Cardiac Ultrasound Online

'Mini Series'

Session 1: Getting Good Images and When Measurements Help (Or Don't!)

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Knobology – getting the most from your ultrasound machine to produce diagnostic echocardiogram

Echoardiography is now a key step in investigation of the majority of cardiac patients, and may offer useful information in other cases without cardiac disease. A key to being able to perform echocardiography is to be able to make the most of the equipment that you have available. Very few cardiologists would not like to have some additional echocardiography feature on their machine, or indeed a brand new "all singing and all dancing" machine. Very few have this opportunity and they have to get the best possible images from what is available, Nevertheless there are some basics without which effective echocardiography is very limited. So an appreciation of the physics of ultrasound and what different buttons, dials or settings on a machine do is essential. The practical application of the technique including such considerations as ambient temperature and lighting, echo tables, seating and patient preparation are also important. In addition, it is essential that we select the right patients for echocardiography and that it becomes part of daily practice to make full use of this technique.

Ultrasound has become a key tool in small animal practice over the last 20 years. In the last few years the acceleration in the level of technology available to veterinary practice has been dramatic. We now have passed the stage where just having a "veterinary ultrasound machine" is sufficient –technology has moved on, so if you have not looked at what is available in the last 2-3 years you may well have been left behind. However, while ultrasound does offer enhanced diagnostic capability to practices, there are limitations that need to be appreciated when considering what is right for your own practice. Key questions are:

- Is ultrasound economically viable for my practice?
- What equipment is appropriate?
- What are the advantages (and disadvantages) of ultrasound compared with radiography?
- Which cases would benefit from ultrasound?
- Do I have the opportunity to develop sufficient skill to make full use of ultrasound?

Economics:

The fees charged for an ultrasound scan obviously vary from practice to practice and depend on general overheads (staff, space etc), the costs of the ultrasound machine, the time taken for imaging and the level of expertise. Fees may vary from as little as £20 for a quick assessment to answer limited questions, to £200 or more charged by some practices with expensive equipment and specialist personnel. However, let us assume that a reasonable machine with single probe costs around £8000-10,000 with printer. The cost of leasing over say 4 years would be around £300 per month. If the average charge is £20-70, you would need to generate around 10 cases per month @ £30 to break even. For a fairly good machine with 2-3 probes expect to pay around £15,000. In our first opinion practice, with the case load of 4 full time first opinion vets, we typically generate 10-20 cases per week, excluding pregnancy scans. This may seem high numbers to many vets who are not in the habit of using ultrasound, but if these habits develop then the case load will mount. Once you start anticipating a case load of say 50 cases a month at an average of around £60 per case, the income of £3K per month or 36K per annum starts to make investment in equipment and the expertise to use it well worthwhile, quite apart from the benefits to your patients and clients. If you have a large small animal case load you are loosing a lot of money if you are <u>not</u> making full use of ultrasound. The key to the economics is that you develop your skills, **develop the ultrasound habit** and make full use of the equipment.

If you have a limited budget, consider investing in a machine with limited objectives. For example, in some of our smaller clinics we have a second-hand machine which cost under £5000, but which are quite adequate to answer some of the immediate questions of first opinion practice such as pregnancy diagnosis and dilemmas such as "is there a pyometra, is there ascites, is there a pleural effusion, is there a large splenic mass, is there a bladder stone"? While this may not be the complete story, it does aid decision making.

Selecting a machine:

There really key here is **image quality**. If you have limited space or multiple small clinics, you may need to invest in a portable machine. If you have one main base consider purchasing a fixed machine which will increase the scope for your to buy a machine with very good image quality. In mixed practice there is a temptation to share a machine with the equine or farm department; this will necessitate a minimum of 2 probes. As these may be more than half of the cost of the machine you are usually better off buying two separate machines each specifically designed for the job in hand. This allows a machine to be on site at all times, which is essential if your practice is to develop the ultrasound habit. You will need to consider what sort of transducer to purchase. Here there has been a rapid improvement in the types of linear array machines and there are few occasions in which I would now recommend a mechanical sector scanner (annular array mechanicals may be an exception). The scope of this article does not allow detailed discussion of probes and machines, but have a look at what is available and seek advice from colleagues with experience in the field. Buying a second-hand static machine may be a good option in some cases, allowing you to purchase machines with a better image quality than that available from portable machines of a similar price.

You should also consider how you can provide the right environment for ultrasound: you will need a quiet room which can be darkened, and a comfortable table with a cut out for echocardiography (it is essential to be able to scan from the underside of a recumbent animal). Have a stool or chair so that you can sit and spend the time necessary for a thorough methodical scan. Ideally have a separate ring main to avoid electrical interference.

What are the advantages (and disadvantages) of ultrasound compared with radiography?

Most of us were trained with radiography as our gold-standard imaging tool, and were taught relatively little about ultrasound. Ultrasound provides similar information to other imaging modalities, but has specific advantages and disadvantages. Like other techniques, it allows us to identify the size, shape, location and the number of different structures. An important difference compared with radiography is that US shows internal structure. This allows us to identify the anatomy of overlying soft tissue structures such as the liver and spleen. We learn to recognise the different organs through their characteristic structures including their echodensity (hyperechoic / hypoechoic), consistency (heterogenous / homogeneous), and outline (clearly demarcated / unclear, smooth / irregular). Ultrasound helps us distinguish fluid *v.s.* soft tissue structures (which have the same radiographic density). Typically most fluids are hypoechoic. Each normal organ will have a typical normal appearance and different disease processes will have specific (if sometimes variable) changes. Unlike radiography, with ultrasound we can assess the motion of organs. The obvious case is heart wall and valve motion. Assessment of bowel motion and the motion of fluids is also useful.

Ultrasound has the advantage of a lack of ionising radiation making restraint of patients easier. This also helps us to use ultrasound as a guide to biopsy tissues. Fine needle aspirates or trucut biopsies are a near daily occurrence in our first opinion practice.

However ultrasound is limited by its lack of penetration through bone and air and limited penetration through fat, which means that specific locations have to be used to see all internal organs, especially within the thorax.

