COMPARATIVE POPLITEAL AND MESENTERIC COMPUTED TOMOGRAPHIC LYMPHOGRAPHY OF THE CAUDAL CANINE THORACIC DUCT

by

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For my family

and all of those who sacrifice of themselves to advance science.

The scientific mind does not so much provide the right answers as ask the right questions.
Claude Levi-Strauss 1908-2009

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α	Probability
ALB	Total serum albumin
b	Regression coefficient
C5	Cervical vertebra 5
Cd3	Caudal vertebra 3
CI	Confidence interval
CR	Count ratio
CT	Computed tomography
DV	Dorsoventral
GLOB	Total serum globulin
HU	Hounsfield units
ID	Identification
kg	Kilogram
kV	Kilovolt
L1	Lumbar vertebra 1
L2	Lumbar vertebra 2
LN	Lymph node
mAs	Milliampere-seconds
mg	Milligram
mgI	Milligrams of iodine
MHz	Megahertz
ml	Millilitre
mm	Millimetre
mSv	Millisievert
NSAIDs	Non-steroidal anti-inflammatory drugs
OVAH	Onderstepoort Veterinary Academic Hospital, University of Pretoria

P	Probability
ROI	Region of interest
SD	Standard deviation
SDIM	Section of Diagnostic Imaging
SG	Specific gravity
SSAS	Section of Small Animal Surgery
T5 - T13	Thoracic vertebrae 5 to 13
TD	Thoracic duct
TSP	Total serum protein
UPBRC	University of Pretoria Biomedical Research Centre
US	Ultrasound
VD	Ventrodorsal
WNL	Within normal limits

APPENDICES

SUMMARY

Comparative popliteal and mesenteric computed tomographic lymphography of the caudal canine thoracic duct

Millward IR. University of Pretoria, RSA, 2010

Thoracic duct (TD) ligation has long been the treatment of choice for canine idiopathic chylothorax. Clear identification of all the TD branches at the surgical site is critical to facilitate complete ligation, and this can be difficult due to the highly variable nature of the TD system in number, location and patency of TD branches. Failure to ligate all of the TD branches may result in persistent flow of chyle into the pleural cavity through any missed ducts, and this is the single most common cause of failure with TD ligation.

Performing direct positive contrast lymphography with a water soluble contrast medium, administered through a surgically implanted mesenteric lymphatic vessel catheter has been the conventional method used to identify TD branches. This procedure involves invasive surgery to both implant and remove the mesenteric lymphatic catheter, which increases patient risk and discomfort, as well as the diagnostic time and cost.

Ultrasound (US) guided percutaneous administration of contrast medium into either a popliteal or mesenteric lymph node (LN) have been proposed as alternatives to mesenteric lymphatic vessel catheterisation, however their comparability with the conventional approach has not been assessed.

Computed tomographic (CT) lymphography of the caudal canine TD was performed in seven beagles with contrast medium administered through a mesenteric lymphatic catheter, and by US guided percutaneous injection into a popliteal LN. Images of the TD system were collected using both helical and sequential CT modalities for each contrast medium administration technique.

It was found that percutaneous popliteal lymphography had a total diagnostic procedure time just 46% of that found with mesenteric lymphatic vessel

administration, and resulted in a time saving of 52 minutes. It also incurred only 29% of the total costs, and patients were assessed to have significantly less discomfort compared to mesenteric lymphatic vessel lymphography.

There was no significant difference in the number of TD branches identified by the two contrast medium administration techniques ($P = 0.256$). However administration of contrast medium into a mesenteric lymphatic vessel did result in the largest TD branch having a significantly greater widest diameter ($P < 0.001$), cross-sectional area ($P < 0.001$) and mean Hounsfield unit (HU) value ($P < 0.001$) than popliteal administration. The significant difference in TD size and contrast medium concentration may help to explain the trend for popliteal administration of contrast medium to detect slightly fewer TD branches ($CR = 0.830$), however this study could not confirm this trend nor its possible causes.

There was no significant difference in the number of TD branches identified by the two CT modalities ($P = 0.417$). However helical CT did result in the largest TD branch having a significantly greater widest diameter ($P < 0.001$), cross-sectional area ($P < 0.001$) and higher mean HU value ($P < 0.001$). It should be noted however that in this study sequential CT was consistently performed after the helical CT was completed, which could explain the differences seen between the two CT modalities in TD branch size and contrast medium concentration. Despite helical CT having the apparent advantage of a larger TD branch which contained a higher concentration of contrast medium, it was actually found that there was a trend for helical CT to detect slightly fewer TD branches ($CR = 0.876$). This is possibly due to the positive pressure breath hold that was used to minimise thoracic respiratory movement for the helical CT; while the sequential CT was performed during normal respiration and was therefore not subject to abnormally elevated intrapleural pressure. This study could not confirm the slight superiority of sequential CT in detecting TD branches nor the possible reasons for this apparent difference.

US guided percutaneous administration of contrast medium into a popliteal LN is an acceptable alternative to administration into a catheterised mesenteric lymphatic vessel for identification of TD branches, when using either helical or sequential CT.

