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A proposed rescue transesophageal echocardiographic protocol for anesthetized dogs

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OBJECTIVE
To describe the acquisition and pitfalls of a 3-view transesophageal echocardiography (TEE) protocol in anesthetized, dorsally recumbent dogs.

ANIMALS
8 beagles, 1 to 2 years old, 7.4 to 11.2 kg.

METHODS
Dogs were anesthetized, mechanically ventilated, and placed in dorsal recumbency. A TEE probe was advanced, and 3 views were performed: midesophageal 4-chamber and long axis (ME 4C and ME LAX) and caudal esophageal short axis (CE SAX) at the level of the papillary muscles. Probe insertion depth, flexion, omniplane angle, and image acquisition time were recorded. Two observers assessed 24 video clips each and identified anatomical structures.

RESULTS
The ME 4C and ME LAX were obtained at 35 (30 to 40) cm insertion depth, omniplane at 0° and 103° (90 to 116), respectively. Views were obtained in ≤30 seconds once the TEE was in the cervical esophagus. Left-sided structures were identified in all cases, whereas right-sided structures were not always simultaneously obtained in the ME 4C, requiring further probe manipulation. All structures were identified on ME LAX. CE SAX was obtained at 40 (35 to 45) cm, omniplane at 0°, and in 15 (10 to 90) seconds. A true SAX view (circular left ventricle at the level of papillary muscles) could not be obtained in all dogs.

CLINICAL RELEVANCE
A 3-view TEE protocol using core views as those described in humans may be applicable to dogs under general anesthesia and in dorsal recumbency. The CE SAX view at the level of the papillary muscles appears more difficult to obtain with consistency than midesophageal views.

Keywords: anesthesia, hemodynamic, cardiac, hypotension, echocardiography

Transesophageal echocardiography (TEE), often indicated during cardiac surgery, is becoming increasingly adopted as a tool when hemodynamic instability occurs during noncardiac procedures in humans.[1–4] Several protocols consisting of a variable number of views, have been described to evaluate cardiac filling, ventricular function, and structure of the heart. Guidelines for comprehensive perioperative TEE examinations performed during cardiac surgeries in human patients include 28 views and can be technically challenging and time-consuming.[5] In contrast to comprehensive TEE examinations, focused TEE protocols consisting of only a handful of views have been developed for the assessment of patients with unexplained hemodynamic decompensation during noncardiac procedures.[6] These protocols, colloquially named "rescue" TEE protocols, are aimed at fulfilling 2 fundamental goals: to be easily and expeditiously performed, and to provide sufficient information to determine potential causes of hemodynamic instability. While several measurements can be performed, subjective assessments based on the observation of ventricular contraction and filling, valvular structure and motion, and the

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use of color flow Doppler imaging, are often sufficient to identify a source of hemodynamic instability or guide therapy.[7–10]

Veterinary cardiologists have described TEE for dogs and its use is commonplace during cardiac procedures.[11,12] However, its use as an intraoperative tool for managing hemodynamic instability is less common in veterinary anesthesiology. Moreover, current imaging acquisition techniques for dogs do not always consider other factors frequently encountered when hemodynamic instability occurs during anesthesia, such as dorsal recumbency or mechanical ventilation, or they focus on views that differ from the ones commonly used for hemodynamic monitoring.[11–13] Therefore, we propose a rescue TEE protocol that might be useful for anesthetized dogs, consisting of the 3 main views that constitute the core examination in several rescue protocols used in people.[6]

We adopted the nomenclature described by the American Society of Echocardiography (ASE) and the Society of Cardiovascular Anesthesiologists (SCA) to describe these views. The objective of this report is to describe a technique for the acquisition of these core views and report the pitfalls and challenges we have encountered associated with each view.

Methods

This study was conducted under IACUC approval (protocol #2021-0016). Eight (4 neutered male and 4 spayed female) beagle dogs participating in a study that included the use of adrenergic agents were included.[14] The dogs were 1–2 years old, weighed 7.4–11.2 kg, with body condition score 4-5/9,[15] and were classified as American Society of Anesthesiologists Physical Status 1 based on physical examination and laboratory testing. The dogs were fasted overnight before anesthesia. Each dog received maropitant 1.0 mg/kg and acepromazine 0.01 mg/kg through a catheter placed in a cephalic vein. General anesthesia was induced with propofol 5–6 mg/kg IV. The trachea was intubated with a cuffed endotracheal tube and the lungs were ventilated with 12 mL/kg tidal volume and 10 to 12 breaths/min. Anesthesia was maintained with isoflurane (end-tidal concentration 1.4–1.8%) in oxygen. Dogs were monitored with continuous electrocardiogram, arterial blood pressure, pulse oximetry, rectal temperature, capnography, and inspired/expired isoflurane concentrations. Further details on that protocol are reported elsewhere.[14]

