal diastolic PA pressure is less than 10

- Diastolic Function and Doppler
  - Definitions
    - Diastolic function of the left ventricle reflects the ability of the myocardium to relax and stretch
    - Diastolic dysfunction occurs when the muscle does not relax as rapidly as it usually does or when the muscle loses its distensibility and LV pressure increases significantly as blood enters the chamber
  - Classes of diastolic dysfunction
    - Class 1: Impaired/delayed relaxation
      - Trans mitral valve flow (Figure 3.15)
        - Early diastolic filling of the LV is impaired, resulting in decreased MV E wave velocity and a reversed E/A ratio

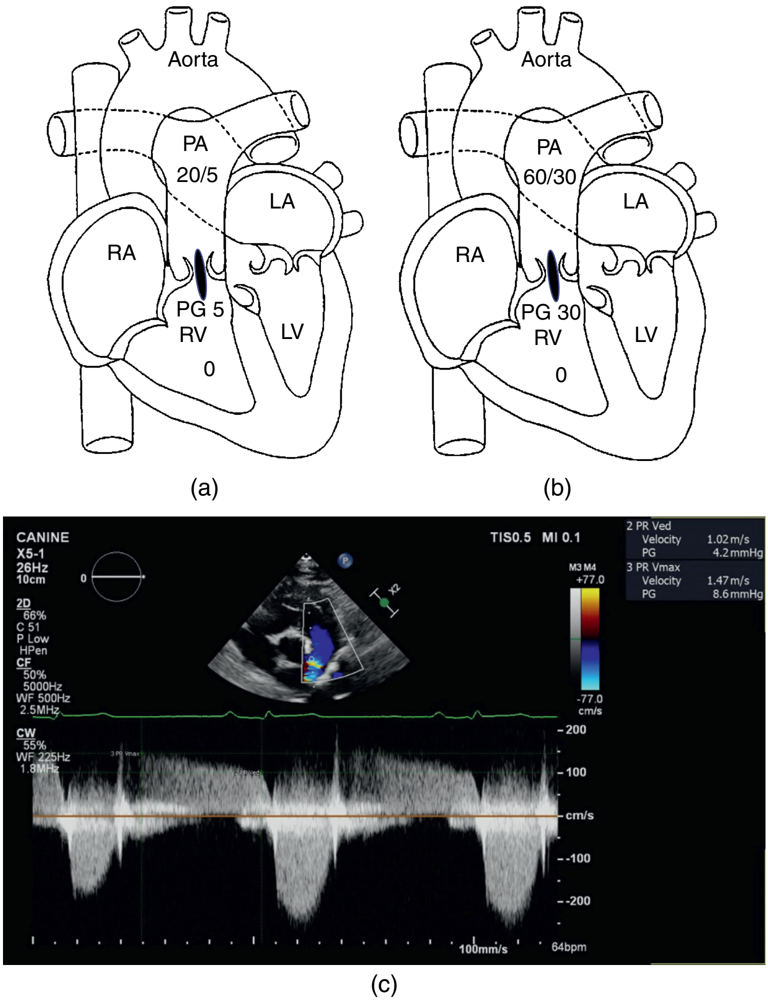


Figure 3.14 Diastolic pressure in the pulmonary artery drives the velocity of pulmonary insufficiency if present and can be used to estimate diastolic pulmonary artery pressure and the presence of pulmonary hypertension. (a) A normal pulmonary artery diastolic pressure of 5 mm Hg will drive an insufficiency jet with a pressure of 5 mm Hg. A normal right ventricular diastolic pressure of about 0 means that the pulmonary artery pressure in diastole is 5 mm Hg higher than 0, and pulmonary artery diastolic pressure is normal. (b) An elevated pulmonary artery diastolic pressure of 30 mm Hg will drive an insufficiency jet with a pressure of 30 mm Hg. A normal right ventricular diastolic pressure of about 0 means that the pulmonary artery pressure in diastole is 30 mm Hg higher than 0, and pulmonary artery diastolic pressure is about 30 mm Hg. There is pulmonary hypertension. (c) Pulmonary insufficiency flow profiles are plateau shaped. Early peak velocity and pressure gradient reflects mean pulmonary artery pressure. In this image the early diastolic PG is 8.6 mm Hg, and this reflects mean pulmonary artery pressure. End diastolic velocity and pressure gradient reflect the actual diastolic pressure. Here an end diastolic pressure gradient of 4.2 mm Hg reflects the diastolic pulmonary artery pressure. Measure the most distinct component of the insufficiency flow profile.

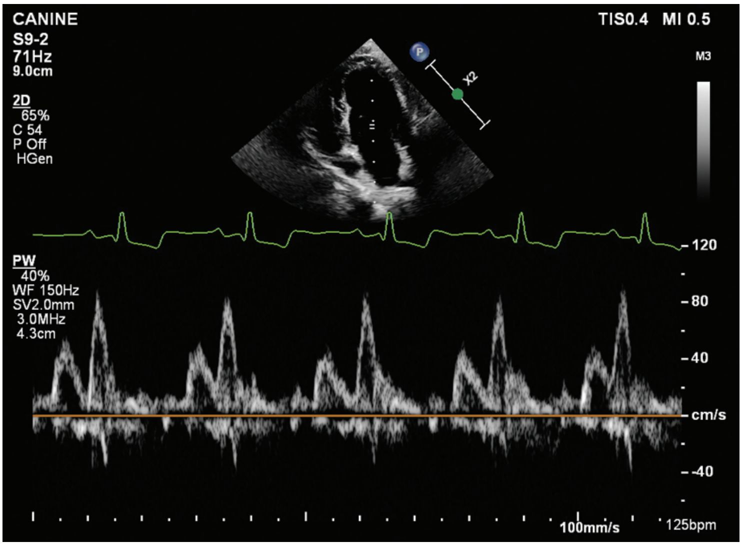


Figure 3.15 When Class 1 diastolic dysfunction exists, early diastolic filling of the LV is impaired because of delayed relaxation resulting in decreased MV E wave velocity and a reversed E/A ratio.

- Impaired relaxation can eventually result in left atrial dilation since the start of ventricular filling is delayed and the time for actual filling of the LV is reduced
- Impaired relaxation can be seen in older animals and is not always associated with pathologic processes
  - Cats older than 8 or 9 usually show a reversed E/A ratio

- Isovolumic relaxation time (IVRT) (Figure 3.16)
  - Impaired relaxation causes IVRT to increase
  - The time from the end of systole to mitral valve opening is prolonged
  - Relaxation is not complete when the mitral valve opens but LV pressure has dropped to the point where the mitral valve can open
  - IVRT may also increase secondary to age-related changes in the myocardium and does not necessarily reflect a pathological change
- Pulmonary venous flow
  - Until left atrial pressure elevates with progressive diastolic dysfunction, pulmonary venous flow is typically normal, but Ar flow can increase as this class moves into Class 2 (Figure 2.11)
- Summary of Class 1 (Figure 3.17)

- Class 2: Pseudonormal
  - Progressive impaired relaxation eventually results in higher left atrial pressure, as the LV cannot fill appropriately
  - At this point left atrial size may be high normal or be slightly increased
    - Trans mitral valve flow (Figure 3.18)
      - Increased LA pressure causes mitral valve early flow velocity to increase secondary to the higher pressure and E wave velocity becomes normal again - pseudonormal

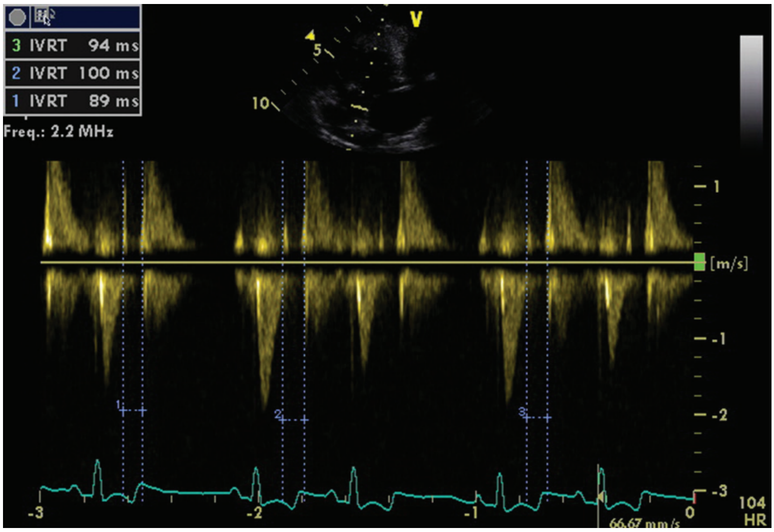


Figure 3.16 When Class 1 diastolic dysfunction exists, relaxation is impaired, causing isovolumic relaxation time (IVRT) to increase.

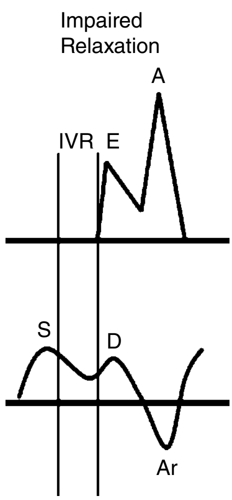


Figure 3.17 Class 1 diastolic dysfunction causes the mitral valve E wave velocity to decrease and isovolumic relaxation time to increase. Pulmonary venous flow remains normal since left atrial pressure is typically not elevated at this point.

- IVRT (Figure 3.19)
  - Increased LA pressure allows left ventricular pressure to drop to LA pressure sooner, allowing the mitral valve to open earlier than it did during the impaired relaxation phase
  - This makes the IVRT normal even though relaxation has not improved - pseudonormal

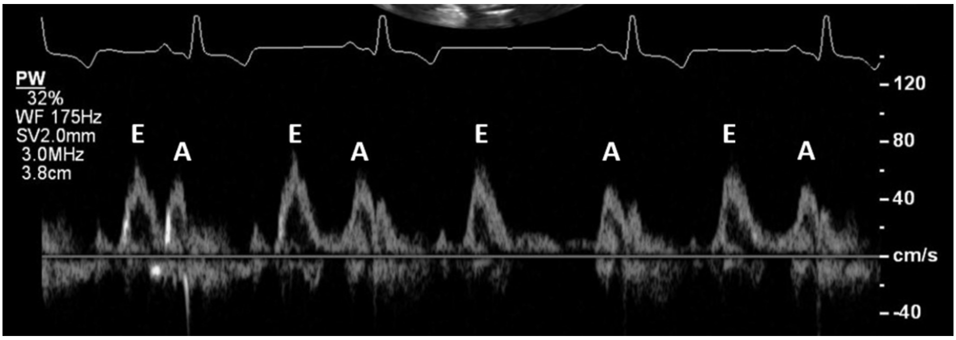


Figure 3.18 As diastolic dysfunction progresses into Class 2, LA pressure increases. This causes mitral valve early flow velocity to increase secondary to the higher pressure and E wave velocity becomes normal again. This is a pseudonormal flow profile.

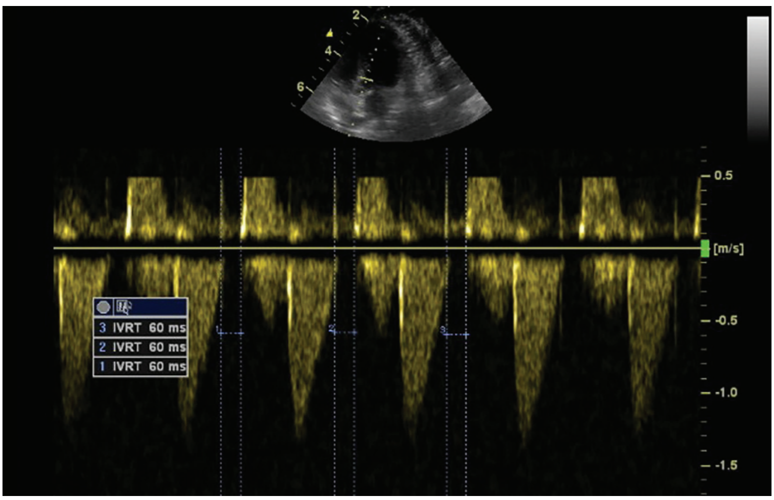


Figure 3.19 Increased LA pressure during diastolic dysfunctional Class 2 allows left ventricular pressure to drop to left atrial pressure sooner after systole ends. This allows the mitral valve to open sooner than it did during the impaired relaxation phase, making the IVRT normal even though relaxation has not improved. This is a pseudonormal IVRT.

