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Resolution, recurrence, and chyle redistribution after thoracic duct ligation with or without pericardiectomy in dogs with naturally occurring idiopathic chylothorax

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OBJECTIVE
To document outcomes of thoracoscopic treatment of idiopathic chylothorax (IC) in dogs with and without constrictive pericardial physiology (CPP) and evaluate patterns of chyle flow redistribution after thoracic duct ligation (TDL).

ANIMALS
26 client-owned dogs.

PROCEDURES
In this prospective cohort study, echocardiography and cardiac catheterization were performed to document CPP in dogs with IC. Thoracoscopic TDL with pericardiectomy was performed if CPP was present (TDL/P group). Dogs without evidence of CPP underwent thoracoscopic TDL alone (TDL group). Dogs underwent preoperative, immediate postoperative, and 3-month postoperative CT lymphangiography studies when possible. Perioperative morbidity, resolution and late recurrence rates, and long-term outcome were recorded.

RESULTS
17 dogs underwent TDL, and 9 underwent TDL/P. Twenty-five of 26 (96%) survived the perioperative period. One dog died from ventricular fibrillation during pericardiectomy. Resolution rates for TDL and TDL/P were 94% and 88%, respectively (P = .55), with 1 late recurrence occurring in the TDL group in a median follow-up of 25 months (range, 4 to 60 months). On 3-month postoperative CT lymphangiography studies, ongoing chyle flow past the ligation site was demonstrated in 5 of 17 dogs, of which 1 dog developed recurrence at 13 months postoperatively. In 15 of 17 dogs, chylous redistribution after TDL was principally by retrograde flow to the lumbar lymphatic plexus.

CLINICAL RELEVANCE
In dogs without evidence of CPP, TDL alone was associated with a very good prognosis for treatment of IC. In the absence of CPP, the additional benefit of pericardiectomy in the treatment of IC is questionable.

Thoracoscopic thoracic duct ligation (TDL) and pericardiectomy are well established as minimally invasive alternatives to open surgery in dogs with chylothorax.[1–4] A recent multi-institutional study[3] reported a 95% resolution rate and 9% late recurrence rate in a cohort of 39 dogs treated uniformly with a combination of thoracoscopic TDL and pericardiectomy at 3 veterinary teaching hospitals. However, it remains uncertain which procedures are contributing to successful outcomes, as multiple procedure approaches are often reported.[1–8]

The role of pericardiectomy in surgical management for chylothorax remains unknown, especially in those dogs lacking obvious pericardial pathology. In human patients, it is well recognized that thickening or fibrosis of the pericardium can limit cardiac preload during diastole, resulting in elevated right atrial and central venous pressures, a condition sometimes referred to as constrictive pericardial physiology (CPP).[9] It has been hypothesized that, in dogs with chylothorax, elevated central venous pressure in turn could lead to lymphatic hypertension, resulting in leakage of chyle from the thoracic ducts.[10] While vena cava ligation has been shown to produce chylothorax in approximately 70% of healthy dogs[11] and some dogs with chylothorax have obvious pericardial thickening, fibrosis, or even neoplasia, CPP doesn't appear to be present in all dogs with idiopathic chylothorax (IC), and recent evidence suggests that surgical protocols that do not include pericardiectomy can have positive outcomes.[7] Furthermore, a convincing effect of pericardiectomy on central venous pressure was not seen in 1 study[7] of dogs with IC. Investigation of the importance of pericardiectomy in management of IC seems justified, especially given that serious complications such as hemorrhage and the development of ventricular fibrillation can result.[3,12]

The primary aim of this study was to evaluate whether screening for CPP could obviate the need for pericardiectomy in a subpopulation of dogs with naturally occurring IC and whether TDL alone would be associated with good outcomes. A secondary aim of the study was to evaluate the patterns of postoperative chyle redistribution in dogs with confirmed complete TDL ligation. The principal hypothesis for the study was that dogs with IC without evidence of CPP treated with TDL alone would have equivalent outcomes to dogs with evidence of CPP that undergo TDL and pericardiectomy.

Materials and Methods

Animals

Client-owned dogs with a diagnosis of IC were included in the study. Dogs with nonidiopathic chylothorax were excluded from the study. The study was approved by the IACUC at the UC-Davis School of Veterinary Medicine.

Study design

Three anesthetic events were planned for each dog. The first 2 events were aimed at diagnosis and surgical treatment; dogs were placed under general anesthesia the day prior to surgery for cardiac catheterization and CT lymphangiography (CTLA). On the second day, dogs underwent thoracoscopic TDL with or without thoracoscopic pericardiectomy followed by immediate postoperative CTLA. Dogs that had evidence of CPP on the basis of results of cardiac catheterization underwent thoracoscopic pericardiectomy in addition to thoracoscopic TDL (TDL/P group), whereas dogs that lacked evidence of CPP underwent TDL alone (TDL group). The third anesthetic event occurred approximately 3 months postoperatively to repeat the CTLA and evaluate the pattern of chyle flow redistribution postoperatively.

