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Effects of postural change on transesophageal echocardiography views and parameters in healthy dogs

Seijirow GOYA[1), Tomoki WADA[1), Kazumi SHIMADA[1), Daiki HIRAO[1), Ryuji FUKUSHIMA[1), Norio YAMAGISHI[2), Miki SHIMIZU[3) and Ryou TANAKA[1)*]

[1)Department of Veterinary Surgery, Faculty of Veterinary Medicine, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu-shi, Tokyo 183-0052, Japan

[2)Department of Veterinary Clinical Medicine, Faculty of Agriculture, Iwate University, 3-18-8 Ueda-cho, Morioka-shi, Iwate 020-8550, Japan

[3)Department of Veterinary Diagnostic imaging, Faculty of Veterinary Medicine, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu-shi, Tokyo 183-0052, Japan

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ABSTRACT. The purpose of the present study is to investigate the effect of postural change on transesophageal echocardiography (TEE) views and parameters of interest anesthesia monitoring in healthy dogs. Twelve Beagle dogs were anesthetized and randomly positioned in one of four postures: right lateral-recumbency, left lateral-recumbency, supine position and prone position. After examinations in one posture, the same examination was demonstrated in another posture and repeated in all postures. In each posture, several standard TEE views were demonstrated: longitudinal cranial-esophageal aorta long-axis-view, transverse middle-esophageal mitral valve long-axis-view and transgastric middle short-axis-view. Additionally, echocardiographic parameters were attempted to measure, and direct blood pressure monitoring was performed in each view. As a result, oriented views, except for transgastric middle short-axis-view, could be obtained in all postures. Stroke volume and peak early diastolic velocity of mitral inflow were lower in supine position compared with those in right and left lateral-recumbency. Heart rate (HR) and systemic vascular resistance were higher in supine position compared with those in right and left lateral-recumbency. Left ventricular pre-ejection period/left ventricular ejection time corrected and uncorrected by HR were higher in supine position compared with those in right and left lateral-recumbency. In conclusion, longitudinal cranial-esophageal aorta long-axis-view and transverse middle-esophageal mitral valve long-axis-view provide useful information of interest anesthesia monitoring, because of their views enable to certainly obtain TEE parameters in various postures. Furthermore, TEE parameters allow to detect the changes of preload, afterload and HR that occur in supine position dogs.

KEY WORDS: cardiovascular system, dog, echocardiography, ultrasound

In human medicine, transesophageal echocardiography (TEE) has been recognized as a useful tool not only for diagnosis of congenital heart disease [14, 24] and for an assessment tool of interventional cardiology [1, 28], but also for a noninvasive intraoperative monitoring of cardiac function in patients with severe conditions, such as heart failure [10, 31, 34]. Although TEE has been mainly used as an assistant tool for catheter intervention in veterinary medicine [23, 30, 33, 35], few reports on the intraoperative cardiac evaluation are available in dogs with heart failure. To enhance anesthetic safety, intraoperative blood pressure has been monitored by way of prevention of acute renal disorders and cerebral ischemia [21].

Considering fully understanding of intraoperative hemodynamics, however, blood pressure measurement alone is not always the answer to explain the mechanism of hypotension. Hypotension can be caused by several factors: decrease in preload, afterload, and contractility and echocardiographic measurements allow to reveal these cardiac information during surgery. For the intraoperative echocardiography monitoring under anesthesia, animal positions undergoing surgery usually depend on the operative procedure and transthoracic echocardiography is sometimes unavailable for evaluation. Therefore, TEE parameters should be the only option, for the purpose of intraoperative monitoring. Several experimental reports addressing the utility of TEE parameters in evaluating canine cardiac function were performed only in lateral-recumbency [7, 13]. Postural change may alter the positional relation of the intrathoracic organs and influence echocardiographic views, and the effects of postural differences on TEE views and parameters

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*Correspondence to: Tanaka, R., Department of Veterinary Surgery, Faculty of Veterinary Medicine, Tokyo University of Agriculture and Technology, 3-5-8 Saiwai-cho, Fuchu-shi, Tokyo 183-0052, Japan. e-mail: ryout@icloud.com should be considered. The present study was conducted to elucidate the effects of postural change on conventional TEE views and echocardiographic parameters.