Proposed rescue TEE examination in dogs

A portable ultrasound system (SonoSite Edge II, Fujifilm SonoSite, Inc) equipped with a multiplane transesophageal transducer (TEExi/8-3MHz Transducer, Fujifilm SonoSite) was used. The shaft of the transesophageal transducer is 110 cm in length and 10.5 mm diameter. Manipulation of the transducer is described from the point of view of an operator standing at the dog's head, with the animal in dorsal recumbency. From this position the transducer can be inserted or withdrawn (caudal and cranial movement), turned or rotated clockwise (toward the dog's right) or counterclockwise (toward the dog's left), anteflexed (flexed toward the sternum) or retroflexed (toward the spine), and the omniplane (sector scan) can be rotated clockwise (forward) from the initial position of 0° (transverse to the transducer's shaft) to 180°, with 90° being parallel to the transducer's shaft.

Using the nomenclature accepted by the ASE/SCA we attempted to reproduce the 3 core views shared in most rescue protocols for humans: (1) midesophageal 4-chamber (ME 4C), (2) midesophageal long axis (ME LAX), and (3) transgastric short axis (TG SAX).[16] The SAX view of the left ventricle (LV), as described in people, is difficult to obtain through a transgastric view in dogs due to the greater distance between the stomach and LV.[11–13] Hence, we used a modified SAX view of the LV from a caudal-esophageal position (CE SAX).

We attempted to obtain each of the 3 core views in order: ME 4C, ME LAX, and CE SAX. With the dog in dorsal recumbency, the TEE probe was inserted orally through a mouth guard and into the cranial esophagus. All probe advancements and withdrawals were performed with the tip in the neutral position (not flexed and unlocked). The probe was advanced into the mid-esophageal region until the ME 4C was obtained. This view aimed to visualize the left and right atria (LA and RA), LV and right ventricles (RV), and mitral (MV) and tricuspid (TV) valves.[16] Color flow Doppler imaging was applied over the MV. Then the omniplane was rotated clockwise until the ME LAX view was obtained, which is characterized by simultaneous visualization of the LA, MV, LV, LV outflow tract (LVOT), and aortic valve.[16] Color flow Doppler imaging was obtained through the MV and aortic valve. The omniplane was reset to 0° and the TEE probe advanced until the cardiac silhouette was lost. Then the tip was anteflexed to obtain the CE SAX view. The goal of the CE SAX view was to obtain a transverse view of the LV below the MV, at the level of the papillary muscles.[16]

For each of the 3 views, a short clip that included 4 to 6 beats was stored for subsequent analysis. A total of 24 video clips (3 per dog) were acquired during isoflurane anesthesia. In addition, images with color flow Doppler were acquired from the mid-esophageal views across the mitral and aortic valves. These images were reacquired after 15 minutes of phenylephrine infusion (1 µg/kg/min) to observe potential changes in transvalvular flow. All images were acquired by a single investigator (MM-F).

For the description of the CE SAX, and to better compare it with the TG SAX (as described in people), we obtained computed tomographic images from a beagle that had been studied under general anesthesia and in dorsal position, for an unrelated project examining lung strain. Multiplanar reformatting was used to show the spatial relationship of the heart, lungs, esophagus, stomach, and liver, and to describe the structures that would be transected by the ultrasound beam placed in the CE and the TG positions.