Instrumentation

For general anesthesia, dogs were instrumented with an 18- to 22-gauge cephalic catheter and a 20- to 22-gauge arterial catheter placed in the dorsal pedal artery. All dogs were administered lactated Ringer solution at a rate of 10 mL/kg/h, IV. Induction of anesthesia was performed using an induction protocol at the discretion of the attending anesthesiologist for all 3 anesthetic events.

Preoperative cardiac/pericardial evaluation

Each dog received a routine echocardiogram (EPIQ 7C; Koninklijke Philips NV) prior to cardiac catheterization to evaluate for echocardiographic signs of constrictive pericarditis. For the purposes of this study, all echocardiographic assessments were performed under the supervision of a board-certified cardiologist (JAS) at a single time point at a digital off-cart workstation (Syngo Dynamic Workplace; Siemens Medical Solutions Inc). Investigators were blinded to treatment received. Specifically, echocardiographic cine loops were evaluated for the presence of right atrial enlargement, septal bounce, pericardial thickening, and caval and hepatic vein enlargement. A score of 1 was given to each criteria fulfilled, and these were summated at the end. For the purposes of this study, an echo score ≥ 2 was considered to be consistent with constrictive physiology.

For cardiac catheterization, a vascular introducer was placed in the right jugular vein through a standard modified Seldinger approach. A balloon wedge catheter was directed to the level of the right atrium, and atrial pressure profiles were obtained via standard manometry techniques. The profile was recorded when stable for a minimum of 6 consecutive cardiac cycles. Atrial pressure profiles were evaluated and recorded. The balloon catheter was then advanced to the level of the right ventricle, and the right ventricular pressure profile was also recorded for a minimum of 6 consecutive cardiac cycles. After data recording was complete, the catheter was withdrawn, the introducer was removed, and direct manual pressure was applied to the jugular venipuncture site for a minimum of 15 minutes. The following invasive hemodynamic criteria were considered evidence of constrictive pericardial physiology[13]: mean right atrial pressure > 6 mm Hg and/or right ventricular end-diastolic pressure > 10 mm Hg. Previously reported normal reference values for mean right atrial pressure and right ventricular end-diastolic pressure are 3 mm Hg (± 2 mm Hg) and 0 to 5 mm Hg, respectively.[13] Right ventricular peak pressure was also measured but not used as a criterion for CPP.

Computed tomography lymphangiography

The CTLA protocol used was similar to that described in previous publications.[14,15] Intra-abdominal lymph nodes were assessed ultrasonographically for their suitability to receive percutaneous injections of 1 to 2 mL of contrast (Isovue-370) using a 27-gauge needle, T-port, and 3-mL syringe. If this technique did not yield a diagnostic study or lymph node size or accessibility was deemed unworthy of attempting lymphangiography, then the popliteal and/or medial iliac lymph nodes were evaluated for potential injection.

The 3-month postoperative CTLA was evaluated to assess for the formation of collateral or missed ducts bypassing the ligation site. Ducts were classified as recanalized/incompletely attenuated if there was contrast flow through ducts that anatomically resembled ducts seen on the preoperative CTLA study and were at the site of previously applied hemoclips. Ducts were classified as collateral ducts if they were not seen on the preoperative study and took a substantially different anatomical course from those seen on the preoperative study. The nature of postoperative chyle flow redistribution at the 3-month postoperative time point was also documented.

Surgical technique

Thoracoscopic TDL was performed using a technique previously described.[2,3] After initial mediastinal dissection, 1 of the following 3 approaches for injection of methylene blue (MB) and/or indocyanine green (ICG) into the lymphatic system was performed: a 5-cm paracostal incision was made to expose a mesenteric lymph node for injection, injection was performed after a surgical cutdown to a popliteal lymph node, or injection was performed subcutaneously in a 4-quadrant fashion in the perineal area with subsequent massage of the injection sites, as has been previously described in cats.[16] Either 1:1 diluted MB (American Reagent Inc) with sterile saline injected at a dose of 0.3 to 0.5 mL/kg and/or ICG (Akorn Inc) at a dose of 0.02 to 0.2 mg/kg diluted was injected. Thoracoscopic ICG/near-infrared fluorescence (NIRF) imaging was accomplished using a commercially available NIR D-light imaging system (Karl Storz Veterinary Endoscopy) using a previously reported technique.[17] Thoracic ducts were isolated, and laparoscopic hemoclips (M/L-10; Microline Surgical Inc) were placed on the ducts.

For the thoracoscopic pericardiectomy procedure, either a subphrenic pericardiectomy[2,3,18] or creation of a large pericardial window with vertical pericardial fillets was performed.[19] After all surgical procedures had been completed, a thoracic drain (MILA International Inc) was placed, the cannulae were removed, and the thoracic port incisions were closed routinely. If continued flow of contrast past the ligation site was evident on the immediate postoperative CTLA, most dogs were returned to the operating room and a second approach was made to locate and ligate any remaining patent TD branches. Anesthesia time was recorded and included time for the surgical procedures and postoperative CTLA. Surgical time from first incision to the placement of the last suture was also recorded.