Chapter 1: INTRODUCTION

1.1 Background

Chylothorax is a problematic condition in veterinary science, the pathogenesis of which is still poorly understood. Any disease that causes a functional obstruction of the thoracic lymphatics may result in the formation of chylothorax.[1]

Medical management is usually only palliative and can result in a number of secondary problems.[2-7] Surgical treatment is often used in cases that are poorly responsive to medical management and ligation of the thoracic duct (TD) is the most common surgical treatment reportedly in use.[1,3,8-16] Unfortunately the success of TD ligation alone is only 53%[12] to 59%[3] and failure to ligate all of the collateral branches of the TD is the most common cause of surgical failure.[16] Clear identification of the number and location of all the TD branches at the surgical site may facilitate their complete ligation and thus improve the surgical success rate.[17]

Presurgical radiographic assessment of TD branches has most commonly been performed using mesenteric lymphography,[1,9,10,17-20] however percutaneous popliteal lymphography[21] and percutaneous mesenteric lymph node (LN) lymphography[22] have been proposed as possible alternatives. Computed tomography (CT) has been found to be superior to conventional radiography for the detection of TD branches and providing topographic information.[17]

1.2 Problem statement

Mesenteric lymphatic vessel catheterisation is an invasive surgical procedure which requires a separate surgical site from the approach for TD ligation. A mid-line coeliotomy is performed to place the mesenteric lymphatic catheter and the coeliotomy incision is temporarily closed before the dog is transferred to a diagnostic imaging suite for lymphography. The dog is then moved back to the surgical theatre for TD ligation and removal of the mesenteric catheter, possibly after performing post ligation TD lymphography. The required patient

movement that occurs with mesenteric lymphography increases the risk of accidental catheter loss.[17] Due to the need to perform a coeliotomy it can be anticipated that there would also be a significant increase in surgical time and cost, anaesthetic and surgical risk, and patient pain and discomfort with mesenteric lymphography. Ultrasound (US) guided percutaneous injection of contrast medium via the popliteal LN may circumvent many of these problems, but it is unknown if popliteal lymphography is comparable with mesenteric lymphography for allowing identification of the TD branches. Administration of contrast medium into a mesenteric lymphatic vessel allows contrast medium to be injected more rapidly and it gives a more direct route to the TD than popliteal lymphography. Therefore mesenteric lymphography may deliver a higher intraluminal pressure to the TD, which may open and dilate more TD branches, as well as providing a higher concentration of contrast medium which could aid clearer identification of TD branches with diagnostic imaging.

Due to the duration of a thoracic helical CT scan, thoracic movement must be minimised during the scan process so as to reduce the amount of movement artefact that appears on the images. This may be achieved by using muscle relaxants to prevent respiratory muscle function, or through the use of positive pressure ventilation to maintain a sustained period of peak inspiratory breath holding. The use of muscle relaxants requires a high level of monitoring and management expertise, which may explain their uncommon usage in most veterinary practices. Some muscle relaxants should be used with caution, or are contraindicated in patients with chylothorax due to concomitant pulmonary or cardiovascular disease, electrolyte imbalances or malnourishment, and may have adverse reactions with medications such as diuretics and anaesthetic gasses.[23] While positive pressure ventilation will avoid many of the potential problems seen with muscle relaxants it will increase the intrathoracic pressure, which may result in the collapse of pressure sensitive intrathoracic structures such as large veins and TD branches. Sequential CT of the thorax does not require a period of thoracic immobilisation due to the short duration required for each sequential CT scan segment.

Studies have not been performed to assess if there is any difference in the ability of helical and sequential CT lymphography to detect TD branches. Also

the ability of the two CT modalities in assessing TD branches has not been compared for contrast medium administration into either a popliteal LN or mesenteric lymphatic vessel. Mesenteric lymphatic vessel administration may result in a greater intralymphatic pressure when compared to popliteal LN administration; while helical CT may result in a greater resistance to intrathoracic contrast medium flow due to increased intrathoracic pressure caused by forced inspiratory breath holding.
This study compares mesenteric and popliteal lymphographic techniques, and assesses helical and sequential CT modalities, for any advantage in facilitating the assessment of TD branches.

1.3 Research questions

- Is contrast medium administration through US guided percutaneous injection into a popliteal LN a suitable alternative to mesenteric lymphatic vessel catheterisation and injection, when CT lymphography is used for the detection and assessment of TD branches?

- Are sequential and helical CT modalities equivalent for the detection and assessment of TD branches with CT lymphography?

1.4 Hypotheses

- No difference exists between US guided percutaneous popliteal lymphography and mesenteric lymphatic vessel lymphography for the detection and assessment of TD branches.

- No difference exists between single sequential slice and single helical slice CT in detecting TD branches during lymphography.

1.5 Objectives

- The primary objective of this study is to assess if popliteal CT lymphography is as sensitive as mesenteric CT lymphography, for the detection of TD branches in the dog from thoracic vertebra 9 (T9) to lumbar vertebra 1 (L1).
- The secondary objectives are to compare the clinical application of US guided percutaneous popliteal LN and mesenteric lymphatic vessel lymphography techniques, and to assess the comparability of helical and sequential CT modalities for the assessment of TD branches from T9 to L1.

1.6 Benefits

This study may provide information to help support the reliability of US guided percutaneous popliteal lymphography in identifying TD branches. This could help to justify the use of a less invasive diagnostic technique in chylothorax cases, thereby reducing the number of surgical procedures, and patient pain, risk, and morbidity, and diagnostic time and cost.