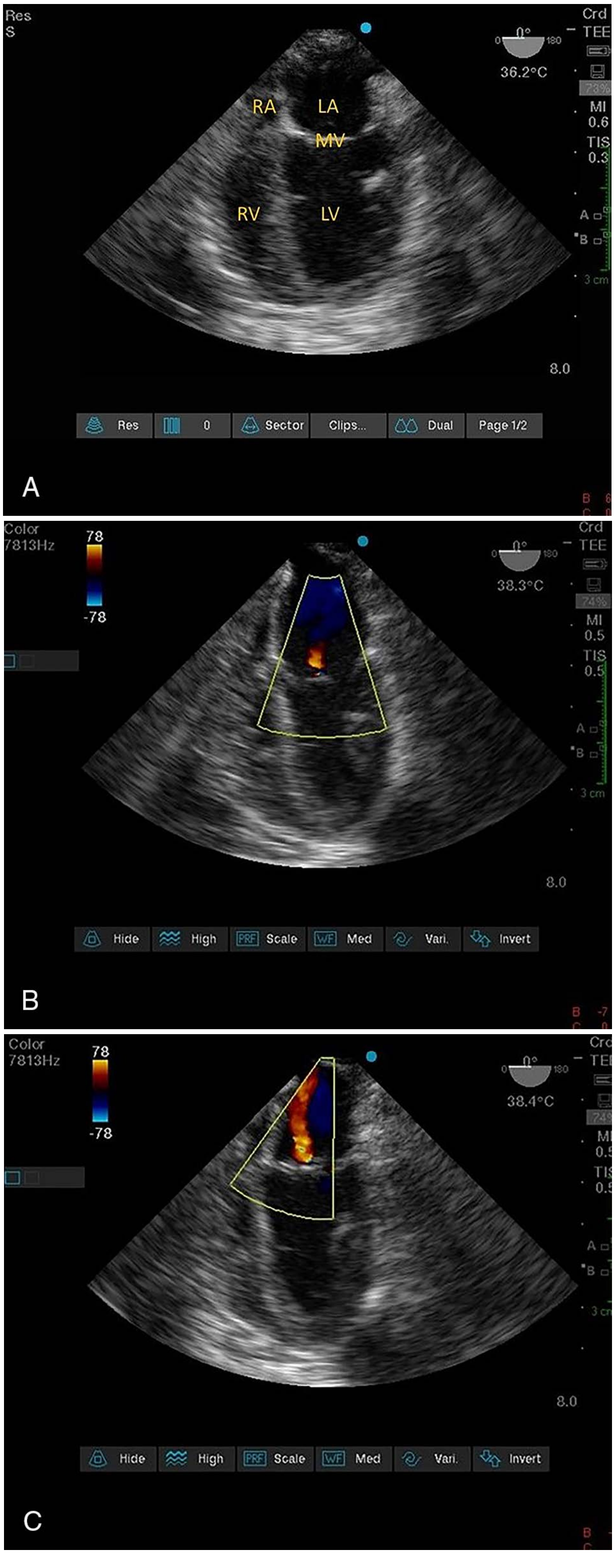

Figure 1—Example of a typical ME 4C view (A), acquired from an anesthetized, dorsally recumbent, and mechanically ventilated beagle. Left-sided structures are viewed on the right side of the screen. The left and right atria (LA and RA), ventricles (LV and RV), and mitral valve (MV) are visible. The tricuspid valve was not appreciated in this case. B and C show a regurgitant jet through the mitral valve before and after administration of phenylephrine 1 µg/kg/min.

Assessment of image acquisition and quality

We recorded the time required to obtain each view, starting from a cervical esophageal location of the TEE for the first view, and starting from the previous view in the subsequent images. The depth of insertion, ante- or retroflexion, rotation of the TEE probe, and the angle of the omniplane were recorded for each view.

Video clips were downloaded and evaluated by 2 observers experienced with the use of TEE and who did not participate in image acquisition. The observers were asked to identify several structures in each video clip.[16] In the case of CE SAX, the presence of the MV was considered to represent an incorrect plane of the image.

Complications

The dogs were observed for inappetence, signs of nausea (salivation and lip licking), vomiting, and melena for the week that followed the procedure, starting the morning after the procedure (procedures were completed between 4 to 5 p.m.).

Statistics

Descriptive statistics of the insertion depth, rotation, flexion, and angulation of the omniplane are presented for each view. Descriptive statistics of the observation of structures are also presented. Data are summarized as median (range).

Results

The study was completed in all dogs without complications. No inappetence or signs compatible with nausea, vomiting, or melena were observed during the week that followed these procedures.

Descriptions of image acquisition, findings, and pitfalls

ME 4C—The probe was inserted in the neutral position without rotation of the omniplane, and advanced into the thoracic esophagus until a 4-chamber view was identified. Slight anteflexion of the probe improved the quality of the image (subjectively, better spatial resolution), and slight clockwise rotation

Table 1—Summary [median (minimum – maximum)] insertion depth relative to the incisor teeth, angle of omniplane rotation, and time required to acquire each image, obtained from 8 healthy adult beagles, under general anesthesia in dorsal recumbency.

