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Prospective evaluation of complications associated with transesophageal echocardiography in dogs with congenital heart disease

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Abstract

Background: Transesophageal echocardiography (TEE) is useful in the assessment and procedural monitoring of congenital heart disease (CHD) with a relatively low complication rate in humans.

Objectives: To evaluate the safety of TEE and report complications in dogs.

Animals: Forty client-owned dogs with CHD.

Methods: Prospective observational study including gastroesophagoscopy before and after TEE imaging. TEE was planned with a GE 6VT-D adult probe in dogs weighing ≥4 kg and a GE 10T-D microprobe alternating with an intracardiac echocardiography probe placed in the esophagus in dogs <4 kg. Difficulties with probe placement, probe interference and TEE probe imaging times were recorded. Dogs were monitored in the recovery period after TEE using an established nausea scoring system.

Results: New gastroesophageal abnormalities were identified after TEE in 4 dogs including 4 areas of mucosal damage involving <25% of the lower esophageal sphincter (n = 4) and 1 lesion at the heart base (n = 1) and were not attributed to longer imaging times or a specific probe. Lesions identified before TEE in 4 dogs remained unchanged after TEE. The 6VT-D probe could not be placed in 1 dog with enlarged tonsils, and it obstructed fluoroscopic views in 3 dogs. The probes did not compress any structures in dogs in which fluoroscopy was performed (n = 20). Four dogs had evidence to suggest nausea after the procedure.

Conclusions and Clinical Importance: While major complications remain possible, complications in this study were mild and few in number. Dog size and probe characteristics are factors to consider when performing TEE.

Abbreviations: 3D, 3-dimensional; BV, balloon valvuloplasty; CHD, congenital heart disease; HB, heart base; ICE, intracardiac echocardiography; LES, lower esophageal sphincter; PDA, patent ductus arteriosus; PS, pulmonary valve stenosis; TEE, transesophageal echocardiography.

1 | INTRODUCTION

Congenital heart disease (CHD) is an important cause of morbidity and mortality in dogs.[1] Minimally invasive and hybrid interventional procedures have emerged as successful treatment options for many congenital cardiac anomalies. As the applications have expanded in the veterinary field to include small dogs, diagnostic imaging and intraoperative monitoring techniques have evolved.[2,3] Transesophageal echocardiography (TEE) allows clinicians to collect superior high-resolution images of the heart during procedures that is not otherwise possible with routine transthoracic echocardiography.[4] Transesophageal echocardiography is an indispensable tool in both the more common procedures, such as patent ductus arteriosus (PDA) occlusion and balloon valvuloplasty (BV) of pulmonary valve stenosis (PS), as well as in the management of less common and complex CHD before occlusion and repair.[3,5-7]

Transesophageal echocardiography has been an important diagnostic imaging and monitoring tool for the management of CHD in human medicine since the 1980s.[8] Multiple types of probes including adult, pediatric, micro and intracardiac echocardiography (ICE) have been used for TEE.[9,10] Multiple studies have assessed the safety of TEE in humans to establish guidelines for its use, particularly in pediatric humans because of their small esophageal dimensions when compared to the TEE probe diameter.[11] Transesophageal echocardiography is considered a relatively safe imaging modality with a low incidence of contributing to death. Complication rates are higher in pediatrics compared to adults which is attributed to smaller size and need for anesthesia to perform TEE.[9,12-20] To minimize complications associated with TEE in pediatrics, recommendations include selecting probes based on size and careful handling when inserting and manipulating the probe.[21] Dogs are similar to pediatric humans in that they are generally small, and anesthesia is required to perform TEE. With the increased utilization of TEE in dogs, an evaluation of safety and potential complications is important.

Complications associated with TEE imaging in pediatric humans with CHD include laceration and bruising of the lips, tongue, or pharynx, in addition to painful swallowing and dysphagia. Esophageal trauma encompasses esophageal laceration and perforation in addition to direct pressure necrosis at points of probe contact and thermal injury secondary to prolonged exposure to the hyperthermic esophageal probe head. In addition, the TEE probe can compress the heart or surrounding mediastinal structures leading to decreased venous return and subsequent systemic hypotension and can obstruct the field of view during fluoroscopic-guided procedures.[9-11,21,22] Few complications occur with the use of TEE in dogs and cats and include probe interference with the fluoroscopic views and compression of vascular structures (aorta in a dog, pulmonary veins in a cat).[7,23]

The primary objective of this study was to report complications associated with TEE using different types of probes in dogs with a varying range of body weights undergoing diagnostic or interventional procedures for CHD.

2 | MATERIALS AND METHODS

Dogs presented to the cardiology service at Texas A&M University for evaluation of CHD that were scheduled for additional diagnostic imaging or catheterization procedures were eligible for inclusion in the study. Dogs were excluded if they had clinical or historical evidence of esophageal or gastric disease, were considered high-risk anesthetic candidates (ie, severe heart disease with evidence of compromised cardiac output or concerns for the dog's stability under anesthesia) or had a history of brachycephalic obstructive airway syndrome and concern for the potential development of pharyngeal edema and worsening airway compromise secondary to the manipulation of multiple probes within the pharynx. This study was reviewed and approved by the Institutional Animal Care and Use Committee and the clinical research review committees at Texas A&M University. Written consent was obtained from each owner before admission of dogs into the study.

