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EXPERIMENTAL LAB RESEARCH

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Evaluation of thoracic duct ligation and unilateral subphrenic pericardiectomy via a left fourth intercostal approach in normal canine cadavers

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Abstract

Objective: To investigate a left-sided fourth intercostal approach to thoracic duct (TD) ligation and unilateral subphrenic pericardiectomy in dogs.

Study design: Retrospective computed tomography (CT) review and cadaveric study.

Animals: Thirteen dogs with idiopathic chylothorax and 10 canine cadavers.

Methods: A retrospective study of CT lymphangiograms in client-owned dogs with idiopathic chylothorax evaluated location and branching of the TD at the left fourth intercostal space. A cadaveric study evaluated the efficacy of TD ligation at this site. Following methylene blue mesenteric lymph node injection, TDs were identified through a left fourth intercostal thoracotomy, ligated, and sealed. Unilateral subphrenic pericardiectomy was performed through the same incision. Computed tomography scans were performed to determine the success of TD ligation.

Results: A review of lymphangiograms revealed a single TD in 10/13 clinical cases at the fourth intercostal space. Three cases had additional branches. Thoracic duct ligation via a left fourth intercostal thoracotomy was successful in nine out of 10 cadavers. A single branch was noted intraoperatively in six out of 10, and two branches were noted in four out of 10 cadavers. All branches were observed on the left side of the esophagus.

Conclusion: TD ligation at the left fourth intercostal space was successfully performed in 9/10 canine cadavers and appeared feasible in a retrospective review of 10/13 clinical cases. Unilateral subphrenic pericardiectomy can also be performed via this approach.

Clinical significance: Fewer thoracic duct branches at this location in comparison with the standard caudal location may simplify TD ligation. If elected, unilateral subphrenic pericardiectomy can be performed through the same incision. Further investigation in clinical patients is warranted.

Abbreviations: CCA, cisterna chyli ablation; CT, computed tomography; ICS, intercostal space; TD, thoracic duct.

1 | INTRODUCTION

Canine idiopathic chylothorax is commonly treated with thoracic duct (TD) ligation combined with subphrenic pericardiectomy.[1–3] This surgery can be performed openly or minimally invasively and has variable success rates, ranging from 60–100% for open, and 85–95% for thoracoscopic TD ligation and pericardiectomy.[1–9] Regardless of the technique, TD ligation in dogs has been performed traditionally via a caudal right approach at the eighth–ninth intercostal space despite multiple TD branches at this level.[1,5,6,8–12] When surgery is performed at a site with multiple branches, there is a risk of persistent chylothorax due to missed collateral vessels that bypass the site of ligation.[5,9,13,14] En bloc ligation of tissues adjacent to the TD at this caudal location has been described in canine cadavers and clinical cases as a potential method for incorporating multiple TD branches in the ligation.[8,15,16] Intercostal thoracotomy for en bloc ligation resulted in clinical resolution of chylothorax in 10/12 (83%) of cases.[16] Thoracoscopic en bloc ligation combined with pericardiectomy resulted in long-term clinical resolution in 6/7 cases (86%).[8] An alternative surgical approach to provide access to a location with fewer TD branches may theoretically increase ease of surgery while decreasing risk of persistent chylothorax.

Cisterna chyli ablation (CCA) is another procedure performed for the treatment of idiopathic chylothorax and has been used as an adjunct to TD ligation with the aim of stimulating the formation of new lymphaticovenous anastomoses in the abdomen.[4,17–19] When combined with thoracic duct ligation, a right thoracotomy or thoracoscopic approach to the chest is performed for TD ligation followed by a celiotomy or laparoscopic port placement for CCA.[17–19] Cisterna chyli ablation has reported success rates of 83–88% when combined with thoracic duct ligation.[4,18]

The thoracic duct courses along the right dorsal aspect of the aorta at the second lumbar vertebra, then crosses from right to left to run lateral to the esophagus prior to entering the cranial mediastinum.[10,11,13,20,21] While nearly all reports of canine thoracic duct anatomy describe multiple branches at the level of the caudal mediastinum, only five reports describe the number of branches cranial to this location based on direct inspection, radiographs and/or CT. In older reports, the branching pattern of 58 canine thoracic ducts was described at the fourth–fifth intercostal space and most dogs had a single left-sided branch at this level. Only 5/58 (8.6%) had branches that may preclude a left-sided cranial approach to the duct.[10,11,22,23] A more recent study reported similar highly variable course and branching of the thoracic duct in 43 canine cadavers from the level of the cisterna chyli to the level of the fourth thoracic intervertebral space, but the anatomy of the duct cranial to the fourth intervertebral space (the area of interest in the present study) could not be well characterized.[24] Despite evidence that a cranial left-sided approach may allow access to a single thoracic duct in select cases, there has been no discussion in the literature about approaching and ligating the duct at this location.