Which cases would benefit from ultrasound?

The range of cases in which ultrasound may offer useful information is so wide that for those with good quality ultrasound machines and sufficient experience it is difficult to think of a day when ultrasound has not been essential to the management of cases. For those with a small case load and limited budget, you may have to have more limited ambitions. Some clinicians will have been deterred from using ultrasound because they feel that they cannot get to grips with Doppler assessment of congenital heart disease or identification of pancreatic disease. Don't be worried, identify the areas that you can use ultrasound for within your budget and expertise, and call for help from a visiting specialist or from a referral clinic when you reach the ceiling of your capability. Splenic tumours and pyometra are more common in general practice that porto-systemic shunts. Ultrasound will give you useful information in many first opinion cases and you do not need Doppler equipment or residency training for every clinical diagnosis.

Do I have the opportunity to develop sufficient skill to make full use of ultrasound?

You need to identify your objectives. Do not be put off by the fact that you have a limited skill base if you have the ambition and determination to improve. There is a high chance that, however much you do there, will be someone with more experience and expertise; but there are few areas of veterinary practice where this is not the case. You need to allow time to learn. Expect the cost of training courses, time off clinical work and buying reference texts to be at least half as much again as the cost of the equipment. Know your limitations and appreciate the advantages of the more detailed examination that may be possible through a colleague with more expertise and better equipment. But if you want your patients and your clients to have the benefits of improved diagnostic skills, if you want to advance you clinical satisfaction, and if you want to improve the profits of your practice, give detailed attention to the latest equipment that you could bring to your practice.

Understanding ultrasound physics and machines

How an ultrasound image is created.

- An ultrasound image is made of a series of lines. The closer the lines are together the better the detail

- An Ultrasound Pulse is transmitted and propagates through tissue at a speed of 1540M/Sec.

- An echo is created by any object, which the pulse interfaces to, with an amplitude relative to the tissue's density.

- Each level of amplitude creates a voltage by the Piezoelectric effect which is subsequently assigned a grey level.

- By mapping the grey level at all points within an imaging field a picture is created. **B-Mode : Brightness Mode**

- This is the term for the most common form of real time **2 dimensional imaging**

- Single frames (images) are acquired and played sequentially to present a moving Image

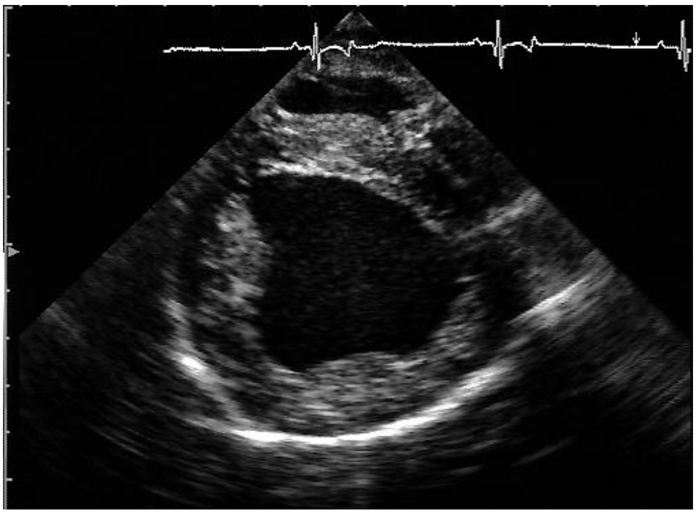
- The number of frames acquired per second is referred to as the "Frame Rate"

- Higher frame rates are required to clearly visualise moving structures

- 2DE images (B-mode)

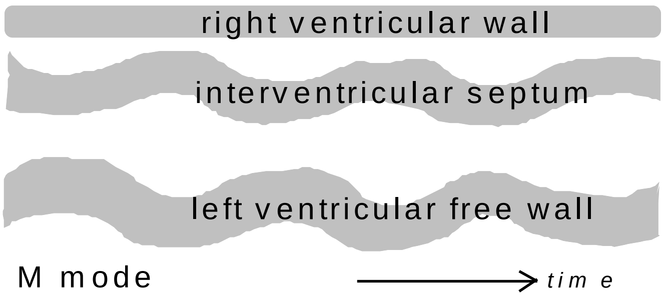
- swept in a sector from the small point at the chest wall

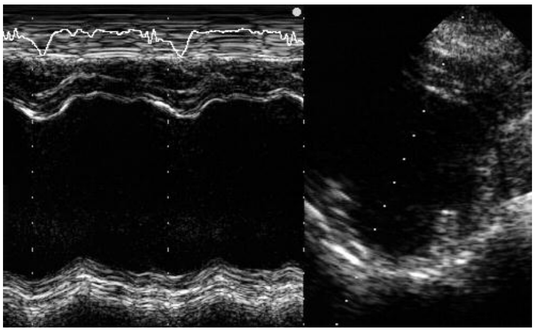
- "real-time" image, easier to understand and see structural abnormality



M-mode echocardiography (motion mode, or time-motion mode)

- beam is a "pencil-beam" of sound.
- Images are acquired in a single direction over a period of time, with echoes displayed on the screen on the Y axis, & time displayed on the X axis
- useful for measurements of cardiac dimensions and identification of motion abnormalities





Your choice of transducer and settings:

There will be a variable selection of probes suitable for your machine. They will not be interchangeable between manufacturer or often even between generations of machine from the same manufacturer. The more probes that you have the more chance of selecting the one for the best possible image from your subject.

You usually need to be constantly switching settings such as depth and focus and also changing probes to get all the information that you need from any one patient.

Transducer Frequency

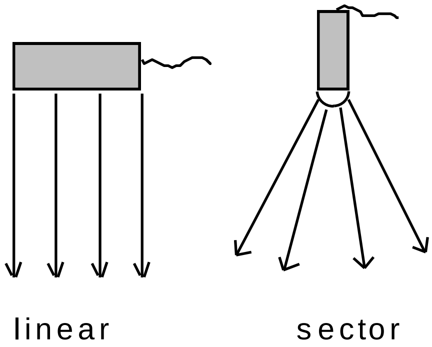
- High frequency (7-14 MHz) gives good image quality (high resolution because acoustic interfaces that are closely spaced can be distinguished)
- High frequency has low power so sound may not be sufficiently strong in deep tissue or where sound is attenuated e.g. by fat.