Postoperative care

All dogs were recovered from anesthesia in the ICU. The thoracic drain was aspirated every 4 to 6 hours for 12 to 24 hours. Analgesia was provided using either intermittent oxymorphone (dose, 0.1 mg/kg, IV, q 4 to 6 h), methadone (dose, 0.1 to 0.2 mg/kg, IV, q 4 h), or fentanyl as a constant rate infusion (dose, 0.05 µg/kg/min, IV). The day after surgery, oral analgesics were initiated if the patient could tolerate them.

Follow-up and outcomes assessment

Complications were recorded, and conversion from thoracoscopic to open procedures was categorized on the basis of a previously reported standardized classification scheme.[20] Resolution of chylothorax postoperatively was defined as a lack of pleural effusion on postoperative imaging substantial enough to cause clinical signs or warrant thoracocentesis in the first 6 postoperative months. Late recurrence was defined as recurrence of chylous effusion > 6 months postoperatively in a dog that had previously shown resolution of chylothorax. Long-term follow-up was obtained by means of contact with the owner or referring veterinarian by telephone or email.

Statistical analysis

Due to the small sample sizes, differences between surgical groups were assessed using the Fisher exact test for categorical predictor variables, with statistical significance set at $P < .05$. Continuous predictor variables were assessed using binary logistic regression.

Sensitivity, specificity, positive predictive value, and negative predictive value were calculated to assess the feasibility of using a less invasive screening technique (echocardiography) to correctly identify dogs with CPP, compared to the more invasive and less accessible gold standard assessment (cardiac catheterization). All analyses were conducted using Stata analysis software (version 15; StataCorp LLC).

Results

Animals

Twenty-six dogs were included in the study. Fifteen dogs were male castrated, 8 were female spayed, and 3 were male intact. Median weight was 25.4 kg (range, 5.8 to 71.7 kg). Median body condition score was 5/9 (range, 2/9 to 8/9). Median age was 59.5 months (range, 18 to 120 months). Breeds represented included 6 mixed-breed dogs, 4 Shiba Inus, 4 Bullmastiffs, 2 Australian Cattle Dogs, and 1 each of Alaskan Malamute, Dachshund, Doberman, Golden Retriever, Husky, Labrador Retriever, Newfoundland, Rhodesian Ridgeback, Shetland Sheepdog, and Tibetan Terrier.

Clinicopathological features

Clinical signs included dyspnea or increased respiratory rate (n = 15), exercise intolerance (5), lethargy (5), inappetence or anorexia (3), and weight loss (1). Clinical signs were absent in 3 dogs in which pleural effusion was diagnosed during evaluation for other conditions. Physical examination revealed decreased ventral heart and lung sounds on auscultation (n = 15), dyspnea, increased respiratory rate or persistent panting (6), poor body condition (3), and heart murmur (2). Five dogs had no significant abnormalities on physical examination. Median time from onset of clinical signs to surgery date was 43.5 days (range, 7 to 1,050 days). The median number of therapeutic thoracocentesis procedures performed preoperatively was 3 (range, 0 to 10). The estimated median total volume of chylous effusion withdrawn from 19 dogs in which reliable estimates could be made from the medical records was 3,000 mL (range, 200 to 11,250 mL).

The results of biochemical screening and CBCs were nonspecific and therefore are not reported in detail. Median pleural effusion triglyceride concentration was 1,197 mg/dL (range, 402 to 3,864 mg/dL), and median serum triglyceride concentration was 61.5 mg/dL (range, 33 to 221 mg/dL). Cytological analysis of pleural fluid was performed in 18 dogs and was consistent with a diagnosis of chylothorax in all cases. Three dogs had fluid culture and sensitivity testing from pleural effusion, none of which exhibited bacterial growth. All 18 dogs screened for heartworm antigen were negative. Three dogs were tested for coccidiomycosis, with 2 reporting negative results and 1 dog demonstrating a 1:1 titer, which was not considered to be a cause of the chylothorax.

Diagnostic imaging

Thoracic radiographs were available for review in 21 dogs, with all dogs demonstrating some degree of pleural effusion. One dog had a suspicious lung nodule that was not evaluated cytologically.

Preoperative CTLA was performed via mesenteric lymph node injection (n = 26) or subsequent popliteal lymph node injection (4; **Table 1**). Eight of 24 (33%) dogs demonstrated cranial mediastinal lymphangectasia, and 4 of 24 (17%) dogs demonstrated leakage of contrast agent in the cranial mediastinum **(Figure 1)**.