- Pulmonary venous flow (Figure 3.20)
  - Elevated left atrial pressure as diastolic impairment becomes poorer creates increased atrial reversed flow velocity and duration with atrial contraction
  - The S and D waves of pulmonary vein flow usually remain unchanged at this state of diastolic dysfunction
  - Accentuated atrial reversed flow into the pulmonary vein differentiates a normal IVRT and E/A relationship from pseudonormal EA and IVRT
- Summary of Class 2 (Figure 3.21)

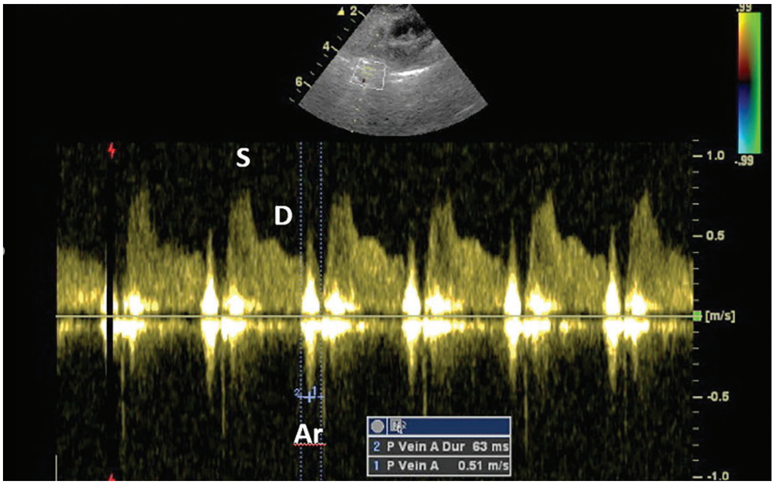


Figure 3.20 Because left atrial pressure has increased in Class 2 diastolic dysfunction, there is increased reversed flow into the pulmonary vein with atrial contraction. The S and D waves are typically normal.

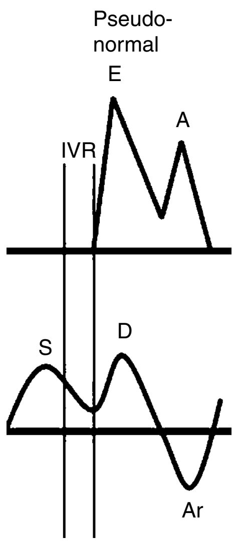


Figure 3.21 Class 2 diastolic dysfunction with mildly elevated left atrial pressure causes the mitral valve E A relationship and IVRT to become pseudonormal. Pulmonary venous flow has increased Ar flow velocity and possibly increased Ar duration of flow secondary to the mildly elevated left atrial pressure. Pulmonary venous flow is the feature that differentiates normal and pseudonormal mitral valve EA and isovolumic relaxation time.

- Classes 3 and 4: Restrictive physiology
  - Diastolic dysfunction is now significant enough to increase left atrial size significantly as LV filling is impaired
  - Myocardial compliance (distensibility) is reduced, creating very high filling pressure as blood flows into the LV

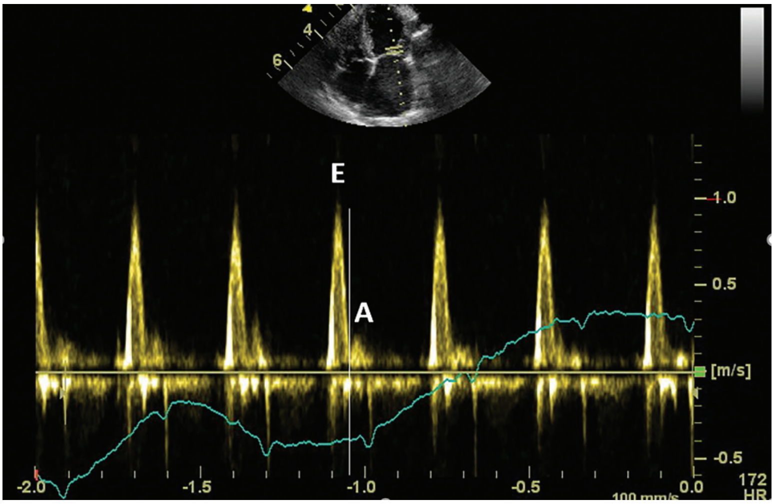


Figure 3.22 Progressively deteriorating relaxation and accompanying poor compliance leads to Class 3 diastolic dysfunction where left ventricular filling pressure becomes significantly elevated. The high left atrial pressure elevates trans mitral valve E wave velocity. Because compliance is poor, elevating left ventricular pressure significantly early in diastole, filling of the left ventricle in late diastole is reduced, making the mitral valve A wave low. The result is a high EA ratio.

- The elevated left atrial pressure creates the following changes
  - Trans mitral valve flow (Figure 3.22)
    - The significant increase in LA pressure elevates E wave velocity
    - Late diastolic filling (A wave) is diminished when the LV cannot accommodate any more volume because of the reduced compliance and high filling pressure
    - This creates an E/A ratio much higher than normal
  - Isovolumic relaxation time (Figure 3.23)
    - Since left atrial pressure is now so high, it does not take as long for LV pressure to reach LA pressure and the mitral valve opens earlier than usual
    - This creates a short IVRT even though relaxation is not improved
  - Pulmonary venous flow (Figure 3.24)
    - High left atrial pressure during ventricular systole when the MV is closed reduces filling of the LA during this time
    - This results in diminished pulmonary vein S wave velocity
    - When the mitral valve opens early in diastole with high flow velocity secondary to the elevated LA pressure, diastolic pulmonary venous flow moves into the atrium via a suction effect, resulting in higher-than-normal D flow
    - Atrial reversed flow is now accentuated as high left atrial pressure and a non-compliant left ventricle create increased reversed flow during atrial contraction
    - Class 4 diastolic dysfunction refers to intractable diastolic heart failure
- Summary of Classes 3 and 4 (Figure 3.25)

- Overview of diastolic function (Figures 3.26 and 3.27)

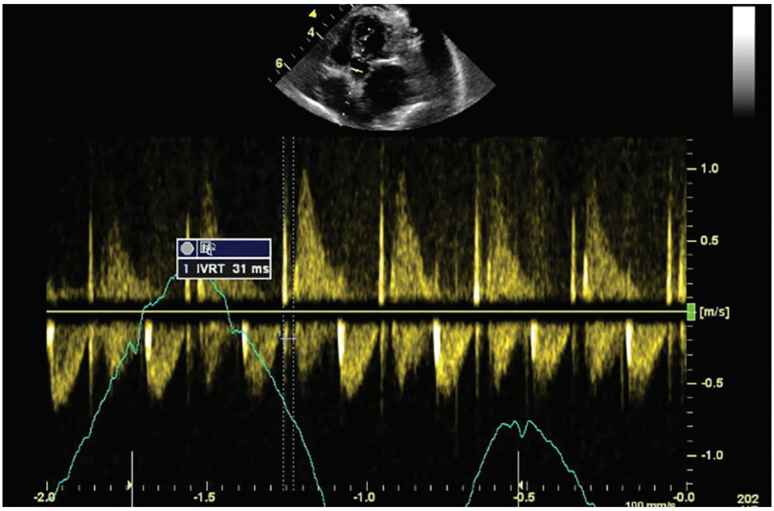


Figure 3.23 Significantly elevated left atrial pressure in Class 3 diastolic dysfunction reduces the time for the left ventricular pressure to drop to left atrial pressure after systole ends. The mitral valve opens sooner, and isovolumic relaxation becomes shorter despite very abnormal relaxation.

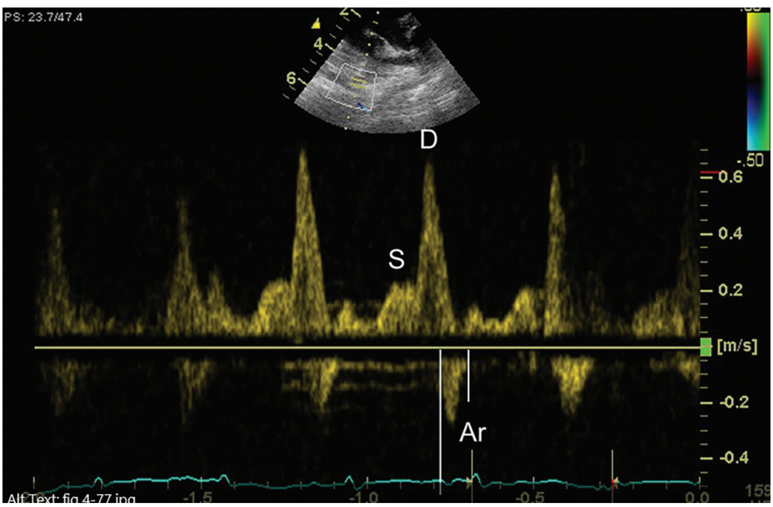


Figure 3.24 Significantly elevated left atrial pressure prevents the atrium from filling well during systole when the mitral valve is closed, reducing pulmonary venous S wave velocity. When the mitral valve opens in diastole pulmonary venous D flow follows trans mitral flow in the ventricle, and these velocities are high. The atrial contraction against high left ventricular filling pressure at the end of diastole causes increased reversal of flow into the vein, accentuating Ar velocity and duration.

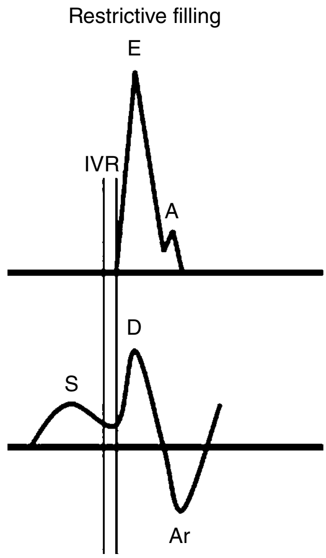


Figure 3.25 Class 3 diastolic dysfunction results in high E/A ratios, short isovolumic relaxation times, decreased pulmonary venous S wave, increased pulmonary venous D wave, and increased pulmonary venous Ar velocity and duration. Class 4 shows the same changes but clinically the animal is refractory to medical management.

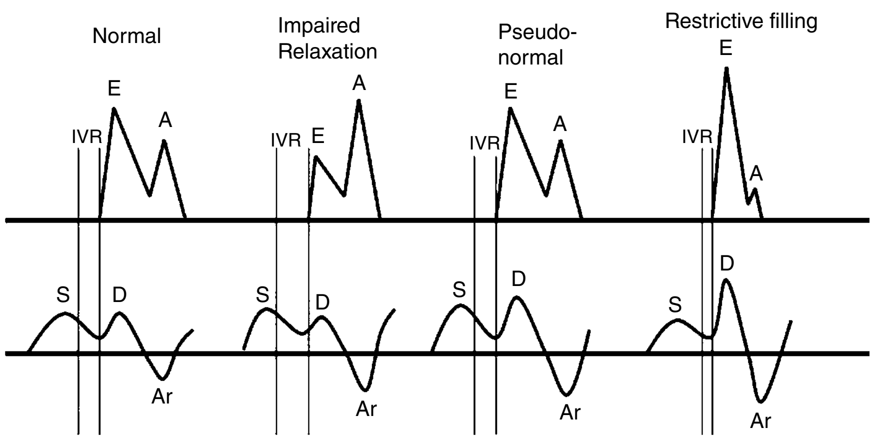


Figure 3.26 This image shows a summary of mitral valve flow profiles, isovolumic relaxation times, and pulmonary venous parameters during of all classes of diastolic dysfunction.

	Normal	Impaired Relaxation	Pseudo-normal	Restrictive Physiology
Trans MV flow				
E:A	> 1	< 1	>1	>>>> 1
Pulmonary Venous Flow				
S:D	.32 – 1.48	normal	normal	<<1
Ar duration	43 – 64 ms	normal/increased	increased	increased
Ar velocity	.17 – .29 m/s	normal/increased	increased	increased
IVRT				
	38 – 54 ms	increased	normal	decreased
LA size	Rt 4 ch < 16 Trans LA/AO < 1.5	normal	normal to increased	increased

Figure 3.27 This table shows a summary of mitral valve flow profiles, isovolumic relaxation times, and pulmonary venous parameters during of all classes of diastolic dysfunction with feline measurements.

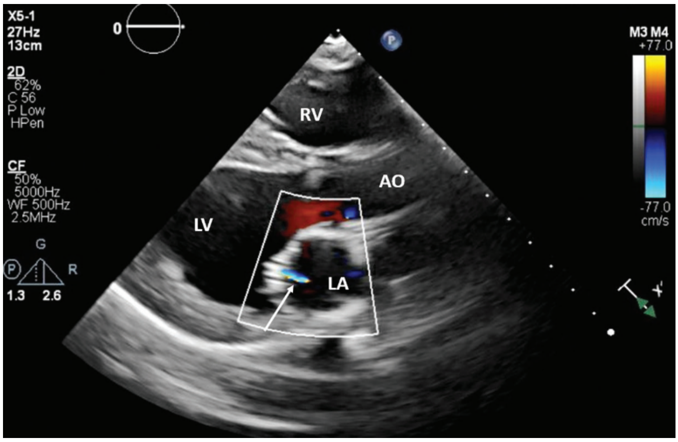
Section 4 Doppler Features in Common Acquired Cardiac Diseases

Doppler features of common acquired heart disease are covered in this section. The two-dimensional and M-mode features are listed, but details of these features are found in *Two-Dimensional and M-Mode Echocardiography for the Small Animal Practitioner*, 2nd edition (Wiley Blackwell, 2017).