MATERIALS AND METHODS

During the study, the dogs were managed and cared for in accordance with the standards established by the Tokyo University of Agriculture and Technology (TUAT) and described in its “Guide for the Care and Use of Laboratory Animals.” This study was approved by the Experimental Animal Committee of TUAT (acceptance no. 26–87).

Animals

We used twelve, 1- to 2-year-old Beagle dogs (8 males and 4 females), weighing 10.0 ± 1.0 kg (range, 8.4–11.7 kg). The dogs were evaluated with general physical examination, blood and serum biochemical evaluations, electrocardiography, thoracic radiography and echocardiography, and then, all were declared as healthy.

Anesthesia and preparatory procedures

Dogs were premedicated with meloxicam (0.2 mg/kg, SC), butorphanol tartrate (0.2 mg/kg, IV) and midazolam hydrochloride (0.2 mg/kg, IV). Induction was achieved with propofol (4 mg/kg, IV), after which the dog was intubated. Anesthesia was maintained by administering a mixture of 1.5–2.0% isoflurane and oxygen. The respiratory rate and airway pressure were maintained with a mechanical ventilator. End-tidal CO_2 was monitored and maintained between 35 and 45 mmHg using a monitoring instrument. A 5 MHz rotary plane transesophageal probe (Aloka UST-52119S, Hitachi Aloka Medical, Tokyo, Japan) connected to an ultrasound machine (Prosound α10, Hitachi Aloka Medical) was navigated according to the technique as described in literatures [9, 19]. The dogs were randomly positioned in one of four postures: right lateral recumbency, left lateral recumbency, supine position and prone position. After the examination in a posture was finished, another posture was selected randomly, and then, the dogs were changed their position quietly. This process was repeated consecutively until the end of examination in all postures. In each posture, the examination was conducted for at least 10 min after hemodynamics stabilization was achieved.

TEE measurements

In accordance with reports [9, 19], the following three views were attempted to be displayed in each posture. Echocardiographic measurements were performed at the end of the expiration period. Data were collected and analyzed by a single investigator. The mean value of 3 heart beats was calculated excluding the maximum and minimum values among the 5 consecutive cardiac cycles.

Longitudinal cranial-esophageal aorta long-axis-view: The probe was inserted in the cranial esophagus in neutral position (not flexed). Then, the transducer tip was retroflexed (bend backward) and advanced caudally until an image of the heart base was produced [9]. With the array angle set to 75–85°, longitudinal views were obtained. By orienting the beam centrally, the aortic arch could be seen. The sample volume was placed at the place between pulmonary artery and right auricle in the center of ascending aorta (Fig. 1). Stroke volume (SV) and cardiac output (CO) were calculated using the cross sectional area of the aorta. Left ventricular pre-ejection period (LVPEP) and ejection time (LVET) were measured, and LVPEP per LVET ratio (LVPEP/LVET) was calculated by using pulsed Doppler in conjunction with electrocardiography. The HR-corrected left ventricular ejection time (LVETc) and LVPEP per LVETc ratio (LVPEP/LVETc) were calculated according to the report [29]. HR is determined from the RR intervals of the beats immediately after preceding those measured.

Transverse middle-esophageal mitral valve long-axis-view: From cranial-esophageal position, by further advancing the probe in neutral position until the point in which interference by the trachea was no longer present, middle-esophageal position views could be produced. A 4 chamber long axis view could be achieved with 0° array angle from this position [9, 19]. Doppler inflow across the mitral valve was measured by use of this view, with the 2 mm sample volume positioned at the tip of the mitral valve (Fig. 2). The transmitral flow velocities were measured to determine the peak early diastolic velocity (E) and peak atrial systolic velocity (A), and peak early diastolic velocity per peak atrial systolic velocity ratio (E/A) was calculated. After that, tissue Doppler echocardiographic examination was performed by use of the same view. The sample volume was placed at the septal mitral annulus, and the peak systolic velocity of mitral annulus (Sm), the peak early diastolic velocity of mitral annulus (Em), peak atrial systolic velocity of mitral annulus (Am) and peak early diastolic velocity per peak early diastolic velocity of mitral annulus ratio (E/Em) were determined.

Transgastric middle short-axis-view: The probe was advanced into the stomach until the liver image was seen on the screen. The transducer tip is then completely anteflexed (bend forward), and the whole probe is slightly pulled to have the stomach wall adhere [9, 19]. Loyer and Thomas reported [19] that there is a short-axis-view of the left ventricle at the level of the papillary muscles. The short-axis-view image of the left ventricle was attempted to measure certain parameters.

