Basic Echocardiography
Performing and Measuring Transthoracic Echocardiograms

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OVERVIEW

Echocardiography is the noninvasive standard for assessing heart disease in veterinary medicine offering balance between convenience, availability, cost-effectiveness, and diagnostic yield. Echo images delineate morphology and function of the heart, along with the appearance of contiguous great arteries and venous entries. Pleural and pericardial effusions, mass lesions within or around the heart, and clinically relevant congenital and acquired diseases of cardiac valves, myocardium, and great arteries can be recognized. When Doppler Echo studies are included, the velocity patterns of normal and abnormal blood flow can be tracked. Complementary Doppler modalities deliver quantitative estimates of heart function, intracardiac pressures, and blood flow.

The echocardiographic study should contribute to a definitive cardiac diagnosis, delineate the severity of disease, inform the prognosis, and guide medical, interventional, or surgical treatments. The study should be placed in clinical context and cannot replace a careful history and physical examination. For example, it would be unusual to diagnose a clinically relevant valvular lesion by echocardiography in the complete absence of a heart murmur. Likewise, basic thoracic radiography remains a critical examination in patients with acute or chronic respiratory signs, considering the broad differential diagnosis of cough, abnormal ventilation, and hypoxemia. Additional examinations including electrocardiography (for arrhythmias), serum biochemistries, heartworm tests, and circulating cardiac biomarkers are often contributory to the diagnosis or to patient management.

Noncardiac US imaging is an essential part of entry-level echocardiography. Learning to recognize ascites and pleural effusions are first steps in substantiating a diagnosis of right-sided congestive heart failure (CHF). Additionally, pulmonary US can be successful in identify lung infiltration or pulmonary edema (B-lines/lung rockets), especially in the point-of-care emergency room setting. However, simple thoracic radiography is often superior for assessing lung pathology or identifying pulmonary edema in cardiac patients once they are stable.

Echocardiography should be performed, and echocardiograms interpreted by examiners with appropriate technical training and understand the landscape of cardiovascular disease, appreciate the issues pertinent to the specific patient, and recognize the limitations of the study. The study should be interpreted by an individual capable of integrating information from all sources, including the history, physical examination, and laboratory studies, should ultimately direct patient management. Having said this, the sonographer must be sufficiently knowledgeable about cardiac diseases to update and refine the examination based on contemporary (in the moment) findings.

There are a number of diagnostic pitfalls that must be appreciated. For example, examiners should not over-interpret day-to-day variability. Many echocardiographic measurements can change by 10% or more due to biologic variability, differences in operator technique, and interobserver factors when measuring images. For example, a decrease of 5% in ejection fraction of the left ventricle (LV) or ventricular fractional shortening might represent a change of clinical importance or just normal daily or measurement variation. Echocardiographic studies can be misinterpreted when normal physiologic findings are mistaken for evidence of disease. This is common when assessing LV systolic function in large-breed dogs due to the emphasis placed on minor axis (fractional) shortening while ignoring apical to basilar contraction. When screening dogs for "occult" dilated cardiomyopathy multiple indices of LV systolic function can point to entirely different interpretations! Ambiguous echocardiographic results become clearer when serial examinations are obtained and more definitive when trends in heart size or cardiac function are observed. In most cases, entry-level examiners should focus on assessing patients with symptomatic disease or overt acquired valve disease such as chronic mitral regurgitation in dogs and relegate the diagnosis of most asymptomatic cardiomyopathies or congenital heart defects to more experienced examiners.

CORE EXAMINATION

Certain 2D images are routinely selected for evaluation of cardiac anatomy and motion.[1,2] Other images are suited for estimating function of the LV and the right ventricle (RV). Still others are chosen to optimize the blood flow information obtained from Doppler examinations. Experienced examiners move quickly across the images with an understanding of their utility and the need to archive those still frames and video loops that characterize the study.

Cardiac lesions are not constrained by standardized imaging planes and the examiner often obtains the optimal alignment to an abnormal flow pattern with unconventional or modified images. Adapting the examination as new findings appear requires both imaging skill and knowledge of cardiac diseases. One should also be aware of extracardiac findings that might suggest a diagnosis of CHF or contribute to the differential diagnosis even if the cardiac examination is normal. Examples include the findings of pleural effusion, pulmonary edema, or intrapulmonary disease. Pulmonary edema is often manifested as multiple, adjacent pulmonary B-lines or "lung rockets".

