**White Paper**

# Understanding Canine Hearts through Ultrasound Examination

# Background

More than twenty years ago, ultrasonography was rarely used in small animal practice. Over the last few decades, several technological advancements were made in the echocardiographic field, helping us to understand the morpho-functional abnormalities underlying cardiological diseases. Today, echocardiography is the gold standard imaging technique for the vast majority of heart diseases in our companion animals.

The most common symptoms that require echocardiographic assessments are not only cough, difficulty breathing, increased respiratory rate, episodes of collapse but also a reduced ability to exercise, decreased appetite, and general fatigue.

Some clinical findings, such as the presence of a heart murmur, abnormal heart rhythms, pulmonary edema, fluid in the thorax and abdomen, can also lead the veterinarian to conduct an echocardiography exam.

Degenerative mitral valve disease (MVD) is the most frequent acquired heart disease in dogs, characterized by valvular degeneration resulting in systolic mitral valve regurgitation (MR).

Conventional B-Mode, M-Mode, and Doppler examination play a crucial role, together with the correct choice of probes, in the initial and longitudinal assessment of patients affected by MVD and other pathologies, providing information on mitral valve anatomy, MR severity, left ventricular (LV) size and function, as well as cardiac and vascular pressures.

More advanced ultrasound techniques such as tissue Doppler imaging (Esaote TVM), strain and strain rate imaging with speckle tracking echocardiography (Esaote XStrain™), provide new parameters to assess regional and global myocardial performance.

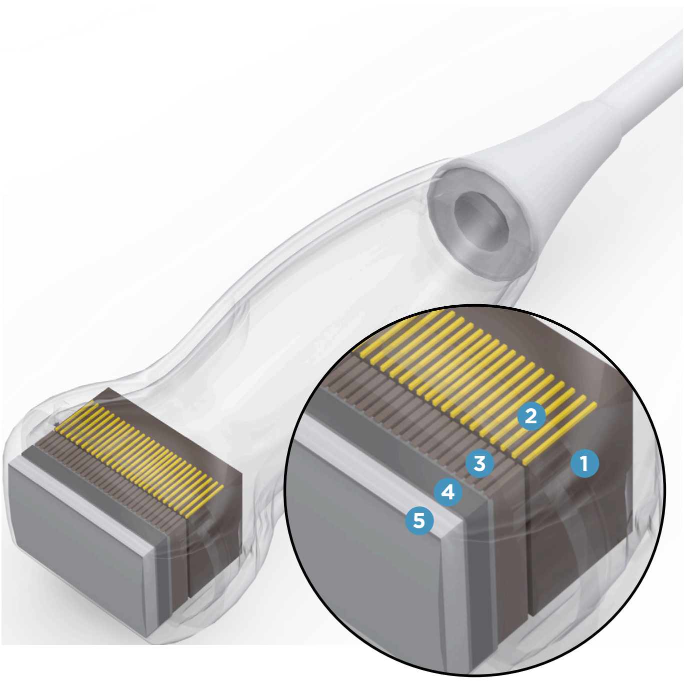
Cardiac ultrasonography is not only a diagnostic tool for several heart diseases (for example, among acquired pathologies, dilated cardiomyopathy, arrhythmogenic right ventricular cardiomyopathy (ARCV), hypertrophic cardiomyopathy, particularly recurrent in cats, but is also used for screening, especially in breeds predisposed to particular congenital or acquired heart diseases.

This investigative method plays an important role in the early detection and follow-up of heart failure with the objective of choosing the correct therapeutic protocol.

Based on these clinical needs, the aim of this paper is to present Esaote's complete cardiological package and advanced solutions.

# The importance of transducer technology

To ensure superior clinical performance, ergonomics and reliability, the ultrasound probe design (figure 1) requires the optimization of the transducer, shape, cable, and system connector, together with an efficient manufacturing process.




1. Backing block
2. Electrical connections
3. Piezoelectric elements
4. Matching layers
5. Acoustic lens

Fig. 1: The core of the ultrasound probe is the transducer, which has four main parts: piezoelectric elements that convert electrical energy to acoustic energy and vice versa; backing material that both dampens the piezoceramic ringing and attenuates unwanted ultrasound traveling in the direction opposite to the patient; matching layer(s) improving ultrasound transfer into the patient and unlocking transducer energy conversion efficiency; an acoustic lens that focuses the ultrasound beam in the plane perpendicular to the electronic focusing plane.

The new Esaote XCrystal Technology, based on a single diamond crystal, leads to enhanced, uncompromising image quality. Compared to conventional lead zirconate titanate (PZT) piezoceramics, a single crystal provides bandwidth up to 20-25% wider (Figure 2), greater sensitivity, and deeper penetration than PZT, enabling more detailed diagnostic information even for patients where there is imaging difficulty. As a result, a single crystal offers noticeably better performance than PZT, in terms of contrast and spatial resolution, uniformity from near-field to far-field, and penetration. Standard imaging, Doppler, color flow and harmonic imaging performances are all enhanced.

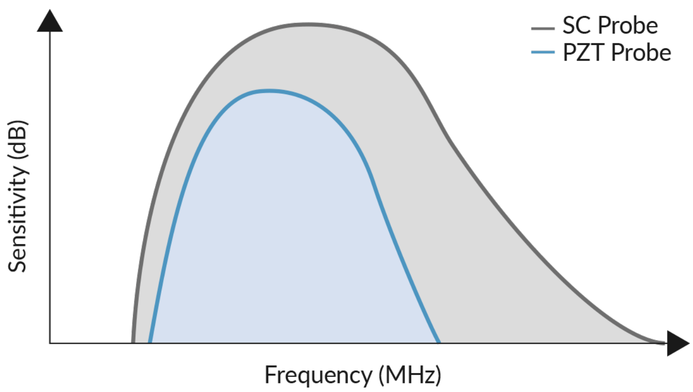



Fig. 2: single crystal material offers up to 20-25% wider bandwidth and greater sensitivity than PZT.

In addition to the single crystal technology, the innovative backing aids the enhancement of the image quality, increasing the ultrasound energy transmitted into the patient's body, while maintaining very wide bandwidth, and improving the thermal efficiency (Figure 3, Figure 4). This directly translates to the highest level of harmony of imaging sensitivity, penetration, and resolution achievable in the entire field of view and leads to improved diagnostic confidence and accuracy for a wide range of patient sizes. As result, speckle noise is reduced, improving the sharpness of edges and fine details of valves and interventricular and interatrial septa, and pulmonary venous color Doppler is enhanced.

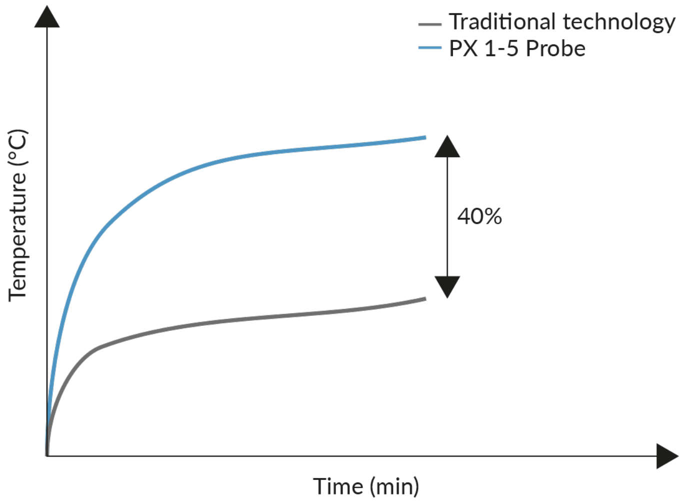



Fig. 3: the newly developed technology allows a 40% increase in thermal efficiency, resulting in decreased probe heating.

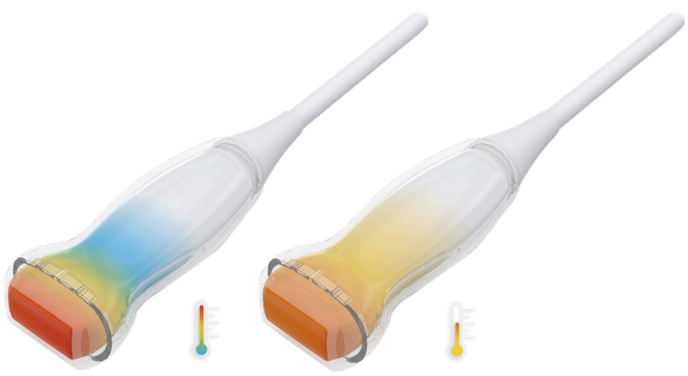


Fig. 4: thermal behavior of the probe without (left) and with (right) thermal efficiency technology. In both cases, the amount of heat does not exceed that allowed by the standards. Nevertheless, due to the lower temperature of the probe surface, the PX 1-5 delivers higher transmit and receive sensitivity and therefore produces a higher quality image and Doppler signal.