Twenty-four of 26 (92%) dogs underwent an immediate postoperative CTLA via mesenteric lymph node injection (n = 24) or subsequent popliteal lymph node (1). Four of 19 (21%) dogs that had diagnostic studies evaluated had persistent flow in the TD system. In all 4 dogs, ICG/NIRF had been used for intraoperative duct identification. Three of these 4 dogs were returned to surgery to have persistent ducts sealed, whereas in 1 of the 4 dogs, multiple ducts were visible ventral and lateral to the aorta that were not evident on the preoperative study and a return to surgery was not pursued, as it was considered unlikely that these ducts would all be amenable to complete ligation. In 1 of 3 dogs that were returned to surgery, a second postoperative CTLA was performed that confirmed complete cessation of contrast flow at the TDL site, whereas

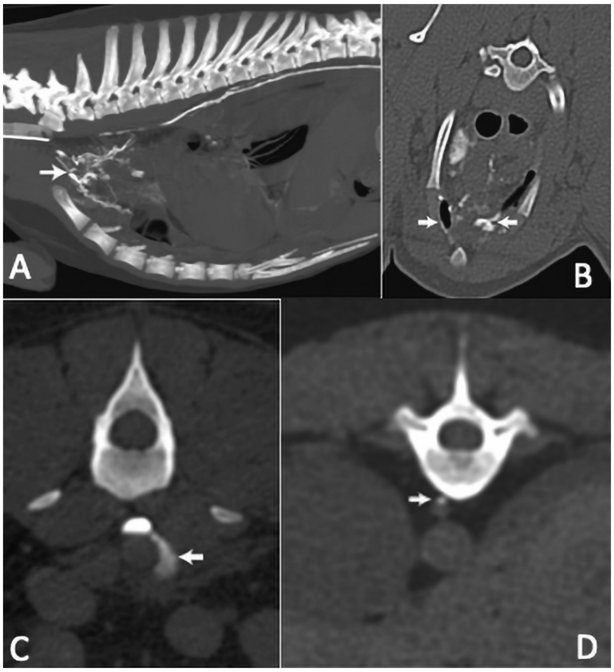

Figure 1—Cranial mediastinal lymphangectasia (white arrow) is evident on this CT lymphangiography (CTLA) study from a dog with idiopathic chylothorax (A). Contrast leakage in the cranial mediastinum can be seen surrounding the cranial lung lobe and dissecting through tissue planes (arrows) on this transverse CTLA image of the cranial thorax (B). Spontaneous rupture of the cisterna chyli is seen in this dog on transverse CTLA study, evidenced by a blush of contrast leakage (arrow) at the level of the cisterna chyli (C). In this 3-month postoperative CTLA image, a collateral thoracic duct (arrow) can be clearly seen just dorsal to the azygous vein (D). This duct was not seen in either the preoperative or immediate postoperative CTLA study performed on this dog.

Table 1—Summary of pre- and postoperative CT lymphangiography (CTLA) studies in 26 dogs undergoing thoracoscopic thoracic duct ligation with or without pericardiectomy.

Variable	All dogs	TDL group	TDL/P group	*P* value
Preoperative CTLA				
No. attempted	26/26 (100%)	17/17 (100%)	9/9 (100%)	
Percentage diagnostic	24/26 (92%)	15/17 (88%)	9/9 (100%)	.42
Median (range) No. of TD branches over T11-L1 spinal segment	4 (1–8)	5 (3–8)	4 (1–8)	.31
No. of dogs with atypical branches	3/24 (13%)	2/15 (13%)	1/9 (11%)	
Evidence of cranial mediastinal lymphangectasia	8/24 (33%)	3/15 (20%)	5/9 (56%)	.09
Evidence of cranial mediastinal chyle leakage	4/24 (17%)	3/15 (20%)	1/9 (11%)	.51
Immediate postoperative CTLA*				
No. attempted	24/26 (92%)	17/17 (100%)	7/9 (78%)	
Percentage diagnostic	19/24 (79%)	14/17 (82%)	5/7 (71%)	.46
No. of dogs without evidence of ongoing flow past clip site†	15/19 (79%)	10/14 (71%)	5/5 (100%)	.26
Incomplete TDL with contrast opacification beyond clips	4/19 (21%)	4/14 (29%)‡	0/5 (0%)	.26
3-mo postoperative CTLA				
No. attempted	19/26 (73%)	14/17 (82%)	5/9 (56%)	
Percentage diagnostic	17/19 (89%)	13/14 (93%)	4/5 (80%)	.47
No. of dogs without evidence of ongoing flow past clip site†	12/17 (71%)	9/13 (69%)	3/4 (75%)	.63
Incomplete TDL with contrast opacification beyond clips	5/17 (29%)	4/13 (31%)	1/4 (25%)	.56

ICG = Indocyanine green. LN = Lymph node. NIRF = Near-infrared fluorescence. P = Pericardiectomy. TDL = Thoracic duct ligation.

*"Immediate" postoperative CTLA studies were performed under the same anesthetic episode for 24 of 25 dogs and after 2 weeks in 1 of 25 dogs; this latter dog experienced chyle leakage intraoperatively and so postoperative CTLA was delayed 2 weeks. †This includes dogs in which contrast was visualized going up to the clips without contrast flow past the ligation site as well as dogs in which contrast did not ascend as far as the clips, presumably due to inadequate contrast volume or because alternative routes of redistribution were the path of least resistance for chyle flow. ‡Three of 4 of these dogs were returned to surgery for remnant TDL. In 1 of these 3 dogs, a second immediate CTLA confirmed complete TDL with contrast ascending to clips but not passing the ligation site.

in the other 2 dogs a second postoperative CTLA was not pursued. In 13 dogs, retrograde flow of contrast to the area of the lumbar lymphatic plexus was seen. In 1 case, spontaneous rupture of the cisterna chyli with chyle leakage could be seen (Figure 1). In 4 dogs, no retrograde contrast flow could be appreciated, and in the remainder, the caudal abdomen was not included in the imaging study.