Transducer type

Broadly, sector probes produce a triangular wedge of image while linear probes produce anything between a rectangular view and a near sector image. The wider the sector the more the lines of the image diverge so poorer detail in the far field.

Probes can also be mechanical or electronic. Some electronic machines are digital and some are analogue.

Don't be swayed by words like digital, lots of measurements and bells and whistles when chosing an ultrasound machine, by the best one that you can afford with a range of probes based on **IMAGE QUALITY**



<u>Mechanical Sectors</u>

- Low technology, low cost
- Fixed focal point
- Good imaging at the focal point/ zone
- Poor imaging outside the focal zone
- Susceptible to mechanical failure but can sometimes be repaired
- Poor Colour Doppler performance

<u>Linear Arrays</u>

- Medium technology, medium cost
- Variable focal point
- Good imaging throughout depth
- Excellent for superficial imaging
- Field of view at greater depths is limited
- Good Colour Doppler performance to low velocity blood flow

Curved Arrays

- Medium technology, medium cost
- Combine the advantages of the Linear arrays and Mechanical sectors
- Lateral resolution decreases as the curvature of the probe gets tighter

Electronic Phased Array sectors

- High technology, High cost
- Quality is proportional to the number of channels employed by the system. More channels = more cost = higher quality
- Allow very high frame rates and good access
- Excellent Doppler sensitivity to High and low velocity blood flow

Transducer footprint

The term footprint refers to the area of the probe in contact with the animal, so for example a curvilinear probe will have a large wide footprint while a high frequency phased array probe will have a small footprint. A wide footprint gives a wide near field but is more difficult to position in small gaps like rib spaces.

Power

- Amount of energy of the outgoing signal
- Usually mid-range
- Will want high end of range for Doppler

Gain

- Amplification of the returning signal

Time gain / depth compensation

- Sliders or regional dials to alter the amplification of the returning signal to allow for increased absorption of sound energy at increased depth
- more important in a fat abdomen than a heart

Frame rate

- Sound has a given speed in soft tissue
- image is constructed of a series of lines

- number of lines is limited
- by depth of image
- Width (angle) of sector

Post processing

- Range of contrast. For echocardiography set so that have a very black and white image, this lacks the grey scale subtly required for abdominal imaging where tissue texture is important

Edge enhancement

- Changes in acoustic impedance are amplified to help define endocardial borders i.e. useful for cardiology (and some tendon scanning)

Frame averaging (sometimes called persistence)

- Increased image detail by summating two sequential frames into one:
- increased detail
- halves the frame rate

Focus

Mechanical sector probes have a fixed focus. Annular arrays and electronic probes have a variable focus. It is very important to make sure that the focal zone is set in your area of interest. On some older machines the way round this was to use a standoff to throw a near field structure further from the probe into the focal zone

More modern machines may allow you to have multiple focal zones which can be useful for good image detail but markedly reduces frame rate

SMALL ANIMAL ECHOCARDIOGRAPHY

Principles of echocardiography

It is no exaggeration to say that echocardiography has revolutionised veterinary cardiology. In human and small animal medicine, radiography and electrocardiography provide useful information about cardiac chamber size, but echocardiography is much more accurate in identifying chamber enlargement and allows identification of the causal disease rather than trying to deduce the cause from its effects on cardiac outline complex size or MEA. Echocardiography is a non-invasive and can be performed in animals that are too distressed and compromised to be suitable for restraint for radiography.

Ultrasound machines are now relatively commonplace in small animal practice, although not all machines are well suited to echocardiography. Even if you do not access to ultrasound, it is essential to appreciate the uses of the technique, so that animals can be referred when appropriate. In addition, anyone with an interest in cardiology should be encouraged to see real-time echocardiography because it provides a clearer understanding of cardiac anatomy and function in normal and diseased animals than is possible from clinical examination and reading of literature alone.

2DE and M-mode echocardiography

The heart is an excellent subject for ultrasonography because of the contrast between hypoechoic blood and relatively hyperechoic myocardium and valves. However, ultrasound does not pass through air or bone, so the ultrasound beam must be aimed through gaps (acoustic windows), to produce images of the heart.

M-mode echocardiography and two-dimensional echocardiography (2DE) are to produce images of the heart in real-time. In **M-mode** echocardiography (motion mode, or time-motion mode), the crystal is stationary and the beam produced is a "pencil-beam" of sound. Echoes are displayed on the screen on the Y axis, with time displayed on the X axis. This produces an almost continuous image of the position of the cardiac structures that are in the line of the beam and is useful for measurements of cardiac dimensions and identification of motion abnormalities.

2DE images (B-mode) can be swept in a sector from the small point at the chest wall, fanning out within the heart, to produce a "real-time" image. 2DE images are more easily understood than M-mode traces because of the greater spatial detail. A comparison has been made between the two techniques and different ways of illuminating a room. M-mode is the equivalent of looking round a dark room with a narrow beam torch. 2DE is the equivalent of using a flood light.

Doppler Echocardiography

Doppler echocardiography is used to provide information about blood flow, following evaluation of the structure and the size of the heart using 2DE and M-mode studies. A thorough Doppler examination requires rigorous technique and is extremely time consuming. Colour-coded Doppler reduces the time required for Doppler examinations and makes them easier to perform, but has the same physical limitations and is extremely expensive. Doppler is most useful in animals with congenital heart disease, when it can be used to quantify the effects of disease. It can also be used to identify and then to "map out" jets of regurgitant blood (and the area of the origin of the jet) as a rough guide to the severity of the valvular incompetence. The use of Doppler has largely removed the need for cardiac catheterisation.