View	Insertion (cm)	Omniplane	Time to acquire (seconds)
ME 4C	35 (30–40)	0°	15 (5–30)
ME LAX	35 (30–40)	103° (90–116)	10 (5–30)
CE SAX	40 (35–45)	0°	15 (10–90)

Time was counted from the probe located in the cranial esophageal region for ME 4C, and from the location of the probe at the previous view for ME LAX and CE SAX.

CE SAX = Caudal esophageal short axis. ME 4C = Midesophageal 4-chamber. ME LAX = Midesophageal long axis.

was used to center the image. An example of a ME 4C view is shown **(Figure 1)**. A summary of the insertion depth, omniplane angle, flexion of the probe, and time to acquire the image is shown **(Table 1)**.

Color flow Doppler imaging of the MV revealed mitral regurgitation in 2 animals, which had no detectable murmurs in the exam before anesthesia. In these dogs, the regurgitant jet became

Table 2—Number of dogs in which each structure was identified for all views, by 2 observers (Obs 1 and 2) who did not participate in image acquisition.

ME 4C			ME LAX			CE SAX		
Structure	**Obs1**	**Obs2**	**Structure**	**Obs1**	**Obs2**	**Structure**	**Obs1**	**Obs2**
RA	3/8	2/8	LA	8/8	8/8	LV	8/8	8/8
RV	6/8	3/8	LV	8/8	8/8	RV	7/8	7/8
TV	3/8	3/8	MV	8/8	8/8	PMs	6/8	8/8
LA	8/8	8/8	LVOT	8/8	7/8	MV	3/8	4/8
LV	8/8	8/8	AV	7/8	7/8	Circular LV	8/8	3/8
MV	8/8	8/8	RV	8/8	8/8			

Images were acquired from 8 adult beagles, under general anesthesia in dorsal recumbency.

AV = Aortic valve. CE SAX = Caudal esophageal short axis. LA = Left atrium. LV = Left ventricle. LVOT = Left ventricular outflow tract. ME 4C = Midesophageal 4-chamber. ME LAX = Midesophageal long axis. MV = Mitral valve. PMs = Papillary muscles. RA = Right atrium. RV = Right ventricle. TV = Tricuspid valve.