The goal of TD ligation is to stop lymphatic flow through the duct in the region of the cranial mediastinum and thereby decrease leakage of lymph into the pleural space. Thoracic duct ligation could theoretically be performed at any level prior to the point of lymph extravasation. When contrast lymphangiograms are performed on dogs with idiopathic chylothorax or experimentally induced chylothorax, leakage or extravasation is seldom reported.[13,25–27] When abnormalities are noted, such as dilated lymphatics or leakage of contrast, these abnormalities are consistently identified cranial to the fourth intercostal space in the mediastinum rather than from the thoracic duct proper. Reports on idiopathic chylothorax provide evidence of chyle leakage in the cranial mediastinum, far cranial to the traditional ligation location.[9,13,23,26–32] Ligation of the TD at the left fourth intercostal space could therefore provide the same therapeutic effect as caudal ligation, while providing access to a single TD branch.

Pericardiectomy is frequently performed in addition to thoracic duct ligation for treatment of idiopathic chylothorax.[1–3] Older reports suggested improved resolution rates when subphrenic pericardiectomy was performed at the time of TD ligation, theoretically due to decreased central venous pressure. However other studies have called the need for pericardiectomy in every case, and its effect on central venous pressure into question.[1,2,4,9] The traditional open approach to treating idiopathic chylothorax has involved two to three incisions in left lateral recumbency: one at the right ninth intercostal space to ligate TD branches; one at the right fifth to sixth intercostal space to perform subphrenic pericardiectomy; and possibly an additional paracostal incision to inject a mesenteric lymph node with methylene blue for TD visualization.[1,2,23,33,34] With a cranial left-sided approach for TD ligation, unilateral subphrenic pericardiectomy could be performed through the same incision, if elected. If this approach is found to be successful in clinical patients, the cranial left-sided approach to the TD could potentially be applied to thoracoscopic surgery as well. This might eliminate the need to reposition the patient following TD ligation if a unilateral subphrenic pericardiectomy is elected.

The objectives of this study were to document cranial thoracic duct branching and location based on review of computed tomographic (CT) lymphangiograms in clinical patients and to evaluate the efficacy of a left fourth intercostal approach in canine cadavers for TD ligation. The ability to remove pericardium via this approach was also evaluated.

2 | MATERIALS AND METHODS

2.1 | Retrospective review of lymphangiograms

Medical and radiological records at the North Carolina State University College of Veterinary Medicine were searched for canine CT thoracic lymphangiograms performed between May 2009 and July 2021. Helical thoracic CT scans were performed with a 512 × 512 matrix, kVp 130, variable mA, and 1.3 spiral pitch factor. Raw data were reconstructed into 3 mm or 1 mm thickness slices and reformatted into 1 mm dorsal and sagittal planes (Siemens Sensation 64, Siemens AG, Munich, Germany). Diagnosis of chylothorax was based on pleural fluid triglyceride concentration greater than serum concentration, and compatible fluid cytology. All studies were performed after injection of either the popliteal lymph nodes ($n = 10$) or the metatarsal pads ($n = 3$) with iodinated contrast material as previously described.[32,35] A board-certified radiologist (author 3) and surgeon (author 2) reviewed each lymphangiogram. The number and location of TD branches at the proposed site of ligation via a left fourth intercostal thoracotomy, dorsal to the aorta, lateral to the esophagus and caudal to the left subclavian artery were noted. Location of lymphatic leakage was also noted if present.