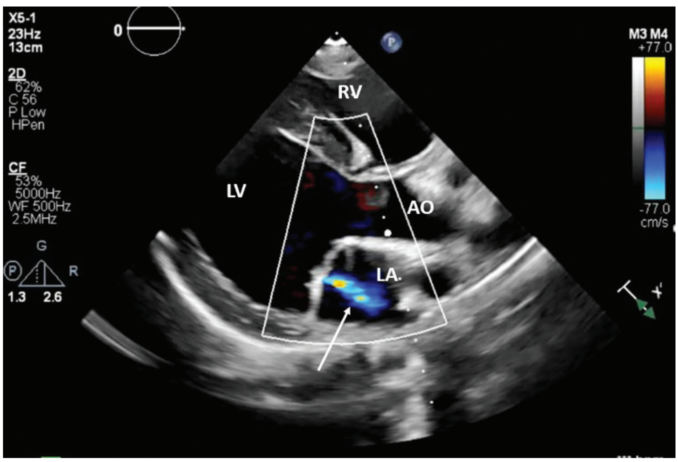
- Chronic Valve Disease
  - 2D and M-mode features
    - Irregularities in mitral leaflet thickness
      - Possible leaflet prolapse or flail leaflet
    - Left ventricular dilation (diastolic chamber size)
      - Degree dependent upon severity of regurgitation
    - Left atrial dilation
      - Degree dependent upon severity of regurgitation
    - Normal EPSS (mitral valve E peak to septal separation)
    - Fractional shortening elevated if contractility preserved
    - Left ventricular systolic chamber size normal if contractility preserved
    - Perhaps some pericardial effusion secondary to congestive heart failure or less commonly a ruptured left atrial wall
  - Color flow evaluation
    - Although the significance of mitral regurgitation (MR) is determined by a constellation of features, the area of the color regurgitant jet in the left atrium plays a large role
      - A jet that barely extends into the left atrial chamber is called trace MR (Figure 4.1 and Video 4.1)
      - A jet that occupies less than 20% of left atrial area is mild MR (Figure 4.2 and Video 4.2)

Doppler Echocardiography for the Small Animal Practitioner, First Edition. June A. Boon.

Companion website: www.wiley.com/go/boon/doppler



Video 4.1 **Figure 4.1** An insufficient jet that barely extends into the left atrial chamber (arrow) is described as a trace amount of regurgitation.



Video 4.2 **Figure 4.2** A regurgitant jet that occupies less than 20% of the left atrium is called mild.

- ▫ A jet between 20% and 60% of left atrial size is moderate MR (Figure 4.3 and Video 4.3)
- ▫ A jet greater than 60% of left atrial area is severe MR (Figure 4.4 and Video 4.4)
  - ◆ There is much overlap between moderate and severe
- ▫ Color jets that essentially fill the LA are referred to as torrential (Figure 4.5 and Video 4.5)

- ▪ The Coanda effect underestimates the severity of MR
  - ▫ Coanda exists if the regurgitant jet flows and wraps along the atrial wall (Figure 4.6 and Video 4.6)
  - ▫ Frictional forces prevent the jet from spreading into the left atrial chamber

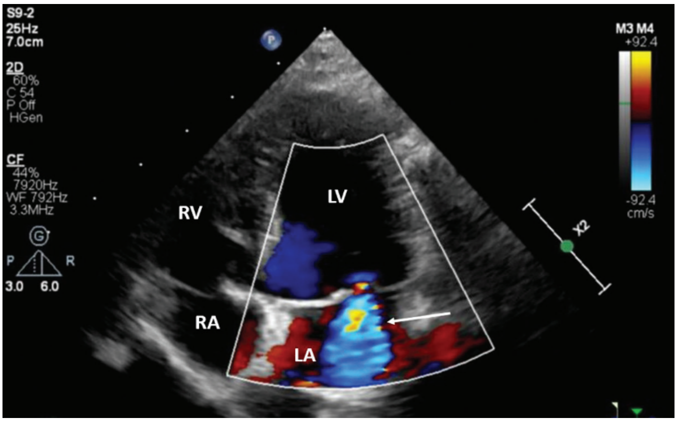


Figure 4.3 Regurgitant jets that encompass between 20% and 60% of left atrial size (arrow) are described as moderate in severity.

Video 4.3

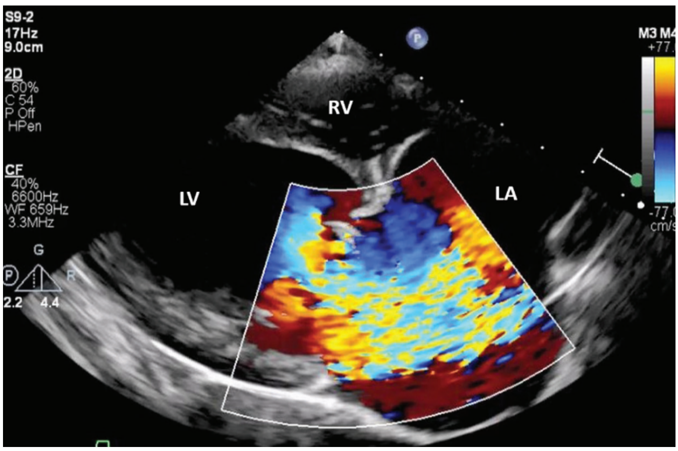


Figure 4.4 Mitral regurgitant jets that occupy greater than 60% of left atrial area are described as severe.

Video 4.4

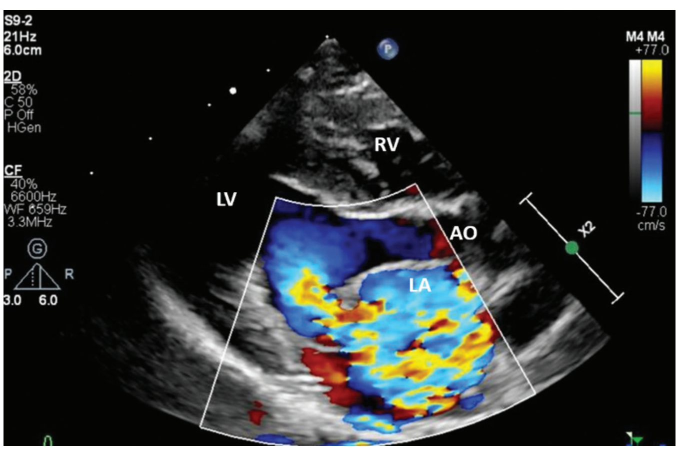
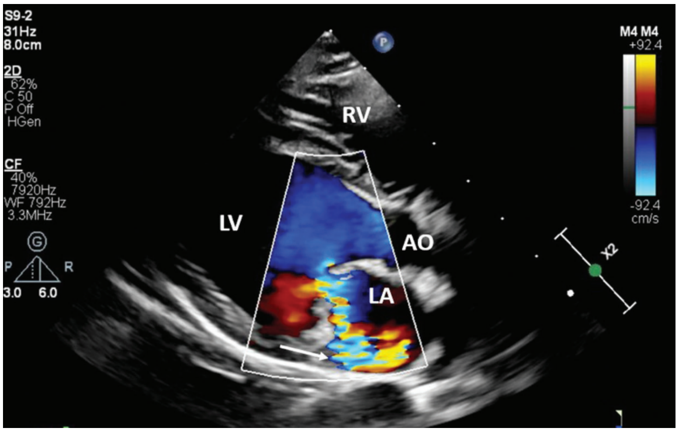


Figure 4.5 Color regurgitant jets that essentially fill the LA are referred to as torrential.

Video 4.5



Video 4.6

Figure 4.6 The Coanda effect underestimates the severity of regurgitant flow. Coanda exists when the regurgitant jet wraps along the atrial wall.

- Spectral Doppler
  - Pressure gradient of MR
    - Peak LV pressure is high during systole – equal to systemic pressure
    - LA pressure is close to 0 in a normal heart and a bit higher when the left atrium is large
    - PG is always high as a result, and MR flow velocities should approximate 5–6 m/s to reflect pressure gradients of 100–140 (Figure 4.7a)
      - When systemic hypertension results in elevated LV pressure, the MR velocity will increase accordingly
      - The MR PG reflects LV pressure and can be used to rule out hypertension if there is no LV outflow obstruction as a cause of the elevated LV pressure (Figure 3.9b)
      - A very low MR PG may be seen with significantly elevated LA pressure or hypotension (Figures 4.7b and c)
  - Evaluation of LA pressure (E:IVRT) (Figures 4.8a and b)
    - Trans MV E flow velocity into the LV is affected by LA pressure and volume moving across the valve as well as early diastolic relaxation
    - IVRT is affected by LA pressure and relaxation
    - The ratio of E:IVRT negates the effect of relaxation and is primarily affected by LA pressure
    - E:IVRT > 2.5 is consistent with an LA pressure of at least 15 mm Hg
      - This LA pressure suggests that congestive heart failure is present or imminent
  - Presence of pulmonary hypertension
    - Elevated LA pressure results in elevated pulmonary artery pressure to keep blood moving into the LA
      - Look for evidence of pulmonary hypertension
    - The lack of the following 2D structural changes does not rule out pulmonary hypertension since mild to moderate pulmonary hypertension may be present without visible structural changes on an echocardiogram

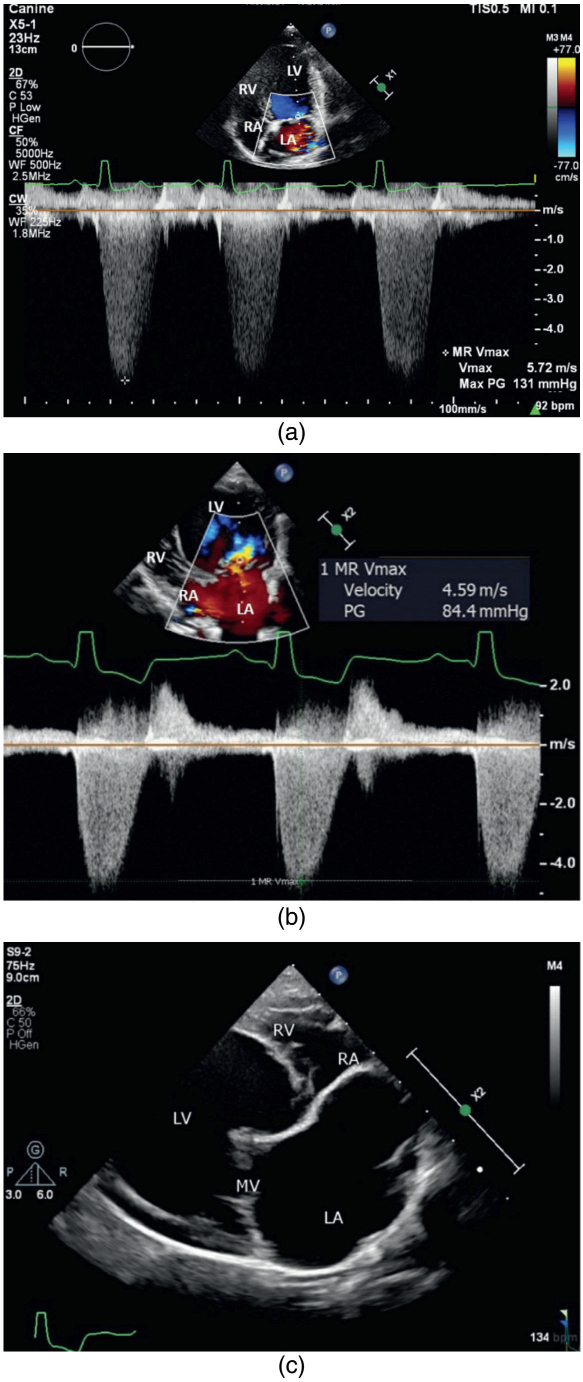


Figure 4.7 (a) Pressure gradients recorded from mitral regurgitant flow are always high since systemic pressure drives them. Expect gradients that approximate systolic blood pressure. Here the mitral regurgitant spectral display has a velocity of 5.72 m/s and a pressure gradient of 131 mm Hg. This means LV pressure is at least 131 mm Hg and it is that much higher in the LV than the LA. (b) Low mitral regurgitant pressure gradients can be seen with hypotension or with high left atrial pressure. Here the velocity of the regurgitant jet is 4.59 m/s with a pressure gradient of 84.4 mm Hg. (c) This severely dilated left atrium has high pressure. The pressure gradient of a mitral regurgitant jet may be lower, reflecting the smaller difference in pressure between a left ventricular chamber with normal systolic pressure and the high left atrial pressure.