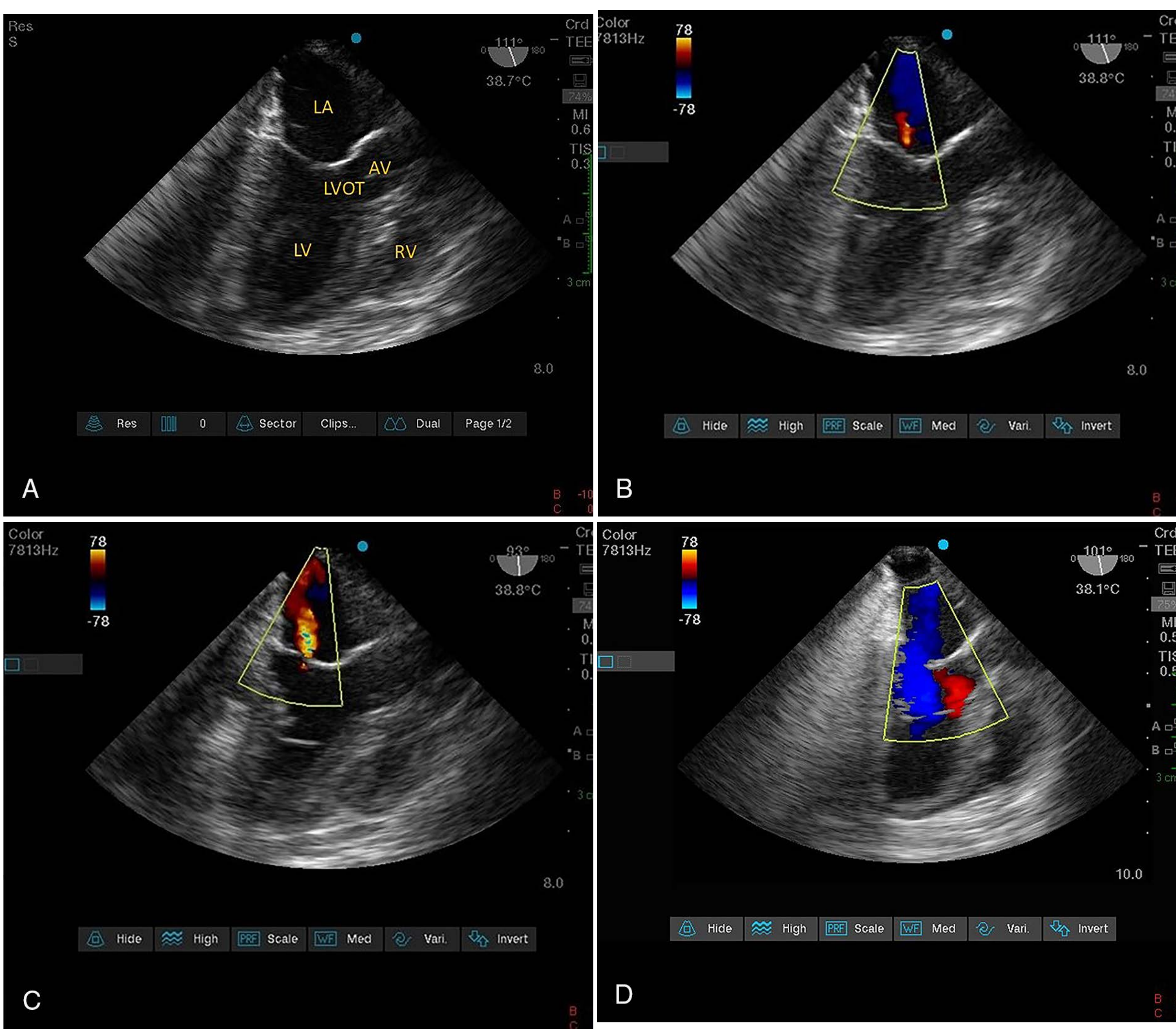

Figure 2—Example of a typical ME LAX view (A), acquired from an anesthetized, dorsally recumbent, and mechanically ventilated beagle. The left atrium and ventricle (LA and LV), mitral valve (MV), left-ventricular outflow tract (LVOT), aortic valve (AV), and right ventricle (RV) are shown. B and C show a regurgitant jet through the mitral valve before and after administration of phenylephrine 1 µg/kg/min. D—shows color flow Doppler applied over the mitral and outflow tract. No regurgitation or turbulence are appreciated.

subjectively more prominent during phenylephrine infusion (Figure 1).

Pitfalls—In general, the RA, RV, and TV were difficult to observe in this view, while the left-sided structures were consistently identified. Slight rotation of the probe often improved visualization of the structures on the right side, but this was to the detriment of those on the left. When anteflexion was required to improve image quality, a slight foreshortening of the LV was noticed. A summary of the assessments is shown **(Table 2)**.

ME LAX—From the previous position, the omniplane was rotated until the long-axis view of the LV, including the LVOT, was identified. An example of a ME LAX view is shown **(Figure 2)**. A summary of the insertion depth, omniplane angle, flexion of the probe, and time to acquire the image is shown in Table 1.

Color flow Doppler imaging of the MV revealed equal findings to those described for ME 4C (Figure 2). Color flow Doppler imaging through the aortic valve showed no appreciable regurgitation or turbulence in any dog (Figure 2).

Pitfalls—Slight anteflexion to improve image quality produced ventricular foreshortening. A summary of the structures identified is shown in Table 2.

CE SAX—From the previous view, the probe was advanced with the omniplane set at 0° and with the tip in the neutral position until the image of the heart was lost. In some dogs, the liver could be seen at this point. Subsequently, complete anteflexion brought the SAX into view. Anteflexion was required in all cases, and slight rotation was used to center the structures on the screen in some cases. An example of a CE SAX view is shown **(Figure 3)**. A summary of the insertion depth, omniplane angle, flexion of the probe, and time to acquire the image is shown in Table 1.

Pitfalls—Since this view was obtained from the caudal esophagus rather than from a transgastric location, as it is performed in humans, a true cross-section of the LV was not always possible, and a slightly oval-shaped image of the LV chamber was obtained in some cases (Figure 3). In some dogs, a SAX view at the level of papillary muscles was obtained, whereas in other dogs only a transverse cross-section at the level of the MV could be performed (Figure 3). In these cases, any additional probe insertion in an attempt to reach a view that included the papillary muscles resulted in a complete loss of image (presumably, from lack of esophageal-to-cardiac apposition, and lung interposition). A summary of the structures identified is shown in Table 2.