The lens consists of specifically designed material and geometry to provide slice thickness (Figure 5), enabling uniform sensitivity and high signal-to-noise ratio across the entire field of view, facilitating access to image windows between ribs, minimizing reverberations, increasing contrast resolution, and improving border definition of anatomical structures. This contributes to aiding apex clarity in the four-chamber view and to imaging for small patients.

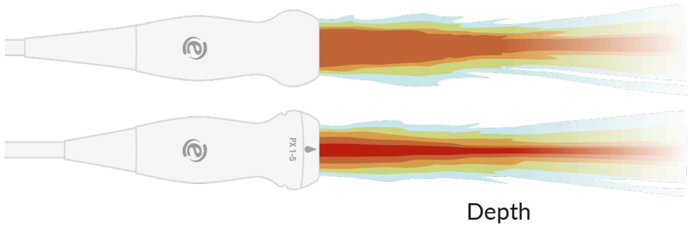



Fig. 5: PX 1-5 transducer elevation focusing was designed to adequately sample a wider range of depths: the focusing in the lens direction provides a sharper, finer and more uniform ultrasound beam, which positively impacts contrast resolution, useful penetration, and plunkability.

In conjunction with more precise clinical images, the acoustic lens design provides effective robustness of the transducer against automation and aggressive cleaning and disinfection methods. This results in a longer product life.

# Clear representation of cardiac muscle and flows

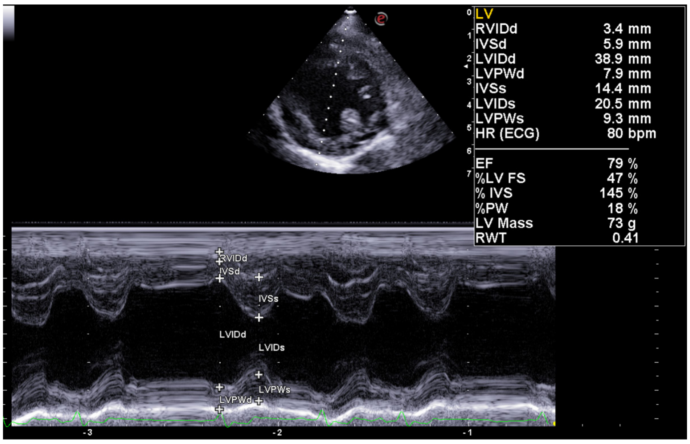



Fig. 7: short axis view, left ventricle at the level of the papillary muscles. Calculation of the left ventricle dimensions in systole and diastole to evaluate the contractility, ejection fraction, and efficiency of the heart.

### Two-Dimensional Echocardiography (B-Mode)

High performance is guaranteed for precise analysis of the cardiac muscle, especially in the assessment of the heart morphology and in the quantification of chamber dimensions.
A complete dedicated measurement package allows you to quickly make measurement with an intuitive workflow (Figure 6).

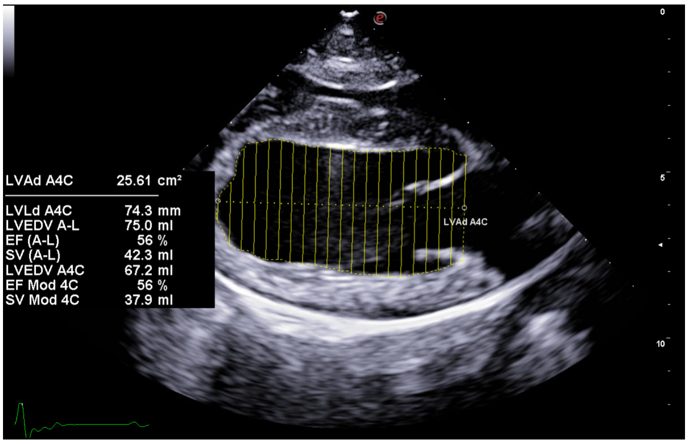



Fig. 6: B-Mode long axis view. Quantification of the left ventricle volume with Simpson methodology.

### M-Mode Echocardiography

To analyze the continuous periodic movements of the heart during the systolic and diastolic phase, M-Mode is the benchmark method (Figure 7). Sometimes, when the position of the heart is not perpendicular to the ultrasound beam, the measurement can be difficult. Esaote CMM technology allows clinicians to correct M-Mode line position by placing it at the correct angle for accurate and reliable measurements. CMM is also available in post-processing allowing time-dependent measurements at any time (chamber dimensions, wall motion).

### Doppler Echocardiography

Doppler Echocardiography uses the Doppler principle: the frequency of a reflected sound wave depends on the direction and velocity of the reflector and the transmitted frequency (producing a Doppler shift), and it means that if the transmitted ultrasound frequency and the velocity of sound in soft tissue and blood are known, then the velocity of red blood cells can be calculated.

Doppler echocardiography is therefore fundamental to characterize abnormalities in the direction and velocity of blood flow and, eventually, to indicate the origin of turbulent blood flow.

This methodology is also used to estimate flow volumes, to assess systolic and diastolic function, and to obtain information about intracardiac pressures.
With Color Flow Doppler (CFM), the blood flow is coded in red (towards the transducer) or blue (away from the transducer) and superimposed on the black-and-white 2D image (Figure 8). With this methodology, it is possible to assess the severity of mitral valve regurgitation based on the percentage of the left atrial area covered by the color jet, through Esaote PISA measurement. If the color jet occupies less than 20% of the left atrium area, the regurgitation is mild; if it occupies between 20% and 40%, the regurgitation is moderate; if it is more than 40%, the regurgitation is severe. Likewise, CFM makes it possible to assess the severity of different valvular regurgitation or any anterograde turbulent flow, for example in stenotic valve diseases.

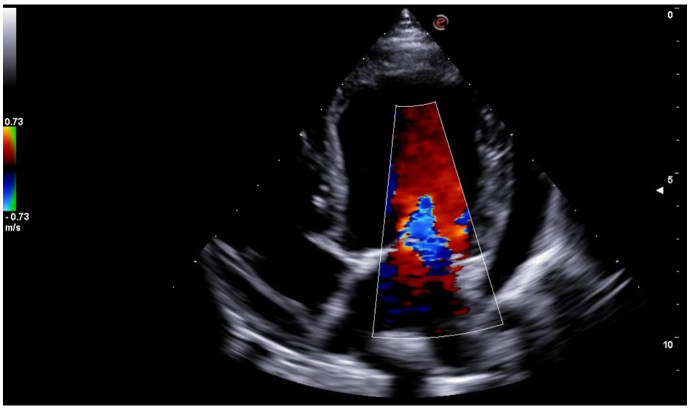



Fig. 8: Apical 4-chamber view. CFM of mitral valve flow.

With Spectral Doppler, the velocity of blood flow can be calculated: a graph of the velocity against time is usually represented with a simultaneous ECG display. Blood flow velocities toward the transducer are displayed as positive (above the baseline), and blood flow velocities away from the transducer are displayed as negative (below the baseline).

With Pulsed Wave Doppler (PW), the ultrasound waves are transmitted as pulses of waves, with the transducer acting at different times as a receiver or transmitter of ultrasound waves, allowing the interrogation of blood flow velocities within a specific region of interest represented by a sample volume on the cursor. The highest speeds that Pulsed Wave Doppler can show without ambiguity are constrained by the phenomenon of "aliasing," in which blood flow is shown as both positive and negative speeds.

The Nyquist limit (half the pulse repetition frequency) determines the velocity at which aliasing will occur, and lower transducer frequencies are therefore able to reach higher velocities without aliasing.

With Continuous Wave Doppler (CW), in contrast, ultrasound waves can be transmitted and received simultaneously, allowing much higher velocities to be displayed. In this case, it is not possible to know the depth from where these velocities are originating.

Several flows can be assessed with spectral dopplers:

- Mitral valve inflow:

A typical application of PW is the assessment of mitral valve inflow obtained from the left parasternal apical 4-chamber view. In this case, the cursor must be placed parallel to the mitral flow and the sample volume must be placed at the tips of the mitral valve leaflets when it is open. The mitral inflow has a typical spectral Doppler waveform consisting of an early diastolic (E) wave and an atrial contraction (A) wave of filling (Figure 9).