It may also clarify if sequential or helical CT has any advantages when assessing TD branches, which may impact upon anaesthetic protocol and safety as well as staff and patient radiation exposure.

This project forms part of the requirements for Dr IR Millward's MMedVet (Small Animal Surgery) degree.

Chapter 2: LITERATURE REVIEW

2.1 Canine thoracic duct

2.1.1 Anatomy of the canine thoracic duct

The canine TD is the cranial continuation of the cisterna chyli, which is located between the origins of the diaphragmatic crura, slightly to the right of the aorta. While the morphology of the cisterna chyli and TD are found to be highly variable, the TD is classically described as starting as a single duct on the right dorsolateral border of the aorta, just ventral to the azygous vein, at the level of L1 where the cisterna chyli achieves its smallest diameter.[24] It runs cranially through the dorsal mediastinum in this location until the level of T6, where it deviates to the left between the aorta and azygous vein. It then runs cranioventrally through the precardial mediastinum before perforating the wall of the left subclavian vein, close to its junction with the left jugular vein. A small ampulla is noted in the TD just before it narrows to perforate the wall of the blood vessel.[24,25]

No valvular structures are present at the entry point of the afferent lymphatics into the cisterna chyli, however the TD contains numerous valvular structures to prevent chylous back flow, one of which is located at the lymphaticovenous junction with the left subclavian vein.[24-26]

It should be noted that the canine TD can be incredibly variable in the number of branches, as well as the location and number of points of ductal termination.[1,8,9,18,24-27] Multiple, normally non-functional lymphaticovenous anastomoses may exist between the TD and surrounding vasculature, and may in fact bypass the TD altogether.[28,29]

2.1.2 Function of the canine thoracic duct

The TD functions as the main route by which lymph is returned to the venous system cranial to the heart, as well as acting as a critical conduit for chyle.[1,8,9,24] Chyle is primarily a combination of lymph, and chylomicrons which are small droplets of fat stabilised by a surrounding layer of

phospholipids.[1,2,8] These fats are absorbed into the intestinal lymphatics from ingesta within the intestinal tract,[1,8] and the chyle then passes from the intestinal lymphatics, through the intestinal lymph trunk and associated lymph nodes, before entering the cisterna chyli.[24]

The TD transports 60-70% of the ingested fat,[1] however chyle also contains fat soluble vitamins, such as vitamin K, and a large amount of plasma protein, all of which are returned to the vascular compartment after exiting it through the capillary beds. The TD also transports antibodies, and the majority of newly formed lymphocytes, from the lymph nodes, to the vasculature. Electrolytes, protein-bound hormones and enzymes such as pancreatic amylase and lipase are also transported to the venous system via this lymphatic route.[1,2,8]

The pelvic limbs and abdomen also make a major contribution to the lymphatic flow into the cisterna chyli and hence the TD, via the lumbar trunk. Lymph from the popliteal, iliofemoral and inguinofemoral lymph centres all drain into the iliosacral lymph centre and then the cisterna chyli. Lymph from the left side of the head and neck, left thoracic limb and left thorax also enters the venous system through the TD into which their lymphatics either drain directly, or indirectly after passing through the left tracheal trunk which then joins the TD close to its anastomosis with the left subclavian vein.[24] Thus all lymph is transferred to the venous system via the TD excluding that from the right side of the head and neck, the right thoracic limb and the right hemithorax all of which returns through the right lymphatic duct.[1,8,24]

The average flow rate of chyle through the TD is approximately 2 ml/kg/hour[1,2,8] of which 50% to 95% is reported to originate from the liver and intestinal lymphatics.[8,30] The TD flow rate can vary considerably with many factors including variations in blood, intra-abdominal, intrathoracic and external lymphatic pressures, food and water intake, abdominal massage and exercise.[31] Although physiological flow rates of between 2-15 ml/minute of chyle through the TD for a 20 to 30 kg dog have been demonstrated, this does not come close to the potential maximum flow rate through an average sized TD of 1.5-2 mm when calculated using Poiseuille's law.[31,32] This maximum calculated flow rate may be erroneously high since it has been shown that in blood vessels leucocytes can adhere to the walls thereby

reducing the vessels functional diameter, and can clump together resulting in an increased drag force, both of which increase the resistance to blood flow particularly through very small vessels. However there is generally minimal adherence of leucocytes to blood vessel walls in a normal healthy patient[33] and to the author's knowledge neither of these factors have been assessed for the TD system. Thus there appears to be a large reserve capacity available for the TD to compensate for variations in the volume of chyle needing to be transported.