Indications for echocardiography in small animals

The decision to perform an echocardiogram is usually made to:

1. Investigate the source and the significance of a cardiac murmur
2. Investigate underlying heart disease and the effects of a cardiac arrhythmia
3. Identify the presence and significance of myocardial disease
4. Identify the presence, significance and cause of pericardial disease
5. Investigate unexplained ascites or pleural effusions
6. Investigate unexplained recurrent pyrexia

In small animals cardiology, the most common abnormality is acquired mitral valve disease in dogs. In this disease, radiography is usually more important than echocardiography as the clinical presentation (usually coughing), physical findings (murmur and strong apex beat), age and breed of dog is often sufficient to make a presumptive diagnosis and radiography allows assessment of pulmonary congestion and oedema, and a fairly accurate assessment of left atrial size. However in **all cats with murmurs**, and **animals with arrhythmias** or the suspicion of **myocardial** or **pericardial disease**, and animals with suspected **congenital heart disease** (CHD), it is difficult to do justice to the case without echocardiography.

By far the most common of these is investigation of the source and, even more importantly, evaluation of the significance of a cardiac murmur. Although echocardiography, especially Doppler, is helpful to identify the source of a murmur, in particular whether a murmur is functional or is related to cardiac disease, the main purpose of echocardiography is to assess

the effects of the disease. The most significant feature is measurement of volume overload which results from valvular regurgitation.

Practical use of echocardiography

Echocardiography is a skill which must be learned and for which there is no substitute other than practice. However, it is important that even the most experienced echocardiographer follows a standardised examination technique so that oversights are avoided. The examination is facilitated by effective restraint of the animal and thorough patient preparation.

Most animals accept the feel of the transducer after a few seconds. It is important that animals are treated calmly so that they become used to the presence of the echocardiographer and equipment; excitement induced tachycardia will not help assessment of the examination. Sedation is best avoided if at all possible. In particular, alpha-$_2$ agonist sedatives such as metedetomidine profoundly reduce contractility.

In most animals it is easier to obtain a good image if hair is clipped from the axillae, before coupling gel is applied to produce good contact between skin and transducer. If owners insist that their animals are not clipped, the hair can be thoroughly soaked with first sprit or soap and water, and then with gel, but the results are unlikely to be as good as with clipping.

The Echocardiographic Examination

M-mode echocardiography can produce an infinite number of one-dimensional "ice-pick" views of the heart; 2DE can produce an infinite number of image planes. There is therefore a need for standardisation of beam position to aid recognition of landmarks and facilitate communication between workers. In quantitative studies, regardless of the type of measurement, a **standardised approach** is needed so that accuracy and reproducibility are optimal. This will allow consistency of method so that measurements can be compared to established normal ranges. Meticulous attention is required in order to obtain correctly oriented imaging planes in relation to internal landmarks. In clinical situations, planes of view can be "lesion oriented", but if this approach is adopted exclusively, abnormalities may be missed. A standardised examination procedure should therefore be followed routinely.

The orientation of M-mode views is traditionally directed by recognition of the characteristic motion of valves and chamber walls and a knowledge of cardiac anatomy, imaged from a fixed transducer location. However, most machines allow the M-mode cursor to be positioned on a 2DE image in order to facilitate identification of landmarks for M-mode imaging. Measurements can therefore be made directly from the 2DE image, or from guided M-mode traces.

For optimal image quality, it is important that the gain and post-processing controls are suitably altered. For echocardiography, the settings are usually quite high because identification of the endocardial borders and the valves is more important that fine detail of myocardial texture. This is the opposite of the situation in ultrasonography of most soft tissue structures such as the liver.

Imaging planes and transducer position

A number of standardised views for 2DE and M-mode imaging have evolved. It is helpful to obtain these views before looking specifically at structures of special interest by angling, rotating or moving the transducer to image lesions. The best 2DE and M-mode images are obtained when the beam is perpendicular to the reflecting surface. Doppler echocardiography requires that the beam is in line with blood flow. This can be difficult or impossible to obtain because of the limited acoustic windows.

Transducer positions required to obtain specific views can be guided by internal cardiac landmarks or the position of the transducer on the chest wall. The transducer needs to be located in the correct position and then angled and rotated to different degrees to obtain the standardised image planes. The transducer location is defined as left or right parasternal, ventral or dorsal and cranial or caudal.

In order to be sure of the position of the ultrasound beam in relation to one's hand, it is helpful to place one's thumb on the guide-mark on the transducer so that the plane of the beam runs parallel with the palm of the hand. With most machines, if the guide-mark and the thumb are positioned dorsally, dorsal structures are displayed on the right of the screen. Convention also dictates that cranial structures are displayed on the right of the screen in short-axis views.

Measurement of cardiac dimensions

Published normal ranges for measurements are now available. The data is shown in the tables. The most useful measurements are of LV, interventricular septal and left ventricular free-wall thickness and LA diameter, although LAD cannot be measured with as much accuracy as LVD. RV diameter, wall thickness and RA size has to be assessed subjectively, with the aorta acting as a useful guide for comparison.

Fractional shortening

The most commonly used echocardiographic parameter of ventricular performance is fractional shortening (FS%); which is calculated from the formula:

$$FS\% = 100 \times \frac{LVDd - LVDs}{LVDd}$$

where LVDd = left ventricular end diastolic diameter & LVDs = left ventricular end systolic diameter, both measured across the major axis of the LV at the chordal level.

Fractional shortening is used as an estimate of myocardial contractility. However, this is only a guide. In particular, excitement may result in an increased FS% as a result of catecholamine release. Valvular heart disease will affect ventricular function before any change in myocardial contractility occurs. For example, mitral regurgitation will result in a decreased afterload because it acts as a "let-off valve" during systole. In addition, if the valvular disease is severe enough to have resulted in volume overload, preload may be increased. These factors increase FS% by decreasing systolic dimensions and increasing diastolic dimensions respectively. Once myocardial failure develops, FS% will fall.

Some ultrasound machines have software which can calculate stroke volume and ejection fraction from echocardiographic measurements. Unfortunately, these estimates are only as accurate as the original measurements, and depend on the use of appropriate formulae. They should not be regarded as accurate measurements, but may be a helpful guide in some circumstances.

Why does the heart look like it does?