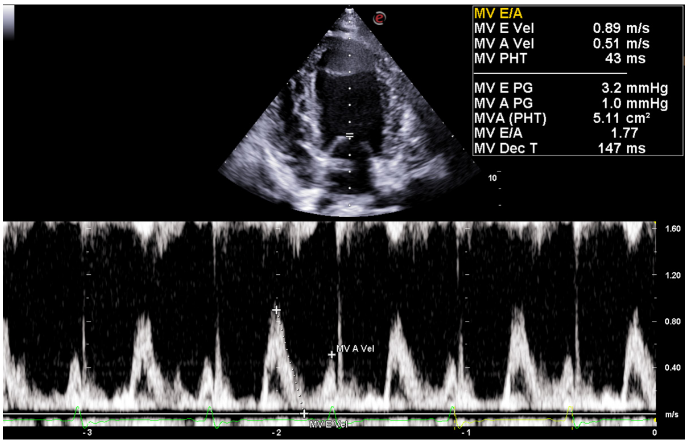



Fig. 9: Apical 4-chamber view. Assessment of mitral inflow with Pulsed Wave Doppler.

- Aortic flow:

The Aortic flow can be assessed with both CW and the PW, depending on the velocity of the flow.

The PW is generally used in laminar anterograde flow with normal peak velocity (Figure 10). When the aortic flow has a very high peak velocity or when the anterograde flow is turbulent, we need to use CW to avoid the phenomenon of aliasing (Figure 11). The aortic flow can be assessed by two different scans: left parasternal apical window, 5-chamber view, or subcostal view. In both cases, the sampling volume must be placed in the ascending aorta.

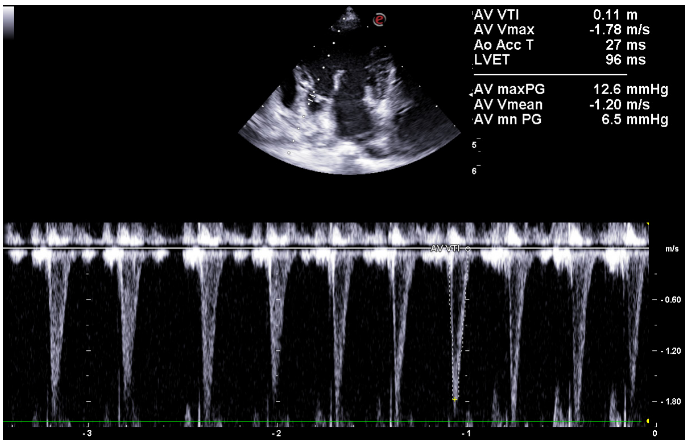



Fig. 10: Apical 5-chamber view. Assessment of aortic flow with Pulsed Wave Doppler.

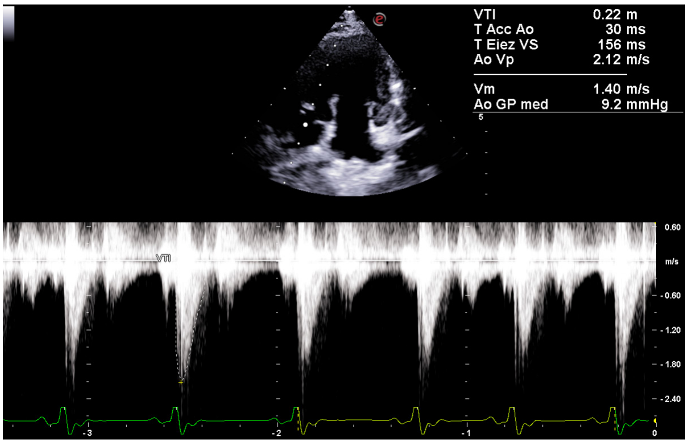



Fig. 11: Apical 5-chamber view. Assessment of aortic flow with Continuous Wave Doppler.

- Tricuspid valve flow:

Tricuspid valve flow is evaluated with PW, from the left parasternal window optimized for the right heart (figure 12).

The sample volume must be placed at the tips of the tricuspid leaflets and the spectral waveform is similar to that of mitral inflow, although an additional systolic forward flow wave is sometimes recorded.

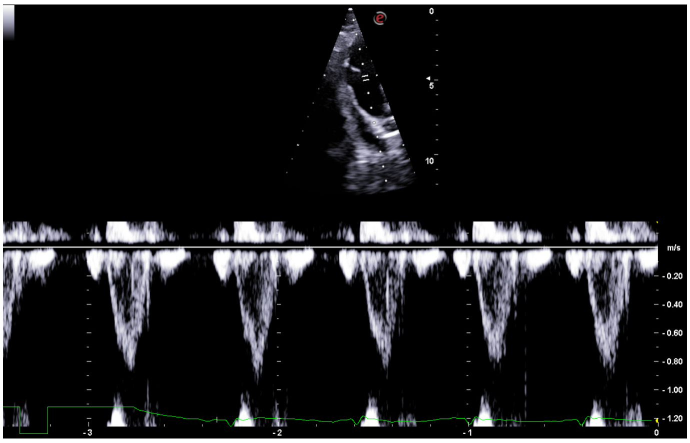


Fig. 12: Left parasternal windows. Assessment of tricuspid flow with Pulsed Wave Doppler.

The last Doppler technique is Tissue Doppler Imaging (TDI), aimed at evaluating myocardial motion velocity. TVM (Tissue Velocity Mapping), Esaote's advanced TDI technology, enables the visual estimation of wall motion providing complete Wall Motion Analysis for both systolic and diastolic myocardial function evaluation. TVM, together with PW, are crucial to the evaluation of ventricular diastolic function. This method is often used to assess mitral annulus velocity, displaying a systolic wave (S), early diastolic wave (E') and atrial wave (A') (Figure 13).

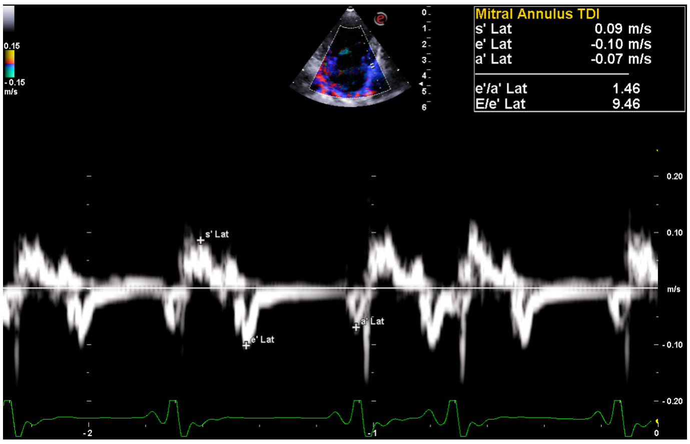



Fig. 13: Apical 5-chamber view. Assessment of aortic flow with Continuous Wave Doppler.

# Automatic tools for fast and accurate cardiac examination

**Augmented Insight™**
The quantification of the ejection fraction (EF) is a key indicator of heart health.
There are several methods to assess this value, from M-Mode to Simpson B-Mode.
Esaote Automatic Ejection Fraction (AutoEF) is an automatic tool to calculate ejection fraction. This tool is supported by artificial intelligence to accelerate the workflow, and with just one click the LV borders are recognized and the EF is immediately displayed (Figure 14). This feature automatically evaluates left ventricle ejection fraction, both in systolic and diastolic phase and, besides saving time in the workflow, will increase the confidence of the assessment: in a few seconds, the LV volume and the relative EF are displayed, increasing the reliability of the measurements as a result of artificial intelligence.

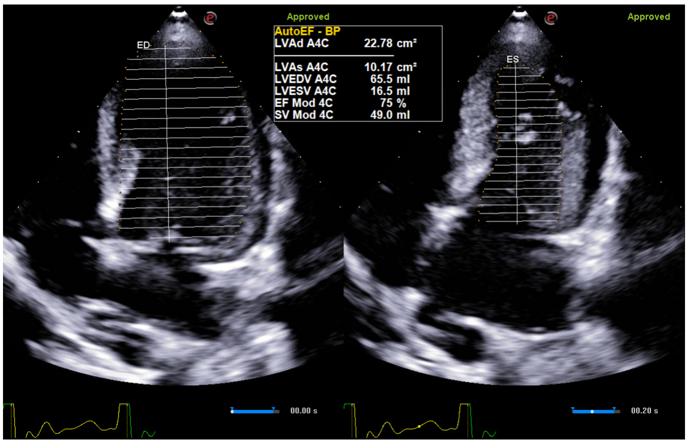



Fig. 14: Automatic assessment of ejection fraction with Esaote AutoEF, powered by artificial intelligence.

Another important methodology to assess heart health is the evaluation of the wall contractility through Speckle Tracking Echocardiography and Strain and Strain ratio measurements.