Studies have looked at various factors that may affect flow through the TD and found that increasing the systemic venous pressure will increase the flow of lymph through the TD of various species due to an increased extravasation of fluids into the interstitial space.[34-38] However when the response of TD flow to increased venous pressure was assessed with the TD system intact, the resultant increase in TD flow was significantly less than that seen when the TD flow was diverted away from the venous system through a TD cannula. This lower than expected flow through the intact TD is probably a result of back pressure exerted on the TD outflow at its junction with the venous system when venous pressures are increased. The restraining effect of this back pressure is bypassed when the TD is cannulated.[34] Certainly in sheep it has been shown that increasing TD outflow pressure, through partial occlusion of the cranial vena cava, caused back pressure on the TD flow which resulted in an increase in lymphatic pressures within the TD.[35] This finding of TD hypertension may help to understand why thoracic lymphangiectasia has been such a common finding in chylothorax cases.[9,22,28,39] It has been shown that in most individuals massive increases in outflow pressure (35 +/- 6 cmH_20) are required to totally occlude lymph flow through the TD,[38] and that large increases in the outflow pressure (20-30 cmH_20) are required before any significant decrease in the TD flow occurs.[36,38] Once this outflow pressure break-point has been reached there is then a much more rapid and proportional decrease in TD lymph flow with increased outflow pressures.[36,38] Significant variation exists between individuals in maintaining TD lymph flow rates in the face of increased TD outflow pressures. While some individuals appear to maintain TD lymph flow against moderate outflow pressure increases, others develop a lymph flow

deficit at proportionately lower increases in outflow pressure. The more pressure resistant individuals developed an initial increase in the frequency of TD pulsation, which may be a compensatory response to the increased outflow pressures, however this increased rate of TD pulsation decreased as venous outflow pressures were further increased.[36]

The effect of respiration on lymph flow through the TD is debatable as some reports have found no effect[36] while others recorded that rapid flow occurred through the TD during inspiration, and that no flow occurred during expiration, between breaths or when respiration was stopped.[31] It is interesting to consider the Starling resistor effect when contemplating the impact of respiration on fluid filled tubes within the thoracic cavity[40] such as the TD. Increased lymph flow through the TD during inspiration, and reduced flow during expiration,[31] is as one would expect from the Starling resistor effect, whereby the negative intrapleural pressure found during inspiration would effectively dilate any fluid filled tubes within the thoracic cavity such as the TD, and thus increase the fluid flow rates through the TD. By contrast the increased intrapleural pressure found during expiration would partially or fully collapse the TD, thereby reducing the flow rate of chyle through the TD. Thus the Starling resistor effect may explain the impact that the normal respiratory cycle appears to have on flow through the TD.[31] Positive pressure ventilation may therefore have a significant impact on flow through the TD system. The normally negative intrapleural pressure created during inspiration, is converted to a positive one due to bypassing the bellows effect that the thoracic wall and diaphragm use to generate lung inflation.[41-43] If positive end-expiratory pressure ventilation is used then end-expiratory intrapleural pressure will also be higher[42] therefore causing even greater collapse of TD branches. To the author's knowledge the impact of positive pressure ventilation, and positive end-expiratory pressure ventilation on the TD, has not been assessed however their impact on the intrathoracic cardiovascular system has been described.[40-42,44]

2.1.3 Imaging of the canine thoracic duct

Various forms of lymphography have been used to facilitate imaging of the lymphatics. Direct lymphography involves injecting contrast medium directly into lymph vessels[1,9-11,13,15,17,18,20,45-48] or lymph nodes,[21,22,48] whereas indirect lymphography involves injecting contrast medium into the interstitial space of tissues which then drains into the lymphatics.[50-52]

For direct lymphography aqueous-based contrast agents have been found to be superior in both the speed of administration and ability to facilitate visualisation of the lymphatics, when compared to oil-based agents.[9,18,52] Direct lymphography has been shown to give superior LN opacification due to a more efficient delivery of the contrast medium.[9,50]

Conventionally lymphography of the canine TD has been performed via a catheter which has been surgically implanted into a mesenteric lymphatic vessel and held in place using sutures such as silk,[1,9,10,17-20] polyglactin 910[14] or polypropylene.[11,47] Corn oil is usually administered orally before surgery to aid visualisation of the intestinal lymphatics and thereby facilitate lymphatic catheter placement. Oral oil dosing has been variously reported as a single dose given 30 minutes before anaesthesia,[18] through to doses given each hour for one to five hours before anaesthesia.[1,9,13,19,20] An alternative approach to facilitate visualisation and catheterisation of an intestinal lymphatic has been described where Evans blue or methylene blue is injected into a colic LN.[14,47,54]

Administration of contrast medium into a mesenteric lymphatic vessel allows a relatively direct passage through the intestinal lymph trunk and cisterna chyli to the TD. This may result in superior opacification of the TD system due to higher concentrations of contrast medium, and may achieve a higher intralymphatic pressure thereby dilating TD branches more and possibly opening up previously non-functional TD branches. The end result may be that a more central administration of contrast medium could result in a greater ability to identify TD branches, when compared to a more peripheral administration technique. Certainly injection of methylene blue into a mesenteric LN was found to be superior to popliteal LN injection in both successful TD colouration and the degree of colouration achieved.[54]

Radiographic contrast medium is often diluted to reduce viscosity,[1,10,11,15,17,28] and is given at various doses ranging from approximately 0.5 ml/kg to 1 ml/kg,[1,9,10,15,18,28,46,47] although doses up to 2.5 ml/kg have been reported.[15] It is generally implied that the contrast medium is given as a rapid bolus,[1,9-11,15,18,28] however the rate of administration is often not specified. Diagnostic imaging of the TD is normally initiated immediately after completion of the contrast medium administration.[1,9,10,17,18] A 1 ml/kg bolus of contrast medium is well above the normal 2 ml/kg/hour basal flow rate of chyle through the TD,[1,2,8] and thus it should help to dilate the TD branches to some degree However this administration rate still falls below the theoretical maximum flow rate through a 1.5-2 mm diameter TD,[31,32] especially when multiple TD branches may also be present.[9,18,24]