Nineteen of 26 (73%) dogs underwent a 3-month postoperative CTLA study (all via mesenteric lymph node injection), performed a median of 92.5 days (range, 60 to 161 days) postoperatively. Five of 17 (29%) dogs with diagnostic studies demonstrated ongoing passage of contrast through patent TDs. Of these, it appeared that 2 dogs had developed collateral TDs: 1 dog had a patent duct on the right side where no duct was seen preoperatively, and in a second dog, a collateral TD was seen dorsal to the azygous vein (Figure 1). In both dogs, resolution of IC occurred, and both dogs remained alive 37 and 50 months postoperatively with no recurrence. In the remaining 3 dogs, ongoing flow of contrast occurred due to recanalization/incomplete attenuation of ducts **(Figure 2)**.

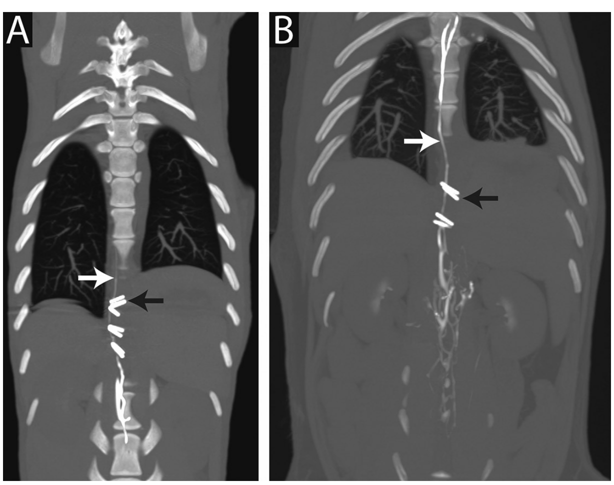

Figure 2—Dorsal plane maximum intensity projection 3-month postoperative CTLA from 2 dogs with recanalization/missed ducts (shown in panels A and B). The most cranial site of ligation is indicated with black arrows, and the contrast column beyond the clips are indicated with white arrows. It is difficult to state with certainty whether ongoing flow represents recanalization of contrast through the applied hemoclips or new ducts are passing over the clips in the area.

These 3 dogs were alive at the time of last follow-up. Two of the 3 had IC resolve without recurrence (follow-up times of 10 and 25 months). In the third dog, resolution occurred, but recurrence was confirmed at 13 months postoperatively (triglyceride level in pleural effusion, 1,387 mg/dL). At the time of last follow-up, no further diagnostic or therapeutic interventions had been elected by the owners of this dog. In 15 of 17 dogs, the 3-month CTLA study showed retrograde flow of contrast to the lumbar lymphatic plexus **(Figure 3)**.

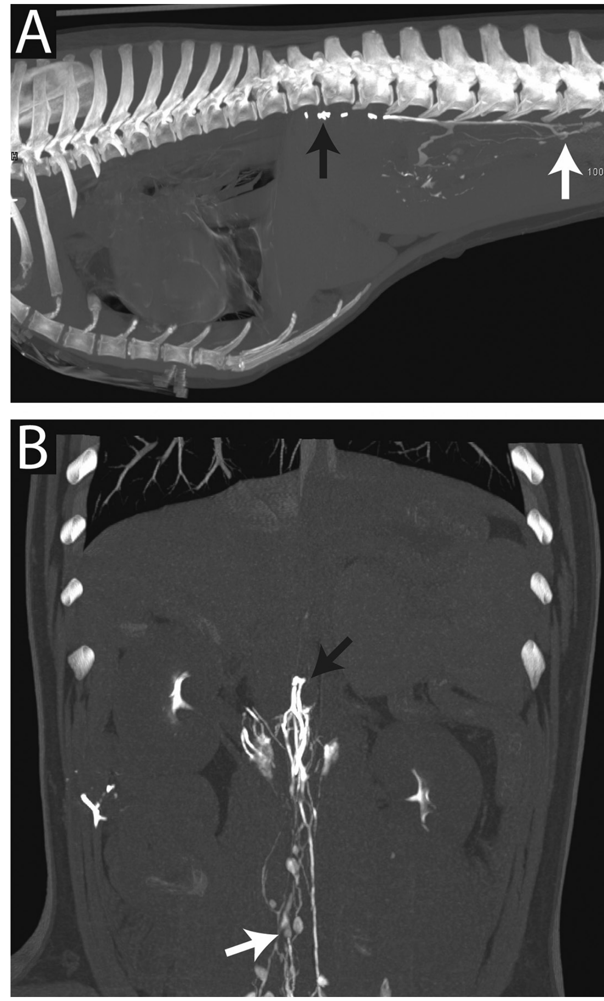

Figure 3—Sagittal (A) and dorsal plane (B) maximum intensity projections from a CTLA performed 3 months postoperatively in a dog that underwent thoracoscopic thoracic duct ligation. Retrograde flow of contrast to the lumbar lymphatic plexus and lymph nodes represented by far the most commonly seen pattern of postoperative redistribution of contrast flow in dogs after thoracic duct ligation.