Strain is the percentage change in the length of a myocardial segment compared to its resting length; strain rate is the rate at which this deformation takes place, expressed as 1/s. Normally, strain and strain rate have negative values in systole when the myocardium shortens, and positive values in diastole when the myocardium lengthens.

In human medicine, strain echocardiography has been shown to be helpful because it is able to preliminarily detect systolic dysfunction before it can be detected with the naked eye or by conventional quantitative measurements.

Esaote XStrain™ is an advanced technology powered by artificial intelligence which, with only one click, detects and tracks endocardial borders speckle by speckle, to provide the GLS (Global Longitudinal Strain) and Strain value of each segment of the left ventricle (Figure 15).

Moreover, with Esaote XStrain™ all-in-one representation of LV segments, contractility is made available through bull's-eye representation (Figure 16).

With XStrain™, immediate tracking and quantification of the deformation for the right ventricle is also possible, as well as the strain evaluation of free strain intraventricular septum and globally.

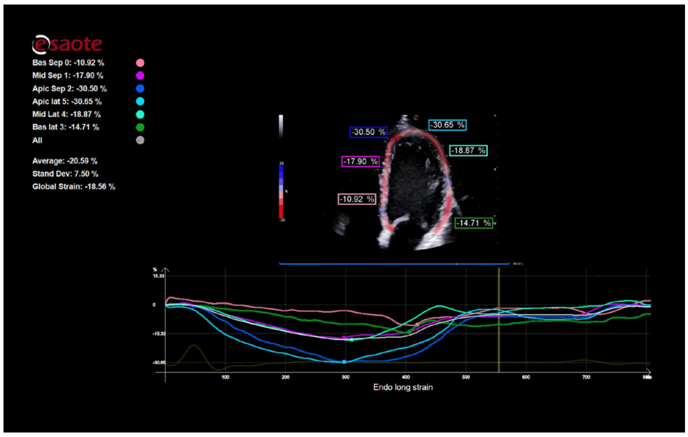



Fig. 15: XStrain™

# Conclusion

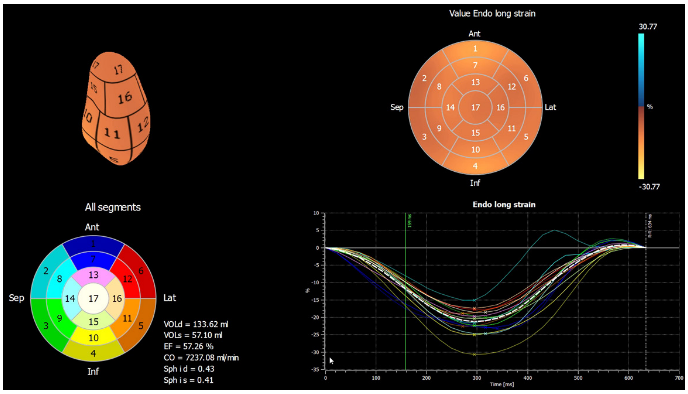



Fig. 16: Bull's-eye representation

Standard echocardiography is the most widely used imaging modality for the assessment of patients affected by heart diseases, for its unmatched ability to combine safety and ease of application with depth of diagnostic and prognostic information.

The newer ultrasound technologies provide valuable insights concerning the vast majority of heart dysfunction, elucidating distinct and precise behavior of heart structures.

All the echocardiographic technologies mentioned above have the advantage of being safe, noninvasive, with a good price-performance ratio, and can be performed everywhere, also made possible by portable ultrasound systems.

These technological advancements promise to further expand the role of echocardiography in the assessment of a wide basket of heart pathologies in the veterinary world.

Anatomical schemas and ultrasound sections of standard echocardiographic examination in dogs are clearly described in the Esaote MyLibrary (QR code), also available directly on Esaote ultrasound devices.

www.esaote.com/veterinary-systems-and-applications/online-libraries/

# Clinical images and pathologies

For each ultrasound modality, a collection of clinical images have been acquired and are explained in the following paragraphs.

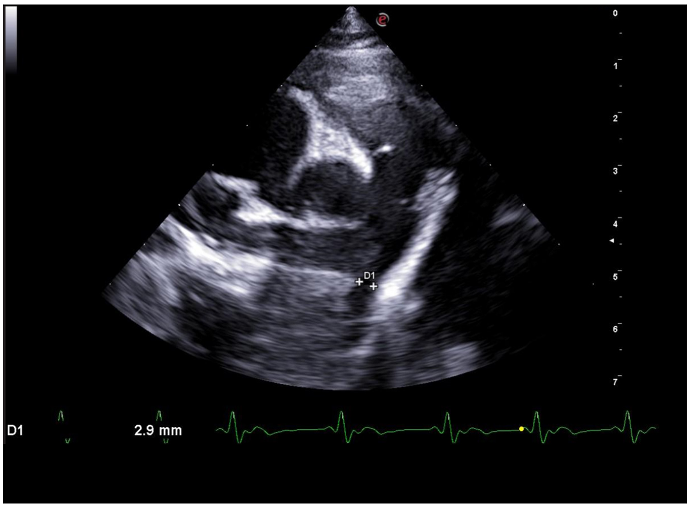



Fig. 17: Right parasternal window, short axis view, optimized for the pulmonary artery. From this view, using the B-Mode, an abnormal connection between the aorta and the pulmonary artery is observed, compatible by position with the Botallo arterial duct (PDA).

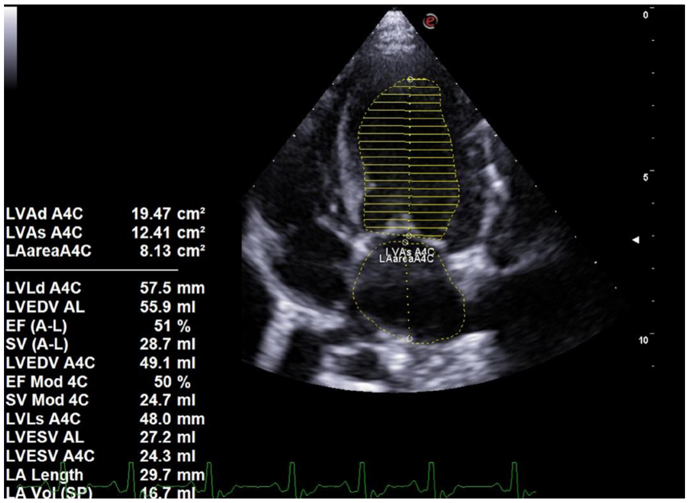



Fig. 19: Left parasternal window, 4-chamber apical view.

B-Mode modality allows, in addition to the study of cardiac morphology, to evaluate the size of the cardiac chambers in the different phases. From these figures, we can observe the measurements of the left ventricular telediastolic (Figure 18) and telesystolic (Figure 19) volumes using the Simpson method.

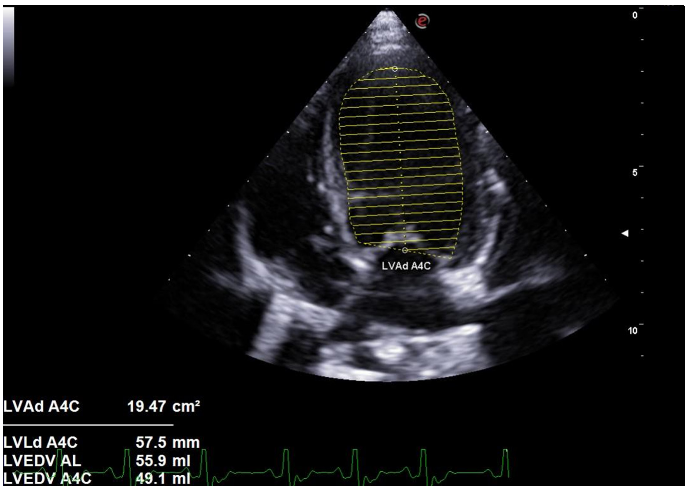



Fig. 18: Left parasternal window, 4-chamber apical view

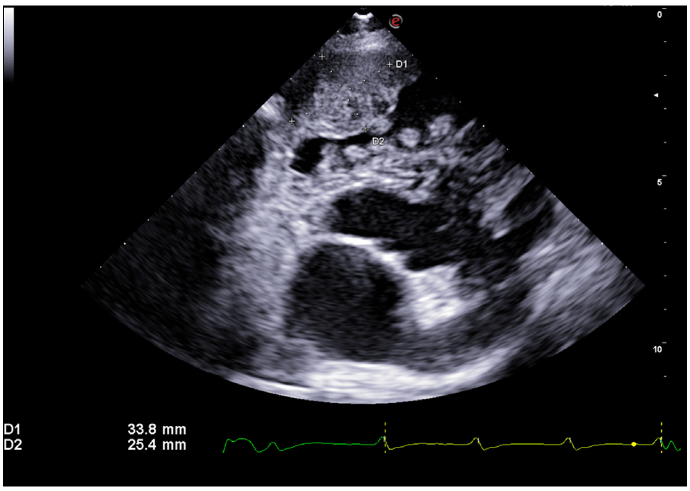



Fig. 20: B-Mode improves study of possible cardiac structural abnormalities.