Obviously the degree of ductal dilation with contrast medium, and therefore TD branch size, may have a significant impact on the ability to detect TD branches. The impact of TD size and contrast medium concentration may be more significant when using conventional radiographs to identify TD branches than with CT, as a significant difference exists between these two diagnostic modalities in the size of objects that can be reliably detected.[17,55,56]

Identification of the TD has been facilitated through administration of contrast medium into a popliteal LN, and LN access was gained either through palpated percutaneous injection[21] or surgical dissection of the LN.[54] In one study intraoperative visualisation of the TD was aided by injection of 0.5 mg/kg of methylene blue into a popliteal LN of ten dogs. It was recommended that a maximum dose of 1 ml/dog of methylene blue (10 mg/ml) be used to avoid leakage from the injected LN.[54] When injection of methylene blue into a popliteal LN was compared to mesenteric LN injection, it was found that mesenteric LN administration gave superior TD colouration. Also only 60% of cases with popliteal LN administration resulted in colouration of the TD, compared to 100% of cases with mesenteric administration. Of the failed popliteal administration cases, 50% had reportedly sustained surgical damage to the LN capsule before methylene blue administration,[54] which may have affected the results.

Iohexol 300 mgI/ml has been injected percutaneously into the popliteal LN of five dogs, to facilitate radiographic visualisation of the canine TD.[21] A dose of

1 ml/kg of contrast medium was administered at 2 ml/minute. Although the osmolality of this contrast medium is twice that of physiological saline, no problems were noted either clinically or histopathologically after injecting the undiluted contrast medium into the popliteal LN. Extranodal leakage of contrast medium did not occur, despite the relatively high rate and volume of contrast medium administered. It was suggested that further studies may be needed to find the optimal infusion rate.[21] There appears to be no time delay in the delivery of contrast medium from a popliteal LN to the TD other than the infusion period.[21,54] Percutaneous popliteal LN injection of contrast medium was less invasive, saved time, was associated with no real morbidity, and resulted in good lymphograms in all four experimental dogs and the single reported clinical case, however a larger volume of contrast medium was required in the clinical case before a suitable lymphogram was attained.[21]
Of the 15 dogs previously reported to have had contrast medium administrated into a popliteal LN to aid TD identification, no difficulties were recorded in detecting a popliteal LN.[21,54] However one study used relatively large dogs with an average body weight of 21.2 kg and approached the LN surgically,[54] while the other study's dogs averaged 12.8 kg and used palpation to isolate the popliteal LN before percutaneous contrast medium injection.[21]
More recently contrast medium has been injected percutaneously into mesenteric lymph nodes while using ultrasonographic guidance, which resulted in good CT TD lymphograms in all six of the reported clinical cases. Between 1.5 ml and 2 ml of contrast medium was injected into one or two intestinal lymph nodes and then a helical CT was initiated five minutes after administration of contrast medium.[22] The closer proximity to the cisterna chyli may result in a higher concentration of contrast medium being delivered to the TD system than the more peripheral popliteal LN administration technique, however mesenteric LN administration may suffer less TD branch dilation than administration directly into a mesenteric lymphatic vessel due to a reduced intralymphatic pressure caused by the less direct injection route. The time delay of five minutes between contrast medium injection and initiation of the CT in this study[22] would most likely have resulted in the loss of any potential benefits from an increase intralymphatic pressure, and may have allowed some dilution of the contrast medium by the normal lymph flow. Such a

prolonged delay between administration of contrast medium, and initiation of the CT should be questioned in the light of the relatively rapid passage of contrast medium found with both mesenteric lymphatic and popliteal LN administration. Certainly with popliteal LN TD lymphography it was found that the TD was seen more clearly when radiographs were taken within 2 minutes of the completion of contrast medium administration.[21] It is interesting to note however that the dose volume of radiographic contrast medium used for the mesenteric LN study[22] was significantly lower than that used for the popliteal study.[21]

Concerns have been expressed as to the ability of popliteal lymphography,[21] and even mesenteric lymphography,[14] to opacify and detect all of the TD branches. However mesenteric lymphatic vessel administration of contrast medium still remains the standard by which other methods of TD lymphography are measured.

One study has shown that with mesenteric lymphography, helical CT was superior in detecting TD branches when compared with conventional radiology due to a lack of superimposition of structures, an improved contrast resolution and the ability to manipulate the CT images to maximise TD identification.[17] A similar superiority for CT was recorded when thoracic radiographs were compared to a single breath hold helical CT for the identification of pulmonary nodules. It was found that CT could detect nodules down to approximately 1 mm diameter, while radiographs were limited to detecting nodules of greater than 6-9 mm diameter.[56] Thus CT facilitates improved assessment of TD branches through greater sensitivity to small structures, with superior resolution of tissue contrast and radiographic contrast medium, elimination of superimposition of overlying structures, and more detailed information on the number and exact three dimensional anatomical location of structures when compared to conventional radiographs. [17,55,56]