General Descriptions of Image Planes

The various 2D images are defined by these identifiers: (1) transducer location (right or left, parasternal/intercostal, apical, subcostal/subxiphoid); (2) plane of the US cut (long-axis, short-axis, apical, or angled/hybrid); (3) the number of chambers or great vessels imaged (2-, 3-, 4- or 5-chamber views); along with other tomographic characteristics. With off angled images the view is often named for the main structures imaged, but nomenclature can become confusing when certain structures are imaged in short-axis while others appear in long-axis. There are clear standards for imaging adults, guided by the European and the American Society of Echocardiography (ASE). The examiner should strive to follow these recommendations and emulate the accepted approaches, employing the right/left invert as necessary. Echocardiographic images are usually displayed on the viewing screen with the cranial and dorsal structures to the viewers' right side as they face the monitor. There are some exceptions, notably the left apical 4- and 5-chamber images, which is displayed with the left atrium (LA) and LV to the viewer's right side and the right atrium (RA) and RV to the left. Operators should be able to use the left-right invert switch to maintain proper orientation.

For most canine and feline breeds the fur coat compromises acoustic contact and imaging is best achieved by clipping the left- and right-sided acoustic windows. The location for right sided studies is approximately the third to the sixth intercostal space on the right hemithorax from sternal edge to slightly above the level of costochondral junctions. For left sided examinations the apical to cranial windows are located approximately from the left third to the eighth intercostal spaces, between the sternal edge to the costochondral junctions. The subcostal (subxiphoid) view is also prepared by clipping a small square at the midline immediately caudal to the palpable xiphoid process. This window is mainly used for optimal alignment to flow in the ascending aorta in dogs, and for assessing hepatic veins and caudal vena caval size and collapsibility in both species. Dogs or cats that are hairless or with fine-coats do not need clipping. When owners do not permit clipping, liberal soaking of the coat with isopropyl alcohol (beware: damage to the transducer face) or water, before applying gel, can be helpful.

Examination Setup & Transducer Manipulation

The majority of canine and feline studies are done as follows: patient recumbent on a table with a cutout used for imaging from below; transducer held in the right hand; operator faces the head of the patient and operates the console with the left hand; the patient is turned and rotated for left-sided images. A “mirror image” approach can be used for those who image with their left hand. The standing position is used by some Echo laboratories. This is also used in point-of-care ultrasound examination, in dyspneic patients, and for very large dogs and large animals.

The transducer index marker appears on the screen as a vendor icon. This location depends on how the left-right invert switch is set and the position of the index within the operator’s hand – under the thumb or under the index finger. Both approaches are commonly used, but it is critical to *display* the image in the proper orientation as noted above.

Scanning maneuvers are nicely illustrated in the ASE Guidelines for Adult transthoracic echocardiography by Mitchell and colleagues (open-access from ASE). Readers are referred to these for detailed definitions and examples of slide, rotate, tilt, rock, angle, and sweep. When In describing the canine and feline imaging planes is practical to emphasize *sliding* for initial placement of the transducer on the body. Follow this transducer *rotation* at that location (relative to the index marker) is performed. In this regard, the terms clockwise and counter-clockwise refer to rotation of the index marker as one looks from the transducer cable towards the transducer lens. After placing and rotating the transducer, the central beam is either *tilted* or *angled*. Imaging through a cutout requires a relatively firm grip on the transducer body and most operators experience less wrist pain when supinating their hand. (In practice, experienced operators often release their hold on the index marker and rotate the transducer with their fingers instead of twisting their wrist, but this maneuver necessitates attention to the location of the orientation marker on the transducer).

Standard Images

Accepting there is no prescribed standard in veterinary medicine for a core examination (currently a standardization committee from the American Society of Echocardiography is working on these), most small and large animal studies begins with 2D long- and short-axis images obtained from the right thorax. Standardized 2D and M-mode image planes have been described for veterinary studies. Accepting that M-mode examinations are relatively less important today, most veterinary examiners still activate the M-mode cursor to estimate LV size and wall thickness and to characterize valve and wall motions. Colorized M-mode can also precisely time flow disturbances and prevent over-diagnosis of valvular regurgitation. Complete examinations also include 2D imaging from the left thorax and routine color Doppler and PWD recordings of transvalvular blood flow. The examination protocol varies based on clinical indications and individual preferences, but the following images are recommended:

From the right side:

1. Long-axis images optimized for the left atrium (LA) and mitral valve and left ventricular (LV) inlet. Especially in the dog, the LA size will be markedly reduced unless an optimized view is obtained; in cats an LV inlet-outlet view should also be recorded.
2. Long-axis images optimized for LV outflow tract and aortic valve and ascending aorta.
3. Optimized long-axis view of the right atrium (RA), tricuspid valve, and right ventricle (RV).
4. Short-axis sweep from papillary muscle of the LV to mitral level to aortic level to pulmonary artery level (4 discrete image planes).
5. Subxiphoid images of the aorta (for Doppler) and assessment of the caudal vena cava.