In this case, a neoformation can be observed at the level of the right ventricular free wall.

## M-Mode

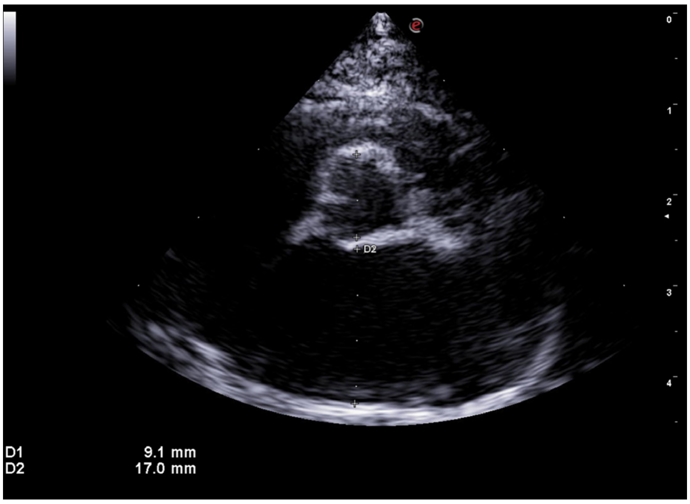



Fig. 21: Right parasternal window, short axis view optimized for heart base.

From this view, B-Mode makes it possible to perform measurement of the left atrium by placing it in relation to the size of the aortic diameter, in order to obtain the measurement of the left atrium-aorta ratio.

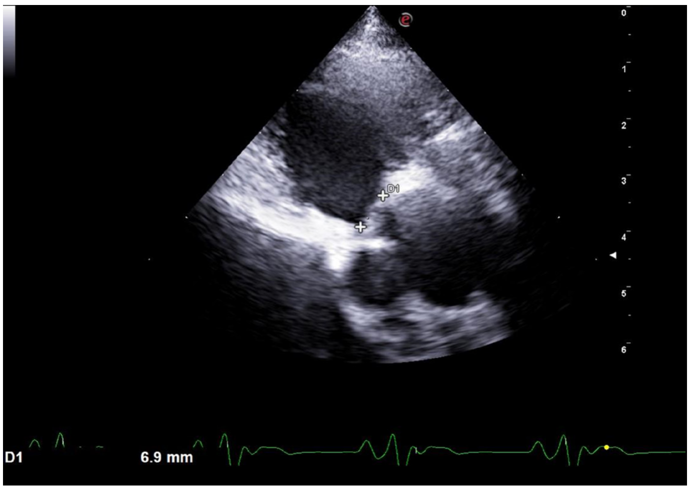



Fig. 22: Left parasternal windows optimized for the right efflux tract and pulmonary artery.

From this scan, it is possible to further study the morphology of the valvular apparatus and to perform possible measurements of the pulmonary annulus.

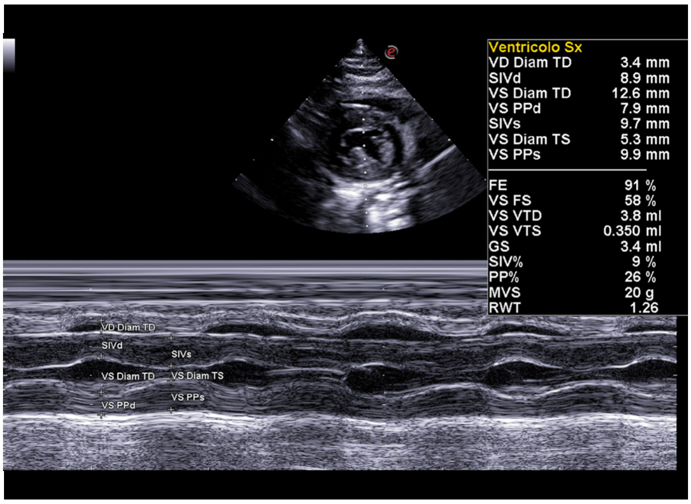



Fig. 23: Right parasternal windows, short axis view.

With M-Mode, it is possible to appreciate an increase in the septal-parietal thickness of the left ventricle, in a cat with hypertrophic cardiomyopathy (HCM).

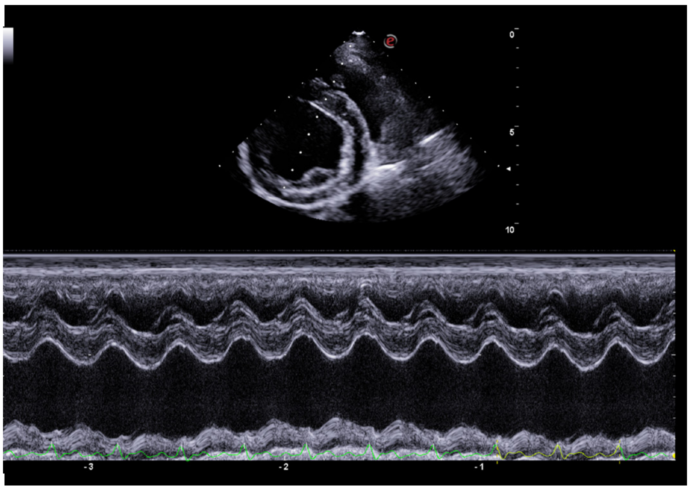


Fig. 24: M-Mode right parasternal window, short axis view.

The M-Mode method makes it possible both to study the ventricular dimensions and to evaluate the left ventricular kinetics.

The figure shows a patient with left ventricular hyperkinesis during mitral insufficiency.

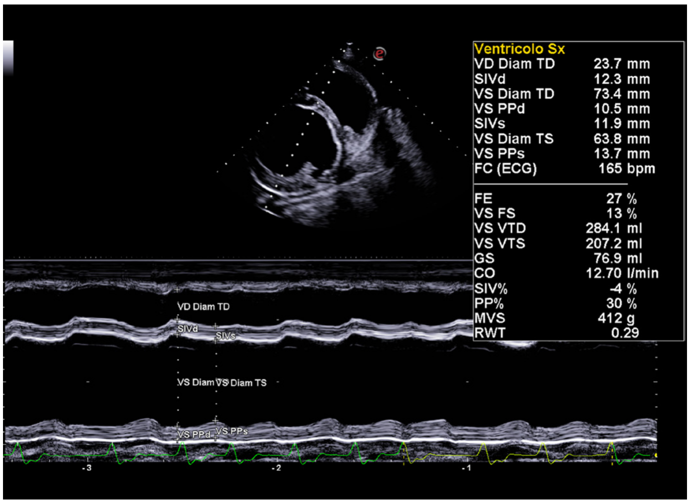



Fig. 25: M-Mode right parasternal window, short axis view.

The M-Mode study in the figure shows a severe increase in left ventricular telediastolic and telesystolic volumes associated with reduced left ventricular kinetics in a patient with dilated cardiomyopathy (DCM).

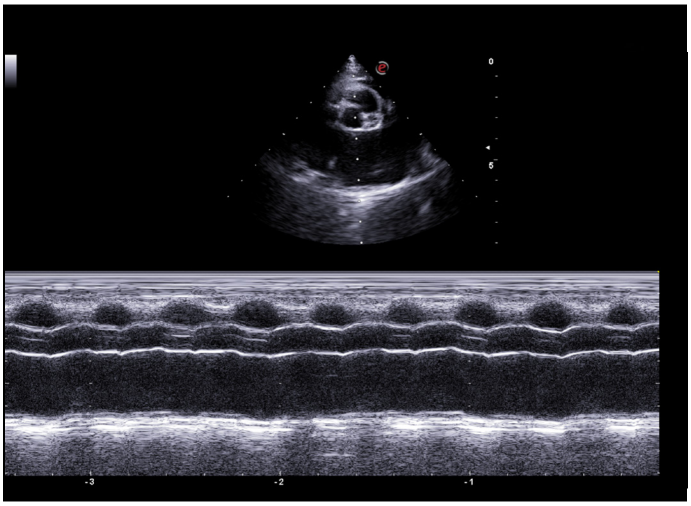


Fig. 27: M-Mode right parasternal window, short axis view optimized for the heart base.