At presentation, a physical examination and a diagnostic evaluation that included transthoracic echocardiography to characterize the CHD, thoracic radiographs if indicated, and serum biochemical profile were performed. Dogs were divided into 2 groups based on body weight. Group 1 included dogs <4 kg in which TEE imaging was performed in randomized, alternating order with both a 10T-D microprobe (GE Vingmed Ultrasound, Horten, Norway) and catheter-based intracardiac echocardiography (ICE) probe (ACUSON AcuNav Ultrasound Catheter, Biosense Webster, Irvine CA) used in the esophagus for TEE. Group 2 included dogs ≥4 kg in which TEE imaging was performed with a 6VT-D adult TEE probe (GE Vingmed Ultrasound, Horten, Norway).

The 3 probes utilized for TEE are presented in Figure 1. The 6VT-D probe has a 5 MHz transducer that provides a 90° field of view with up to 20 cm of field depth in addition to single plane, multiplane, and 3-dimensional (3D) imaging. It is recommended for use in adult humans that weigh greater than 20 kg. The probe tip is 14.3 × 12.7 mm. The probe tip can be deflected down/anteflexion (120°), up/retroflexion (40°), and has lateral motion capabilities (40° to each side). This probe has a tip deflection break which, when applied, allows the operator to maintain ante or retroflexion if no force is applied to the scanhead. The probe has an autotemp shut down feature set at 42.5°C. When this temperature is reached, the probe is no longer capable of imaging until the temperature decreases below a predetermined temperature set by the manufacturer.
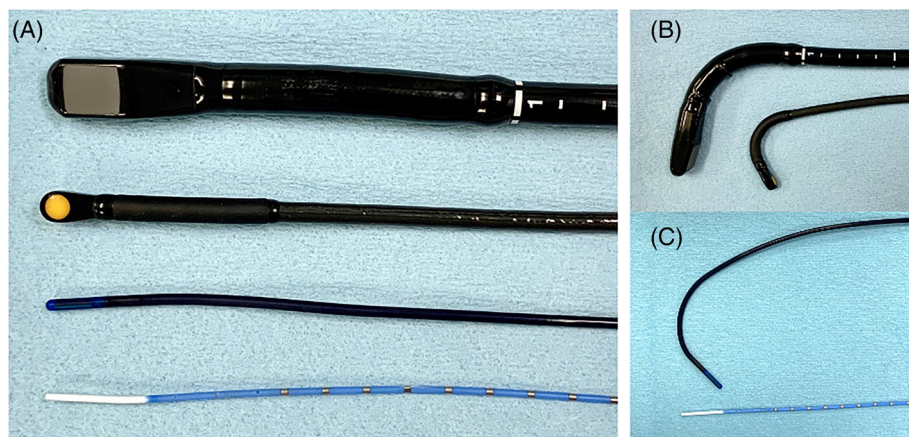
The 10T-D microprobe is a single plane imaging probe recommended for use in pediatric humans greater than 2.5 kg of body weight. The probe tip is 11 × 7 mm and has the capability of downwards deflection to 120° and upwards deflection of 90°. It has a friction-based deflection brake that when applied will hold the up and down deflection position for the operator. The 10T-D microprobe lacks lateral motion. This probe also has an automatic shutdown safety feature set at 42.7°C similar to the 6VT-D probe.

The ICE probe is supplied as a sterile, single use, disposable catheter-based probe designed for intracardiac and intraluminal evaluation of the heart and vasculature and has been used for TEE in infants with median weight of 3 kg and in rats and rabbits.[10,24,25] It is an 8 Fr diagnostic catheter with an outer diameter of 2.8 mm that consists of a 90 cm flexible ultrasound catheter with a transducer located on the distal tip to provide 2-dimensional imaging in a longitudinal plane. The catheter probe tip has 4-way articulation controlled by steering knobs that allow for flexion of the catheter tip 160° in each direction. This catheter has a tension control knob that when applied will minimize movement of the distal transducer tip from the desired angulation, and does not have an automatic shutdown safety feature.

Dogs were hospitalized overnight before the procedure. Food was withheld for a minimum of 10 hours before anesthetic induction in dogs >8 weeks of age and weighing >2 kg.[26] Antiemetic medications were not part of the preanesthetic protocol. Anesthesia protocols were tailored to each dog and approved by board-certified anesthesiologists. Briefly, general anesthesia was induced after premedication using 1 or combination of methadone, alfaxalone, acepromazine, fentanyl, hydromorphone, or midazolam. Injectable agents administered at time of induction included 1 or combination of propofol, etomidate, ketamine or midazolam and anesthesia was then maintained through a combination of constant rate infusions that included midazolam, fentanyl, ketamine, propofol, or dexmedetomidine and sevoflurane inhalant. All dogs had an opioid included in their anesthetic protocol.

After induction of anesthesia, dogs were positioned in left lateral recumbency. No anesthetic monitoring equipment was placed into the esophagus before endoscopy. A bite guard was positioned in the mouth to prevent damage to the endoscope, and gastroesophagoscopy was performed by a board-certified internist in a routine manner with either an Olympus GIF-160 video gastroscope with an 8.6 mm outer diameter or a Olympus GIF-XP190N video gastroscope with an outer diameter of 5.8 mm based on dog size (Olympus Corporation, Center Valley, Pennsylvania).[27] During esophagoscopy, the esophagus was insufflated to allow full visualization and was divided into 4 separate anatomic regions, namely the upper esophageal sphincter and proximal esophagus, the heart base (HB), the distal esophagus, and the lower esophageal sphincter (LES).

Each region of the esophagus was thoroughly evaluated for evidence of erythema, edema, mucosal erosion or ulceration, hematoma, petechiation, or perforation. The location of any abnormalities was documented along with the circumferential extent of the lesion (≤25%, 26%-50%, 51%-74%, and ≥75%). In addition to mucosal lesions, the appearance of the LES and the presence of fluid or food within the esophagus were noted. Following evaluation of the integrity of the esophageal mucosa, the scope was advanced through the LES and into the stomach; the presence and estimated amount of ingesta was noted. Following gastroscopy, air was suctioned from the stomach and esophagus and the endoscope was carefully removed to minimize the risk of iatrogenic injury to the esophageal mucosa and the outer diameter of the endoscope was recorded. Still photographs and video recordings of endoscopic procedures were saved for review.