Blood flow goes in predictable directions because of pressure gradients. The chambers need to receive blood and pump it on, with the valves prevent backward flow. At the time of filling the pressure needs to be higher in the delivery chamber than in the receiving chamber. Disease processes can affect the ability of the delivery chamber to pump or of the receiving chamber to relax and to stretch to accommodate infilling blood. Preload, afterload, myocardial contractility and heart rate also affect these processes

To understand cardiology, and to appreciate why the heart looks like it does, I is important to know the pressures that we would expect within the cardiac chambers at the different stages of the cardiac cycle. We express these in mmHg.

Chamber	LV	RV	LA	RA
systole	120	30	6-10	3-4
diastole	-1	-1	0-6	0-4

Interestingly if you look up these figures in physiology texts you will find different numbers reported in each, these figures here are approximations based on different sources

Taking into account these pressures, we can see that the LV is a high pressure pump as reflected by piston shape and thick walls. While the LV is a high pressure chamber, it will respond to different forms of load in different ways. If there is increased volume filling the LV it will dilate, with an increase in wall mass to reduce wall stress such that the wall thickness remains in proportion to the LV diameter. This is known as eccentric hypertrophy. When faced with a pressure overload the wall tension is kept at normal values by an increase in wall thickness and in LV mass, in a similar manner to other muscle that is stressed in an isometric manner. This is known as concentric hypertrophy. In addition different diseases may cause abnormal wall thickening through primary or secondary trophic effects as seen with hypertrophic cardiomyopathy.

The RV is a bellows shape rather than a piston and is not suited to such high pressure as the LV, so when it is subjected to a sudden increase in systolic pressure it will dilate to a degree as well as responding to reduce wall tension by hypertrophying. However if the pressure overload occurred in the fetus, when PA pressure is normally high, then the stimulation can cause RV hypertrophy without dilation

The atria are thin walled structures which are not designed for high pressure and when faced by an increase in pressure (and to a lesser degree volume) will dilate. Since many diseases either result in mitral regurgitation or abnormal relaxation and filling of the LV with an increased filling pressure, LA enlargement is a salient finding in many conditions and the degree of dilation reflects the severity of the mitral regurgitation or the diastolic dysfunction.

Echocardiography – avoiding pitfalls and understanding measurement error

Echocardiography is now a daily event for many people interested in cardiology, indeed some will perform multiple echocardiograms every day. However it is easy to be either blasé and complacent through repetition, or daunted, depending on your level of experience. In either situation it is useful to take a broad view and review what information we want to get from our echocardiograms and how accurate our measurements are. This helps us to make more accurate measurements and also to interpret the results appropriately.

This review aims to remind us where errors can occur. Common sources of error are highlighted. The review will take at times a philosophical view as to what measurements actually mean and how they help us with our patients or research.

When we perform an echocardiogram we can make subjective and objective observations. Objectivity is a great asset of echocardiography - it allows us to make measurements of cardiac dimension and indices of function. However accurate technique and subjective assessment requires both rigorous technique and experience. Additionally, the production of numbers (with any quantitative technique) is hazardous for the discerning clinician if the numbers are inaccurate or inappropriately applied. In addition, the margins between normal and abnormal are subtle or blurred in many cases and we need to be aware that making black and white decision when measurements are in the grey area is hazardous.

We need the measurements to be <u>accurate</u> (i.e. bear close resemblance to the real dimensions) and repeatable (= consistent, reproducible). We need to understand where any lack of repeatability results from (e.g. it could be real biological variation, it could be an ambiguous protocol, it could be skill or unavoidable difficulty getting the correct image plane, could be cursor/calliper placement).

Sources of variability in echocardiography:

- We want to identify real biological changes from normality.
- Any measurement technique has noise and we need to distinguish this from real change.
- We need to know what normal is.
- We need to know what information we want.
- We need to know what is relevant to this patient
- We need to know what is relevant to our studies

For example, a small variation in E:A ratio, or FS% may be important in a study of a large number of animals but not in an single study in an individual animal. Do not be tempted to generate vast amounts of numbers unless they help you to manage the patient (and do not compromise the patient).

Sources or difference in measurements within the population.

Different cardiac dimension and indices of function will be found in different individuals. This can result from

- Different species, breed, age, sex, body weight, body condition
- Exercise training (e.g. fly ball dogs, elite equine athletes)
- Cardiovascular disease
- Systemic disease
- Drugs
- Changes in sympathetic tone (excited, asleep)

Within the individual

Different cardiac dimension and indices of function will be found in the same individual under different circumstances. This can result from

- Cardiovascular disease (our principle interest)
- Systemic disease
- Drugs
- Body position
- Phase of respiration
- Changes in sympathetic tone (excited, asleep)
- Diurnal rhythm, feeding, pregnancy?

The loading conditions of the heart are one of the principle factors affecting measurements. Whenever we perform an echocardiogram we should be considering these issues which will affect the measurements that we make:

Preload: the force distending the ventricles

Increased by:	volume overload conditions (MVD, TVD, AR, DCM, PDA, VSD etc)
	Fluids, pregnancy, abdominal pressure
Decreased by:	Pericardial effusion with tamponade
	Volume depletion
	Some drugs (eg frusemide, nitrates)

Afterload: the force against which the ventricles eject blood, principally dependent on the systemic resistance and wall stress

Increased by: hypertension, increased sympathetic tone, some drugs, hypoxia

Decreased by: mitral regurgitation, vasodilation, some drugs including many sedatives

Contractility: the ability of a given fibre length to contract

Increased by: changes in myocardium itself (e.g. training?)

Decreased:myocardial disease, some drugs

The force of contraction is not only dependent on contractility. Afterload and preload have profound effects.

Heart Rate: this will affect all of the above. Marked bradycardia or tachycardia will have a profound effect on cardiac measurements

Other technical issues will also affect our ability to make accurate measurements within the individual.