In the cat, in this view, it is possible to use the M-mode method to evaluate the left atrial dimensions by measuring the left atrium-aorta ratio.

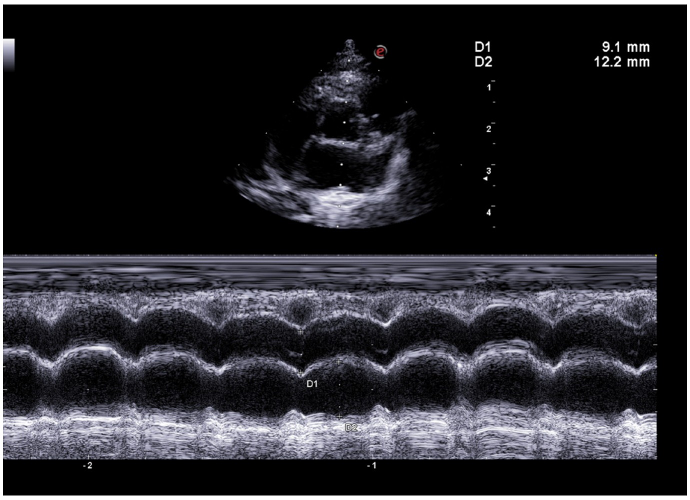



Fig. 26: M-Mode right parasternal window, short axis view optimized for the heart base.

Physiological condition.

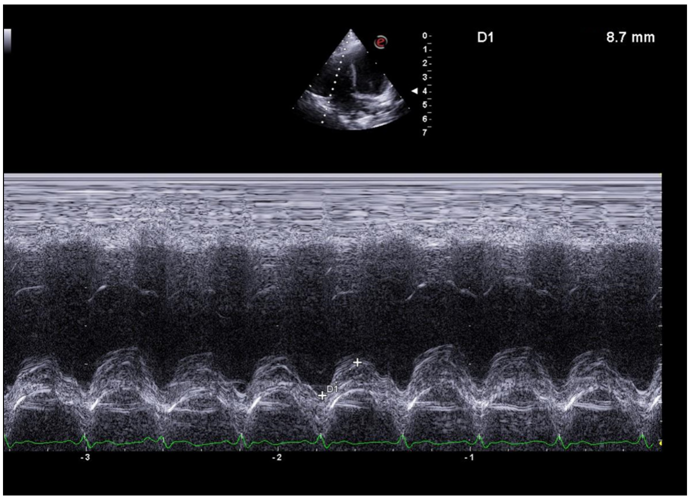



Fig. 28: Left parasternal window, apical 4-chamber view.

Using M-Mode, placing the line at the right ventricle free wall, it is possible to measure tricuspid annular plane systolic excursion (TAPSE), to evaluate the longitudinal systolic function of the right ventricle.

## CFM

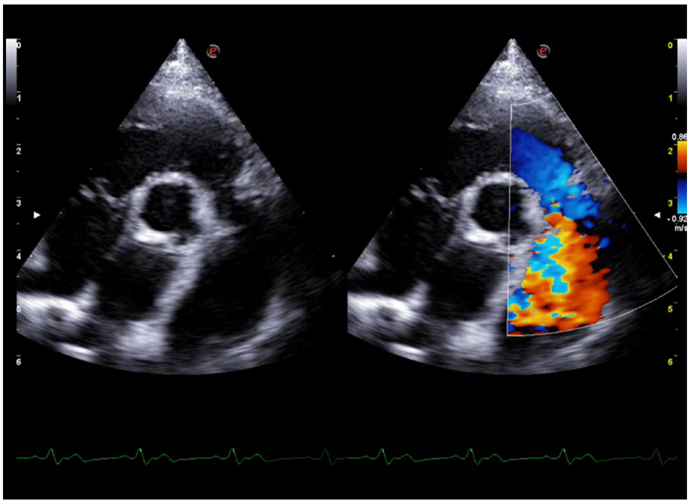


Fig. 29: Right parasternal window, short axis view optimized for the pulmonary artery.

B-Mode method associated with color Doppler in a dual color visualization makes it possible to observe a pathological morphology of the pulmonary valve.

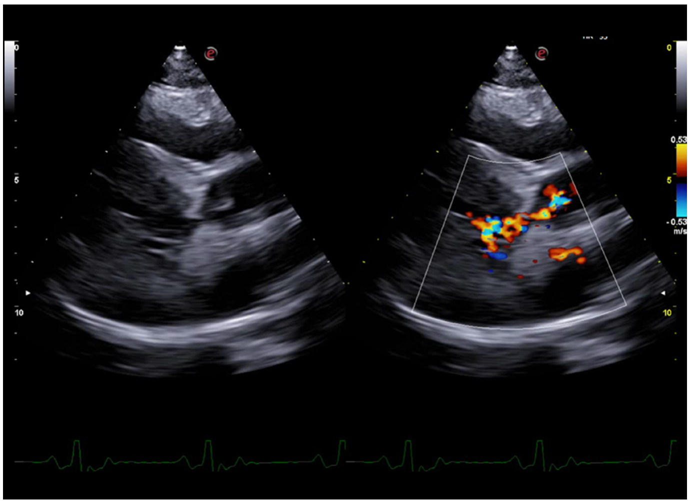


Fig. 30: Right parasternal window, long axis view, standard 2.

This view, optimized for the aorta, makes it possible to observe the left outflow tract in a patient with sub-aortic stenosis type 2.

The Dual Color visualization can highlight the morphology of the part and at the same time the turbulence of the flow at different stages of the cardiac cycle.

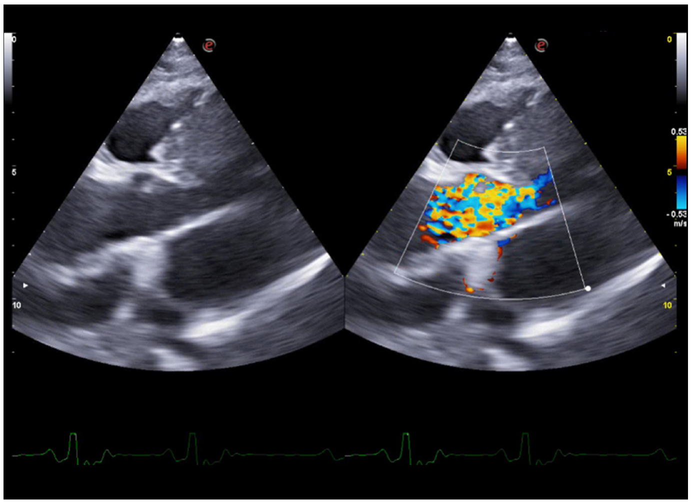


Fig. 31: Right parasternal window, long axis view, standard 2.

Similar observations in Figure 29. Patient with sub-aortic stenosis type 2.

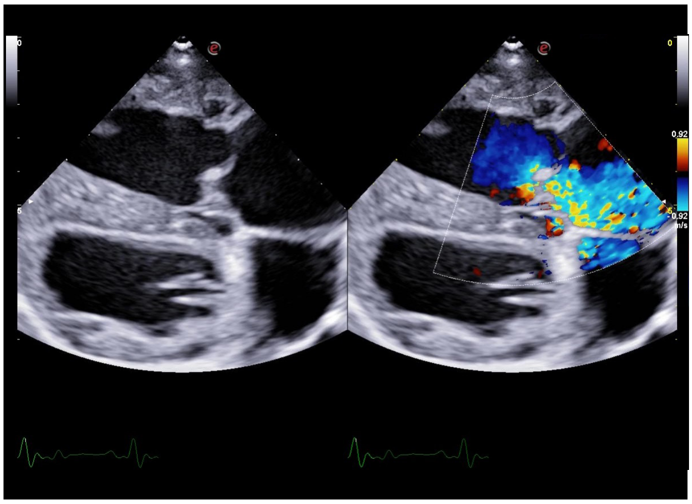


Fig. 32: Right parasternal windows, long axis view, standard 1.

With dual color visualization, tricuspid dysplasia is detected, which generates severe insufficiency, with regurgitation in the right atrial chamber.