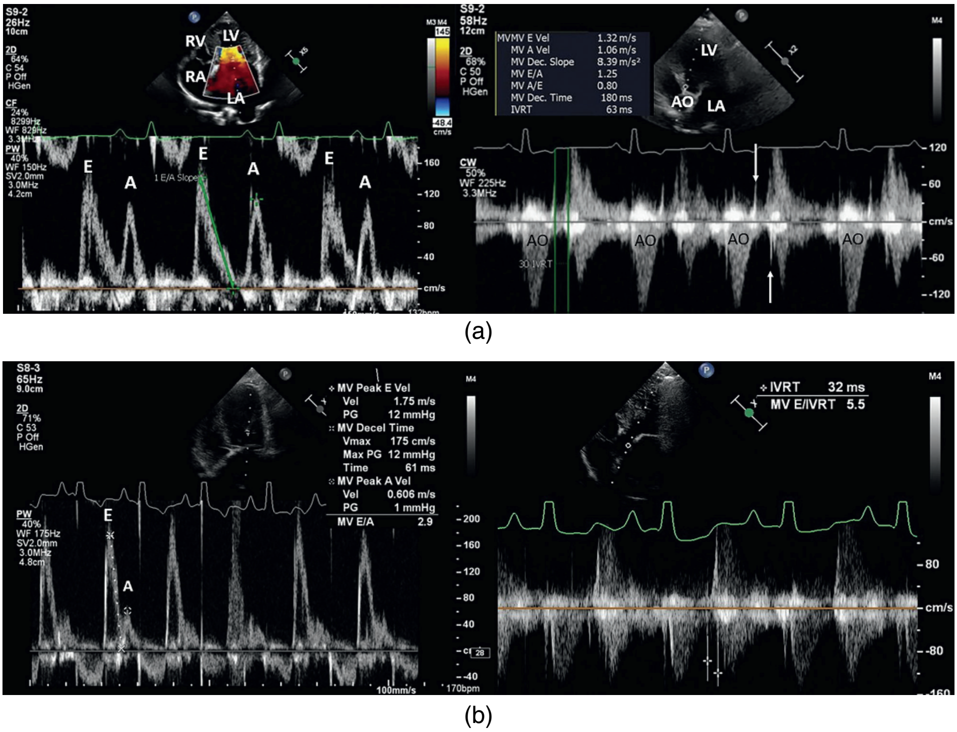


Figure 4.8 Left atrial pressure drives the E wave velocity of mitral flow into the left ventricular chamber. Isovolumic relaxation time (IVRT) varies with atrial pressure. Higher atrial pressure allows the left ventricular pressure to reach left atrial pressure sooner. The mitral valve will open sooner as a result and IVRT is shorter. The ratio of E:IVRT reflects atrial pressure. (a) An E wave velocity of 1.32 m/s and an IVRT of 63 ms yields a ratio of 2.1. (E wave velocity is converted to cm/s in the ratio.) (b) An E wave velocity of 1.75 m/s and an IVRT of 32 ms yields an E:IVRT of 5.5. Ratios higher than 2.5 are consistent with left atrial pressure greater than 15 mm Hg and suggest the presence of congestive heart failure or impending congestive heart failure.

      - Dilated and/or hypertrophied RV
      - Dilated pulmonary artery
      - Flattened interventricular septum
    - Doppler evidence of pulmonary hypertension
      - A tricuspid regurgitant flow velocity with a PG greater than 30 mm Hg (Figures 3.11 and 4.9) in conjunction with normal PA systolic flow velocity
        - A normal PA systolic flow velocity rules out pulmonary stenosis as a cause of the elevated RV pressure
      - Pulmonary insufficiency peak PG higher than 20 mm Hg or a diastolic end PG higher than 10 (Figures 3.14c and 4.10)
- Dilated Cardiomyopathy
  - 2D and M-mode features
    - Increased systolic left ventricular chamber size
    - With progressive disease there is an increase in diastolic left ventricular chamber size

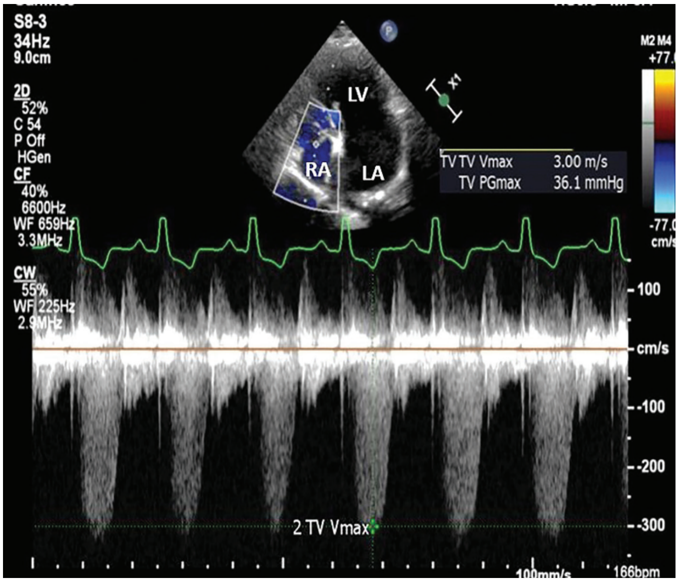


Figure 4.9 The pressure gradient (PG) of a tricuspid regurgitant jet reflects right ventricular (RV) pressure. A PG greater than 30 mm Hg is consistent with elevated RV pressure and in conjunction with a normal pulmonary artery flow velocity indicates the presence of pulmonary hypertension. Here, a PG of 36.1 mm Hg indicates an elevated RV pressure of at least 36.1 mm Hg.

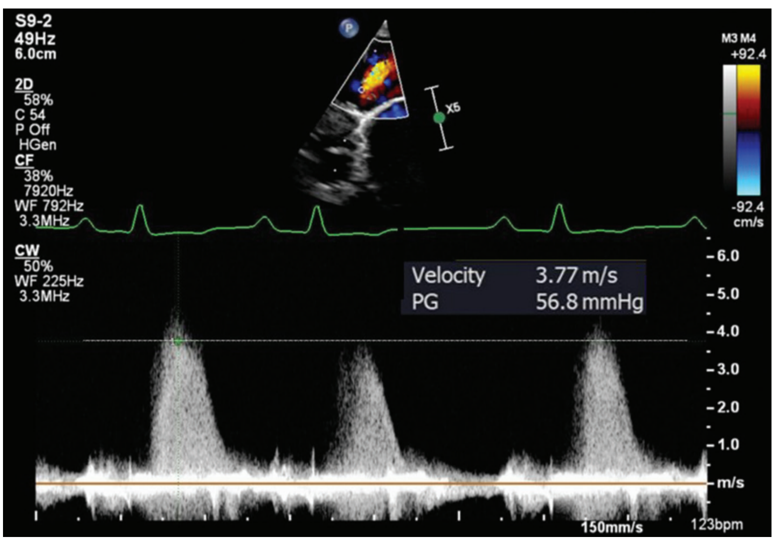
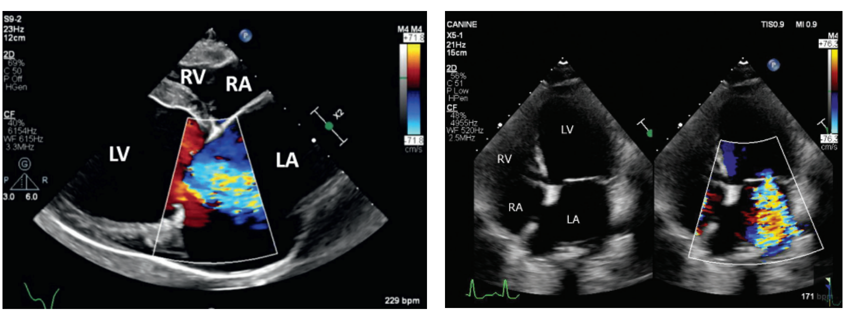


Figure 4.10 Pulmonary insufficiency can also reveal the presence of pulmonary hypertension. A peak diastolic pressure gradient of 56.8 mm Hg is consistent with a mean PA pressure of at least 56.8 mm Hg. Normal mean PA pressure is in the teens. Note that on this flow profile, a distinct early point and distinct late point are not well defined, but the peak velocity measured reflects the at least early peak velocity and PG.

    - Depressed fractional shortening
    - Dilated left atrium
    - Increased EPSS (E peak to septal separation)
    - May have small pericardial effusions if in congestive heart failure
  - Color flow evaluation (Figures 4.11a and b, Videos 4.11a and b)
    - Mitral regurgitation associated with poor function is typically a central jet and referred to as functional mitral regurgitation
      - Secondary to annular stretch
      - Secondary to poor papillary muscle and myocardial contraction
      - Typically, mild to moderate in severity
  - Spectral Doppler
    - Pressure gradient of MR (Figure 4.12)
      - The MR PG reflects the difference between left ventricular and left atrial pressures
      - Low LV pressure or hypotension results in low MR pressure gradients
      - High LA pressure can result in low MR pressure gradients
    - Evaluation of LA pressure (E:IVRT) (Figure 4.13)
      - As with chronic valve disease, the ratio of E:IVRT can predict the presence of elevated LA pressure (see above under MR)
      - An E:IVRT of greater than 1.9 is consistent with LA pressure more than 15 mm Hg and predicts the presence of or impending congestive heart failure in dogs with DCM
- Hypertrophic Obstructive Cardiomyopathy
  - 2D and M-mode features
    - Concentric left ventricular hypertrophy
      - May be symmetric or asymmetric
        - Symmetric means the wall and septum are both thick
        - Asymmetric means either the wall or septum is thick or there are areas of focal hypertrophy at the apex, base of the septum, or papillary muscles



(a) (b)

Video 4.11

Figure 4.11 (a) This right parasternal 4 chamber view shows a centrally directed mitral regurgitant jet typical of the functional regurgitation seen in dilated cardiomyopathy. (b) This apical 4 chamber view shows a centrally directed mitral regurgitant flow typical of functional mitral regurgitation.

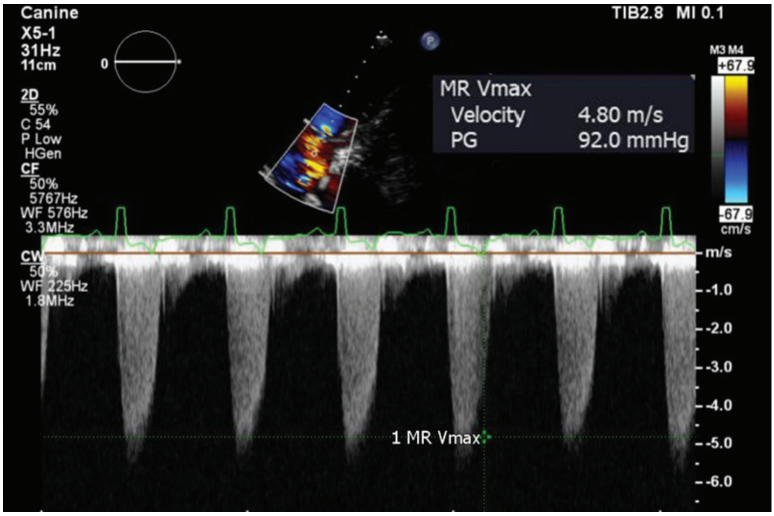


Figure 4.12 The pressure gradient of a mitral regurgitant flow reflects left ventricular and left atrial pressure. The pressure gradient of 92 mm Hg in this heart with dilated cardiomyopathy reflects either hypotension (resulting in low LV systolic pressure) or high left atrial pressure (creating less of a pressure difference between the LV and LA).