Unfortunately in the above mentioned TD CT lymphography study[17], there was a delay of up to 30 minutes between administration of the contrast medium and the start of the CT, whereas the radiographs were taken immediately after contrast medium injection. As mentioned previously this prolonged and variable time delay after completion of contrast medium administration may have significantly affected the ability to assess the TD

branches[21] due to variations in the degree of TD branch dilation, and the intraductal contrast medium concentration. The average chylous flow rate through the TD is approximately 2 ml/kg/hour,[1,2,8] therefore significant dilution or loss of contrast medium from the site may have occurred in the period between performing the radiographic and CT studies. All of these factors may potentially have compromised the comparison between conventional radiographs and CT for performing TD lymphography. These factors may also explain why some (unidentified) individuals in this study[17] needed to have injection of contrast medium repeated again before performing the CT study. Obviously with the TD being such a pressure sensitive high flow system, the time difference between injection of a high volume of contrast medium and assessment, either radiographically or by CT, should be standardised. This would minimise any risk of variation due to either an injection pressure related TD dilation, or intraductal contrast medium dilution. The radiographs, and apparently the CT of the above mentioned study, were performed in dorsal recumbency, which is not a normal physiological position and could have had a significant influence on the TD function. Patient position has been found to have a significant impact on the cardiopulmonary system including alterations in heart rate, blood pressure and vascular resistance,[57] all of which may affect lymph flow rates through the TD.[34-38] Also patient position has shown a significant effect on the sensitivity on other positive contrast studies such as mesenteric portography.[58] No information was given as to the method by which thoracic respiratory movement was minimised, however due to the time required to perform a helical CT it must be assumed that some precautions, such as a period of breath holding, were instituted for the duration of the CT so as to avoid problems with movement artefact.

Positive pressure ventilation of 15 cm of water has been used to maintain a forced breath hold and thereby reduce thoracic respiratory movement during helical CT in some studies.[22] This forced inspiration will increase the intrathoracic pressure[41-43] and thus may cause the reduced flow through, or collapse of, pressure sensitive intrathoracic structures such as the TD due to the Starling resistor effect. Certainly blood flow through the intrathoracic veins and the right atrium has been shown to significantly reduce during positive pressure ventilation,[40,43,44,59,60] though the degree of impact is less than would

be anticipated.[59,60] It has been suggested that this minimised effect may be due to concurrent caudal movement of the diaphragm when the lungs are maximally inflated, which results in a combined increase in intra-abdominal and intrathoracic pressures. Due to the many valve-like structures which prevent back flow in both the intra-abdominal and intrathoracic veins, the raised intra-abdominal pressure increases intra-abdominal intravenous pressure, which increases venous return from the abdomen to the thoracic vasculature, thereby lessening the effect of positive pressure ventilation on intrathoracic venous flow.[59,60] By comparison neither the afferent lymphatic vessels of the cisterna chyli, nor the cisterna chyli itself, have any valve-like structures to prevent back flow of lymph[24-26] as would occur with an increase in intra-abdominal pressure. However the TD has multiple valve-like structures present to prevent back flow.[24-26] Therefore it may be anticipated that the cranial flow of lymph through the TD should be much more severely affected with a combined increase in intra-abdominal and intrathoracic pressures, than occurs with blood in the venous structures.

Activation of the renin-angiotensin-aldosterone system also occurs with positive pressure ventilation, causing vasoconstriction and an increased blood volume through water and sodium retention, thereby further increasing systemic venous pressure.[59] As mentioned earlier periods of increased systemic venous pressure have been shown to result in a concurrent increase in the lymph flow through the TD.[34-38]

Sequential CT scans require a much shorter time for each scan segment and thus do not require the cessation of respiratory movement during thoracic CT. Ventrodorsal (VD) radiographs show more TD branches than the lateral radiographic views, due to superimposition of TD branches on the lateral view.[17] This may become clinically important where intraoperative radiographs are taken in theatre when a single procedure is used to perform the lymphography and TD ligation. Due to a right intercostal thoracotomy being used routinely for TD ligation,[3,8-12,16,47,61-65] patients are often positioned in left lateral recumbency. Therefore their lymphogram is often performed through a right paracostal incision[1,9,10,18,28,66] immediately before TD ligation, which can preclude intraoperative patient repositioning for radiographs. Although it was originally recommended that lateral and dorsoventral (DV) radiographic views

be obtained,[18] it is often reported that only the less reliable lateral radiographic view is taken.[10,28] It should be noted that a single lateral view may be adequate when assessing the success of TD occlusion immediately after TD ligation where it is most important to visualise if there are any TD branches left patent. While some authors strongly recommend post-ligation lymphography to confirm ligation of all TD branches,[9,12,28,63] others dispute the efficacy of post-ligation lymphography in identifying persistent TD branches.[14]

With CT lymphography the patient does not have to be repositioned during the CT examination which simplifies the diagnostic procedure as well as lowering the risk of accidental removal of the mesenteric lymphatic catheter. However if intraoperative lymphography was to be performed using CT then the patient would still need to be moved from theatre.[17]

The author could not find any canine studies comparing helical and sequential CT modalities for assessment of the TD system. Only one canine study comparing the efficacy of both CT modalities in assessing soft tissue structures could be found.[67] The authors concluded that there was no significant difference between the two CT modalities in evaluating thoracolumbar intervertebral disc extrusion despite the superior image quality produced with sequential CT, however sequential CT took a significantly longer time to perform than helical CT. A human study comparing the two CT modalities for assessing structures of the brain concluded that no significant difference existed between helical and sequential CT modalities with regards to the image quality, tissue contrast or the artefacts found.[68] However they recommended using helical CT wherever rapid scanning or high quality secondary reconstructions were required.