Evaluation for constrictive pericardial physiology

Seven of 26 dogs had an echo score of 2 or greater **(Table 2)**. Using a mean right atrial pressure of ≥ 6 mm Hg as the gold standard for diagnosis of CPP, sensitivity and specificity of an echocardiography score ≥ 2 to detect CPP were 94% and 66%, respectively. The positive predictive value of an echocardiography score ≥ 2 to detect CPP was 89% and negative predictive value was 80%.

Surgery and intraoperative imaging

Seventeen dogs underwent a TDL alone, and 9 dogs underwent TDL/P **(Table 3)**. For the TDL procedure, a 3-port technique was used in 23 dogs and a 4-port technique was used in 3 dogs. Ports were inserted in variable combinations in intercostal spaces 8 through 11. In 25 dogs, a right-sided approach was

Table 2—Summarized results of evaluation for constrictive pericardial physiology (CPP) based on the results of preoperative echocardiography and cardiac catheterization in 26 dogs with idiopathic chylothorax.

Variable	All dogs	TDL group	TDL/P group
Echocardiography			
Right atrial enlargement	3/26 (12%)	1/17 (6%)	2/9 (22%)
Septal bounce	3/26 (12%)	0/17 (0%)	3/9 (33%)
Pericardial thickening	10/26 (39%)	6/17 (35%)	4/9 (44%)
Vena caval/hepatic vein enlargement	6/26 (23%)	2/17 (12%)	4/9 (44%)
Echocardiography score ≥ 2	7/26 (27%)	1/17%(6%)	6/9 (67%)
Cardiac catheterization			
Mean right atrial pressure (mm Hg)	4.5 (1.7–11.6)	4.2 (1.7–5.9)	6.4 (6.1–11.6)
Right ventricular end-diastolic pressure (mm Hg)	6.9 (1.8–14.5)	6.8 (1.8–9)	10 (6.3–14.5)
Right ventricular peak pressure (mm Hg)	27.3 (21.5–48.3)	28 (21.5–43.5)	28.1 (26.8–48.3)

See Table 1 for key.

Table 3—Summary of clinical variables and outcomes for 25 of 26 dogs that survived thoracoscopic thoracic duct ligation with or without pericardiectomy for treatment of idiopathic chylothorax.

Variable	All dogs	TDL group	TDL/P group	*P* value
Surgical time (min)	135 (75–250)	130 (75–203)	208 (115–250)	.007
Anesthesia time (min)	285 (165–540)	265 (165–540)	360 (285–420)	.046
Days in hospital	4 (3–9)	4 (3–9)	3 (3–5)	.12
Hours in hospital postoperatively	48 (40–159)	51 (40–159)	46.5 (43–65)	.14
Perioperative mortality	1/26 (4%)	0/17 (0%)	1/9 (11%)	.35
Resolution rate*	23/25 (92%)	16/17 (94%)	7/8 (88%)	.55
Late recurrence rate*	1/25 (4%)	1/17 (6%)	0/8 (0%)	.71

See Table 1 for key.
*For the 24 dogs that survived the postoperative period and no ongoing chyle flow in the TD system could be demonstrated.

initially performed, and in 1 dog, a bilateral approach was performed due to the presence of obvious TDs on both the right and left sides of the aorta in the CTLA study.

In 12 dogs operated on earlier in the study, direct injection of mesenteric lymph nodes (n = 10) or injection into the mesenteric root (2), for cases in which no mesenteric lymph nodes were identified, was performed through a 3- to 5-cm right-sided paracostal incision. Where mesenteric lymph nodes were directly injected, ICG/NIRF and MB were successfully visualized in the thoracic ducts in 8 of 8 (100%) and 2 of 4 (50%) dogs, respectively. For the 2 dogs in which the mesenteric root was injected, only ICG/NIRF was used and was successful in imaging the thoracic ducts in 1 of 2 (50%) dogs. In 13 dogs operated on later in the study, 4-quadrant subcutaneous perineal injections were performed. Successful visualization of ICG/NIRF and MB was achieved in 11 of 13 (85%) and 0 of 1 (0%) dogs, respectively. For 2 dogs in which no flow of contrast was seen after perineal subcutaneous injection, a paracostal approach was subsequently made and direct mesenteric lymph node injection was performed. In a single dog, a cutdown to a popliteal lymph node was performed. In this dog, ICG/NIRF and MB were injected, with only ICG/NIRF being successfully visualized.

Dissection into the caudal mediastinum was performed at a median of 2 spaces between vertebral arteries (range, 1 to 5). A median of 4.5 hemoclips (range, 2 to 12) were used for TDL. Median total anesthesia time for all dogs was 285 minutes (range, 165 to 540 minutes). Median total surgical time for all dogs was 135 minutes (range, 75 to 250 minutes). Median number of days in the hospital was 4 days (range, 3 to 9 days), and median number of postoperative hours in the hospital was 48 (range, 24 to 159 hours). Dogs in the TDL/P had significantly greater surgical (P = .007) and anesthesia (P = .046) times than dogs in the TDL group. No differences were detected in hours in hospital postoperatively between the TDL/P and TDL groups (P = .14).