2.2 | Cadaveric study

Canine cadavers ($n = 10$) of various breeds, recently euthanized for reasons unrelated to this study, were obtained from local shelters. Due to use of cadaveric specimens, an institutional animal care and use committee (IACUC) exemption was granted by the IACUC committee after review of the study protocol. Cadavers were intubated with an 8.0–10.0 mm endotracheal tube within 3 h of euthanasia, and surgical procedures commenced within 4 h of euthanasia. Cadavers were prepped in right lateral recumbency and placed on a ventilator (Hallowell EMC, Pittsfield, Massachusetts, USA) to simulate live surgical conditions, with ventilator settings of peak inspiratory pressure of 20 cm H_2O and respiratory rate of 10 breaths per minute. A left paracostal incision was made to access a right colic lymph node. A solution of 1% methylene blue (Fisher Scientific, Hampton, New Hampshire, USA) (0.5 mg/kg diluted 1:1 with 0.9% NaCl) was injected into the node with a 1 mL syringe and 25 gauge needle over 30–60 s to colorize the thoracic duct as previously described.[34] All surgical procedures were performed by a single board-certified surgeon (author 2). The thoracic duct was approached with a left-sided fourth intercostal thoracotomy, and the number of visible thoracic duct branches lateral to the esophagus and dorsal to the aorta were noted. The thoracic duct was ligated with 10 mm vascular clips (EndoClip II, Medtronic, Minneapolis, Minnesota, USA). One clip was placed cranial to the planned site of thoracic duct transection, and two clips were placed 5–6 mm apart caudal to the site of planned transection (10–15 mm caudal to the cranial clip) (Figure 1). The thoracic duct was then sealed and transected with a harmonic scalpel (Ethicon Endo-Surgery, Cincinnati, Ohio, USA) between the cranial and caudal clips (Figure 2). The right side of the esophagus was inspected for additional thoracic duct branches by dissecting through the mediastinum dorsally. Following TD ligation and transection, a unilateral subphrenic pericardiectomy was performed by removing all parietal pericardium ventral to the phrenic nerve to the ventral midline.

Upon completion of the surgical procedures, the cadaver was moved to left lateral recumbency in preparation for iodinated contrast administration into the caudal thoracic duct. The caudal six ribs were removed; the cranial aspect of the cisterna chyli was identified, and the number of thoracic duct branches was noted. The largest visible branch of the thoracic duct at the level of the tenth intercostal space was catheterized with a 24 gauge catheter. The

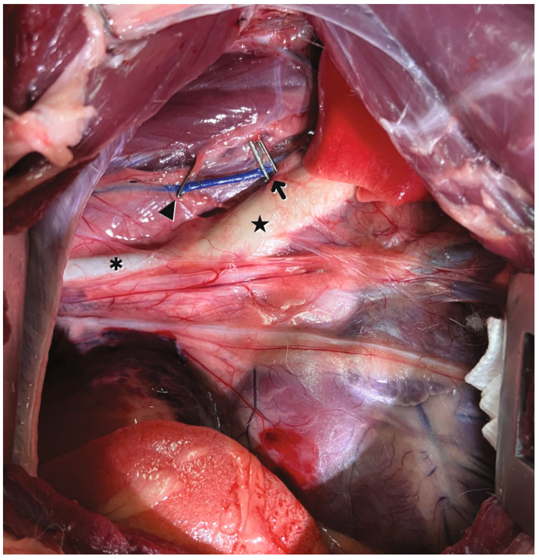

FIGURE 1 Regional anatomy at the level of the left fourth intercostal space in a canine cadaver. Cranial is to the left. The left cranial lung lobe has been reflected caudally to expose the thoracic duct highlighted with methylene blue on the lateral surface of the esophagus. Two surgical clips have been placed across the duct caudally (arrow) and one cranially (arrowhead). The aorta (star) and left subclavian artery (asterisk) lay ventral to the thoracic duct.

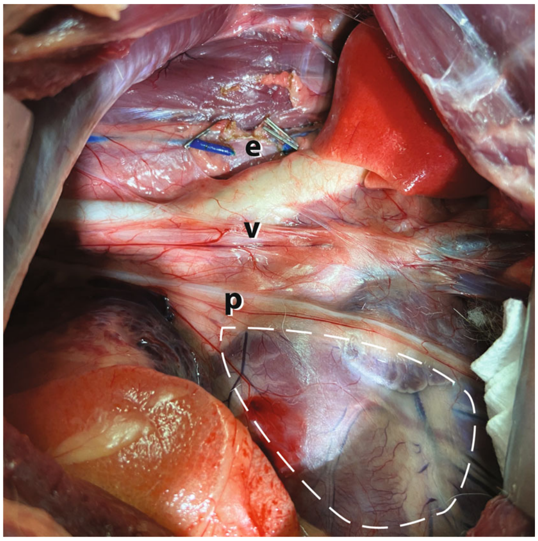

FIGURE 2 The same cadaver following transection of the thoracic duct between surgical clips with a bipolar sealing device. Cranial is to the left. Esophagus (e), vagal nerve (v), phrenic nerve (p). The location of the subphrenic pericardiectomy is outlined (dashed line).