With improved identification and assessment of the exact number and topographical location of TD branches with CT, it would be anticipated that this should allow improved surgical planning as occurs at other surgical sites,[68] and may increase the success rate for surgical treatment of chylothorax.[17,18,22] Exact topographical information could also allow for the wider use and greater success of less invasive TD ligation techniques such as thorascopic ligation.[15,69]

As with the administration of methylene blue into the popliteal LN,[54] it would be expected that a lower concentration of radiographic contrast medium

would be present in the TD when compared to mesenteric administration of contrast medium. Thus the greater sensitivity of CT in detecting contrast medium may improve identification of TD branches even when using a more peripheral contrast medium administration site.

Percutaneous administration of contrast medium into the popliteal LN[21] or mesenteric LN[22] would allow the entire diagnostic procedure to be performed in the CT suite, thereby avoiding any need to perform surgical catheterisation of a mesenteric lymphatic before the CT. This would result not only in less patient handling, but also shorter anaesthetic and surgery times which would lower the associated diagnostic costs and risks. The chance of accidental mesenteric catheter removal during patient transfer and positioning for the CT would also be avoided.

Concern has been expressed over the efficacy of popliteal administration of contrast medium in delineating the TD when compared to mesenteric lymphatic vessel administration,[21] though no comparison has been made between these two administration routes. Variations could come about due to greater dilution of the contrast medium, or there possibly being a difference in pressures generated within the TD system between the two techniques. Direct catheterisation of a mesenteric lymphatic closer to the TD may be superior to more peripheral contrast medium administration in facilitating visualisation of any anomalies in the TD,[21] especially when combined with a more rapid contrast medium infusion rate which may increase the intralymphatic pressure and cause greater TD dilation.[18]

Ultrasound guided access to a LN is significantly less invasive than mesenteric lymphatic catheterisation. As mentioned previously in two reports describing injection of contrast medium into the popliteal LN,[21,54] neither described problems with LN identification in any of the 15 dogs involved although neither used US guidance. One study did suggest that the use of US may help to identify possible contrast medium leakage.[21] No difficulties were mentioned in the six dogs reported using US guided percutaneous injection of contrast medium into an mesenteric LN,[22] however ultrasonographic identification of intestinal lymph nodes is reported to be more difficult than peripheral lymph nodes due to their small size and having echogenicity similar to surrounding structures such as mesenteric fat.[70,71] Fortunately the

mesenteric lymph nodes are the largest in the abdomen[70] and with the use of higher resolution US equipment and appropriate clinical experience they should be able to be visualised in most individuals.[72] However this does not address the difficulty of stabilising a highly mobile intra-abdominal structure to allow needle placement, and maintaining this throughout the duration of contrast medium injection, whilst avoiding trauma to adjacent structures such as the spleen, intestinal lymphatics, blood vessels, and intestinal loops. Whenever possible the distance from the skin surface to the LN should be kept to a minimum by applying pressure to the abdomen and this will also serve to displace any overlying intestinal loops, however needle placement may still be difficult with small mobile structures.[73]

In the author's opinion a peripheral LN such as the popliteal LN provides superior access compared to an intra-abdominal LN when ease of identification, needle introduction, stabilisation during an extended period of injection, and risk to surrounding critical structures are all considered.

Both popliteal and mesenteric LN administration techniques may suffer less TD branch dilation due to reduced intralymphatic pressure when compared to direct mesenteric lymphatic vessel administration. However mesenteric LN administration may possibly benefit from delivery of a higher concentration of contrast medium in the TD system due to its closer proximity to the TD origin.

Concern has been expressed about just how effective lymphography is at showing all of the TD branches that are present,[3,14,21] and whether there are normally non-functional lymphaticovenous anastomoses that bypass the TD[28,29] which may become functional only after TD ligation, due to the associated increased intralymphatic pressure. Thus intralymphatic pressure may be a critical point in increasing the sensitivity of TD branch detection.

2.2 Canine chylothorax

2.2.1 Overview

Canine chylothorax is an uncommon disease which can be very frustrating to manage. It is characterised by the accumulation of chyle within the pleural cavity, with the resultant clinical signs of dyspnoea, tachypnoea, coughing, exercise intolerance, weight loss and anorexia.[1,74]

Diagnosis is made through thoracocentesis and confirming that the milky appearing pleural effusion is in fact chyle.[1,3,8,10,74]

Chylothorax may occur secondarily to any disease that causes a functional obstruction of the thoracic lymphatics, thereby either directly affecting the flow of chyle through the TD, or by increasing the venous pressure within the cranial vena cava that then increases the TD outflow pressure.[28] Clinical examples include congestive cardiomyopathy,[75] constrictive pericarditis,[10,76] congenital abnormalities of the heart or lymphatics, [8,45,77] dirofilariasis,[78,79] thrombosis or occlusion of the cranial vena cava,[28,80,81] granulomas,[82,83] neoplasia[66,74,84,85] and generalised lymphangiectasia.[86,87]

Traumatic rupture of the TD has been proposed as the possible cause of idiopathic chylothorax.[88] However TD lacerations have been shown to heal within 10 days of surgical transection and, despite developing an initial chylothorax, none of the cases developed a chronic chylothorax.[46]

Chylothorax seen with diaphragmatic rupture may be as a result of concurrent direct trauma to the TD. This proposal is supported by two cases which developed chylothorax after an initial traumatic incident but then had the chylothorax rapidly resolve with medical management alone,[89] possibly after healing of a TD tear.