Equipment factors:

<u>Factors that you will most likely be unable to change</u>: Make, transducer frequency, monitor, off line measurement, callipers, calibration (machines should be calibrated *v.s.* a phantom)

<u>May be able to alter</u>: transducer frequency, frame rate, gain, post-processing

Performing the echocardiogram:

How we perform the echocardiogram is the essential step in getting useful (and avoiding misleading) information

Echo Technique:

A suitable echo table is essential to allow the animal to lie comfortably on its side. It may take a few minutes for the image to become optimal (for the acoustic window to enlarge as the lungs collapse, for gel to soak in). A good echo also required the animal to be adequately restrained, for lighting to be appropriate, and for the echocardiographer to be comfortable.

Know the limitations of your equipment – select the best probe and settings

Preparation for the echo:

Assess the patient – how will this affect the echocardiogram

Species, breed, age, size (fit the table) obsess/thin, degree of excitement

Should we **sedate** or not? If so - with what (I try to echo everything unsedated if only for a quick subjective look before using low dose sedatives if necessary. Sedative affect measurements but so does stress).

I use tiny doses of Acepromazine 0.02 mg/kg (or less) and buprenorpine 0.0075 mg/kg or Acepromazine 0.02 mg/kg (or less) and butorphanol 0.1 mg/kg IV for dogs, acepromazine 0.1mg/kg / butorphanol 0.25mg/kg or 0.25 mg/kg midazolam & 5.0 -7.0 mg/kg ketamine IV for cats.

Any sedation does affect measurements and it may be difficult to appreciate how much (or what) effect is due to the drugs; however a moving target and excitement also has important effects.

Initial subjective impressions:

Is the acoustic window what you would expect (will be affected by position, breed, lung disease).

Is there anything in the chest which should not be there (pleural effusion, mass, bowel, abnormal lung)

Is motility normal, are there regional differences

Are the chambers and wall thickness in proportion?

Are any structural defects seen?

Is the shape of the ventricles normal?

Quantitative assessment:

A consistent methodology is essential. This requires considerable practice. The echocardiographic measurements will depend on the:

- Protocol for imaging follow a/the standard procedure
- Image plane hand/eye/heart coordination
- Image / Frame selection which image is the best to measure
- Landmark selection what fits the criteria. This depends on:
- Timing identification end diastole / end systole. Use an ECG to be accurate except in extenuating circumstances when it may hinder the scan

- Border identification M-mode generally leading edge to leading edge. Less relevant these days as endocardial bloom is less of a problem. Border ID is often more difficult with 2DE and when the endocardium is parallel rather than perpendicular to the beam
- Positioning of callipers

Data collection. Often machines will do this but this can lead to error if you fail to spot the garbage in which leads to garbage out. Think – is this measurement likely to be real?

- Correct maths
- Suitable statistics - is there a suitable normal range comparisons for the species, breed or size of your patient. This is still a deficiency in the data available
- Remember that 5% of the normal population will fall outside of typical normal range (95% confidence limits)
- If a body weight norm appropriate linear measurements may be better measured vs linear e.g. height, volume measurements best compared with weight. Breed vary widely. Comparison with other baseline structures (eg aorta) may be better still (similar to concept of Buchanan's Heart Sum for heart size on radiographs).

Interpretation of results.

No echocardiographer has perfect echocardiograms in every case – rest assured that you are not the only one that struggles with some cases. If the echo is imperfect consider what effect this will have on measurements. It is possible that in some patients **you will be better off not making measurements if your image is substandard** for any reason. Wrong measurements are dangerous. It is better to rely on subjective assessment in these cases.

Common pitfalls for core measurements:

Left ventricular diameter (LVD) and wall thickness

M-mode guided from a 2DE short axis view is the traditional method because it is not limited by frame rate so it has very good temporal resolution and border identification is easier. It is possible to make measurements from 2DE.

- Cursor incorrectly placed (too lateral or obligue), not a true cross section, too basal or apical, timing.
- It is not always possible to get good measurements – may be very difficult if there is right-sided overload, a flapping IVS, dyskinesis, panting, lung interference affecting image plane.

Other ways of measuring LVD

- 2DE, limited by frame rate unless ECG synchronised and border ID more difficult, however may be suitable in some cases especially those with regional wall abnormalities
- off a long axis view – seems easier but that is because it is less exacting. Not the same as more accurate or repeatable.

In most studies LVD measurements are very repeatable and therefore reliable. This is especially true in horses (slow rate, big structure) c.f. smaller animals where a 1 mm calliper placement error makes a big difference. Wall measurements are considerably less repeatable.

Right ventricular and right atrial measurements

It is difficult to get reliable measurements of the RV diameter or wall, or RA, so be very cautious about subtle changes. This is due to poor landmarks to make consistent image plane, near field clutter in right parasternal views, trabeculation, small measurements.

Left atrial size:

There is debate about which method is best. The Tufts/Uppsalla 2DE method (short axis) is now widely used but no definitive method accepted. Producing a ratio to aorta root size is standard (the original M-Mode method was obtained with the cursor bisecting the aortic root, however this method is well known to be insensitive for LA dilation because it goes through the LAA rather than the body of the LA). Lung interference, oblique angle of inception and failure to identify pulmonary vein ostia are common causes of inaccuracy.

Identification of left atrial enlargement is a critical finding in many of the conditions that we see. Spend a long time getting this as good as possible rather than measuring less repeatable and less informative measurements even if they are trendy and exciting.

Fractional shortening:

- There is often a misconception of what this measurement actually means. It is markedly affected by mitral regurgitation as well as other factors affecting afterload, preload and contractile function. FS% ≠ Contractility
- Ratios are always more dangerous as error is potentially amplified
- FS% is derived from one plane and this will not reflect regional wall variation. This is particularly problematic in cats.
- Wall thickening fractions are to be regarded with caution (smaller measurements are even more liable to profound changes in %ages)

End point to septal separation (EPSS):

This can be a very useful measurement but is not free from error. Oblique planes through the AML will result in artefactually increased EPSS. Cursor positioning to one side of midline can give falsely low measurements

Substantial CV% even in expert hands

Be cautious about how much each measurement will affect how you manage a case.

Summary:

1. Practice your technique because obtaining the correct image planes and identification of landmarks is the critical step
2. Think about what features of the patient will affect the measurements that you make.
3. Objective is not always “better” than subjective – they are complimentary
4. Decide which measurements will actually help you manage the patient. More numbers is not necessarily a better study.
5. Always consider the possibility that the numbers are wrong – and what the implications would be. Don’t just look at the numbers in isolation.