Arterial blood pressure measurements

In a total of dogs, 24-gauge intravenous catheter was inserted into the dorsalis pedis artery for direct pressure monitoring [40]. The invasive arterial blood pressure was directly recorded by means of a pressure transducer (DX-300, Nihon Kohden, Tokyo, Japan) connected to the catheter. Systolic arterial pressure (SAP), mean arterial pressure (MAP) and HR were determined from the arterial pulse and recorded by use of the monitoring instrument. Systemic vascular resistance (SVR) was calculated as SVR (Wood)=(MAP−central venous pressure)/CO [41]. Central venous pressure was defined as 5 mmHg, considering a lack of right

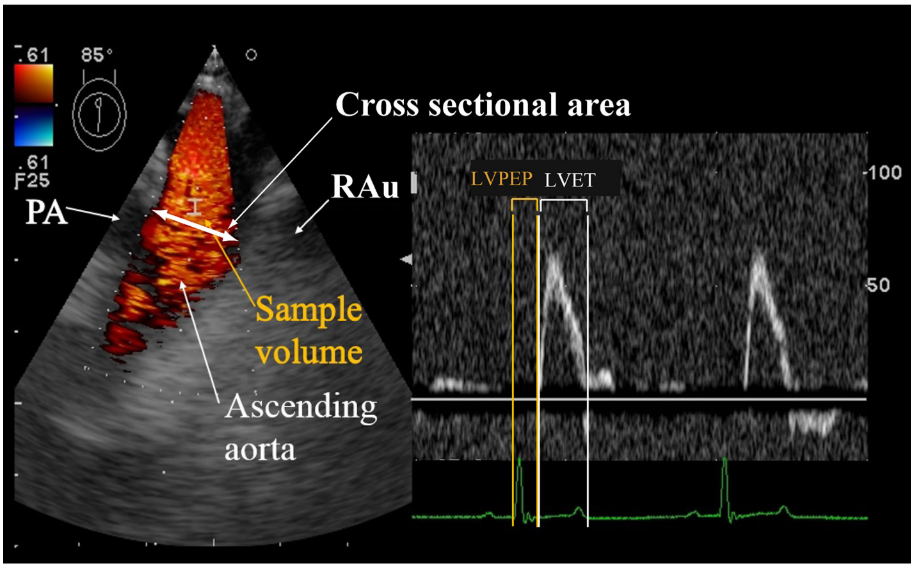

Fig. 1. Longitudinal cranial-esophageal aorta long-axis-view was obtained with the array angle set to 75–85°. The sample volume was set at 2 mm and was located in the center of the ascending aorta between PA and Rau. LVPEP was the duration from Q of ECG to left ventricular ejection onset. LVET was duration of the blood flow from the left ventricule. PA: pulmonary artery; Rau: right auricle; LVPEP: left ventricular pre-ejection period; LVET: left ventricular ejection time.

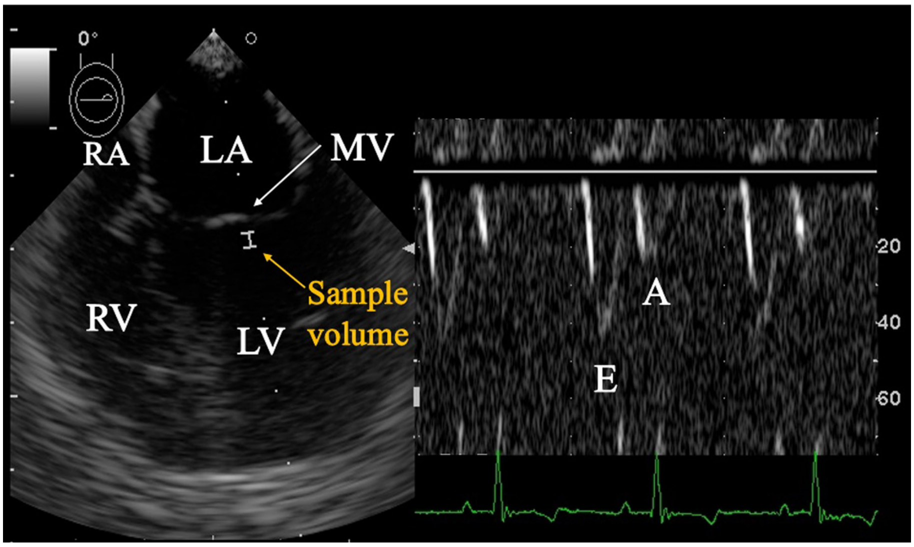

Fig. 2. Transverse middle-esophageal mitral valve long-axis-view was obtained with the array angle set to 0°. The sample volume was set at 2 mm and was placed at the tip of mitral valve. LA: left atrium; LV: left ventricle; MV: mitral valve; RA: right atrium; RV: right ventricle; E: the peak early diastolic velocity; A: the peak atrial systolic velocity.

atrium enlargement or jugular distension.