Dogs were repositioned in right lateral recumbency and the bite guard was confirmed in place or replaced to protect the TEE probe. The TEE operator was unaware of the endoscopy results. Initial probe selection was as previously detailed based on body weight. Before probe placement, a water-based gel lubricant was applied to the tip of the probe using an amount sufficient to ensure 2 mm depth of coverage of the transducer. Resistance to TEE probe placement into the oropharynx and esophagus was monitored and recorded. If resistance occurred, the probe was removed and replaced with a smaller size probe. The operator did not use the tip deflection brake or tension control knob. The total time that the TEE probe was within the esophagus and the time that the probe was utilized for active image

generation, were recorded in minutes. Of note, our team routinely freezes the image (eg, probe remains in the esophagus but is not actively imaging) after acquisition of diagnostic images or while not actively providing procedural guidance in an effort to prevent inadvertent thermal injury thus these 2 times were recorded separately. The time spent imaging in 3D with the 6VT-D probe was recorded when this feature was used. Activation of the autotemp shutdown feature while imaging was recorded along with the number of times it occurred during the procedure. During fluoroscopic-guided procedures, obscurement of relevant anatomic structures (eg, the heart or great vessels) by the TEE probe or evidence of compression of cardiac or mediastinal structures were also recorded. The TEE probes were removed from the esophagus when imaging was complete when TEE was utilized for diagnostic imaging purposes or at the end of the procedure between the time of vascular access closure and removal of surgical drapes.

After completion of the planned imaging or interventional procedure, a second gastroesophagoscopy was performed. The same endoscope was used, and on all but 2 occasions, this was performed by the same internist as the initial gastroesophagoscopy. The dogs were placed in left lateral recumbency and a bite guard was positioned. Gastroesophagoscopy was performed and abnormalities scored as previously detailed. Particular attention was paid to the region of the HB where the TEE probe tip is predominantly situated in this section of the esophagus during TEE imaging. Lesions documented during the first esophagoscopy were reevaluated and scored as (0) not observed, (1) unchanged, (2) increased in size, or (3) increased in depth. Newly identified mucosal lesions were scored using the previously described scoring system.

Dogs were also reevaluated for LES abnormalities and the presence of fluid or food within the esophagus. Following esophagoscopy, air was suctioned from the stomach and esophagus and the endoscope was removed. Still photographs and videos of endoscopic procedures were saved for review.

Dogs were recovered from anesthesia under direct supervision and the time of extubation was recorded. No antiemetic drugs were given unless considered medically indicated. Dogs were continuously monitored by trained technical staff and recordings were made at hours 3, 6, 12, and 18 after extubation to document clinical signs of hypersalivation, lip licking, increased frequency of swallowing, exaggerated swallowing motion, retching, reflux, regurgitation, or emesis if observed.[28,29] If any of these clinical signs were observed, the time was recorded, the attending clinician was notified, and an antiemetic was administered.

2.1 | Statistical analysis

Descriptive statistics were calculated. Continuous variables were assessed for normality using the Shapiro-Wilk test and reported as median and range (minimum-maximum) because they were not normally distributed. Continuous data were compared using Mann-Whitney U test. Categorical data compared with Fisher's exact test was reported as frequency. Values of $P < .05$ were considered significant.

3 | RESULTS

A total of 40 client-owned dogs with confirmed CHD were enrolled between September 2019 and November 2020. Four dogs anesthetized for procedures that were not enrolled included 1 dog with severe subvalvular aortic stenosis that was not considered stable for prolongation of anesthesia, 2 French bulldogs with a history of gastrointestinal disease or stertorous breathing attributed to brachycephalic obstructive airway disease, and 1 dog in which the owner declined to participate. The study sample consisted of 26 females (17 intact, 9 spayed) and 14 males (8 intact, 6 neutered). Breeds included mixed (15), Chihuahua (4), Maltese (3), Australian shepherd dog (2), American pit bull terrier (2), German shepherd dog (2), Scottish terrier (1), Australian cattle dog (1), Boykin spaniel (1), American bulldog (1), Labrador retriever (1), Alaskan KleeKai (1), toy poodle (1), standard collie (1), Pomeranian, Cavalier King Charles spaniel (1), and miniature Dachshund (1). Clinical characteristics and TEE probe details and timing are reported in Table 1.

The majority of dogs (n = 37) had food withheld for >8 hours before anesthetic induction. Three dogs that weighed <2.1 kg had food withheld for shorter times. Four dogs received maropitant citrate (Cerenia Pfizer Animal Health, New York, New York) inadvertently out of study protocol before TEE. It was administered before anesthetic induction as part of routine protocol for surgical ligation of PDA in 3 dogs, and the night before anesthetic induction because of a single episode of vomiting in hospital in 1 dog. No dogs were receiving proton pump inhibitors or histamine 2 receptor antagonists at the time of enrollment.