Figure 4 shows a representation of the expected location of the TEE probe for the acquisition of a TG and CE SAX view. The TG view suggests that the liver and lung would be observed in the near field of a TEE image, interposed between the TEE probe and the LV.

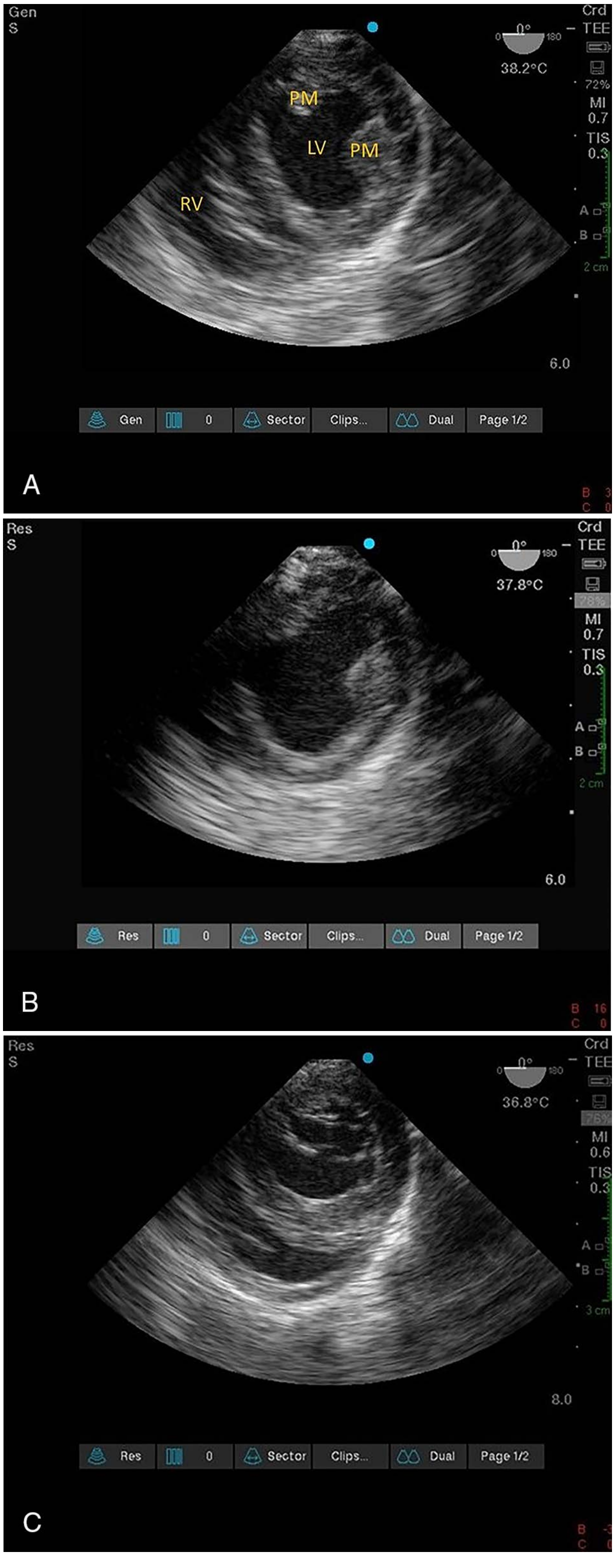

Figure 3—Example of a typical CE SAX view (A), acquired from an anesthetized, dorsally recumbent, and mechanically ventilated beagle. A transverse view of left and right (LV and RV) ventricles, and papillary muscles (PM) are observed. B—shows an oval-shaped, rather than circumferential, view of the left ventricle, indicating that the view is not a true transverse section. C—shows a more basilar view, where the mitral valve can be identified within the left ventricular lumen.