catheter was secured with 4–0 monofilament suture and tissue adhesive. Caudal to the catheter, and cranial to the cisterna chyli, thoracic duct branches were ligated to prevent backflow of contrast. Iodinated contrast agent (Omnipaque 350, GE Healthcare, Chicago, Illinois, USA) was injected slowly into the duct via pre-filled extension tubing connected to the catheter in increments of 1 mL. Within 10 min of contrast administration, a lateral radiograph was taken to confirm evidence of contrast at the level of TD ligation. If contrast was not present in the cranial thorax, additional 1 mL boluses of contrast were administered until contrast was observed at the level of the caudal clips. Upon confirmation of contrast in the cranial thorax, helical thoracic CT scan was performed to determine the success of ligation and to evaluate TD anatomy with a 512×512 matrix, kVp 130, variable mA, and 1.3 spiral pitch factor. Raw data were reconstructed into 3 mm or 1 mm thickness slices with a medium or soft-pass algorithm and reformatted into 1 mm dorsal and sagittal planes (Siemens AG). The width and height of the pericardial resection was then directly measured from the cadaveric specimens and recorded.

3 | RESULTS

3.1 | Retrospective review of lymphangiograms

Twenty-five studies were identified of which 13 were determined to be from dogs with idiopathic chylothorax. Twelve studies were excluded due to a diagnosis of secondary chylothorax associated with cardiac disease, venous thrombi, generalized lymphangectasia, cranial mediastinal, heart base or thoracic wall masses, or lung lobe torsion. One of the 13 cases had what was thought to be a small/incidental pulmonary carcinoma, not expected to be a source of chylous effusion.

The 13 dogs with idiopathic chylothorax had a median bodyweight of 28.3 kg (range: 9.1–57.1 kg). Median age was 3 years, 9 months (range: 1 year, 6 months–13 years, 2 months). There were nine neutered males, three spayed females and one intact male. Breeds consisted of three golden retrievers and 1 each of the following: Goldendoodle, labradoodle, Labrador retriever, curly coated retriever, German shepherd, standard schnauzer, miniature schnauzer, mastiff, Australian heeler, and mixed breed.

All thoracic ducts (13/13, 100%) originated on the right of midline in the caudal mediastinum with a highly variable number of branches and morphology. Median number of TD branches at the level of the ninth and tenth intercostal spaces were 3 (range:1–4), and 2 (range 1–4) branches, respectively. In all cases, the main thoracic duct crossed the midline to the left, at mid-thorax. It then came to lie lateral to the esophagus and dorsal to dorsomedial to the aorta, caudal to the origin of the left subclavian artery. Cranial to the proposed left fourth intercostal surgical site the duct then emptied into cranial mediastinal veins or ramified into numerous cranial mediastinal lymphatic vessels and lymph nodes.

More specifically, at the left fourth intercostal space on the left lateral surface of the esophagus dorsal to the aorta and caudal to the left subclavian artery there was a single thoracic duct with no other branches noted in 10/13 cases (76.9%). In addition to a single left sided thoracic duct branch on the lateral surface of the esophagus, two cases had two branches which lay medial to the aorta and ventral to the esophagus. An additional case had two branches on the left lateral surface of the esophagus dorsal to the aorta, but also had one branch medial to the aorta, and one ventral to the trachea.

Leakage of lymphatic contrast was noted in 8/13 cases (61.5%) diagnosed with idiopathic chylothorax. Leakage appeared to originate from the cranial mediastinum in 5/8 (62.5%) of these cases. Leakage site was unclear, but extravasated contrast was seen dorsal to the third–fifth sternebrae in three out of eight cases. In nine out of 13 cases (69.2%), numerous tortuous small lymphatic vessels were noted within the cranial mediastinum. Leakage was not associated with the caudal mediastinal portion of the main thoracic duct in any case.