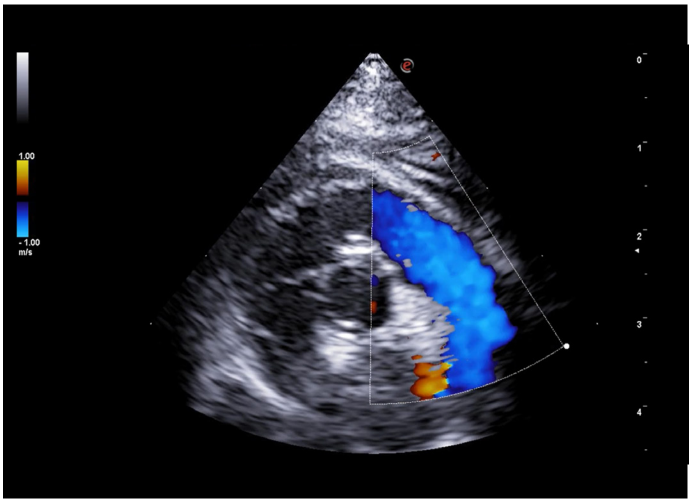



Fig. 33: Right parasternal window, short axis view optimized for the right efflux tract.

With Color Doppler, in this healthy patient, there is an anterograde laminar pulmonary flow.

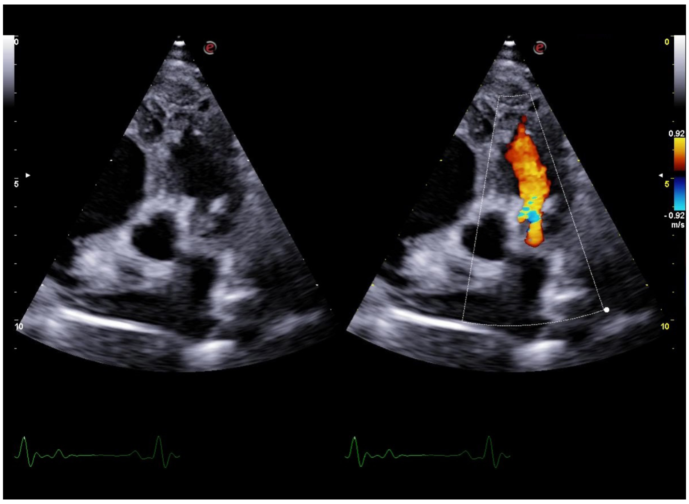



Fig. 34: Right parasternal view, short axis optimized for the pulmonary artery.

With Color Doppler, pulmonary insufficiency resulting from pulmonary valvuloplasty can be observed.

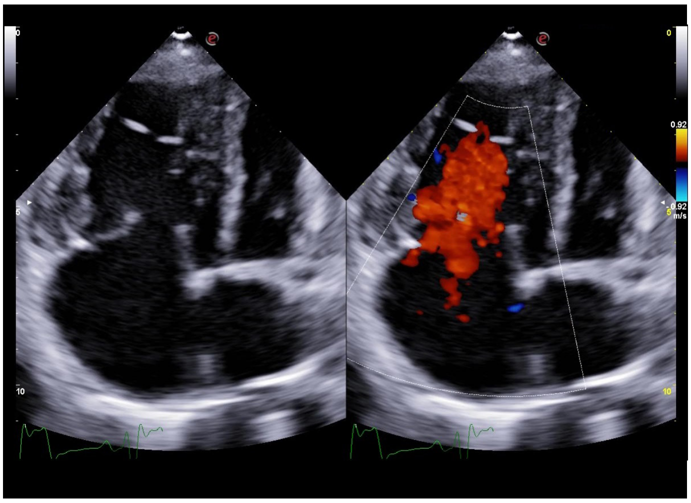



Fig. 35: Right parasternal window, apical 4-chamber view optimized for the right heart.

From this projection it is possible to observe tricuspid insufficiency with Coanda effect, along the wall of the interatrial septum, highlighted by Color Doppler, because of severe valve dysplasia.

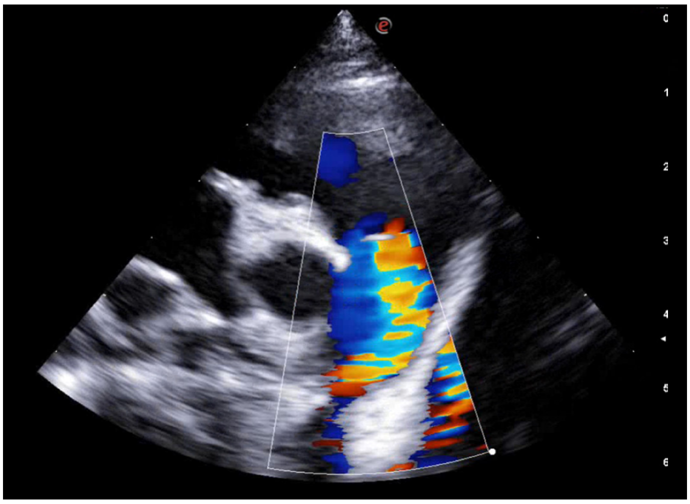


Fig. 36: Right parasternal window, short axis view.

A turbulence flow with left-right direction is detected with Color Doppler in the area of projection of the Botallo ductus arteriosus.

## PW

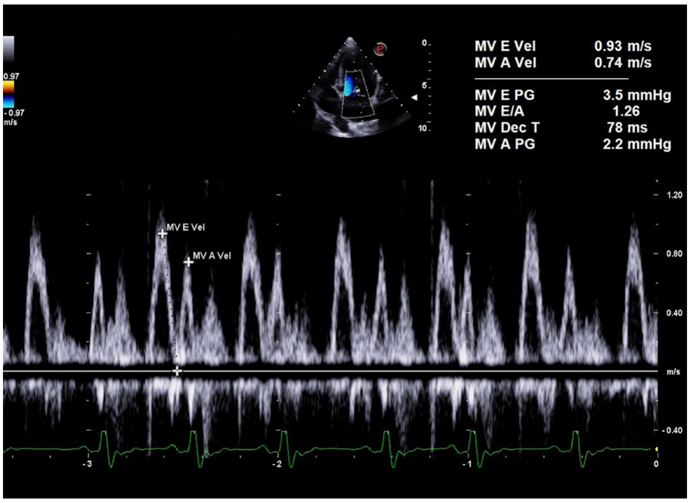



Fig. 37: Left parasternal window, apical 4-chamber view.

This projection, with Pulsed Doppler, makes it possible to study the trans-mitral profile by placing the sample volume at the mitral sub-bladder level. In the figure, a normal profile is observed in a healthy adult patient.

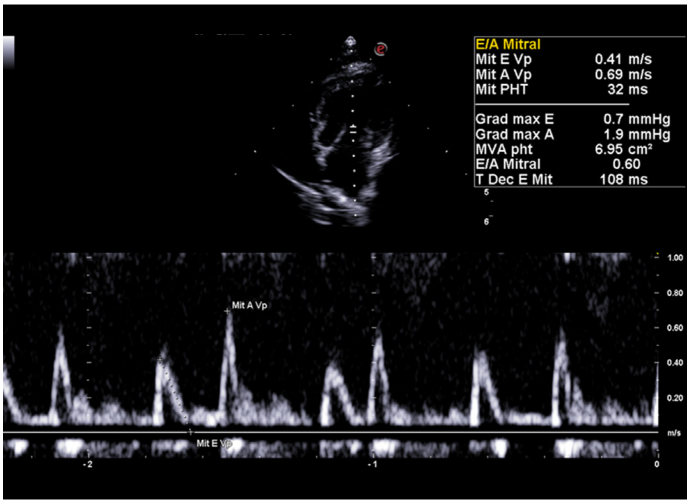



Fig. 38: Left parasternal window, apical 4-chamber view.

In this figure a trans-mitral profile with morphology to altered release is observed in a healthy elderly patient.

## TVM

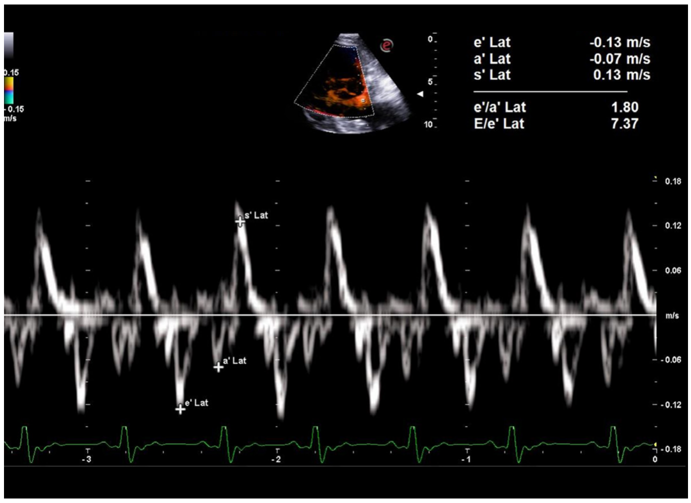



Fig. 39: Left parasternal window, apical 4-chamber view.