Statistical analysis

All data are reported as mean ± standard deviation (SD). The differences among postures in normally distributed data were analyzed using one-way repeated measures analysis of variance and Tukey’s multiple comparisons test. Non-normally distributed data were analyzed using the Kruskal-Wallis test and Dunn’s multiple comparisons test. Linear regression analysis for R and P values was conducted to determine the Pearson correlation coefficient. Statistical significance was defined as $P<0.05$. GraphPad Prism (GraphPad Prism version 5.0a, GraphPad, San Diego, CA, U.S.A.) was used to perform these statistical analyses.

Table 1. Mean ± SD values for the aortic flow parameters obtained from longitudinal cranial-esophageal aorta long-axis-view in 4 postures (n=12)

Variable	Posture			
	Left lateral-recumbency	Right lateral-recumbency	Supine position	Prone position
SV (m*l*)	14 ± 3	14 ± 2	10 ± 3$^{a,b)}$	13 ± 3
CO (*l*/min)	1.3 ± 0.3	1.3 ± 0.3	1.0 ± 0.3	1.2 ± 0.2
LVPEP (ms)	61 ± 5	59 ± 5	72 ± 11$^{a,b)}$	66 ± 9
LVET (ms)	210 ± 9	212 ± 15	185 ± 11$^{a,b)}$	201 ± 20
LVPEP/LVET	0.29 ± 0.03	0.28 ± 0.03	0.40 ± 0.08$^{a,b)}$	0.33 ± 0.06
LVETc (ms)	338 ± 21	337 ± 17	338 ± 29	335 ± 25
LVPEP/LVETc	0.29 ± 0.02	0.28 ± 0.02	0.35 ± 0.04$^{a,b)}$	0.31 ± 0.03

SV: stroke volume; CO: cardiac output; LVPEP: left ventricular pre-ejection period; LVET: left ventricular ejection time; LVPEP/LVET: a ratio of PEP to ET; LVETc: HR-corrected LVET; LVPEP/LVETc: a ratio of LVPEP to LVETc. a) Significant difference with left lateral-recumbency ($P<0.05$). b) Significant difference with right lateral-recumbency ($P<0.05$).

Table 2. Mean ± SD values for the transmitral flow and the motion of the septal mitral annulus parameters obtained from transverse middle-esophageal mitral valve long-axis-view in 4 postures (n=12)

Variable	Posture			
	Left lateral-recumbency	Right lateral-recumbency	Supine position	Prone position
E (cm/sec)	57 ± 8	59 ± 9	46 ± 8$^{a,b)}$	51 ± 8
A (cm/sec)	26 ± 6	26 ± 7	24 ± 5	26 ± 7
E/A	2.3 ± 0.8	2.4 ± 0.9	2.0 ± 0.4	2.1 ± 0.6
Sm (cm/sec)	6.0 ± 1.2	6.2 ± 1.4	6.5 ± 1.6	6.5 ± 1.3
Em (cm/sec)	7.1 ± 1.0	8.0 ± 1.5	5.7 ± 1.2$^{a,b)}$	6.3 ± 0.9$^{b)}$
Am (cm/sec)	3.9 ± 0.7	4.1 ± 1.5	3.1 ± 0.5	4.3 ± 1.5
E/Em	8.4 ± 1.6	7.5 ± 1.0	8.5 ± 2.4	8.2 ± 1.5

E: the peak early diastolic velocity; A: the peak atrial systolic velocity; E/A: a ratio of E toA; Sm: the peak systolic velocity of mitral annulus; Em: the peak early diastolic velocity of mitral annulus; Am: the peak atrial velocity of mitral annulus; E/Em: a ratio of E to Em. a) Significant difference with left lateral-recumbency ($P<0.05$). b) Significant difference with right lateral-recumbency ($P<0.05$).