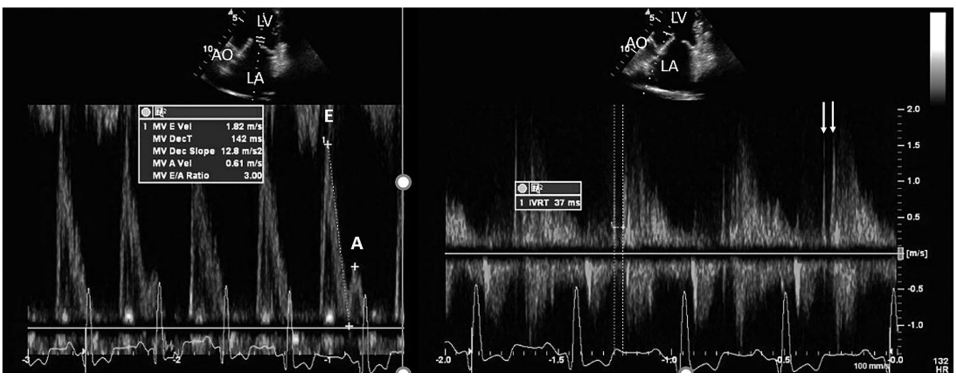
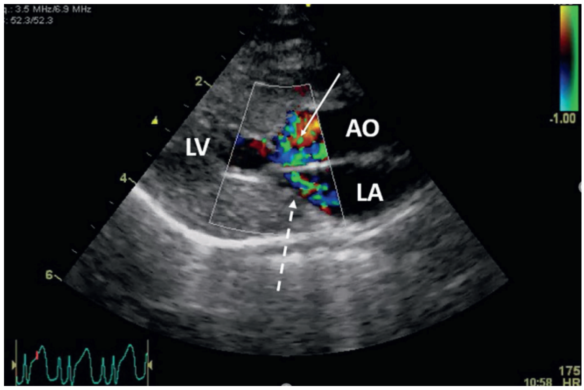


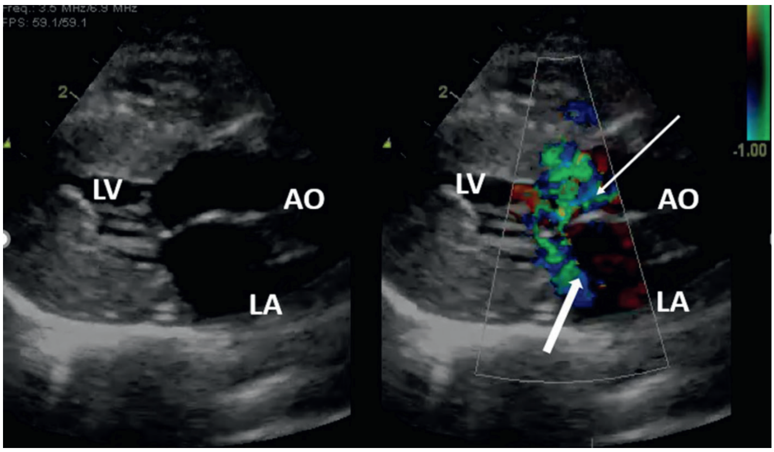
Figure 4.13 The ratio of E:IVRT can predict the presence of elevated LA pressure. An E:IVRT of greater than 1.9 in dilated cardiomyopathy is consistent with LA pressure more than 15 mm Hg and predicts the presence of or impending congestive heart failure. The E:IVRT in this image is 4.9 (182/37).

- Possible left atrial dilation
  - Does not need to be dilated in HCM
  - If dilated it is a sign of diastolic dysfunction
    - If dilated there is increased risk for thrombus
- Systolic anterior mitral valve motion
- Systolic function typically increased
- Pleural or pericardial effusions possible

- Color flow evaluation
  - The left ventricular outflow obstruction creates rapid turbulent flow through the outflow tract during systole (Figures 4.14a and b and Videos 4.14a and b)



(a)

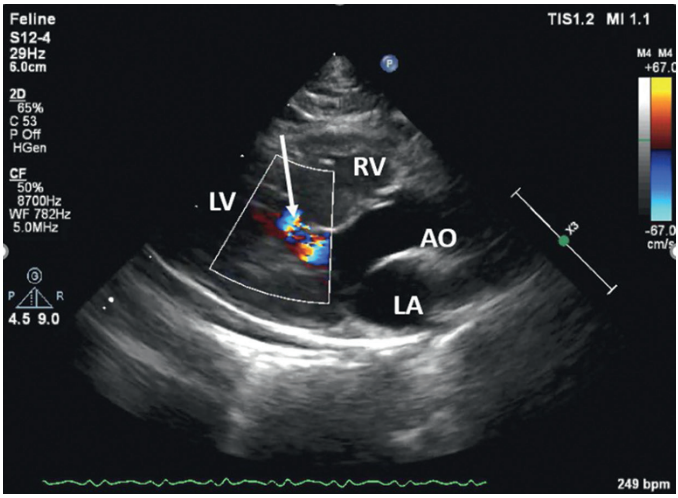


(b)

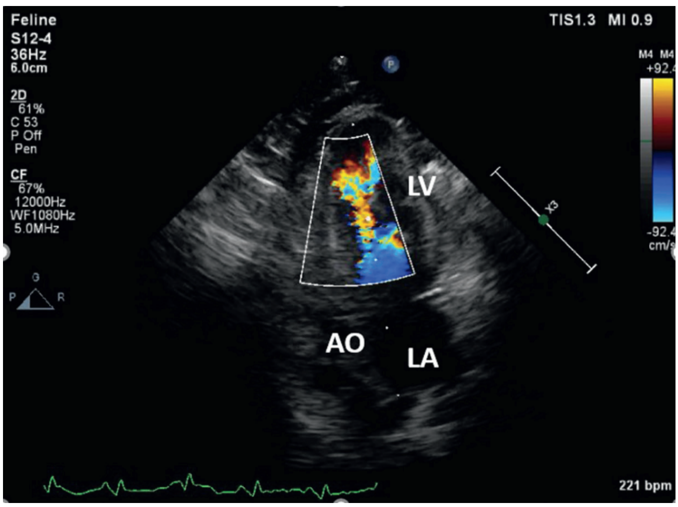
Video 4.14

Figure 4.14 (a) Left ventricular outflow obstruction in hypertrophic obstructive cardiomyopathy (HOCM) creates rapid turbulent flow through the outflow tract during systole (solid arrow). Systolic anterior motion also results in some degree of mitral regurgitation (dashed arrow) in cats with HOCM. Left atrial size is normal here, indicating minimal diastolic dysfunction. (b) Left ventricular outflow obstruction in HOCM creates rapid turbulent flow through the outflow tract during systole (thin arrow). Systolic anterior motion creates some degree of mitral regurgitation (thick arrow). Left atrial size is increased here, indicating some degree of diastolic dysfunction.

- Systolic anterior motion also results in some degree of mitral regurgitation (Figures 4.14a and b)
  - The mitral regurgitation is secondary to SAM and is not the cause of significant atrial dilation
  - Significant atrial dilation is the consequence of diastolic dysfunction in this disease
- Some cats develop enough hypertrophy of the myocardium or papillary muscles in the mid-section of the left ventricular chamber that an obstruction is created
  - Color flow shows turbulence in the mid-LV area on long axis right parasternal and apical views of the left ventricle (Figures 4.15a and b and Videos 4.15a and b)



(a)



(b)

Figure 4.15 (a) Sometimes an obstruction to flow out of the left ventricle (LV) exists in the mid-portion of the chamber. Here turbulent flow is seen in this mid-section of the LV chamber (arrow). (b) On an apical 5 chamber view, mid-ventricular turbulence and a narrowed pathway through this mid-portion of the chamber is seen.

Video 4.15

- Spectral Doppler
  - Outflow obstruction
    - All obstructions whether at the LV outflow tract or in the mid-LV are dynamic
    - As systole progresses the pathway becomes narrower and narrower, creating peak obstruction at the end of systole
    - This results in peak velocities to be highest at end systole, and the flow profile is "dagger" shaped (Figure 3.10 and Figure 4.16)

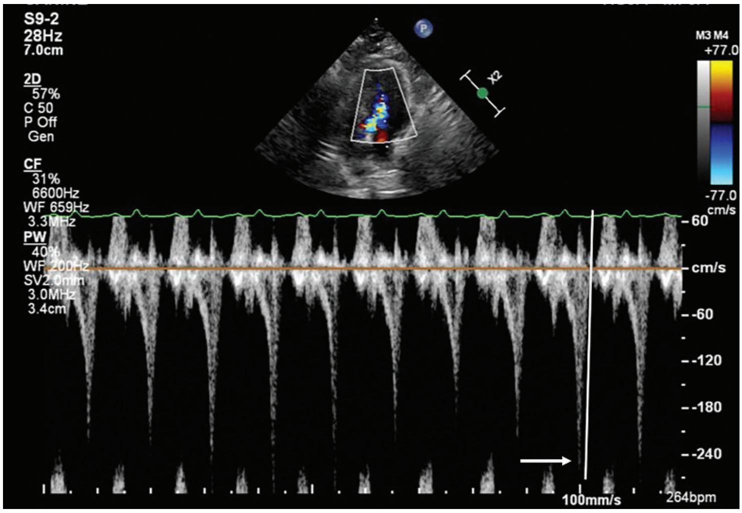


Figure 4.16 As systole progresses in hearts with hypertrophic obstructive cardiomyopathy, the pathway becomes narrower and narrower, creating peak obstruction at the end of systole. This means peak velocity is also highest at end systole (arrow and line) and the flow profile is "dagger" shaped. This is also called a dynamic obstructive flow profile.

        - Left atrial appendage function
            - Size and function of the enlarged left atrium and auricle are determining factors in thrombus development
            - Flow in and out of the left auricle is evaluated by placing a PW gate at the atrial-auricular junction
            - Flow velocities in or out of the auricle less than .25 m/s place the cat at risk for spontaneous echo contrast (smoke)and ensuing development of thrombus (Figure 4.17)
            - If smoke and thrombus are already present then flow is usually not detectable in and out of the auricle
    - Diastolic function
        - The classes of diastolic dysfunction are described in Section 3 (Figures 3.26 and 3.27)
        - A cat may remain in Class 1 or 2 for an extended period of time or move quickly through the classes until congestive heart failure develops
        - Increased atrial size secondary to diastolic dysfunction increases the risk of thrombus development (Figures 4.18a–c and Videos 4.18a–d)
- Dynamic Right Ventricular Outflow Tract Obstruction (DRVOTO)
    - 2D and M-mode features
        - DRVOTO may occur when there is no evidence of cardiac disease
            - 2D and M-mode will show no abnormalities
        - There may be concurrent other disease (i.e., HOCM)
        - DRVOTO is clinically unimportant but may be the cause of a murmur when all other pathologic disease processes have been ruled out

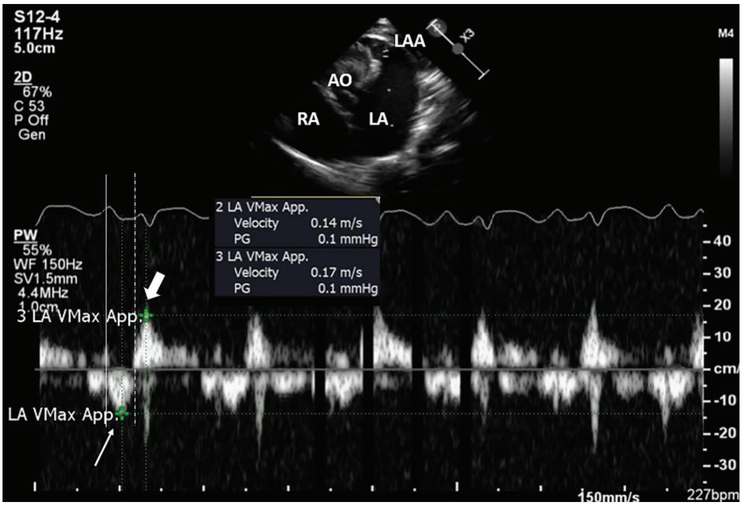


Figure 4.17 Flow velocities in or out of the auricle less than .25 m/s place the cat at risk for spontaneous echo contrast (smoke)and ensuing development of thrombus. Here flow leaving the left auricle is downward with a velocity of .14 m/s (thin arrow) and flow filling the left auricle is .17 m/s (thick arrow). The solid vertical line indicates the start of atrial contraction and emptying of the auricle, and the dashed vertical line indicates the start of ventricular systole and filling of the left auricle.