Features of an Ultrasound Machine suitable for Echocardiography

- Sector scanner (or some curvilinear small head) transducers. These days most will be phased array, some still have mechanical probes.
- Must have facility for M-mode echocardiography, ideally with different sweep speeds and easy switching from 2DE to M-mode without the need to go through a menu
- Frequency can vary from 15 MHz for cats to 2.5-3.5 for big dogs, depending on manufacturer. This will also depend on the fatness of the animal and chest wall thickness and the need or not for Doppler (which is best performed with low frequency probes)
- Table for examination, this is really essential in most cases
- ECG display to allow accurate timing of events
- Measuring software
- Doppler (stearable CW, stand alone CW, pulsed-wave Doppler, colour flow Doppler). There are many machines which have colour flow Doppler but which are not suitable for echocardiography, rather the colour is good for low velocity flow such as that in peripheral vessels and in abdominal organs
- High quality video recorder / other recording devices, these days often there is a hard drive archive which can be linked to a USB memory stick or hard wired with a DICOM network to a database

- Other additional features are Anatomical or Compass M-mode (terminology depends on manufacturer), harmonic imaging, tissue Doppler imaging, strain measurements and a variety of off line analytic packages. All of these have a role and can be very helpful

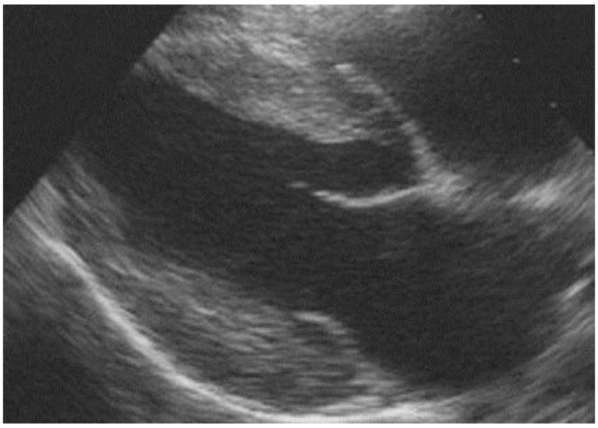
THE ECHOCARDIOGRAPHIC EXAMINATION

Preparation

- Consider suitable restraint of the animal (try careful manual restraint, but if going to sedate do not use A2 agonists like domitor which have a profoundly negative inotropic effect). Try low dose of ACP and buprenorphine. Be more cautious if checking for DCM or pericardial effusions
- Clip hair from the axillae except in very fine haired animals
- Clean dirt and grease away with spirit or with soap & water
- Apply acoustic gel
- Attach the ECG clips
- Select cardiac presets if applicable, sector angle, depth, +/- line density
- Alter the gain settings and post-processing as appropriate

Examination

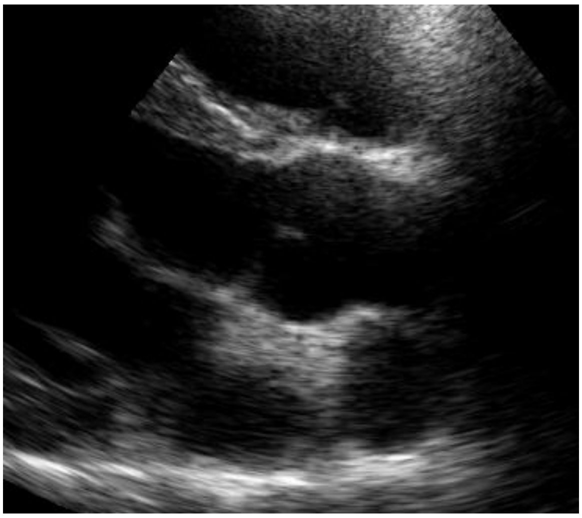
Start with **right parasternal long-axis view optimized for the left atrium**



Assess: image quality, must be adequate for thorough exam
overall size and shape of left ventricle
overall size and shape of right ventricle
overall size and shape of right atrium
IVS especially just below the aortic root (site of most VSDs)
tricuspid valve structure
mitral valve structure
relative size of aorta, LV and left atrium
aortic valve and aortic root structure
LV, IVS, mitral valve and aortic valve motion

Doppler examination of tricuspid flow

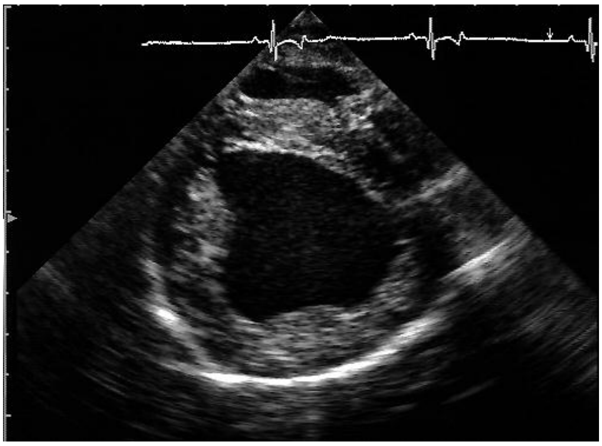
Angle cranial and dorsal and rotate slightly to optimise for **aortic outflow**:



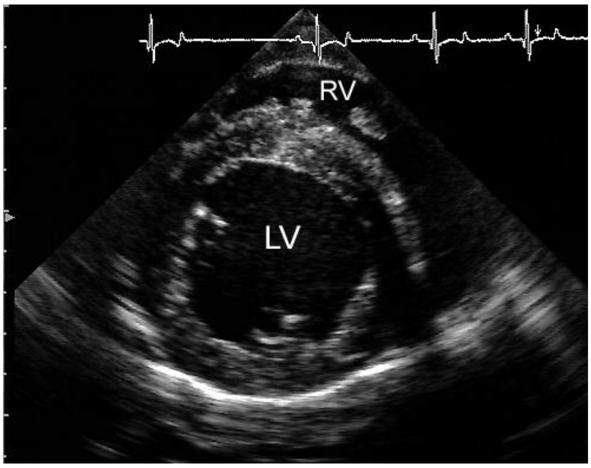
Rotate transducer to obtain a **right short-axis view**