RESULTS

Longitudinal cranial-esophageal aorta long-axis-view was obtained by the same technique among any posture in all dogs. In regard to the effects of postural change on echocardiographic parameters, SV and LVET in supine position were significantly lower compared with those in right and left lateral-recumbency. LVPEP was significantly prolonged in supine position compared with that in right and left lateral-recumbency. LVPEP/LVET and LVPEP/LVETc were significantly higher in supine position compared with those in right and left lateral-recumbency (Table 1).

Transverse middle-esophageal mitral valve long-axis-view was obtained by the same technique among any posture in all dogs. E was significantly lower in supine position compared with that in right and left lateral-recumbency. Em was significantly lower in supine position compared with that in right and left lateral-recumbency, and significantly lower in prone position compared with right lateral-recumbency (Table 2).

Transgastric middle short-axis-view was not obtained by the clear image among any posture in all dogs.

HR and SVR increased significantly in supine position compared with those in right and left lateral-recumbency. SAP, MAP and DAP did not show significant differences among postures (Table 3). Figure 3 (1) and (2) shows the correlation between HR and SV, LVET. HR was weakly correlated with SV ($P<0.0001$, R=−0.55) and LVET ($P=0.0005$, R=−0.48).

DISCUSSION

In the present study, conventional TEE techniques allowed to display longitudinal cranial-esophageal aorta long-axis-view and transverse middle-esophageal mitral valve long-axis-view and to measure echocardiographic parameters in any posture. On the other hand, the present study also revealed the difficulty of obtaining transgastric middle short-axis-view with TEE in any posture. Loyer and Thomas reported [19] that transgastric middle short-axis-view could seldom be obtained by TEE in dogs, lacking image or additional useful information. Unlike in humans, the anatomical spatial gap between the heart and stomach results from the vertical positional relationship between the cardiac longitudinal axis and esophagus. This is why the transgastric middle short-axis-view was not available in dogs.

In human medicine, transgastric middle short-axis-view is used for the calculation of fractional area change, which is a reliable,

Table 3. Mean ± SD values of HR, SAP, MAP, DAP and SVR in 4 postures (n=12)

Variable	Posture			
	Left lateral-recumbency	Right lateral-recumbency	Supine position	Prone position
HR (bpm)	88 ± 14	88 ± 12	108 ± 21$^{a,b)}$	104 ± 15
SAP (mmHg)	89 ± 14	91 ± 16	100 ± 15	101 ± 19
MAP (mmHg)	63 ± 11	64 ± 11	72 ± 12	71 ± 14
DAP (mmHg)	49 ± 11	50 ± 10	59 ± 12	57 ± 13
SVR (Wood)	49 ± 18	48 ± 12	71 ± 23$^{a,b)}$	59 ± 15

HR: heart rate; SAP: systolic arterial pressure; MAP: mean arterial pressure; DAP: diastolic arterial pressure; SVR: systemic vascular resistance. a) Significant difference with left lateral-recumbency (*P*<0.05). b) Significant difference with right lateral-recumbency (*P*<0.05).

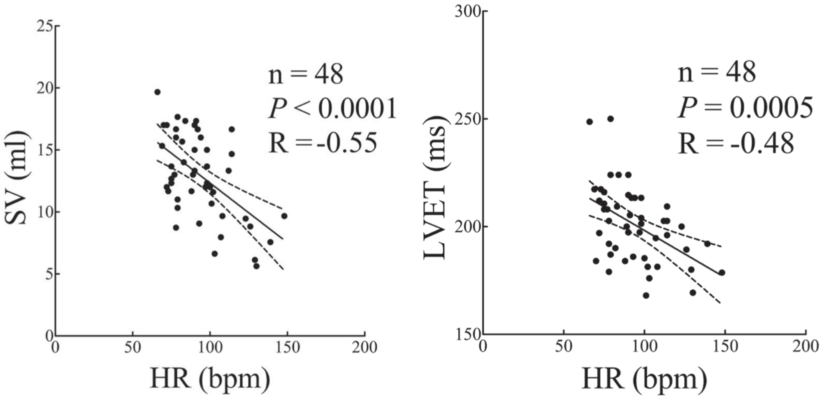

Fig. 3. (1) Relationship between SV and HR in all postures. A significant negative correlation was found between SV and HR. SV: stroke volume; HR: heart rate. (2) Relationship between LVET and HR in all postures. A significant negative correlation was found between LVET and HR. LVET: left ventricular ejection time; HR: heart rate.