Observations were made during gastroesophagoscopy before TEE in 10/40 (25%) dogs. In 5 dogs, general observations made by the internists included prominent vasculature within the wall of the esophagus (n = 2), a raised and irregular esophageal mucosal surface (n = 2), and appearance similar to that of a vascular ring anomaly that was ruled out with contrast angiography of the aorta during CHD intervention (n = 1). In 5 additional dogs, abnormalities included 1 with pinpoint gastric ulceration and hemorrhage and 4 with esophageal mucosal hyperemic or erythematous tissue (2.1 kg Maltese, 11.6 kg mixed breed, 25.6 kg German shepherd, 26.2 kg American pitbull terrier) without any reported history of vomiting, regurgitation, or hard swallowing to suggest esophageal reflux (n = 4, Table 2, Figure 2). During endoscopic evaluation, food or fluid was noted in the esophagus in 6 dogs (15%), and ingesta was documented in the stomach in 18 dogs (45%) (Table 2). All of these dogs had been withheld from food for a minimum of 8 hours before induction.

For the majority of dogs (n = 39), the selected TEE probe advanced smoothly or required only slight manipulation. Resistance to advancement of the 6VT-D probe was noted in 1 dog weighing 4.4 kg and was attributed to severe bilateral tonsillar swelling noted on endoscopy before TEE. In this dog, TEE placement and imaging was performed successfully with the 10T-D microprobe. Therefore, the 10T-D microprobe was used in 11/40 (28%) dogs with a weight range of 1 to 4.4 kg. Twenty-nine dogs with a weight range of 4.3 to 30.8 kg had TEE performed with the 6VT-D adult probe. The TEE

TABLE 1 Characteristics of 40 client-owned dogs grouped by body weight ≤4 kg (group 1) and >4 kg (group 2) with congenital heart disease (CHD) that had transesophageal echocardiography (TEE) performed

Characteristics	All dogs	Group 1	Group 2	P
Number of dogs	40	10 (25%)	30 (75%)	NA
Age (months)	7.5 (2.6-101.5)	4.9 (2.6-48)	7.8 (3.3-101.5)	NS
Sex (M/F)	14/26	4/6	10/20	NS
Weight (kg)	8.7 (1-30.8)	2.7 (1-3.2)	11.3 (4.3-30.8)	<.00001
CHD (PDA/PS)	27/13	9/1	18[a]/12	NS
Procedure (PS BV/PDA ligation/PDA occlusion)	13/18/9	1/9/0	12/9/9	NA
TEE probe (6VT-D adult/10T-D microprobe/ICE)	29/11/10	0/10/10	29/1[b]/0	NA
Time with probe in esophagus (min)	27 (10-141)	21 (11-28)	38 (10-141)	.01
Time imaging in esophagus (min)	25 (10-102)	20 (11-28)	30 (10-102)	.02
Number of dogs imaged in 3D	23 (58%)	0 (0%)	23 (79%)	NA
Time imaging in 3D (min)	4 (1-8)	0	4 (1-8)	NA
Probe interference with fluoroscopic view	3 (8%)	0	3 (10%)	NA
Probe compression of anatomic structures	0	0	0	NA

Abbreviations: 3D, 3-dimensional; BV, balloon valvuloplasty; ICE, intracardiac echocardiography; PDA, patent ductus arteriosus; PS, pulmonary valve stenosis.

[a]Includes 1 dog with both PDA and mild PS that had surgical ligation of PDA performed and was included in the group with PDA.

[b]One dog that weighed 4.4 kg had severe bilateral swelling of the tonsils that prevented the 6VT-D probe from advancing into the esophagus and the probe was exchanged for the 10T-D microprobe only.

TABLE 2 Endoscopic findings identified before transesophageal echocardiography (TEE) in 40 dogs with congenital heart disease (CHD) grouped by body weight ≤4 kg (group 1) and >4 kg (group 2)

Variables	All dogs (n = 40)	Group 1 (n = 10)	Group 2 (n = 30)
Lesions at the upper esophageal sphincter and proximal esophagus	1 (3%)	1 (10%)	0
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	0/0/0/1	0/0/0/1	0/0/0/0
Lesions at the level of the heart base	1 (3%)	0	1 (3%)
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	0/0/0/1	0/0/0/0	0/0/0/1
Lesions at the level of the distal esophagus	0	0	0
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	0/0/0/0	0/0/0/0	0/0/0/0
% lesions at the level of the lower esophageal sphincter	4 (10%)	1 (10%)	3 (10%)
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	1/0/1/2	0/0/1/0	1/0/0/2
Ingesta in the stomach	18 (45%)	6 (60%)	12 (40%)
Small amount	11 (28%)	3 (30%)	8 (27%)
Large amount	7 (18%)	3 (30%)	4 (13%)
Presence of food or fluid in the esophagus	6 (15%)	2 (20%)	4 (13%)

probe interfered with fluoroscopic imaging in 3/20 (15%) dogs undergoing fluoroscopic-guided procedures (2 PS, 1 PDA). Compression of anatomic structures was not noted during fluoroscopy in any dog (Table 1). The autotemp shutdown safety feature activated in 1 dog while imaging with the 6VT-D probe during surgical ligation of a PDA. This dog did not develop clinical signs of nausea or have mucosal lesions on gastroesophagoscopy.