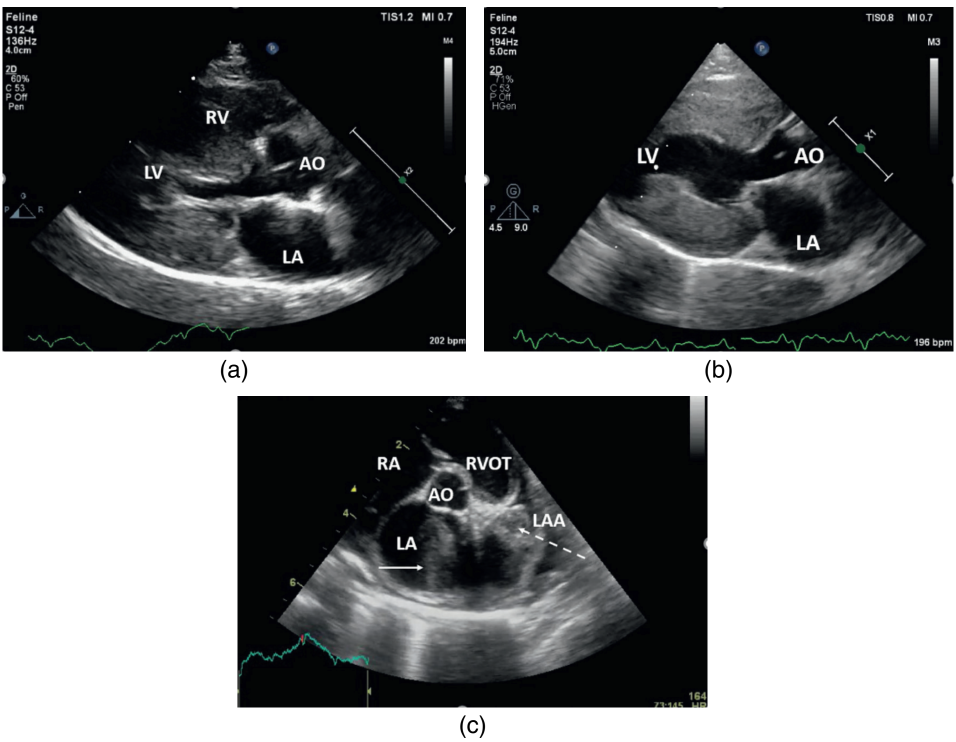
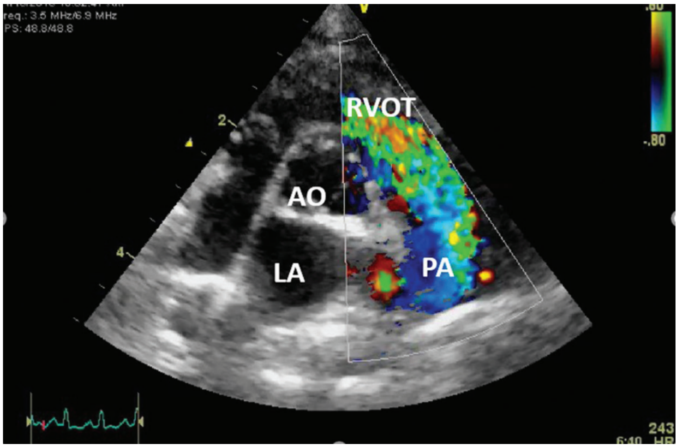


Figure 4.18 Once in Class 2 (pseudonormal) atrial size may start to increase, and increasing atrial size moves the phase of dysfunction into Class 3, where atrial pressure is high enough to create congestion and heart failure. (a) Left atrial size on this inflow outflow view of the heart is normal, indicating minimal diastolic dysfunction. (b) Left atrial size is large in this heart, consistent with some degree of progression from Class 2 to Class 3 diastolic dysfunction. (c) This dilated left atrium on a transverse right heart base view shows “smoke” (spontaneous echo contrast) (solid arrow)and thrombus in the atrial appendage (dashed arrow).

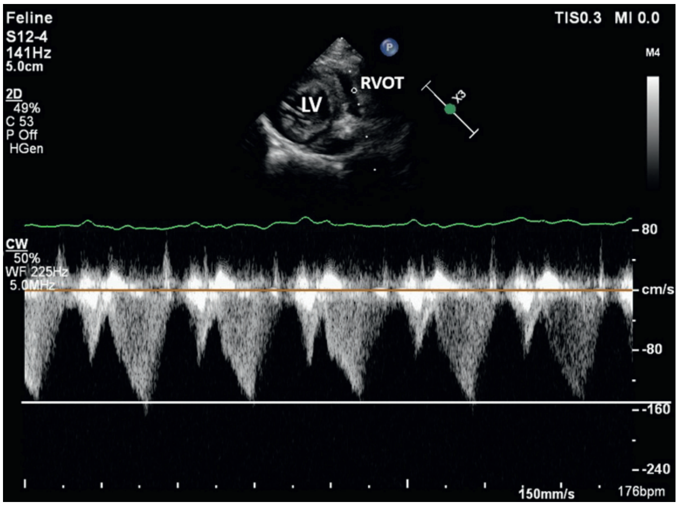
Video 4.18



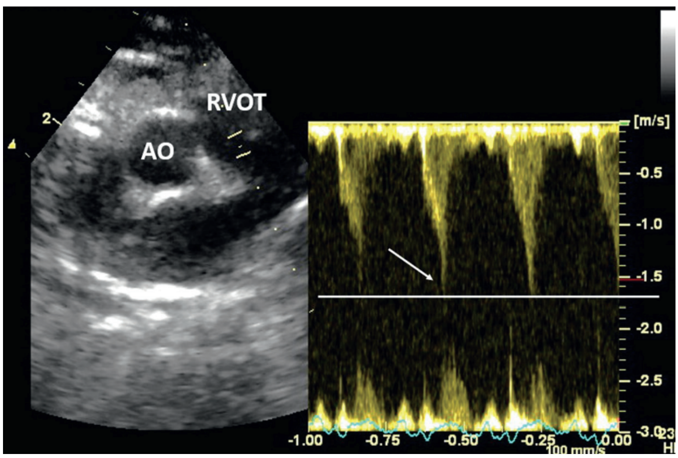
Video 4.19

Figure 4.19 Turbulent color flow is seen in the right ventricular outflow tact proximal to the pulmonary valve on this right parasternal transverse view of the heart base.

  - Color flow evaluation
    - Turbulent flow is seen in the right ventricular outflow tract proximal to the pulmonary valve (Figure 4.19 and Video 4.19)
    - The outflow tract dynamically contracts secondary to any number of things that result in physiologic elevations in contraction and flow velocity
  - Spectral Doppler
    - As the name implies this is a dynamic outflow obstruction that creates late peaking flow profiles as obstruction is at its greatest late in systole (Figures 4.20a and b)
    - Flow velocities and pressure gradients are low
      - Usually not exceeding 3 m/s
- Nonspecific Cardiomyopathy
  - 2D and M-mode features
    - Left ventricular chamber maybe completely normal in size and systolic function
    - As the disease progresses the LV may dilate
    - Rarely the RV is involved
    - An irregular endocardial surface may exist
      - There may be areas of fibrosis, hypokinesia, and infarction
  - These result in diminishing systolic function
      - Endomyocardial fibro elastosis has muscular bridging lesions within the LV chamber
    - Left atrial size is always increased
      - Thrombus and/or smoke is common
  - Color flow evaluation
    - Typically, centrally directed jets of mitral regurgitation exist secondary to atrial dilation and annular stretch (Figures 4.21a and b and Videos 4.21a and b)
      - The regurgitation is typically mild to moderate and rarely severe
    - Although outflow obstructions and SAM are reported, this is a rare occurrence



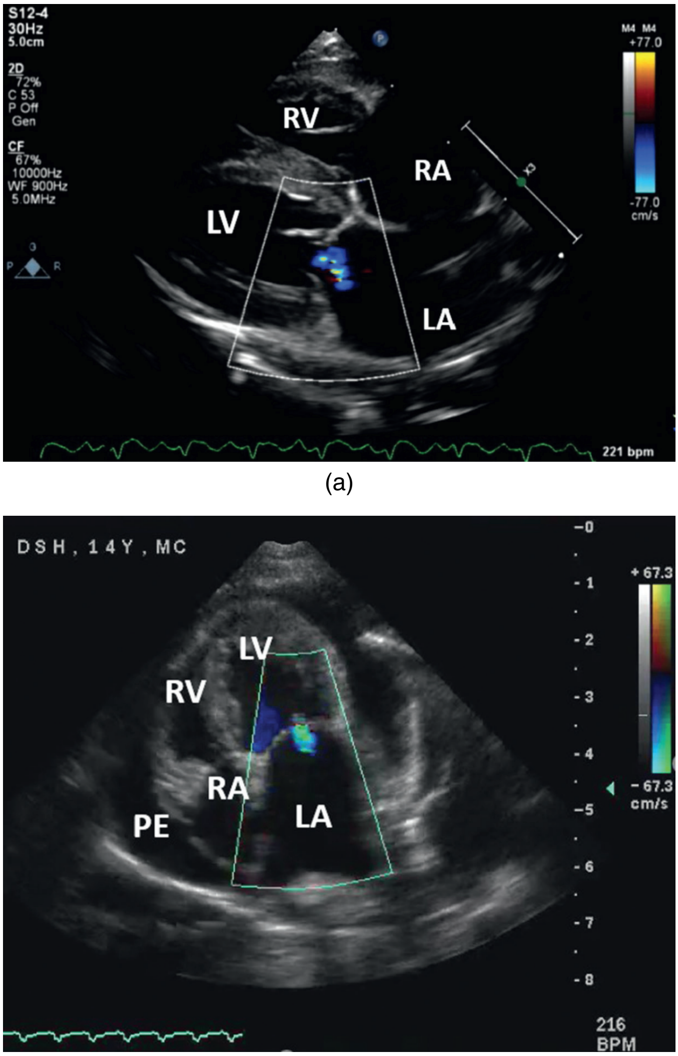
(a)



(b)

Figure 4.20 Dynamic right ventricular outflow tact obstruction (DRVOTO) creates a late peaking spectral envelope. Flow velocity is typically only mildly elevated, but the turbulent flow is enough to create a murmur. (a) Peak velocity of this dynamically obstructive flow profile is mildly increased at just under 1.6 m/s. (b) The PW gate is placed proximal to the pulmonary valve when ruling in or out the presence of dynamic right ventricular outflow tract obstruction. The flow profile shows a late peaking mildly elevated velocity.

- Spectral Doppler
  - The spectral Doppler features characteristic of nonspecific cardiomyopathy relate to diastolic function
    - Cats with NSCM always have large left atrial chambers – a hallmark feature of this disease
    - This puts them in diastolic dysfunctional Class 3 or 4
  - Spectral Doppler features of these classes include (Figures 3.26 and 3.27)
    - Short IVRT



(a)

(b)

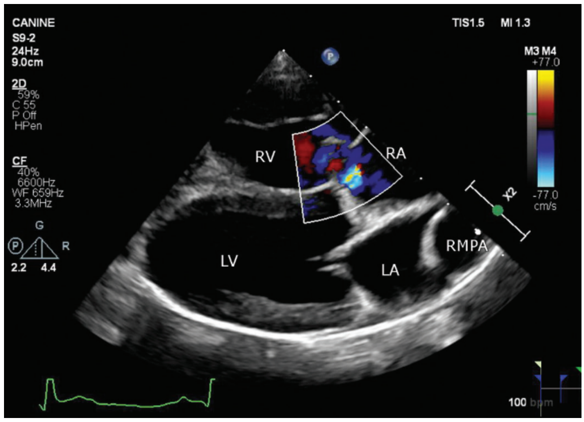
Video 4.21

Figure 4.21 (a) Nonspecific cardiomyopathy usually has no outflow obstruction or systolic anterior motion, but there is often a centrally directed mild to moderate mitral insufficiency. This is secondary to annular stretch or dysfunction. (b) This apical view shows the mild mitral regurgitation often seen in nonspecific cardiomyopathy.