quick index of cardiac contractility [32]. Fractional shortening, an index of contractility, measured in transgastric middle short-axis-view, is also obtained using transthoracic echocardiography in veterinary medicine. Sm, which correlated with the peak value of the positive first derivative of left ventricular pressure, is detectable in transverse middle-esophageal mitral valve long-axis-view. Longitudinal cranial-esophageal aorta long-axis-view also can show SV and CO and provides the important information related to anesthesia monitoring. The longitudinal cranial-esophageal aorta long-axis-view and transverse middle-esophageal mitral valve long-axis-view are views available for contractility monitoring in any postures in dogs.

The decrease in SV and the increase in LVPEP/LVET and LVPEP/LVETc were observed in supine position compared with that in right and left lateral-recumbency in the present study. Several studies have reported that the corrected and uncorrected LVPEP/LVET are better correlated with the ejection fraction, dP/dt and SV [6, 11, 12, 22]. These results show a reduction in pump function in supine position. This hemodynamic change could be considered to be caused by several factors: an increase in afterload, a decrease in preload and a reduction in cardiac contractility. However, the effect of the reduction in contractility is likely negligible, because a significant difference was not observed in Sm. The increase in SVR shows the increase in afterload in supine position than right and left lateral-recumbency. The preload was decreased in supine position, as shown by the reductions in E and Em [26]. LVETc is a preload indicator [16, 20]; however, LVETc is also affected by afterload [36] and cardiac contractility [2, 18]. Unchanged LVETc indicates the simultaneous decrease of preload and/or the increase of afterload. A prolonged LVPEP indicates the increase in afterload and/or depression of cardiac contractility [4, 42]. To summarize the above, the reduction of pump function in supine position was caused by the increase in afterload and the decrease in preload. Postural change significantly affects hemodynamics in human [8, 17, 37–39] and animals [3, 15, 27]. In normal pregnant women, cardiac output was increased by postural change from supine to lateral position [17, 38, 39]. Compression and relief of the inferior vena cava by the gravid uterus caused this physiological phenomenon. Furthermore, the decrease in cardiac output was observed in not only pregnant women but also anesthetized dogs [27]. Nakao *et al.* suggested that the preload reduction in supine position resulted from the compression of the inferior vena cava by intra-abdominal organs [27]. Hoffman *et al.* also observed altered SV caused by postural change, which is associated with the Frank-Starling mechanism [15]. If the compression of the inferior vena cava by intra-abdominal organs occurs also in our study, the increase in afterload might also be derived from the compression of the celiac artery. The reduction of SV along with postural change is a physiological change, detected and assessed by TEE parameters.

Furthermore, the postural change influenced the modulation of the cardiac autonomic nervous system [5, 25]. Cardiac vagal activity is greatest in right lateral-recumbency, and the sympathetic tone is increased in supine position in normal human subjects [5] and patients with congestive heart failure [25]. The finding that HR was higher in supine position than in lateral-recumbency concurs with the canine study made by Bornscheuer *et al* [3]. Consequently, CO was unchanged due to the rise of HR compensating for the reduction in SV. The rise of HR along with postural change related to the variation of several TEE parameters, such as SV and LVET, and significant difference is not found in CO and LVETc among 4 postures. The effect of HR should be considered when assessing cardiovascular function using TEE. Longitudinal cranial-esophageal aorta long-axis-view and transverse middle-esophageal mitral valve long-axis-view provide the same views and stable parameters in any posture: however, some parameters are influenced by the physiological changes in supine position.

A limitation of the study reported here is that no catheter examination was performed for the accurate assessment of cardiac function. There may be some differences between the actual values obtained using a catheter and the TEE parameters. Therefore, the dogs in this study are all normal, so we cannot reveal whether the healthy dogs are the same as the dogs with cardiovascular disease. Also, we cannot exclude the possibility of the anesthetic effect on the TEE parameters. Finally, only 1 breed of 1 particular body weight and chest conformation was assessed in our study. The results might not be automatically transferable to dogs of different breeds, age, body weights and chest conformations.

Although postural effects on TEE parameters must be considered, longitudinal cranial-esophageal aorta long-axis-view and transverse middle-esophageal mitral valve long-axis-view obtained using TEE provide useful information for monitoring intraoperative hemodynamics in dogs.

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