Esophageal mucosal abnormalities were identified in 8 dogs during the second endoscopy after TEE was performed. Four of these dogs had mucosal abnormalities identified before TEE that were unchanged on repeat examination (Figure 2). New esophageal lesions were noted in 4 dogs (4/40, 10%, 1 in group 1, 3 in group 2) after TEE (Table 3, Figure 3). For these 4 dogs, the CHD was PS (2) and PDA (2), and the median time the TEE probe was within the esophagus was

FIGURE 2 Endoscopic images before (A, C, E) and after (B, D, F) transesophageal echocardiography (TEE) in 3 dogs with unchanged esophageal mucosal abnormalities observed before and after TEE with the 6VT-D probe. Panels A and B are images of the lower esophageal sphincter (LES) that show the preexisting superficial mucosal erosions occupying ≥75% of the LES. Panels C and D are images of a lesion at the level of the LES that included a focal spot of erythema (circle) involving ≤25% of the circumference of the LES in 1 dog. Panels E and F are images of a dog with hyperemia and erythematous raised nodules identified at the level of the LES occupying ≥75% of the circumference
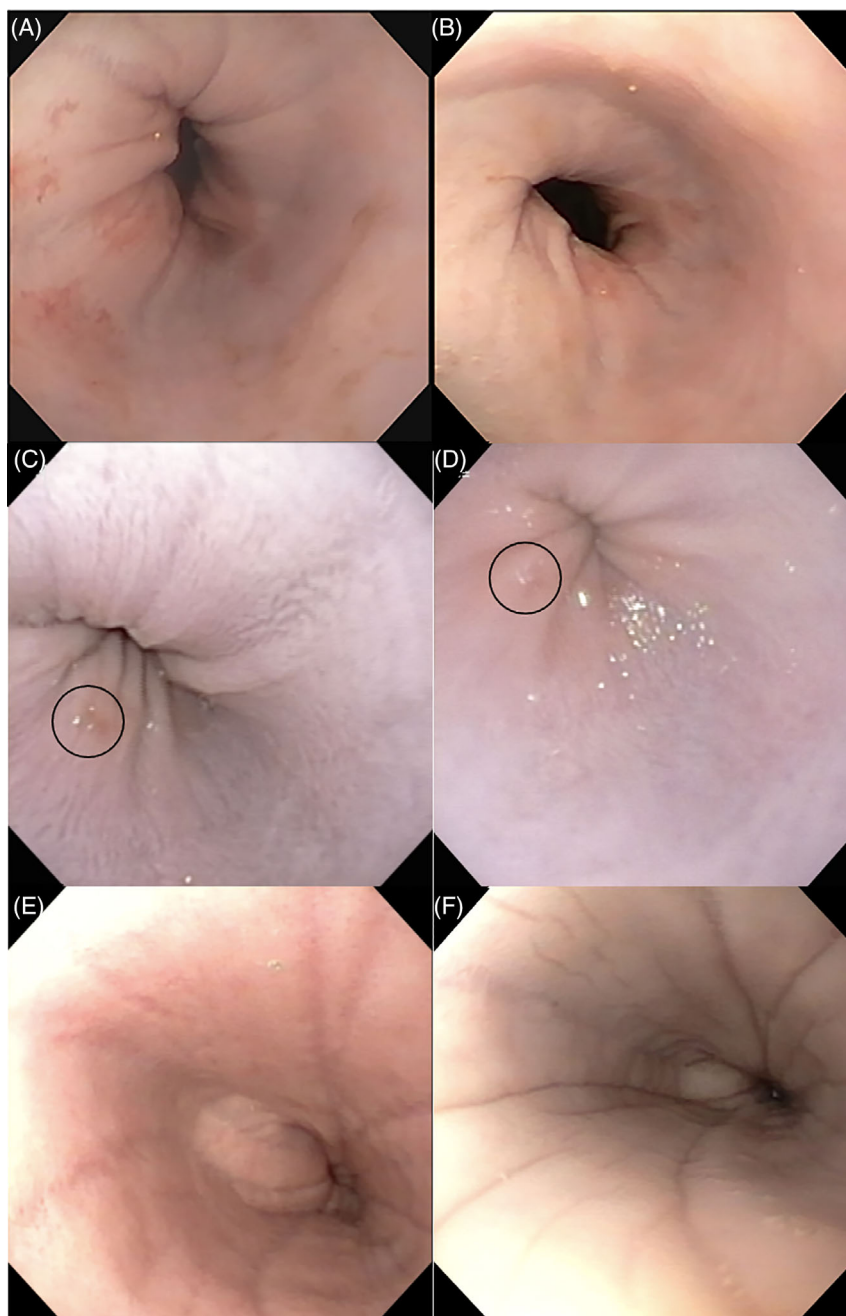
83 minutes (33-110 minutes) and the median time spent actively imaging was 61 minutes (33-102 minutes) including 3D imaging with the 6VT-D probe in 2 of the 4 dogs for 5 and 6 minutes each.

Two dogs had their first and second endoscopies performed by separate internists, both of which confirmed no lesions before or after TEE. The 5 dogs with general observations made by the internists during the first endoscopy before TEE and the single dog with gastric ulcerations and hemorrhage were unchanged on endoscopic examination after TEE. Ingesta was noted within the esophagus after TEE in 4 dogs (10%), 2 of which had a similar finding before TEE. Following evaluation of the esophagus, the stomach was reevaluated for the presence of food and fluid (Table 3).

Complications were documented in 4 dogs associated with endoscopy (n = 3) and TEE (n = 1). One dog had focal iatrogenic injury associated with endoscopy before TEE that led to mucosal hemorrhage at the level of the LES. Active bleeding resolved before the repeat endoscopy performed after TEE. In 1 dog, a loose deciduous tooth was dislodged during placement of the bite guard. Small fragments of soft plastic foreign material from breakdown of the ICE probe were identified within the esophagus and stomach in 1 dog. In another dog, a large volume of air was noted within the esophagus and stomach during the second endoscopy as an incidental finding. This was attributed to air insufflated during the initial endoscopy.