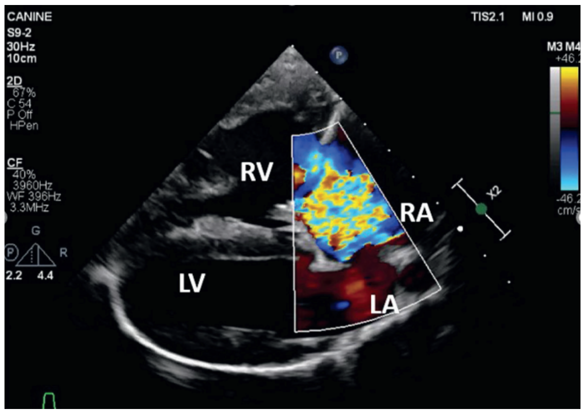
- Increased E/A ratios – with little to no contribution of atrial contraction to LV filling
- Increased pulmonary atrial reverse flow and usually decreased S wave and increased D wave velocities

- Pulmonary Hypertension
  - 2D and M-mode features
    - Mild to moderate pulmonary hypertension may show none of the following changes, and not all are present in animals with significant pulmonary hypertension

        - The lack of any of these features does not rule out the presence of pulmonary hypertension
            - Right ventricular hypertrophy and/or dilation
                - More chronic hypertension will show hypertrophy
                - More acute hypertension will show dilation
                - There is often a mixed dilation and hypertrophy pattern
            - Dilated pulmonary artery
            - Decreased pulmonary artery distensibility
            - Right atrial dilation if TR present
    - Color flow evaluation
        - There are no specific color flow findings with pulmonary hypertension
        - Tricuspid and/or pulmonary insufficiencies are often present in normal hearts and are not specific for pulmonary hypertension (Figures 4.22a–c and Videos 4.22a–c)
        - The degree of pulmonary hypertension does not necessarily relate to the severity of PI or TR
            - Severe TR and PI may be seen with normal RV and PA pressure
            - No to trace TR and PI may be seen with severe pulmonary hypertension
    - Spectral Doppler
        - Regardless of the degree of tricuspid or pulmonary insufficiencies, their pressure gradients will be elevated and reflect elevated RV pressure (Figures 4,.23a–d)
            - There are cases where the TR PG overestimates RV pressure
            - Elevated RV pressure may be secondary to pulmonary hypertension or pulmonary stenosis
                - A normal pulmonary systolic flow velocity rules out pulmonary stenosis as a cause of the elevated RV pressure, and pulmonary hypertension can be diagnosed
        - Pulmonary artery flow profile
            - Normal pulmonary artery systolic flow profiles are symmetrical in shape, and peak velocity occurs during the middle third of systole. This is described as a Type I flow profile (Figure 4.24)
            - Higher RV pressure ejects blood with more force and pulmonary artery systolic flow will accelerate more rapidly than normal, referred to as a Type II flow profile (Figure 4.25a)
            - Measuring the ratio of acceleration time to ejection time provides a measure of this rapid acceleration (Figure 4.25a) (Figure 2.8)
                - A ratio of AccT/RVET of <.32 is consistent with pulmonary hypertension
            - As pulmonary hypertension becomes more significant, the flow profile changes even more and often develops a “cutoff” sign during deceleration that can progress to notching during deceleration (Figures 4.25b and c)
                - These are called Type III pulmonary flow profiles
                - The lack of a cutoff sign or notch does not imply milder hypertension
        - Mitral valve diastolic flow
            - Moderate to severe pulmonary hypertension may decrease volume moving into the left side of the heart
            - Decreased preload into the LA reduces the PG and volume flowing from the LA into the LV early in diastole
                - This results in a reversed E/A flow profile (Figure 4.26)



(a)



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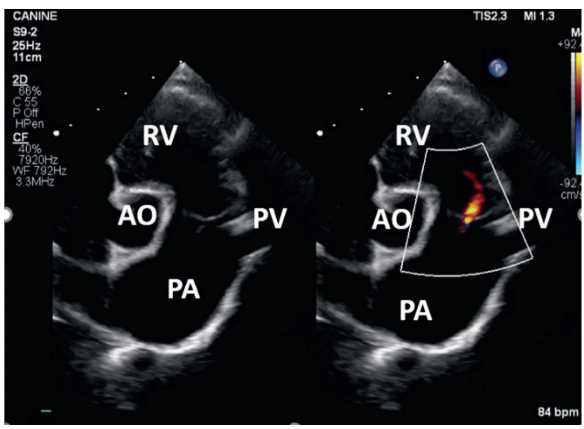


(c)

Video 4.22

Figure 4.22 Tricuspid and pulmonary insufficiencies are common in normal hearts and are not specific for pulmonary hypertension or degenerative valve disease. (a) This mild tricuspid insufficiency does not necessarily mean there is hypertension or any degree of valve disease. The tricuspid valve should be looked at carefully to rule out the latter. There is evidence of right ventricular hypertrophy here, which does suggest elevated RV pressure. The dilated right branch of the pulmonary artery (PA) can be seen with either pulmonary hypertension or pulmonary stenosis. In either of these two possibilities the tricuspid regurgitant flow velocity and pressure gradient would reflect RV pressure. (b) More significant tricuspid insufficiency is seen in this heart. A pressure gradient may be normal or elevated, and the severity of the insufficiency does not necessarily mean a high tricuspid regurgitant pressure gradient. The right ventricle is dilated in this heart. (c) The trace amount of pulmonary insufficiency seen here can be used to evaluate pulmonary artery pressure, and despite the small amount of regurgitation pulmonary artery pressure may be significantly increased. The pulmonary artery is dilated here, consistent with the presence of pulmonary hypertension.

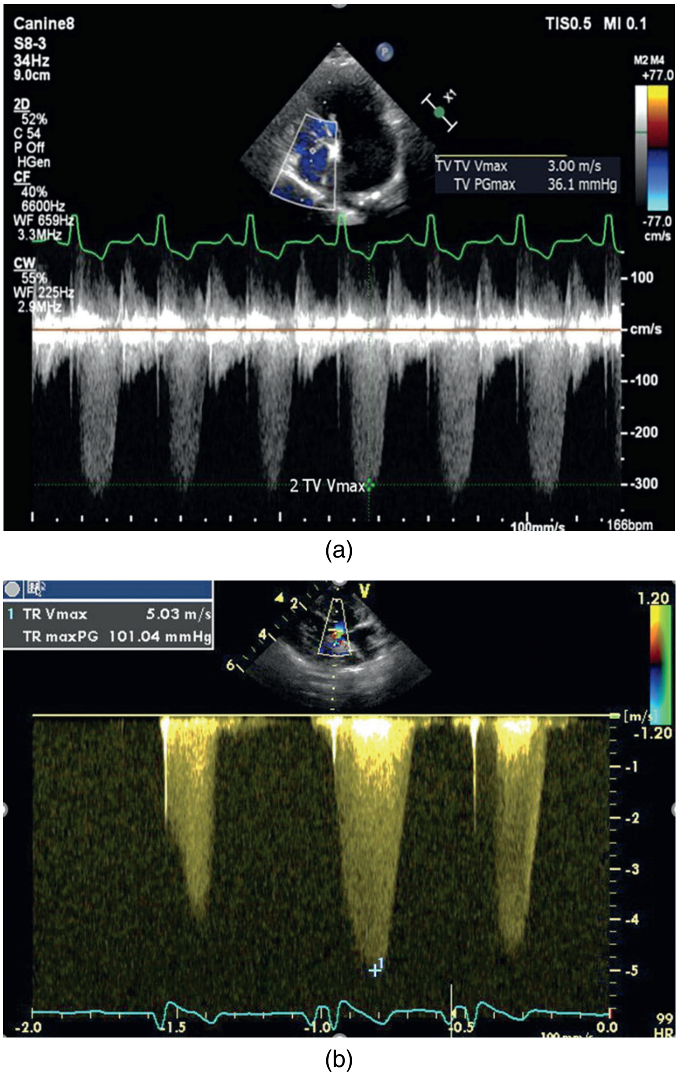
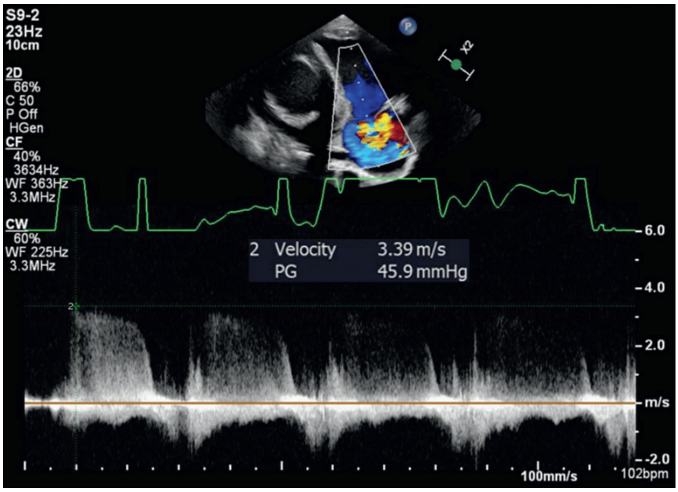
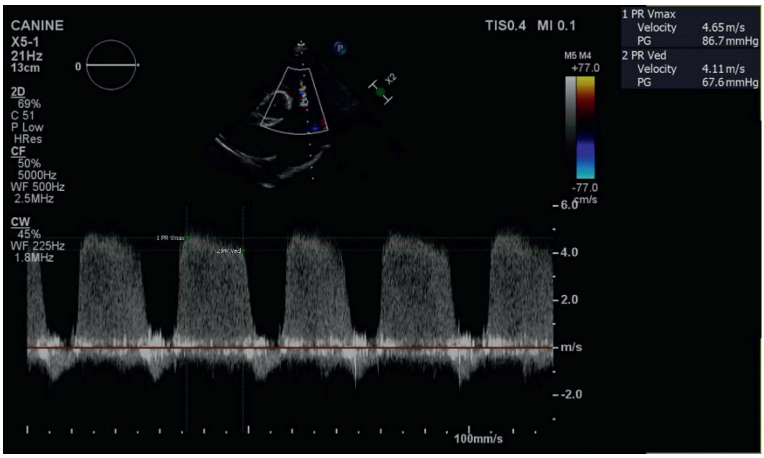


Figure 4.23 Pulmonary stenosis needs to be ruled out before the diagnosis of pulmonary hypertension is made when a tricuspid regurgitant pressure gradient indicates elevated right ventricular pressure. (a) The pressure gradient of this tricuspid regurgitation is 36 mm Hg, suggesting mildly elevated right ventricular pressure. (b) This pressure gradient of 101 mm Hg is consistent with severely elevated RV pressure. Elevated pressure gradients obtained from pulmonary insufficiency flows are always consistent with pulmonary hypertension. (*Continued*)



(c)



(d)

Figure 4.23 (*Continued*) (c) This pulmonary insufficiency early peak pressure gradient reveals a mean pulmonary artery pressure of at least 45 mm Hg. (d) The early peak pressure gradient of this pulmonary insufficiency flow reveals a mean pressure gradient of 86.7 mm Hg. The end pressure gradient reflects a diastolic pressure of 67.6 mm Hg.

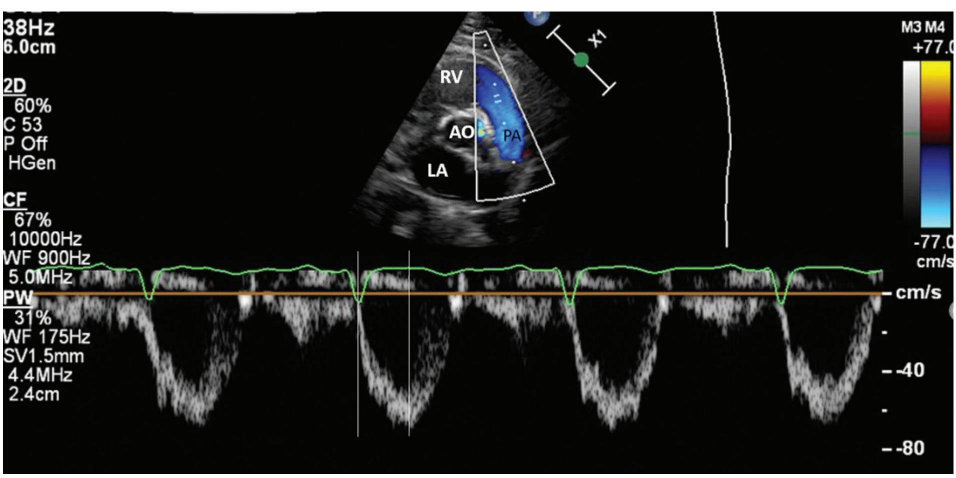
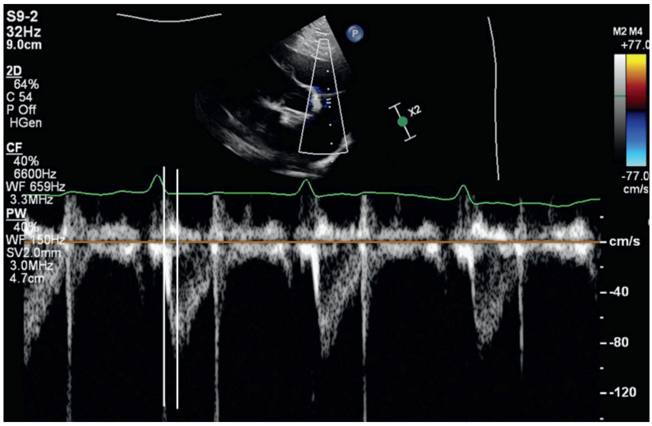
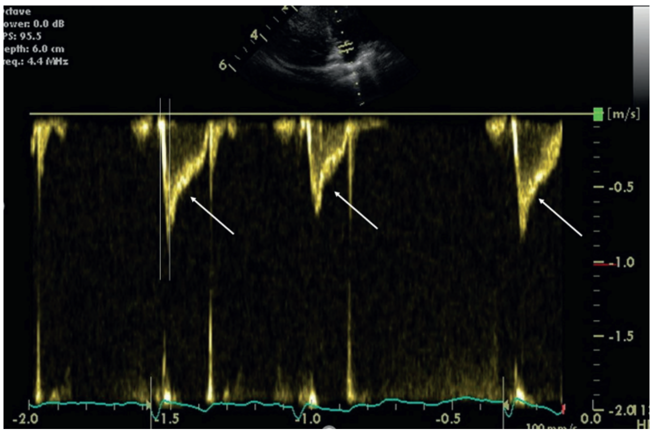


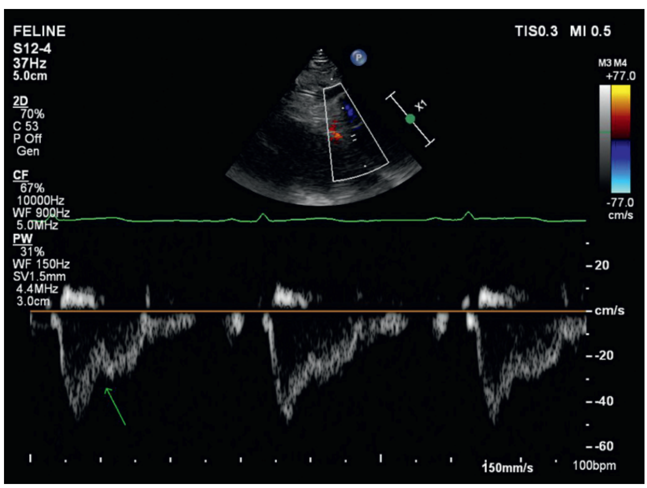
Figure 4.24 Normal pulmonary artery flow profiles are symmetrical with peak velocity in the middle third of systole. This is a Type I flow profile.