From the left side:

1. Apical 4-chamber, 2-chamber, 3-chamber (apical long axis) images.
2. Modified left apical image optimized for the RV and RV.
3. Cranial long axis image optimized for the LVOT, aortic valve and aorta.
4. Sweep from position 3 to include the pulmonary artery and the right atrial appendage.
5. RV inflow-outflow tract view that displays the aorta in short-axis and pulmonary artery in long-axis.
6. In cats, an image that optimizes the left atrial appendage (auricle), especially if there is LA dilation.

Nomenclature

Considering dogs and cats (and horses and most other large animals) are quadrupeds the location and structure of organs and the direction of imaging planes are somewhat different from those found in human textbooks (see *Nomia anatomica veterinaria* [NAV] https://www.wava-amav.org/wava-documents.html). However, veterinary cardiologists and sonographers mainly use accepted human terminology. For example, most refer to the anterior mitral valve leaflet (as opposed to the “cranioventral leaflet of the left atrioventricular valve”) and identify the aortic valve (not the “left semilunar valve” as it might be labeled in Anglicized NAV terminology). Yet, there are notable exceptions, particularly as these relate to directional nomenclature, as with cranial and caudal vena cava. When compared to humans the following synonyms can be used when comparing veterinary to human studies: cranial to superior; caudal to inferior; ventral to anterior; dorsal to posterior; and medial-lateral and right-left having the same meanings.

APPROACH TO INTERPRETATION

While the sonographer obtain standard images, an ongoing process of image interpretation should also be accomplished. **Table 1** offers a general guide for image interpretation.

Table 1. Image Interpretation

Cavity effusions?
a. Is there a pleural effusion? b. Is there pericardial effusion? c. Is there ascites?
Pericardial space: Is there pericardial effusion present?
a. If pericardial effusion is present, is it small volume secondary to CHF, or moderate to large with evidence of cardiac tamponade?
b. Is there an obvious mass lesion of the right atrium or heart base?
Intrapulmonary disease: Is there evidence of intrapulmonary fluid or infiltration?
Left Ventricle: Is the left ventricle (LV) obviously dilated or thickened (hypertrophied)?
LV systolic function – is it subjectively normal, increased or reduced?
a. If abnormal, is it mild - moderate – severe based on measurements and calculations?
b. Is there obvious dyssynchrony between septum and LV wall that might cause overestimation of functional impairment?
Left atrium: Is the left atrium dilated? If so, is enlargement mild, moderate, or severe?
a. Is LA dilation determined by subjective dilation, ratios, or absolute measurements?
b. For cats: if the left atrium is dilated, is there spontaneous contrast or auricular thrombus?
Right heart: Are the right atrium or ventricle subjectively enlarged when compared to the left side of the heart (optimally from the left apical views?
Great Vessels: Pulmonary Trunk & Branches | Aorta: subjectively enlarged?
a. Pulmonary artery to vein ratio – normal or altered?
Cardiac valves (2D imaging): Is there obvious valvular heart disease?
a. For dogs: is the mitral valve or tricuspid valve thickened or prolapsing?
b. For younger animals: is there valve malformation or outflow tract obstruction?
c. Are there motion abnormalities (e.g., Systolic anterior motion of the MV in a cat)?
If color Doppler studies were performed: is there mitral, tricuspid, or aortic regurgitation present?
a. Was the timing and the duration of the abnormal flow event confirmed (by color M-mode or spectral Doppler)?
If spectral Doppler studies were obtained: are the outflow tract velocities normal?
If CW Doppler was recorded: What is the velocity of any mitral or tricuspid regurgitant jet?
If a left-to-right shunting lesion is suspected: Is there an obvious shunt into the right atrium, right ventricle, or pulmonary artery on color Doppler imaging?
a. Can shunting be confirmed in multiple planes
b. If the right ventricle is hypertrophied, is the shunting bidirectional or right to left?
c. What is the velocity of flow across the shunt if recorded by CW Doppler?

APPROACH TO MEASUREMENTS

The general approaches to identifying cardiac chamber enlargement and impaired ventricular function include a) subjective assessment; b) linear, area or volumetric measurements and calculations normalized to body size (often allometrically scaled or indexed to weight); and c) calculation of ratios (most often to the patient's aorta or a normalized bodyweight-adjusted aortic size). There are advantages and issues with each approach. This subject is expansive and for this seminar some suggested approaches are offered and demonstrated. For tables of reference values, the reader is referred to the references.[1-5]

Allometric scaling (a non-linear method of predicting normal measurements) is critical to use for dogs; ideally this is done within a breed. In multiple breed studies, the usual scaling exponent for the left ventricle in diastole (internal dimension is approximately 0.31 to 0.33. Sighthounds and some other breeds depart from these generalizations. In cats allometric scaling is less critical but weight still exerts some influence on normal predicted values.