Thirty-six dogs did not receive an antiemetic drug before the procedure. Four of these (11%) had signs of nausea or esophageal discomfort after the procedure. Two dogs displayed hypersalivation and lip licking at 6- and 12-hours after the procedure. One dog would take hold of food but not swallow and also vomited approximately

TABLE 3 New lesions identified with endoscopy and reevaluation of the presence of food and esophageal reflux after transesophageal echocardiography (TEE) in 40 dogs with congenital heart disease (CHD) grouped by body weight ≤4 kg (group 1) and >4 kg (group 2)

Variables	All dogs (n = 40)	Group 1 (n = 10)	Group 2 (n = 30)
New lesions at the upper esophageal sphincter and proximal esophagus	0	0	0
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	0/0/0/0	0/0/0/0	0/0/0/0
New lesions at the level of the heart base	1 (3%)	1 (10%)	0
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	1/0/0/0	1/0/0/0	0/0/0/0
New lesions at the level of the distal esophagus	0	0	0
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	0/0/0/0	0/0/0/0	0/0/0/0
New lesions at the level of the lower esophageal sphincter	4 (10%)	1 (10%)	3 (10%)
% circumference involved: ≤25%/26%-50%/51%-74%/≥75%	4/0/0/0	1/0/0/0	3/0/0/0
Ingesta in the stomach	19 (48%)	6 (60%)	13 (43%)
Small amount	14 (35%)	4 (40%)	10 (33%)
Large amount	5 (13%)	2 (20%)	3 (10%)
Presence of food or fluid in the esophagus	4 (10%)	1 (10%)	3 (10%)

12 hours after the procedure. The fourth dog vomited approximately 12 hours after the procedure. Two of these 4 dogs did not have residual ingesta in their stomachs on endoscopy, 1 had a small amount of residual ingesta seen during endoscopy both before and after TEE, and 1 dog had a small amount of fluid/ingesta documented during endoscopy after the procedure. In addition to having TEE performed, the 4 dogs had opioid analgesics administered after the procedure as a single dose of buprenorphine (n = 3) or fentanyl constant rate infusion (n = 1). A single dose of maropitant citrate was administered to all 4 dogs and clinical signs resolved without further intervention. None of the 4 dogs with new esophageal lesions documented after TEE had clinical signs of esophageal discomfort or nausea after TEE. The skill level and stage of training of the sonographer was similar in the 4 dogs that developed new lesions and was not attributed to new lesion identification. The dog that 1 time before TEE had received an antiemetic for vomiting in hospital did not have evidence of esophageal abnormalities at time of endoscopy and did not have any further clinical signs suggestive of nausea or esophageal discomfort after the procedure.

4 | DISCUSSION

The results of our study suggest that complications associated with TEE are relatively uncommon but can occur in dogs with CHD. Complication rates associated with TEE in pediatric humans with CHD range from 0.03% to 6.7%[12-20] and are generally higher than those reported in adults (range, 0.18%-2.8%).[30-36] Many of the dogs in which TEE is performed for CHD are young (median age in our study was 7.5 months) and relatively small (median weight in our study was 8.7 kg) similar to pediatric humans. The adult size probes are frequently used in dogs despite the probe size because of the wider range of imaging capabilities.[3,7,37] The 6VT-D adult probe, for example, is recommended for humans that weigh >20 kg.

Traumatic injury to the oropharynx associated with TEE imaging in humans includes laceration and bruising of the lips and pharynx, injury to dentition, odynophagia, and dysphagia.[13,21,31-33,35,36,38,39] In 1 dog in our study, a loose deciduous tooth was dislodged while placing the bite guard for endoscopy before TEE. Esophageal injuries associated with TEE in humans include minor esophageal mucosal injury (eg, regions of petechiation, erosion, hematoma), esophageal laceration and perforation, direct pressure necrosis, and thermal injury from prolonged probe contact.[9-11,13,21,35,36] In our study, abnormalities identified with endoscopy before TEE were no worse after TEE imaging. In 4 dogs new abnormalities were identified endoscopically after TEE. One of the 4 dogs developed focal pinpoint mucosal erosions over the HB and the LES, while the other 3 dogs developed focal mucosal changes at the level of the LES with several pinpoint regions of isolated hemorrhage. We theorized the mucosal abrasions at the LES occurred during positioning of the TEE or endoscopy probe or secondary to decreased LES tone or esophageal reflux.