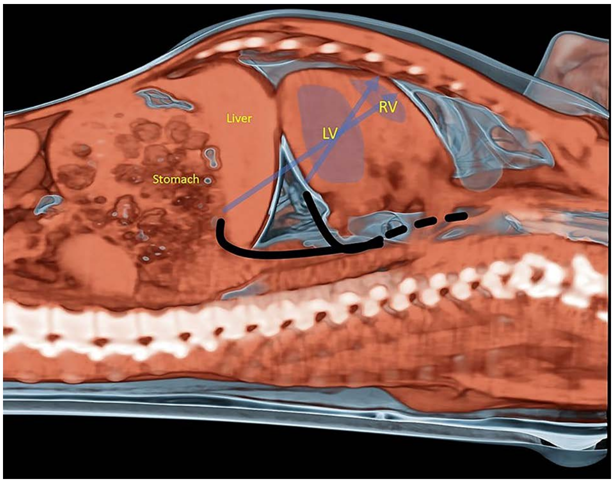

Figure 4—Multiplanar reformatting (MPR) of a computed tomography (CT) image of the thorax and cranial abdomen of a an anesthetized, dorsally recumbent beagle. The approximate position of a transesophageal echocardiography probe for a caudal esophageal and transgastric locations are represented, as well as the ultrasound beam. The CE position results in direct apposition of the esophagus and the heart, whereas the TG position results in liver and lung being interposed between stomach and heart.

Discussion

In this report, we describe techniques and pitfalls for the acquisition of 3 core TEE views in dorsally recumbent, mechanically ventilated, anesthetized beagles. These views are shared by most rescue TEE protocols described for humans and can be used to assess ventricular volume and contractility, valvular function, including dynamic obstruction of the LVOT, and the presence of pericardial effusion.[6–10] Notwithstanding some caveats, these views were in general easily acquired, and images of acceptable quality for assessment were often obtained in a short period. Therefore, we believe that this abbreviated imaging protocol could help anesthesiologists assess cardiac function in anesthetized dogs placed in dorsal recumbency, which is likely the most common position encountered in clinical practice.

Midesophageal views

These images were obtained with relative ease in all dogs. However, true 4-chamber images were difficult in some cases, as either the left or right cardiac structures could be seen, but not always simultaneously. It is neither necessary nor expected that both the left and right sides will be visualized simultaneously in all cases. As mentioned, the slight rotation of the probe allowed us to visualize all structures. Importantly, the left-sided structures, which are the target structures during rescue protocols, were always observable. The 2 observers disagreed on whether the RV could be identified in some cases. Those likely represent cases of incomplete RV views, with 1 observer considering it identifiable while the other did not. In light of this discrepancy, we conclude that images that simultaneously show the LV and RV were not always possible.

In some animals, image quality was improved by a slight anteflexion of the probe, which increases the contact of the probe to the LA through the esophagus. This maneuver, however, can foreshorten the ventricles so that the LV appears rounder, and the apex is not observed entirely. Despite this caveat, which could affect length and volume measurements of the LV, ventricular wall movements, valvular morphology, and valvular function could still be evaluated. Color flow Doppler imaging can be applied over the MV and TV to assess valvular function. In 2 dogs, previously undiagnosed mitral regurgitation was observed, which subjectively appeared to worsen during phenylephrine infusion. In this view, the MV and TV can also be aligned for Pulsed-Wave Doppler measurements of the inflow or regurgitation through either valve, a technique that could help quantify the regurgitant flow but that was not performed in the current study.

Rotation of the omniplane to approximately 100° produced a long axis view of the left structures, whereby the LVOT and aortic valve come into view. This differed from the ME LAX view in humans, which is typically obtained with the omniplane set at approximately 120 to 160°.[16] Color flow Doppler can be performed over the MV and aortic valve; however, the alignment of the AV relative to the cursor does not allow for Pulsed-Wave Doppler measurements of the velocity-time integral (VTI) across the aortic valve, a common measurement for assessing stroke volume. In humans, a deep TG long-axis view is required for such measurements. A similar technique has been described in dogs.[17,18] The ME LAX view also allows observation of the LVOT, and cases of dynamic obstruction can be identified.[19,20] As was the case for the 4C view, slight anteflexion improved contact and image quality but can foreshorten the LV. Similar to the 4C view, color flow Doppler imaging over the MV confirmed cases of turbulence. Color flow Doppler imaging through the aortic valve showed no turbulence in our dogs, which is suggestive of the absence of aortic stenosis.

Caudal esophageal view

The short-axis view of the left ventricle is widely used for the assessment of systolic function and ventricular volume in humans, particularly since this view allows the simultaneous evaluation of all walls of the LV and the diagnosis of regional wall abnormalities. The LV SAX view is also commonly used in humans to subjectively assess ejection fraction. Moreover, indices obtained from a LV SAX view have been successfully used to assess fluid responsiveness in dogs.[21,22] This view, however, could be the most problematic one for dogs. The SAX view of the LV should be obtained at the level of the papillary muscles.[16] A more basilar view can be obtained to observe the MV. In some instances, only a SAX view at the level of the MV could be acquired, but not at the level of the papillary muscles. The inclusion of the MV in the view may affect assessments of contractility, as the valvular annulus differs from the ventricular myocardial muscle.