3.2 | Sample population of cadavers

A total of 16 canine cadavers were evaluated initially, but six of the cadavers could not be utilized due to extravasation of contrast (suspected to be due to autolysis or

TD damage during catheter placement). Ten canine cadavers were used in the study. All dogs appeared to be adults but their exact ages were not known. The median weight was 26.2 kg (range 14.2 kg–34.3 kg). There were seven male dogs (all intact) and three female dogs (neuter status not evaluated). Cadaver breeds included five mixed breeds, three American pit bull terriers, one Siberian husky and one German shepherd. No dog had overt evidence of thoracic or lymphatic disease. Surgery was performed as soon as possible after euthanasia (within 4 h) to limit damage from autolysis.

3.3 | Description of cadaveric thoracic duct anatomy

All cadaver dogs had either one or two branches at the fourth intercostal space (Table 1). Six out of 10 dogs (60%) had a single branch at the site of TD ligation, whereas four out of 10 (40%) of dogs had a second branch in close proximity. In dogs with second branches, the branches were readily identified with the methylene blue dye and easily approached through the same incision. None of the dogs in the present study had any thoracic duct branches identified on the right lateral side of the esophagus. The number of branches present in the caudal mediastinum (eighth–ninth intercostal space) varied considerably (median 2: range 1–5 branches) (Figure 3).

3.4 | Thoracic duct ligation

Successful thoracic duct ligation, defined as confirmation on CT scan of cessation of contrast at the level of the caudalmost hemoclip with no contrast cranial to the cranialmost hemoclip, was achieved in nine out of 10 specimens (90%) (Figure 4). No contrast was seen between the cranialmost and caudalmost hemoclips in any of the 10 specimens. In one specimen, a small amount of contrast was noted in the cranial mediastinum due to subtle extravasation of contrast medium from the TD catheter, discovered after study completion.

3.5 | Pericardiectomy

Unilateral subphrenic pericardiectomy was performed easily in 10 out of 10 specimens (100%) via the same

TABLE 1 Description of thoracic duct anatomy of cadavers.

Dog	Branching description at left fourth–fifth ICS	Crossover location[a]	Branching description at right eighth–ninth ICS
1	One single branch	Midbody T6	One large branch to right of midline
2	One single branch	Midbody T5	Two branches: One main branch to right of midline and thin branch closer to midline
3	One single branch	Midbody T5	One branch on midline
4	One single branch	T5–6 intervertebral disc space	three branches: Two branches to right of midline, one large branch to left of midline
5	One branch identified that forks into two branches cranially (only one branch at site of ligation)	Cranial endplate T6	Two branches: One main branch just to the right of midline with smaller branch laterally
6	Two branches running in parallel lateral to esophagus on left	Cranial endplate T6	Two branches diverging and coalescing; one branch to right of midline, one branch to left of midline
7	One single branch	Caudal endplate T5	One branch to right of midline
8	One main branch and one smaller, easily visualized branch ventral and lateral to main branch	Caudal endplate T5	Five branches: Large plexiform network of multiple thoracic duct branches to right of midline with thin undulating branch to left of midline
9	Two branches converge 15 mm caudal to where left subclavian branches from aorta (site of ligation)	Midbody T5	Three branches on midline
10	Two large branches running in parallel and converging to single branch at site of ligation	Never, always right sided	Three branches to right of midline

[a]Crossover location defined as the point where all branches cross from right to left over the midsagittal plane cranial to the origin of the posthepatic cava diaphragm origin. Intercostal space (ICS).

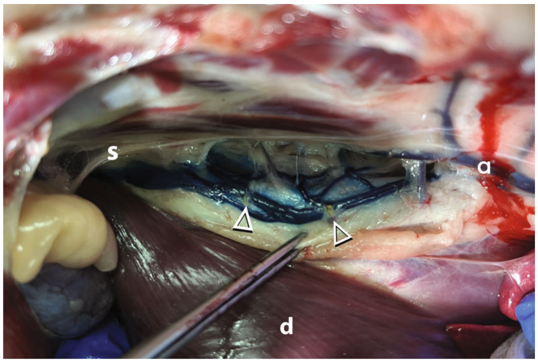

FIGURE 3 The regional anatomy at the right ninth intercostal space in a canine cadaver. Cranial is to the right. The aorta is retracted ventrally by forceps and two intercostal arteries (open arrowheads) have been transected with a bipolar sealing device to expose the thoracic duct on the dorsal surface of the aorta. Note the complex of thoracic duct branches, highlighted with methylene blue, at this standard thoracic duct ligation site. Diaphragm (d), sympathetic chain (s), azygos vein (a).