To avoid complications, recommendations for probe selection and TEE imaging have been published for humans.[9] In pediatric humans a higher risk of complications during TEE is attributed to relatively small esophageal dimensions when compared to TEE probe diameter, need for anesthesia to perform TEE, and long imaging durations with complex CHD.[11,21] Choice of probe size is considered 1 of the most important factors to minimize risk of complications.[18,21,40] Transesophageal echocardiography probes that are used in dogs and cats are not veterinary specific and do not come with recommended size considerations for veterinary use. In our study, probe size was
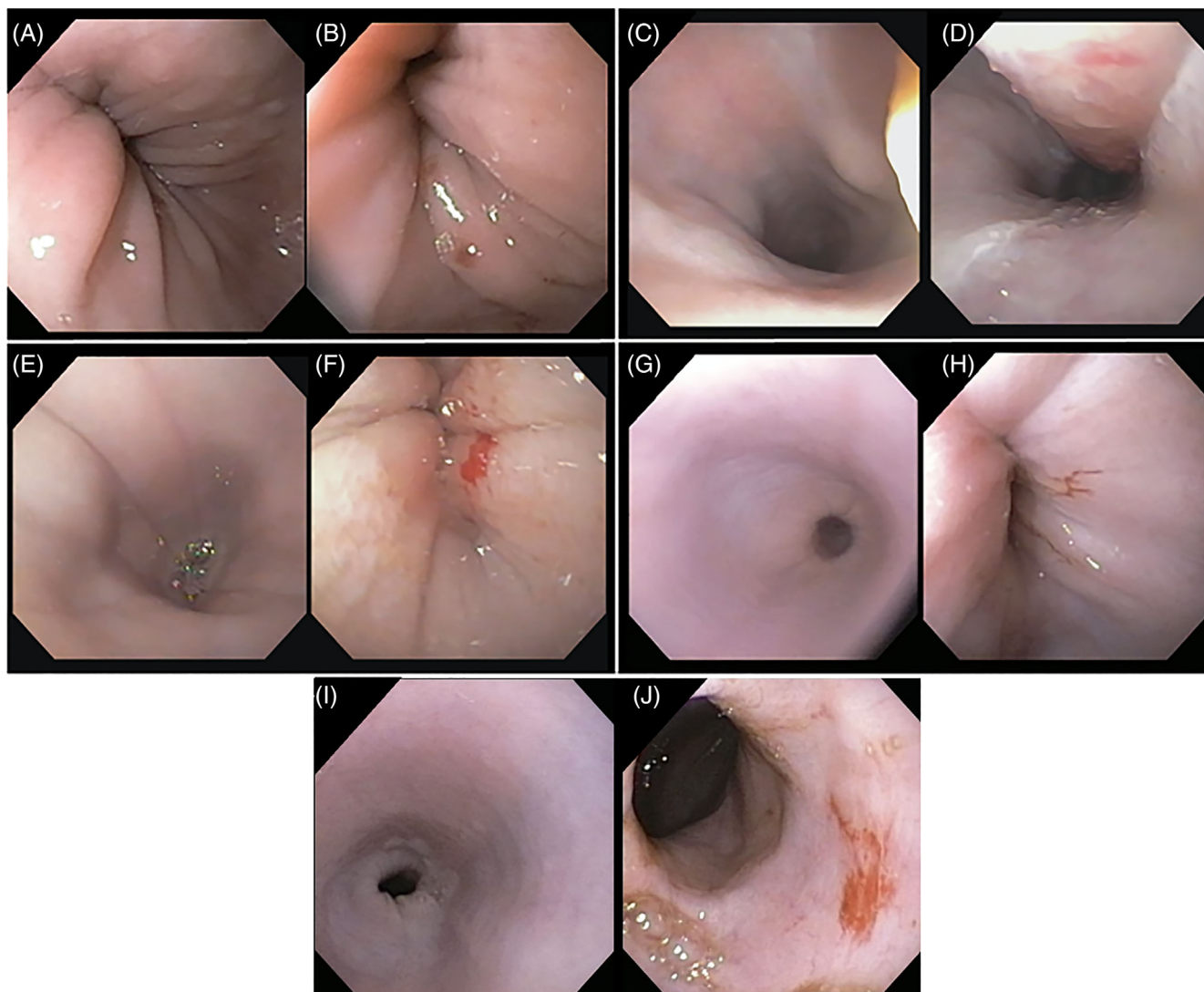
FIGURE 3 Endoscopic images before and after transesophageal echocardiography (TEE) in 4 dogs with esophageal mucosal abnormalities observed after TEE. Panels A and B are images of the lower esophageal sphincter (LES) in a dog with pulmonary valve stenosis (PS) before (A) and after (B) TEE with the 6VT-D probe with pinpoint mucosal erosions observed after TEE. Panels C-F are from a dog with a patent ductus arteriosus (PDA) with mucosal abnormalities at 2 regions including images at the level of the heart base before (C) and after (D) TEE with the 10T-D micro and intracardiac echocardiography probes with a focal region of erythema identified after TEE. Panels E and F of the same dog show pinpoint mucosal erosions before (E) and after (F) TEE. Panels G and H are images of the LES in a dog with PS before (G) and after (H) TEE with the 6VT-D probe with pinpoint mucosal erosions and scant hemorrhage identified after TEE. Panels I and J are images of the LES in a dog with PDA before (I) and after (J) TEE with the 6VT-D probe with a new lesion occupying ≤25% of the circumference of the LES which included a single moderately sized abrasion with scant hemorrhage in addition to decreased LES tone and scant esophageal reflux

selected based on previous experience and ease of placement. For this study, the 6VT-D probe was restricted to use in dogs >4 kg. Operator experience and knowledge of probe characteristics are also important considerations as limited range of motion (ie, lack of side-to-side motion with the 10T-D microprobe) can make image acquisition more challenging and thus the probe manipulation more challenging. At our institution, TEE is performed by cardiologists with expert level experience and by residents in varying stages of training under the supervision of veterinary cardiologists.

Probe placement and manipulation during imaging are factors to consider when avoiding potential complications. If initial probe advancement from the oropharynx to the esophagus is met with resistance, the probe should not be forced. Instead, attempts can be made to adjust the probe or dog's head position to a more favorable angle. Gentle manipulation of the probe and minimizing extreme angulation of the probe is important to avoid damage to the esophagus while advancing the probe into position and once the probe is in an ideal position for TEE imaging. The TEE probes have different ranges of flexibility that affect the ability to acquire images in multiple planes (Figure 1). Some probes have a friction brake, which when activated, maintains the probe tip at a selected deflection angle. This brake is not a lock per se but provides a source of resistance to maintain probe

position. Maximal probe angulation can place pressure on the surrounding esophageal tissue increasing the likelihood of tissue damage. It is important to note that activation of the friction brake can increase the risk of esophageal mucosal damage from prolonged high-pressure imaging.[9] Several studies in multiple species have attempted to induce pressure necrosis within the esophagus through use of extreme flexion of the TEE probe. In 1 study, 4 cynomolgus monkeys and 8 dogs were anesthetized and underwent TEE for 1 to 1.5 hours and 5.5 to 8.5 hours, respectively. The animals were subsequently euthanized and the esophagus was excised for gross and histopathologic examination. None had macroscopic or histopathologic evidence of mucosal or thermal injury.[41] A second study was designed to measure the pressure generated against the esophageal mucosa with manipulation of the TEE probe in humans and dogs.[22] In humans, up to 60 mm Hg of pressure could be generated with maximal probe deflection within the esophagus. In dogs, the maximal pressure was reported to be <10 mm Hg and was not accompanied by either gross or microscopic evidence of injury on histopathology.[22]