Complications and conversion

Chyle leakage from the TDs during dissection occurred in 2 of 26 (8%) dogs (Table 3). In 1 dog, leakage was stopped by application of further clips on the abdominal side of the leak. In the second dog, complete cessation of leakage was not possible; this dog initially resolved but then experienced a recurrence of chylothorax at 77 days postoperatively and underwent a pericardiectomy and a subsequent en bloc TDL but was classified as a nonresolving case, as pleural effusion didn't resolve within 6 months postoperatively. The dog eventually died 36 months postoperatively after developing pulmonary metastatic disease.

In 2 of 26 (8%) dogs, emergent Grade 4 conversion to an open approach was performed. In 1 dog, during the TDL, laceration of a vertebral artery occurred and was successfully treated by artery ligation. In a second dog, conversion was performed during the pericardiectomy to perform cardiopulmonary resuscitation after ventricular fibrillation had developed. Despite attempts at resuscitation, the dog died, resulting in an overall perioperative mortality rate of 1 in 26 (4%) dogs.

Long-term outcomes

Sixteen of 17 (94%) dogs in the TDL group and 7 of 8 (88%) dogs in the TDL/P group exhibited resolution of chylothorax, results of which were not statistically different (P = .55; Table 3). There were no statistically significant relationships between age (P = .68), weight (P = .22), time from onset of clinical signs to surgery (P = .49), number of preoperative thoracocentesis episodes performed (P = .62), or volume of pleural effusion (mL/kg) withdrawn preoperatively (P = .39) and the chances of resolution.

One of 25 (4%) dogs in the study (TDL group) developed late recurrence of chylothorax. At the time of last follow-up, 3 dogs in the TDL group had died from unrelated causes at a median of 33 months (range, 24 to 36 months) while the remaining 14 dogs were alive at a median of 16.5 months (range, 10 to 60 months). In the TDL/P group, of the 8 dogs that survived the perioperative period, 2 had died, one at 22 months postoperatively from an unrelated cause and the other at 4 months postoperatively because of nonresolution of chylothorax. The latter dog underwent a necropsy evaluation, which showed widespread pulmonary arterial embolic disease and chronic myocardial fibrosis and fatty infiltration but no obvious underlying cause of the chylothorax. Six of 8 dogs in the TDL/P group that survived the perioperative period remained alive at a median of 47 months (range, 13 to 56 months).

Discussion

A selective approach to surgical treatment for IC by screening patients for evidence of CPP was performed in this study. Of the dogs that survived the perioperative period, overall resolution rates did not differ between the TDL and TDL/P groups. This lends support to the hypothesis that a personalized approach to surgical management of IC can yield very good outcomes while sparing the cohort of dogs without CPP the potential risks associated with pericardiectomy. Fatal ventricular fibrillation developed in 1 dog undergoing a pericardiectomy procedure in this study. This generally fatal complication was recently highlighted in a report of 16 dogs that developed ventricular fibrillation during pericardiectomy, of which 7 were being treated for IC.[21] In addition to the potential morbidity associated with pericardiectomy, in this study, the procedure added a median of 73 minutes of surgical time over TDL alone, a difference which was statistically significant. On the basis of these findings, there does not appear to be very good evidence to support the use of pericardiectomy in dogs without evidence of CPP.

Dogs with IC are routinely screened for cardiac disease as part of a diagnostic work-up aimed at ruling out possible underlying diseases. The value of echocardiography as a screening tool for diagnosis of CPP has been rigorously evaluated in human patients previously,[22] but comparison of the results of echocardiography to cardiac catheterization parameters in a cohort of dogs with IC has never been reported. In this study, we evaluated the sensitivity and specificity of a cumulative scoring index of several echocardiographic parameters that are commonly associated with CPP using mean atrial pressures ≥ 6 mm Hg obtained by cardiac catheterization as a gold standard. As cardiac catheterization is technically challenging and relies on special expertise and equipment, an assessment of echocardiography, which is much more widely available, would be helpful in guiding treatment planning, especially in centers where cardiac catheterization may not be available. Given the high sensitivity found in this study, it appears that few false negatives will occur if echocardiography is relied on as a sole diagnostic tool for diagnosis of CPP. Conversely, a specificity of only 66% means that false positives will regularly occur and some dogs that do not have CPP will be diagnosed with the condition and may undergo an unnecessary pericardiectomy if the decision to perform that intervention is based on a diagnosis of CPP.