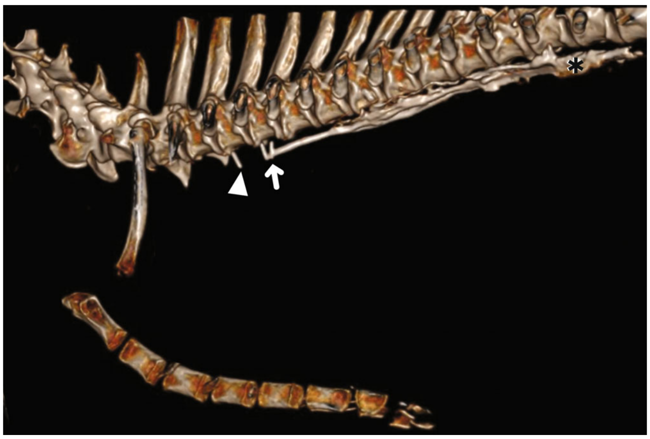

FIGURE 4 Computed tomographic lymphangiogram of the thoracic duct following clip placement and transection at the level of the left fourth intercostal space. Multiplanar reformation image with cranial to the left. Cranial thoracic duct clip (arrowhead), caudal thoracic duct clips (arrow), thoracic duct injection site (asterisk). Note the multiple lymphatic branches caudally, which merge into a single thoracic duct cranially.

approach. The median area of the pericardial defect was 69.7 cm^2 (range 42.2–85.5 cm^2).

4 | DISCUSSION

The present study confirmed the feasibility of a cranial left-sided approach to thoracic duct ligation in canine cadavers. Thoracic duct ligation and unilateral subphrenic pericardiectomy were performed easily and quickly, and the TD at this location was manipulated easily and undermined prior to ligation. The bodyweight of cadavers studied was similar to the clinical cases available for retrospective review. Results from this study support further investigation into the use of this cranial left-sided approach in clinical patients to potentially decrease the morbidity of surgical treatment of idiopathic chylothorax in comparison with a traditional right-sided double thoracotomy approach. A disadvantage of standard open TD ligation and pericardiectomy is the long operative time.[1] The decrease in surgical dose with this approach to the TD has the potential to reduce morbidity associated with a traditional right-sided thoracotomy approach to TD ligation and pericardiectomy with its greater number of incisions and longer anesthesia time.[33]

The majority of cadavers had a single TD branch observed at the level of the fourth intercostal space, but four out of 10 had two branches observed at this location. These additional branches were distinct and easily accessible with the described approach and did not impact procedure efficacy. In the single cadaver that had contrast present outside of the TD (suspected to be due to leakage from the TD catheter), ligation still appeared successful as no contrast was present between the hemoclips. There were no TD branches observed on the right side of the esophagus, either visually or on CT images of these 10 cadavers. This stands in contrast to descriptions of the thoracic duct at the traditional location at the caudal thorax, where multiple branches have been described in highly variable branching patterns.[11,21,28,29] Cadavers exhibited variable branching numbers and morphology in the present study, with a median of two branches, and up to five branches noted, in the caudal mediastinum. More limited branching at the fourth intercostal space may lead to easier access to the thoracic duct, and thus potentially higher rates of postoperative resolution of chylothorax. Preoperative CT lymphangiograms, as previously described, should be considered to guide the clinician as to the feasibility of this approach in individual cases as patient size and TD branching may influence the approach.[32]