The duration of active imaging during TEE can increase the likelihood of mucosal injury.[9] The wide range in active imaging time in dogs in this study was attributed to the inclusion of both diagnostic studies to characterize anatomy which could lead to shorter imaging times and procedural monitoring leading to longer imaging times. The presence of esophageal lesions after TEE in 4 dogs in our study was not consistently associated with longer imaging times. Autotemp shutdown is a safety feature of the 6VT-D probe and 10T-D microprobe that activates when the probe head reaches a temperature of 42.5°C and 42.7°C, respectively. The TEE probe will automatically freeze until the temperature of the probe decreases to a manufacturer set safe range. This is a built-in safety feature that is not available in all TEE probes and is designed to prevent thermal injury to surrounding tissue.[42] This feature was activated in only 1 dog in our study and was not associated with esophageal lesions or clinical signs of gastrointestinal discomfort.

Transesophageal echocardiography probes can obstruct fluoroscopic views during imaging and compress anatomic structures.[7,23] Obstruction of the fluoroscopic view was uncommon. Interference with the fluoroscopic image was easily rectified by repositioning or withdrawing the probe. Complications reported in humans associated with TEE probe compression of adjacent thoracic structures include secondary hypotension, induction of cardiac dysrhythmia (ventricular and supraventricular), bronchospasm, accidental extubation, endotracheal tube malposition, airway obstruction, ventilatory problems, and hypoxia.[9,12,14,16,21,31] None of these occurred in any dogs in our study. However, compression of the aorta with the TEE probe has been reported in a dog and resolved with repositioning of the probe without causing any complications.[7] Compression of the pulmonary veins by the TEE probe was attributed to the development of cardiopulmonary arrest in a cat.[23]

Gastrointestinal discomfort characterized by odynophagia, dysphagia, hoarseness, and nausea are described in humans after imaging with TEE.[13,32,33,43] In our study, dogs were monitored for clinical signs suggestive of nausea and esophageal discomfort in the recovery period for at least 18 hours after extubation but not beyond discharge

to their owners. Four dogs that did not have antiemetics administered in the period before the procedure but did receive opioid analgesics after the procedure were documented to have lip licking or vomiting within 12 hours of extubation. Anesthetic agents and opioid analgesics can alter gastric motility, LES tone and facilitate gastroesophageal reflux or vomiting.[44-46] In addition to the influence of anesthetic medications on reflux or vomiting, there is also the potential for reflux or vomiting secondary to the 2 gastroendoscopic examinations and TEE imaging performed for this study.

An unexpected finding in this study was the presence of ingesta in the stomach in 18/40 dogs despite the routine withholding of food for >10 h. Gastric emptying times in normal dogs range from 5 to 24 hours with small amounts of residual kibble and wet diets observed within the stomach.[47-49] A significant prolongation in gastric emptying time occurs in dogs hospitalized compared to in their home environment based on a wireless motility capsule.[50] Exposure to various stressors can factor in to delayed gastric emptying time in a number of different species including rats, dogs, guinea pigs, and monkeys.[51-54] Dogs in this study had similar stressors including travel and hospitalization; however, how individual dogs handled these stressors could account for the variable presence in gastric contents after food was withheld across the sample group. The American Society of Anesthesiologists currently recommend a light meal followed by withholding food for >6 hours before general anesthesia to reduce the risk of aspiration,[42] and although there is limited consensus in veterinary medicine, similar protocols are routinely suggested for dogs >16 weeks old.[43,55,56] Environmental stressors, food type offered and use of opioids in anesthetic protocols could have impacted gastric emptying time in dogs in this study.

The results of this study are limited by the number of dogs enrolled. While the number of humans in studies reporting complications associated with TEE ranges from as many as 10 000 sedated adult humans to as few as 57 in specific scenarios with humans undergoing cardiac surgery,[9,36] the numbers of pediatric humans is typically smaller ranging from 18 to 1650.[13,19] Esophageal and oropharyngeal complication rates after TEE in humans vary considerably, and are as low at 0% to 0.2% in adults and as high as 64% in neonates undergoing interventional cardiac procedures but this type of information is lacking in dogs.[21,36] While minor complications were observed in dogs in our study, some complications reported in dogs (compression of structures) were not observed, and major complications reported in humans (perforation, death) were not encountered in this study. Additionally, this study was not designed to determine risk factors for complications nor was it designed to evaluate for long term complications associated with TEE that are reported to occur in humans.[35] It was not possible to standardize anesthetic protocols, which were designed to meet the individual dog's needs with different types of CHD. Imaging practices and probe availability for TEE undoubtedly vary among users and best practices should be considered when performing TEE and endoscopy including standardization of techniques which can include training and additional variables for scoring.

In summary, TEE was a relatively safe imaging modality in dogs with CHD in this study although minor complications can occur and

major complications including esophageal perforation and death remain possible. Although, no major or life-threatening traumatic injuries were identified in this study, the endoscopic findings highlight the need for careful placement and manipulation of the probe to minimize potential for trauma. Dog size, ease of probe placement and probe features are factors to consider when performing TEE in dogs.

CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Approved by the Texas A&M University Animal Ethics committee IACUC number 2019-0282 C.

HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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