(a)



(b)



(c)

Figure 4.25 (a) Higher RV pressure ejects blood with more force and pulmonary artery systolic flow will accelerate more rapidly than normal if RV function is normal. This is called a Type II flow profile. Peak velocity is early in systole. The first vertical line represents the start of systole. The second vertical line shows peak velocity, which occurs during the first third of systole. A ratio of <.32 for AccT/RVET is consistent with pulmonary hypertension. (b) This Type II flow profile with a rapid decrease in flow velocity (cutoff sign) (arrows) during deceleration is often seen as pulmonary hypertension progresses. (c) Notching during deceleration (arrow) is consistent with pulmonary hypertension and increased vascular resistance. This is referred to as a Type III flow profile.

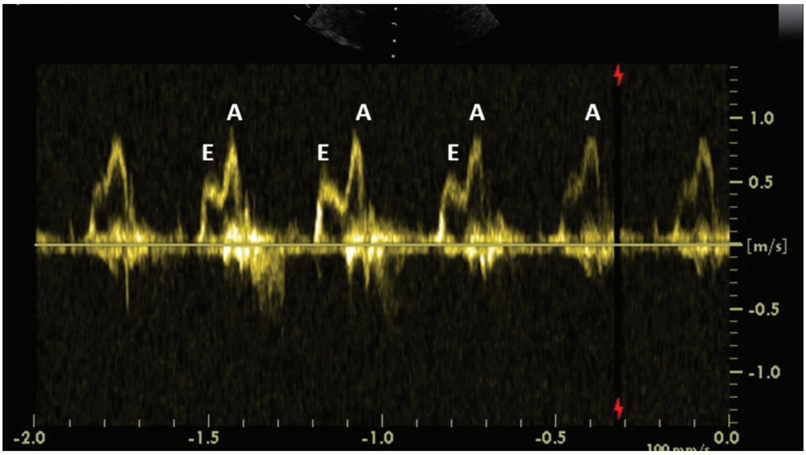


Figure 4.26 Significant pulmonary hypertension often decreases volume through the lungs and into the left side of the heart. Poor preload reverses the trans mitral valve E and A ratio since early diastolic filling is diminished.

Appendix 1 Spectral Doppler Reference Ranges for the Dog and Cat

Canine Aorta and Pulmonary Artery

	Chetboul[1] X ± SD	Darke[2] X ± SD	Kirberger[3] X ± SD	Bonagura[4] X ± SD	Brown[5] X ± SD	Gaber[6] X ± SD	Baumwart[7] 95% CI			Yuill[8] X ± SD
Weight (kg)							3–15	15.1–35	35.1–55	
Aorta										
Vmax (cm/sec)	129 +/– 22	119 ± 24	157 ± 33	115.4 ± 15.3	106.0 ± 21.0	118.9 ± 17.8				118.1 ± 10.8
Pulmonary artery										
Vmax (cm/sec)	105 +/– 19	99 ± 22	125 ± 26	106.0 ± 13.8	84.0 ± 17.0	99.8 ± 15.3				98.1 ± 9.4
AccT (msec)		70 ± 20	79 ± 17							
ET (msec)			184 ± 28		219 ± 18		177–194	174–191	184–204	
N	100			15	28 Sedated	28	15	15	15	20

X = mean, SD = standard deviation, Vmax = peak velocity, AccT = acceleration time also called TTP= time to peak velocity, ET = ejection time also called FT = flow time and RVET = right ventricular ejection time, N = number.

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Canine Mitral Valve, Tricuspid Valve, Pulmonary Veins, IVRT, and Left Atrial Appendage

	Schober[9] range					Chetboul[10] range	Gaber[6] X ± SD	Garncarz[11] range
Age	**< 2**	**≥ 2–< 4**	**≥ 4–< 6**	**≥ 6–< 10**	**≥ 10**			
Mitral valve								
MV E (m/sec)	.63–.93	.54–.92	.52–.91	.52–.82	.52–.81	.58–1.17	75.0 ± 11.8	.59–.66
MV A (m/sec)	.37–.68	.35–.67	.39–.64	.45–.70	.45–.78	.39–0.86		.49–.54
E:A	1.16–1.98	.93–1.86	1.10–1.60	.98–1.70	.68–1.42	.92–2.72		1.20–1.38
MV dec time (msec)	53–79	53–107	54–110	49–98	73–98			72.92–80.63
Pulmonary vein								
PV S (m/sec)	.30–.60	.31–.53	.30–.60	.24–.70	.34–.75			
PV D (m/sec)	.44–.69	.39–.82	.38–.82	.36–.75	.41–.86			
S:D	.46–1.23	.53–1.18	.55–1.38	.47–1.17	.53–1.09			
PV Ar (m/sec)	.16–.26	.16–.29	.15–.29	.19–.30	.22–.28			
PV Ar (msec)	53–80	53–87	53–103	57–80	48–60			
MV A dur: PV Ar dur	1.05–1.64	1.05–1.70	.92–1.64	1.03–1.73	1.26–1.65			
Miscellaneous								
IVRT (msec)	31–62	40–65	43–63	41–65	41–73			
N	30	30	13	11	8	100	28	82
Weight (kg)	4–29	8–33	7–36	8–40	9–23	6–49		
HR	67–162	74–120	73–138	93–134	69–129	70–171		

A = late diastolic flow; Ar = atrial reverse flow; D = diastolic flow; E = early diastolic flow; IVRT = isovolumic relaxation time; kg = kilogram; m/sec = meters/second; msec = millisecond; MV = mitral valve; N = number; PV = pulmonary vein; S = systolic flow; SD = standard deviation; dec = deceleration.

Feline Aorta, Pulmonary Artery, Mitral Valve, IVRT, and Pulmonary Vein

	Disatian[12] generic	**Disatian[12] generic < 1 yr**	**Disatian[12] generic 1–8 yr**	**Disatian[12] generic > 8 yr**	**Chetboul[13] generic**		**Chetboul[13] Maine coon cats**		**Chetboul[13] domestic shorthair**		**Santilli[14] generic**	**Bright[15] generic**
	X ± SD	X ± SD	X ± SD	X ± SD	X ± SD	Range	X ± SD	Range	X ± SD	Range	X ± SD	X ± SD
AO Vmax (m/sec)					1.1 ± 0.2	0.8–1.9	1.1 ± 0.2	0.8–1.9	1.1 ± 0.2	0.8–1.5		
PA Vmax (m/sec)					0.9 ± 0.2	0.5–1.6	1.0 ± 0.2	0.7–1.6	0.8 ± 0.2	0.5–1.2		
Mitral valve												
MV E (m/sec)	.70 ± .14	.87 ± .13	.68 ± .13	.69 ± .13	0.7 ± 0.1	0.5–1.1	0.7 ± 0.1	0.5–0.9	0.7 ± 0.1	0.5–1.0	.67 ± 0.13	.70 ± .04
MV A (m/sec)	.65 ± .14	.71 ± .14	.63 ± .14	.65 ± .12	0.5 ± 0.1	0.3–0.9	0.5 ± 0.1	0.3–0.8	0.5 ± 0.1	0.3–0.7	.59 ± 0.14	.29 ± .04
E:A	1.12 ± .22	1.23 ± .3	1.1 ± .29	1.21 ± .29	1.5 ± 0.3	1.1–2.9	1.5 ± 0.4	1.1–2.9	1.4 ± 0.3	1.1–2.4	1.19 ± 0.30	2.49 ± .28
MV EA fused (m/sec)					0.9 ± 0.1	0.7–1.1	0.8 ± 0.1	0.7–0.9	1.0 ± 0.1	1.0–1.1		
MV E dec time (msec)											59.9 ± 14.07	
MV A dur (msec)	52.9 ± 13.5	48.9 ± 12.3	57.8 ± 11.4	37.3 ± 11.5								
IVRT (msec)	46.2 ± 7.6	39.2 ± 7.0	48.0 ± 6.8	47.6 ± 6.7	43 ± 9	34–56	55 ± 11	38–88	50 ± 11	29–80	55.40 ± 13.24	45.7 ± 3.3
Pulmonary vein												
PV S (m/sec)	.48 ± .14	.53 ± .14	.46 ± .13	.48 ± .13							.39 ± .12	
PV D (m/sec)	.47 ± .10	.43 ± .10	.49 ± .10	.44 ± .10							.44 ± .09	
PV S:D											.90 ± .29	
PV Ar (m/sec)	.23 ± .06	.20 ± .06	.24 ± .06	.22 ± .06							.22 ± .07	
PV Ar dur (msec)	53.5 ± 10.3	49.4 ± 10.9	53.9 ± 10.4	57.8 ± 10.1								
MV A: PV Ar	1.01 ± .28	.93 ± .23	1.09 ± .27	.78 ± .37								
Left auricle[16]												
Emptying (m/s)	.19 – 1.0											
Filling (m/s)	.24 – .93											
HR	127–308	218 ± 48	186 ± 28	191 ± 33	184 ± 33	100–261	183 ± 35	113–252	187 ± 30	100–243	-	-
Age	3 mo–19 yr	< 1 yr	1–8 yr	> 8 yr	3.6 mo–12 yr		8.4 mo–6.5 yr		3.6 mo–12 yr		1 yr–18 yr	
Kg	4.6 ± 1.8				4.6 ± 1.2		5.0 ± 1.2		4.0 ± 1.2		3.68 ± 1.28	
N	87	11–17	42–53	13–17	100		51		31		20	12

acc = acceleration; AO = aorta; dec = deceleration; dur = duration; HR = heart rate; IVRT = isovolumic relaxation time; kg = kilogram; m/sec = meters/second; msec = millisecond; MV A = mitral valve late diastolic flow; MV E = mitral valve early diastolic flow; N = number; PA = pulmonary artery; PV Ar = pulmonary vein atrial reverse flow; PV D = pulmonary vein diastolic flow; PV S = pulmonary vein systolic flow; SD = standard deviation; Vmax = peak velocity; X = mean.

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Appendix 2 Abbreviations

A	atrial
AccT	acceleration time
AO	aorta
Ar	atrial reverse flow
BP	blood pressure
cm/s	centimeters per second
CW	continuous wave
D	diastolic
dec	deceleration
dur	duration
DCM	dilated cardiomyopathy
DRVOTO	dynamic right ventricular outflow tract obstruction
ECG	electrocardiogram
EPSS	E point to septal separation
HCM	hypertrophic cardiomyopathy
HOCM	hypertrophic obstructive cardiomyopathy
IVRT	isovolumic relaxation time
LA	left atrium
LAA	left atrial appendage
LV	left ventricle
LVOT	left ventricular outflow tract
Max	maximum
MHz	megahertz
mm	millimeter
mm Hg	millimeters of mercury
msec	milliseconds
MR	mitral regurgitation
m/s	meters per second
MV	mitral valve
MV A	mitral valve A wave
MV E	mitral valve E wave

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NSCM	nonspecific cardiomyopathy
PA	pulmonary artery
PG	pressure gradient
PI	pulmonary insufficiency
PRF	pulse repetition frequency
PS	pulmonary stenosis
PV	pulmonary valve
P vein	pulmonary vein
PW	pulsed wave
RA	right atrium
RMPA	right main pulmonary artery
RV	right ventricle
RVET	right ventricular ejection time
RVOT	right ventricular outflow tract
S	systolic
SAM	systolic anterior motion
TR	tricuspid regurgitation
Vmax	maximum velocity
2D	two dimensional

Recommended Reading

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