Different levels:

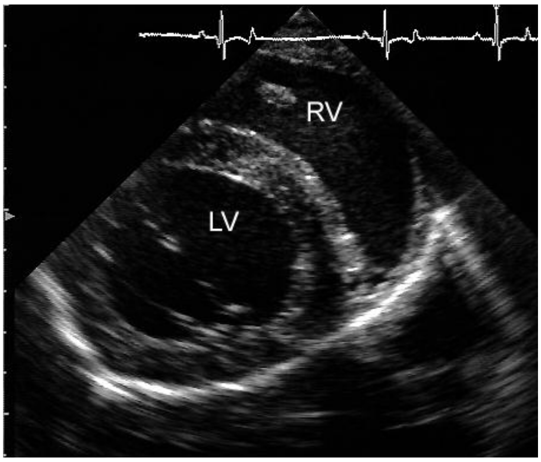
Papillary level – assess papillary muscles and motion



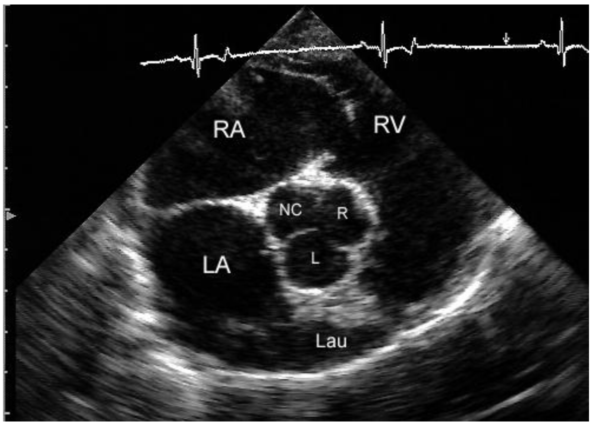
Chordal level – see M-mode below



Mitral valve level (fish mouth view) – study valve structure and motion

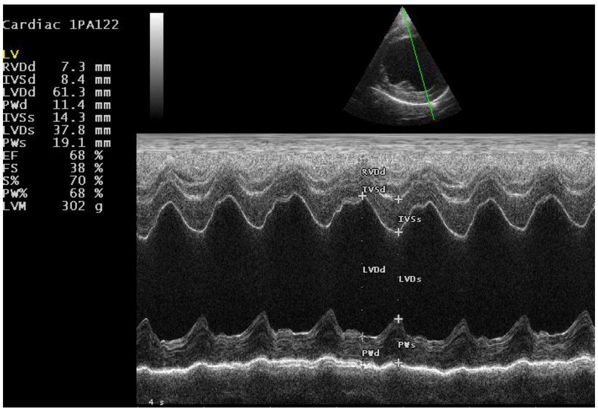


Aortic valve level – compare Aortic root with left atrial dimensions, look at valve



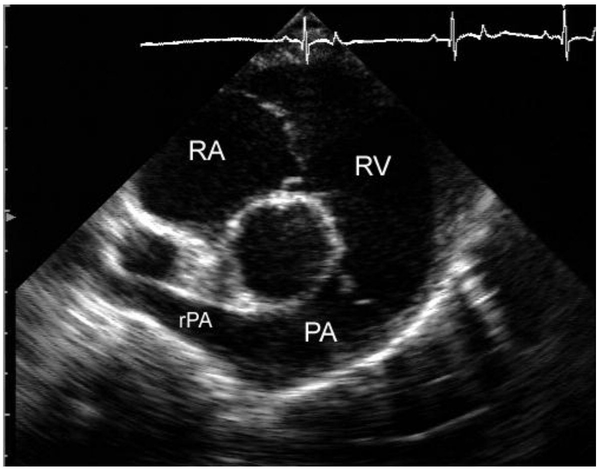
Assess: aortic valve structure and left atrial size at aortic valve level
IVS structure (especially just ventral to aortic root)
LV and IVS motion (chordal level)

Position the M-mode cursor across the middle of the LV (bisecting the chordae) and switch to **M-mode**. Must ensure that this truly bisects the LV and is at the chordal level
Measure LVD at end-diastole and end-systole (minimum 5 measurements)
Calculate FS%



Assess: motion, velocity and pattern of IVS, mitral valve
and aortic valve motion (can measure systolic time intervals)

Rotate and angle the transducer to image the pulmonary valve (**RV inflow-outflow view**)



Assess: tricuspid valve structure

tricuspid valve motion

pulmonary valve structure

pulmonary valve motion

Measure the size of pulmonary artery using 2DE

Doppler examination of pulmonary flow and pulmonary root

Normal echocardiographic measurements in some breeds of dog

	LVDd	LVDs	FS%	
Cocker spaniel	33 +/- 4	22 +/- 3	34 +/- 5	Gooding et al (1992)
G Retreiver	45 (37-51)	27 (18-35)	39 (27-55	Morrison et al (1992)
Greyhound	44 +/- 3	32 +/- 4	25 +/- 7	Page et al (1993)
Deerhound	51 +/- 5	34 +/- 5	33 +/- 6	Vollmar (1998)
IWH	54 +/- 5	35 +/- 5	35 +/- 5	Vollmar (1996)
IWH males	53 +/- 5	38 +/- 4	28 +/- 5	Brownlie (1999)
IWH female	52 +/- 4	37 +/- 4	29 +/- 4	Brownlie (1999)
Dobermann	39 (32-45)	31 (26-38)	21 (13-30)	O'Grady et al (1995)
Boxer	40 (+/- 4.5)	27 (+/ 4)	32 (+/- 7)	Herrtage et al (1994)
Gt Dane	44-59	34-45	18-36	Koch et al (1996)
Newfies	45 +/- 4	34 +/- 3	25 +/- 3	Dukes-McEwan
Salukis	46 +/- 4	33 +/- 4	28	Brownlie