The use of immediate postoperative CTLA in this study is novel and was performed to document whether complete sealing of the TD system was achieved. In 4 of 19 (21%) dogs with diagnostic CTLA studies performed immediately postoperatively, ongoing flow of contrast beyond the level of the ligation was observed. In all 4 of these dogs, preoperative CTLAs were obtained and intraoperative NIRF imaging was performed. Three of 4 of these dogs were returned to the operating room to attempt ligation of the remaining branches. Detection and prompt treatment of missed ducts at the time of surgery may be 1 factor contributing to the high resolution of IC in this canine cohort and highlights the risk of ducts being missed, even when thorough preoperative anatomical duct mapping using CTLA and the use of intraoperative NIRF imaging are employed. In a recent study,[23] missed ducts were detected in 3 of 14 (21%) dogs and postulated to be a reason for treatment failures in these cases. The performance of immediate postoperative CTLA studies has become the standard of care at the authors' institution as a result of this study to try and minimize the risk of missed ducts. In a fourth dog in this study, flow of contrast through at least 2 TD branches ventral to the aorta that were not seen on the preoperative CTLA study were detected. These ducts may have been present preoperatively but may have taken up inadequate contrast to be visible on the preoperative study, a situation similar to the so-called "sleeping" TD branches reported recently.[23] In that study,[23] CTLAs from dogs with IC, performed 1 week postoperatively, revealed "sleeping" branches in 4 of 14 (28%) dogs, an incidence considerably higher than the incidence in the present study (1/19 [5%]) but nevertheless an important potential cause for treatment failures in dogs with IC.

In this study, a second postoperative CTLA study was performed 3 months after surgery for 2 reasons: first, to identify how commonly collateralization of TDs around the ligation site in the caudal mediastinum occurs and to establish its clinical significance, and second, to describe the course of chylous redistribution after complete TDL in dogs several months postoperatively. A total of 5 of 17 (29%) dogs demonstrated flow of contrast in the TD system past the ligation site. Interestingly, only 2 dogs demonstrated convincing collateralization of contrast flow around the ligation site. The remaining 3 dogs with ongoing contrast flow appeared to have recanalized or perhaps developed incomplete attenuation through the original ligation site, as contrast was seen to flow through ducts that appeared clipped but had flow continuing beyond the clip. In some cases, it can be difficult to say precisely whether the contrast is going around or through the clip site, as shown (Figure 2). Interestingly, 4 of 5 dogs with ongoing flow through the TD system at approximately 3 months had IC resolve and have not, to date at least, developed recurrence. One dog that underwent TDL experienced recurrence of IC. This dog remains alive, but further diagnostic evaluation has not been performed. This finding brings into question the clinical significance of collateralization in this cohort of patients and suggests that further surgical intervention in dogs with collateralization but without recurrence of pleural effusion is probably not warranted. It is perhaps possible that, in these dogs, enough intra-abdominal redistribution of chyle flow has occurred to allow some TD flow to occur without clinical effusion recurring.

Chylous redistribution was also evaluated on 3-month postoperative CTLA studies. Redistribution of contrast flow in this cohort of dogs occurred most commonly in a retrograde manner to the lumbar lymphatic plexus. This redistribution pattern was seen in some dogs on the immediate postoperative CTLA studies, suggesting that these pathways are already established in these patients but become the path of least resistance once the TD system is completely occluded. Caudal redistribution to the lumbar plexus was also seen in some of the dogs with ongoing TD contrast flow, perhaps providing further evidence for the hypothesis that as long as some redistribution of chyle occurs postoperatively, it may be enough for that dog to no longer effuse chyle into the pleural cavity.

Previously published studies documenting outcomes of surgical TDL alone for IC have reported much less successful results than those reported here. Success rates of only 59% were reported in a cohort of 27 dogs.[24] It is critically important to understand that the approach used in this study was significantly different from that used in previous studies. Improvements in the results of TDL as a sole therapy for IC may be due to several factors: advances in the understanding of TD anatomy; improvements in pre-, intra-, and postoperative TD imaging; and superiority of TD visualization using modern thoracoscopic imaging platforms. Anatomical studies published in the 1970s were the first to describe widespread variability in TD anatomy in dogs.[25] The widespread use of preoperative CTLA has confirmed this variability and allowed patient-specific TD road maps to be obtained preoperatively that allow surgeons to anticipate TD location and number.[14,26] Intraoperative localization of ducts, shown to be present on the CTLA, has been facilitated by the use of NIRF, the superiority of which over the use of visual dyes has recently been shown.[17]

Significant limitations to this study were certainly present. A larger cohort of dogs would have improved our ability to draw firmer conclusions. It is logistically difficult to do these kinds of studies in a multi-institutional fashion, which may have allowed an increased cohort size, although keeping a single institution model allowed for less heterogeneity, as all surgeries were performed or overseen by 1 of 2 board-certified surgeons, both of whom are experienced American College of Veterinary Surgeons subspecialty fellows in minimally invasive surgery. Not all dogs were able to return for a successful CTLA study at 3 months postoperatively for a variety of logistical reasons.

In conclusion, this study has demonstrated that successful outcomes can be achieved when TDL is used as a sole procedure for dogs with IC without evidence of CPP when pre- and postoperative CTLA and intraoperative use of either MB or NIRF with ICG is used for intraoperative TD visualization. Outstanding questions that cannot be answered by the data include whether dogs with IC and evidence of CPP would have poorer outcomes if a TDL without pericardiectomy were performed. Further studies would be required to answer this question. A clear explanation for why a small percentage of dogs that appear to have a complete ligation at the time of TDL ligation collateralize also cannot be elucidated by the results of this study.

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