Previous studies that have described the location of the TD in the cranial thorax report a single left-sided TD in the majority of cases. In only 5/58 cases, a right-sided branch was reported.[10,11,22,23] A more recent study in 43 canine cadavers depicted the TD as a single structure, or two branches joining to form a single structure, on the left of the aorta at the region of the fourth intervertebral space (the region of investigation in our current study) although the number of branches at this location was not described in the text.[24] In 35 out of 43 cadavers, the thoracic duct migrated to the left of the aorta in the region of the fifth thoracic intervertebral space whereas in eight out of 43 cadavers this occurred just cranial to the intercostal artery at the fourth intervertebral space. The ductal anatomy cranial to this could not be described in 21 (49%) of the specimens due to tissue damage. In the other 22 specimens the duct terminated at the left venous angle (18) or left external jugular vein (4) but it was not specifically stated whether this was as a single branch.[24] In our retrospective review of 13 lymphangiography cases, 10 out of 13 dogs had a single left-sided duct and three out of 13 had branches that would make a left-sided approach challenging (either to the right of the esophagus or medial to the aorta). In our subsequent cadaveric study, we found that the right side of the esophagus was easily visualized using the cranial left-sided approach, but it is not known if right-sided branches could be ligated from the left in clinical cases with chylothorax. The precise cause of idiopathic chylothorax has not been ascertained but TD ligation has historically been performed in the caudal mediastinum despite the presence of multiple TD branches at this location in many patients.[1,5,6,8–12] Leakage of the caudal TD has not been identified in dogs with idiopathic chylothorax but leakage of contrast media on lymphangiograms has been identified in the cranial mediastinum along with dilated cranial mediastinal lymphatics in numerous studies.[29–32] In a study of 13 dogs with idiopathic chylothorax, leakage of chyle was identified on preoperative lymphangiogram in three cases, all of which had leakage in the cranial mediastinum.[30] In another study of six dogs with idiopathic chylothorax, one case of leakage was identified at the level of the second sternebra.[33] Cranial mediastinal lymphangiectasia was noted in eight out of 24 (33%) preoperative lymphangiograms in a more recent study and cranial mediastinal leakage was noted in four out of 24 (17%) cases.[9] The fourth intercostal space is caudal to the reported location of these abnormalities but cranial to the point where TD branches have been reported to coalesce into a single branch on the left side.[10,11,22,23] The retrospective review in the present study revealed leakage of contrast in eight out of 13 cases, with leakage from the cranial mediastinum in five out of eight cases. In three cases, the origin of the cranial contrast extravasation was unclear. Torturous small lymphatic vessels were noted in the cranial mediastinum in nine out of 13 dogs, supporting previous findings that canine patients with idiopathic chylothorax may have abnormal cranial mediastinal lymphatic anatomy that may lead to leakage of chyle at this location. Theoretically, ligation of the TD at any point caudal to the cranial mediastinum may therefore be equally efficacious in resolving idiopathic chylothorax, including at the level of the left fourth intercostal space where TD branching may be less variable and where pericardial access, if elected, is available through the same intercostal incision.

Patients with chylous effusion are often found to have thickened pericardial tissue, likely due to chronic irritation, which could lead to constrictive pericarditis and potentially increase systemic venous pressures.[36] One study found that nine out of 26 dogs with idiopathic chylothorax had constrictive pericardial physiology, as determined by echocardiogram and cardiac catheterization.[9] Pericardiectomy has been thought to increase the success of TD ligation when treating idiopathic chylothorax in dogs by decreasing right-sided venous pressures and increasing ventricular compliance.[1,36] Variations of pericardiectomy for treating idiopathic chylothorax in dogs have included near-total pericardiectomy, subphrenic pericardiectomy in which all parietal pericardium ventral to the phrenic nerves is resected via a unilateral thoracotomy or a minimally invasive subxiphoid approach, or use of a pericardial window with additional incisions.[1,2,4,9,33]

Studies in humans with contrictive pericarditis secondary to tuberculosis have shown that right atrial pressures improve following partial pericardiectomy performed through a lateral thoracotomy, albeit to a lesser extent than if total pericardiectomy is performed via sternotomy.[37] A decrease in central venous and right atrial pressures has been reported after total or partial pericardiectomy in humans with constrictive pericarditis but we are unaware of similar postoperative pressure studies in dogs with constrictive pericarditis.[37,38] Changes in central venous pressures were not observed after near-total pericardiectomy via a right lateral approach in one published study in dogs with chylothorax where parietal pericardium was removed from the base of the pulmonary vessels on the right to just ventral to the phrenic nerve on the left.[4] Additional studies in dogs have described successful resolution of chylothorax when TD ligation and subphrenic pericardiectomy was performed via right lateral thoracotomy, where pericardial access would be expected to be similar to the left-sided approach described in this study.[1,2,33] These studies do not specify if additional pericardial releasing incisions were made. One study in normal dogs showed that exposure of the epicardium was improved to 80–100% by adding releasing incisions (pericardial fillets) to a thoracoscopically created pericardial window.[39] Veterinary studies using the term "pericardial window" have removed 4–25 cm^2 of pericardium.[39–42] In this study we removed all parietal pericardium on the left side between the phrenic nerve and the ventral midline (median: 69.7 cm^2). We did not make releasing incisions, although we have done so in clinical patients via this approach with no difficulty.