The Tissue Doppler examination of the left ventricular free wall presents a normal profile in a healthy patient.

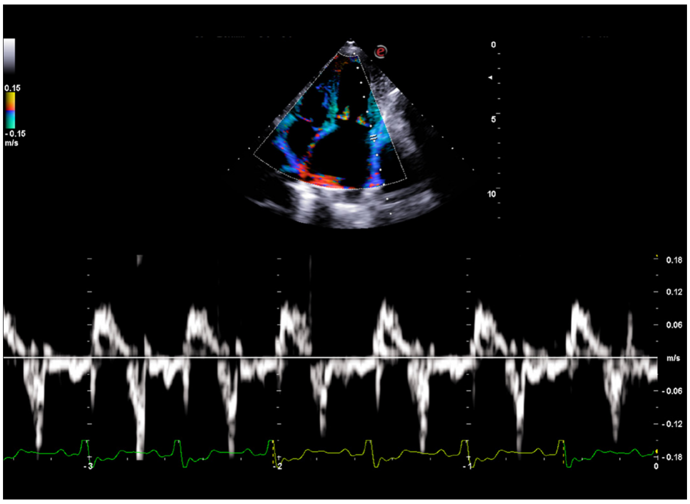


Fig. 40: Left parasternal window, apical 4-chamber view.

Patient with severe mitral insufficiency and severe left atrioventricular dilation. Tissue Doppler examination of the left ventricular free wall presents a restrictive profile.

## CW

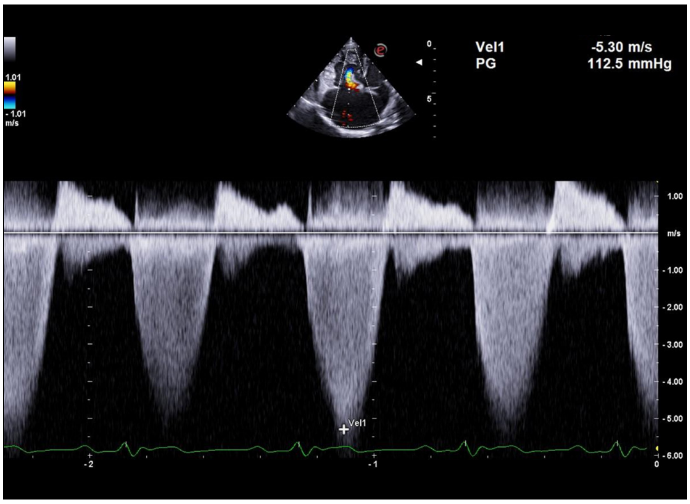



Fig. 41: Left parasternal window, apical 4-chamber view.

With Continuous Wave, a tricuspid regurgitation jet with a severely increased velocity peak rate is observed in a dog affected by severe type B pulmonary stenosis.

The increasing of the peak velocity is related to the elevated pressure in the right ventricle resulting from pulmonary stenosis

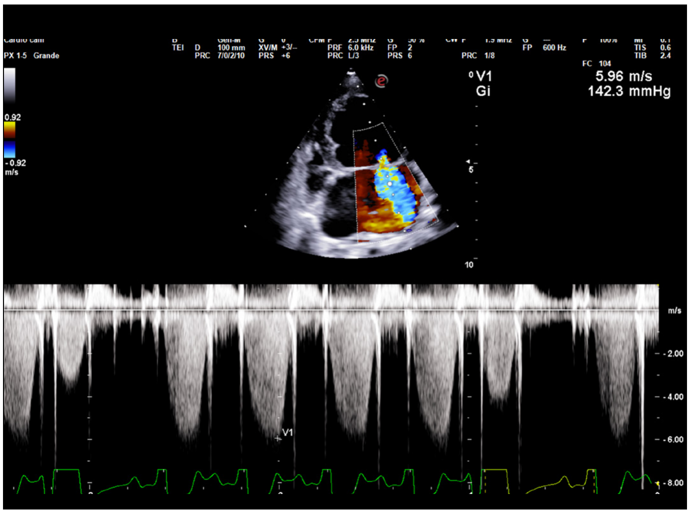



Fig. 42: Left parasternal window, apical 4-chamber view.

The Continuous Doppler signal of a large mitral regurgitation jet is observed in a patient suffering from degenerative mitral valve disease with severe cardiac remodeling. The regurgitation flow rate is reduced in conjunction with premature ventricular ectopic beats (indicated with an asterisk).

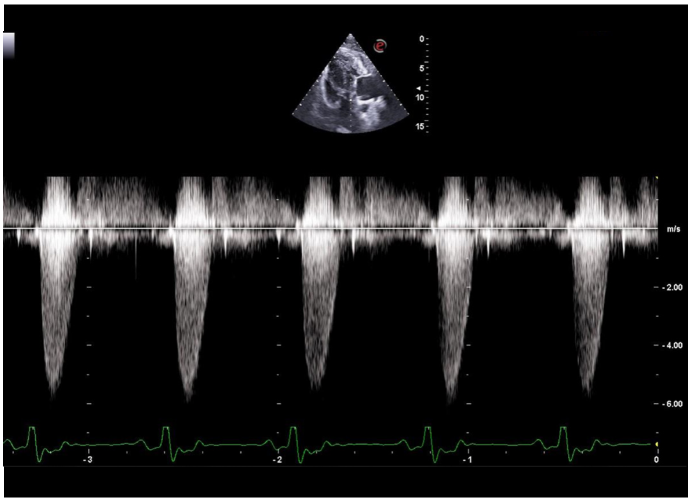


Fig. 43: Retrosternal window.

Continuous Doppler makes it possible to study flows characterized by increased speed; it is therefore, often applied in cases of valvular stenosis in order to assess the degree of severity of pathology.

The figure shows the aortic anterograde flow from retrosternal scanning in a patient with severe sub-aortic stenosis.

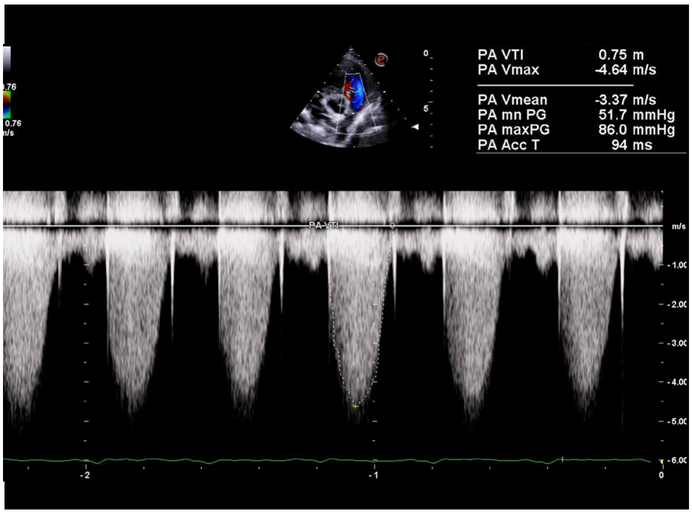



Fig. 44: Right parasternal window, short axis view.

In this figure, a pulmonary anterograde flow is examined in a patient with severe type B pulmonary stenosis.

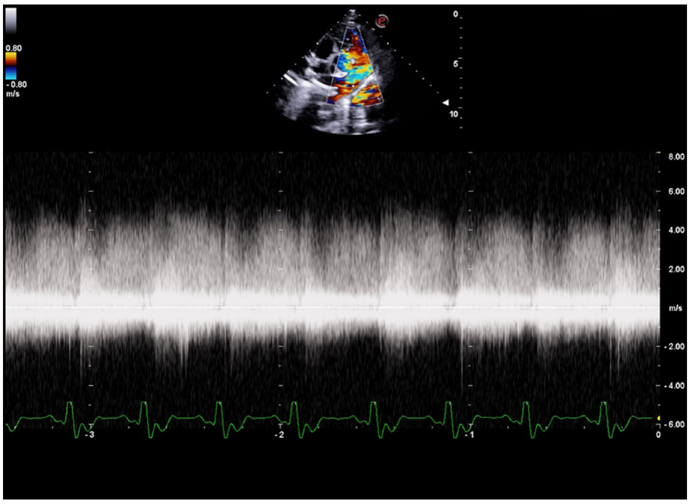



Fig. 45: Right parasternal window, short axis view.

The right short axis parasternal view is one of the projections where continuous Doppler enables the study of ongoing continuous flow of patency of the Botallo ductus arteriosus (PDA). In this way, the flow velocity can be studied and the left-right direction of the shunt is confirmed.

# Notes

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