Table 2 provides some approaches for cardiac mensuration.

Table 2. Approaches to Cardiac Measurements

For the left atrium:	
a.	Measure the end-systolic dimension of the LA in the right parasternal, long-axis 4-chamber plane and the maximal opening distance between the aortic valve leaflets (that is, the maximal aortic orifice diameter) in the right parasternal, LV outflow tract, long-axis plane; consider both absolute size, allometric scaling, and the ratio of LA to aortic valve
b.	Measure the early diastolic left atrial dimension in the right, parasternal short-axis plane; construct LA/Ao ratios in both long- and short-axis images; and
c.	Optionally, in dogs and cats, trace the area of the LA at end-systole and at the R-wave (end-diastole) to estimate atrial areas and fractional area change
d.	Canine Abnormalities: Dogs: 2D Long-axis normalized LA diameter >1.7 in most breeds (using an exponent of 0.31, as LA (cm)/Weight (kg)^0.31); a long-axis 2D LA: Aorta >2.6 is relatively sensitive for enlargement in most breeds (with LA measured in Long-axis, at end-systole and the aorta between the opened aortic leaflets in systole); 2D LA to Aortic ratio ("Swedish") >1.7 is relatively specific for LA dilation but there are issues of cursor path + timing of the "early diastolic" measurement; an estimated LA volume (by Simpson's method of discs) >1.65 ml/kg (from the right parasternal long-axis) image.
e.	Feline Abnormalities: LA diameter from right parasternal long-axis of >16 mm (with >19 critical) is usually enlarged for cats but is somewhat weight related; the short-axis LA/Ao (early-Diastole) >1.6 to 1.7 using "Swedish" approach is considered significantly enlarged.
For the left ventricle:	
a.	Measure LV end-diastolic and end-systolic dimensions and FS from the right parasternal short-axis plane, including guided M-mode Echo exam
b.	Repeat the LV diastolic measurements in the right parasternal long-axis plane as a check against poor cursor placement
c.	Construct LV/Ao ratios from long-axis images (similar to the LA/Aortic valve for long-axis), and if any of these are abnormal or borderline:
d.	Estimate LV systolic and diastolic volumes and EF using the Simpson's method of discs from right parasternal long-axis (or apical 4-chamber images, or both); and

e.	Optionally, trace the LV diastolic and systolic areas in short-axis to calculate fractional area change and perform mitral annular plane systolic excursion (MAPSE) to further measure LV longitudinal contraction.
f.	Canine Abnormalities: Subjective assessment – rounding, increased sphericity; Breed normal reference ranges – limited data are available – see References[1-4]; Allometric scaling used to generate the "Normalized" LVID (LVEDDN) – the LVEDDN >1.65 is suggestive of LV dilation for most non-sighthound breeds (2,3); A ratio of LV diastolic dimension/Aorta in long-axis of >2.6 is suggestive across breeds that mild LV dilation is present, but this assumes a normal aorta & precise AV measurement; LV volumes – now a number of specific breeds & multi-breed studies have been reported and an LV end-diastolic volume >3.0 to 3.3 ml/kg using Simpson's method of discs is suggestive of LV dilation.
g.	Feline Abnormalities: The LV diastolic dimension is usually <18.5 mm in most cats but is bodyweight and breed related and can be as large as 20 to 21 mm in some breeds (Maine coon cats).
h.	LV wall measurements in dogs are challenging inasmuch as most reference charts have wide prediction intervals so that mild wall thickening is difficult to identify; most cases of moderate to severe LV wall thickening can be identified subjectively. In cats LV wall thickness are bodyweight dependent (2), with wall thicknesses >5.2 to 5.5 mm in diastole "suspicious/sensitive" and values ≥6 mm are specific for LV wall thickening.
i.	Currently there is no one "best" system but these are all useful
For the right ventricle:	
a.	Subjectively compare the right and left heart chambers in the parasternal long-axis and left apical 4-chamber views
b.	Record RV longitudinal shortening (TAPSE) and optionally, RV diastolic and systolic areas to calculate fractional area change from the left apical view optimized for the RV
c.	Compute a ratio of right atrial traced area to aortic dimension
d.	Currently most assessments of the RV and RA are subjective

References/Suggested Reading

1. Bonagura JD, Luis Fuentes V: *Echocardiography* in Mattoon JS, Sellon RK, Berry CR (eds): *Small Animal Diagnostic Ultrasound*, 4th ed. Philadelphia, PA; 2020; Chapter 8. Saunders/Elsevier.
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