This study had several limitations. The study was performed with cadavers; however, efforts were made to simulate live conditions by performing the cadaveric procedures on a ventilator to produce inflation of the lungs. The cadavers utilized in this study also had an unknown medical history with no overt evidence of lymphatic disease. Thoracic duct anatomy in the cranial mediastinum may be variable in patients with idiopathic chylothorax, and pleuritis secondary to chronic chylothorax may make visualization of the duct and dissection more difficult.

The use of cadavers introduced a challenge in obtaining appropriate imaging. The procedures were performed within 4 h of euthanasia to ensure that the specimens were as fresh as possible. However, after injection of contrast, extravasation of contrast was noted at or just cranial to the injection site on the radiographs of six cadavers. This finding was attributed to TD damage during catheter insertion rather than antemortem pathology of the lymphatic system. These six cadavers were not included in the study because leakage of contrast precluded evaluation of the TD at the site of ligation.

Another limitation to this cadaveric study is the inability to assess the efficacy of this intervention. Much remains unknown about the etiology of idiopathic chylothorax. With cranial TD ligation, formation of collateral vessels may occur, as has been documented following caudal ligation of the thoracic duct.[9,14,29] In one study, four out of 14 dogs with CT lymphangiogram performed 7–10 days following caudal TD ligation had evidence of lymphatic flow around the ligation site. These "bypass" vessels were assumed to be due to "sleeping" lymphatics, or small/collapsed lymphatics that were not evident on preoperative lymphangiograms or at the time of surgery.[14] The authors hypothesized that changes in lymphatic pressure following ligation of the main TD may result in lymph flow through these previously undetected vessels. Similar collateralization past the TD clip placement site was seen on 3-month postoperative CT lymphangiograms in two out of 17 dogs in another study.[9] It is unclear if the formation of collateral vessels would also occur in the cranial thorax or if they would decrease efficacy of treatment in patients with idiopathic chylothorax.

In addition to the potential to decrease surgical time, pain, and morbidity in comparison with the standard double right-sided thoracotomy approach to TD ligation and pericardiectomy, this single left-sided thoracotomy approach could have the added advantage of simplified TD anatomy at this location, which may be beneficial, regardless of whether or not any form of pericardiectomy is performed. The simpler structure of the thoracic duct at this location has the potential to result in a more effective ligation, which could increase the effectiveness of surgical treatment of idiopathic chylothorax. It would also be prudent to investigate a thoracoscopic cranial left-sided approach to the TD.

4.1 | Conclusions and clinical significance

A left-sided approach to TD ligation at the fourth intercostal space combined with unilateral subphrenic pericardiectomy was successfully performed in nine out of 10 canine cadavers. Thoracic duct ligation at this location appeared to be feasible in a retrospective review of 10 of 13 clinical cases. Thoracic duct branching at this site was limited when compared with the number of branches at the standard caudal ligation site in both clinical cases and cadavers. Further study evaluating the left fourth intercostal approach to TD ligation in purpose-bred dogs and in canine patients with idiopathic chylothorax is warranted.

AUTHOR CONTRIBUTIONS

Price AK, DVM: Substantial contribution to the conception and design of this study, acquisition, analysis, interpretation of data, drafting and revision of work, and final approval of the version to be published. Mathews KG, DVM, MS, DACVS: Substantial contribution to the conception and design of this study, acquisition, analysis, interpretation of data, drafting and revision of work, and final approval of the version to be published. Lawver JE, DVM, DACVR: Substantial contribution to the design of this study, interpretation of data, revision of work, and final approval of the version to be published. Scharf VF, DVM, MS, DACVS: Substantial contribution to the design of this study, interpretation of data, revision of work, and final approval of the version to be published.

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CONFLICT OF INTEREST STATEMENT

The authors have no conflicts of interest or financial support to declare.

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