While a deep transgastric short-axis view has been described in dogs,[17,18] acquisition of transgastric images has been difficult or impossible in previous studies in dogs.[11–13] In humans, this view is acquired through a transgastric position, whereby the apposition of the stomach, diaphragm, and LV allows a transverse view of the LV to be obtained. The distance that separates the diaphragm and heart of the dog results in some volume of pulmonary parenchyma being interposed between these structures and, hence, the view cannot be obtained (at least not consistently) because the gas-filled alveoli are a poor medium for ultrasound imaging. This limitation, which has been previously described,[11,12] is also supported by the multiplanar reformatting image of a beagle dog that we performed. To circumvent this, we attempted to obtain transverse views of the LV from a caudal esophageal position, which allows more direct contact against the heart. We did not confirm the ultimate location of the probe with an independent method, such as radiography. However, the presumed CE location of the probe is supported by the observation of the LV posteromedial wall in the near field, which indicates an intimate apposition of the TEE probe (through the esophagus) and the LV. This technique, however, will likely put pressure on the esophageal wall as the TEE probe is anteflexed. A previous study in anesthetized dogs, subjected to complete flexion of the probe for prolonged periods did not reveal lesions or a high pressure exerted against the esophageal wall.[23] We did not observe inappetence, or signs compatible with nausea, vomiting, or melena in any case, suggesting that no lesions of clinical consequence were produced.

In addition to a basilar view that included the MV in some dogs, an elliptic rather than circular LV was sometimes observed during SAX acquisition. This is likely a result of the limitations dictated by the canine anatomy described above. An elliptical LV will affect measurements of fractional shortening or fractional area changes, which rely on a circular ventricle for accurate measurements. An angular view that results in an oval LV will increase the cranio-caudal diameter and consequently the area measurements. We suspect, however, that subjective assessment of contractility may still be possible. Interestingly, there was a discrepancy between observers on whether the LV was circular or elliptical in some dogs. The discrepancy resides largely on the tolerance of each observer to classify the shape as circular. Some observers may tolerate small deviations from a circular shape. Despite these discrepancies, it seems clear that a circular LV, which is to say, a true short-axis view, was not consistently obtained.

The goal of this study was to describe a short series of views that can be completed promptly and provide sufficient information to make presumptive diagnoses of the causes of hemodynamic instability. The views were generally acquired promptly and with ease in this study, with the first view being obtained in no more than half a minute. We measured the time to acquire the images once the TEE probe was placed in the cervical esophagus, which does not include the time taken to place the probe orally. We did this because, in practice, the probe can be placed early and left on site until needed. When an examination is required, the image is activated, and the probe is manipulated. It is likely that oral insertion of the probe will vary among different breeds and conformations. In humans, the usefulness of these views for evaluating contractility, valvular function, volume status, or the presence of pericardial effusion has been described, and rescue TEE protocols are increasingly implemented as an intraoperative tool. We speculate that these views can be implemented in veterinary anesthesia to help guide the management of hemodynamically unstable dogs. Further studies and experience will likely result in improvements and expansion of this protocol; different views can be added, and quantitative measurements may be implemented.

There are several limitations to this study. These views were obtained from a small number of beagle dogs, which were healthy and uniform in their age, size, and body condition score, and by a single investigator. We expect that other pitfalls and difficulties will be encountered as dogs of different conformations and undergoing different surgeries or ventilatory strategies are assessed. Larger clinical studies will likely elucidate the impact of anatomical differences between breeds, the use of positive end-expiratory pressure or larger tidal volumes, the effects of increased intra-abdominal pressure during laparoscopy, or changes in spatial relationships during thoracic interventions. Moreover, while negative consequences of TEE have been studied in humans and dogs, it remains to be studied in a larger canine population whether anteflexion at the caudal esophageal position may result in injuries to the esophagus. Little information is available regarding the incidence and severity of injuries secondary to TEE in dogs, however, complications appear to be either rare or mild.[12,24]

In summary, a 3-view rescue TEE protocol using core views as described in humans may be applicable to dogs under general anesthesia and placed in dorsal recumbency. The CE SAX view at the level of the papillary muscles appears more difficult to obtain with consistency. Larger clinical studies with a variety of breeds and body conformations will test the broader applicability of this protocol.

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