Chylothorax can also occur with lung lobe torsion,[11,90-93] particularly in the Afghan hound.[91,93] While the underlying pathophysiology of this association is unknown, it is reported that the lung lobe torsion probably occurs secondarily to the chylothorax and not as the initiating cause.[1,3] This may be supported by the fact that lobectomy of the affected lung rarely results in resolution of the chylothorax.[3]

Congestive heart failure has been shown to greatly increase the rate of lymph flow through the TD, however this increased lymph flow must overcome the resultant higher central venous pressure present in the cranial vena cava.[34] However as mentioned previously the venous pressure needs to be significantly raised before a significant reduction in the TD lymph flow will occur, although increased TD outflow pressure does result in TD lymphatic hypertension.[35,36] There is significant variation between individuals in the venous pressure required to reduce TD flow.[36] All three of these studies[34-36] support a previous hypothesis[10] that increased venous pressure results in lymphatic hypertension within the TD system. Thoracic lymphangiectasia is a common finding in cases with chylothorax[9,22,28,39] and may be a result of lymphatic hypertension within the TD system. Certainly pulmonary lymphangiectasia in humans can result in a chylous pleural effusion.[94,95] It has also been proposed that an underlying lymphangiectasia may be the primary cause of many idiopathic chylothorax cases, with the loss of protein, lipids and fluid into the pleural space from the pathologically dilated intrathoracic lymphatics.[96] Loss of chyle from the TD into the pleural space would certainly be enhanced by TD hypertension and the low intrapleural pressures found during respiration.

Of eleven chylothorax cases which had ultrasonographic examination results recorded for the pericardium,[10,76] one had a confirmed thickening of the pericardium[76] and was diagnosed as having restrictive pericarditis that was thought to be secondary to a previous haemorrhagic pericardial effusion. Of the ten remaining dogs, six were thought to have a subjective thickening of the pericardium.[10] It may be speculated that more often than not the pericardial thickening seen in chylothorax cases is probably a result of the body's reaction to the presence of chyle in the pleural cavity, as is seen to occur on other intrathoracic organs such as the lungs with fibrosing pleuritis.[6] Therefore it may be proposed that congestive heart failure secondary to pericardial thickening may occur as a secondary change, rather than being a primary initiating cause of chylothorax. Due to the fact that a restrictive thickening of the pericardium is not present in all dogs with chylothorax, and the relative rarity of chylothorax when compared with congestive heart failure,

it appears there must be other factors which are important for the development of chylothorax.

Lymphangiectasia is a common finding in dogs with chylothorax[9,22,28,39] and it may be caused by any functional obstruction to the flow of chyle, including high central venous pressure. Impedance of chyle flow through the TD rather than complete TD obstruction was proposed as the cause of idiopathic chylothorax, when it was found that complete ligation of the cranial end of the TD at the lymphaticovenous junction did not result in development of chylothorax. It was found that these patients actually developed intra-abdominal lymphaticovenous communications within six weeks of the TD ligation, thereby bypassing the occluded TD.[28] However when the cranial vena cava was ligated in ten dogs, seven subsequently developed chylothorax, one developed a non-chylous pleural effusion, and two dogs did not develop any pleural effusion.[28] All of the dogs showing persistent chylothorax two to six weeks after cranial vena cava ligation had developed intrathoracic lymphangiectasia, which was probably the result of lymphatic hypertension. Three dogs in which the pleural effusion had become serosanguineous had no detectable lymphangiectasia. The two dogs which did not develop any pleural effusion may support that some individuals have pre-existing intra-abdominal lymphaticovenous anastomoses, which can facilitate the rapid bypassing of chyle into the caudal vena cava instead of it having to traverse the TD system. In the portocaval system it is accepted that numerous communications exist between the portal and systemic venous systems in the foetus, and that these may become functional in the presence of chronic portal hypertension.[97]

Other mechanisms must also be present to explain the rarity of chylothorax despite the commonality of central venous hypertension. The varying ability of individuals to maintain TD flow despite increased venous pressure at the TD outflow[36] has already been discussed. The highly irregular nature of TD lymphaticovenous connections,[18,24,25,27] the innate reserve capacity of the TD system,[31] and the above mentioned possibility of pre-existing intra-abdominal lymphaticovenous connections which may only become patent when supraphysiological intralymphatic pressures occur such as is seen with lymphatic hypertension in some dogs,[28,29] could all help to explain the

unpredictability of dogs developing chylothorax when there is central venous hypertension. These same factors may also contribute to understanding the variable success rate that is seen when chylothorax is treated by TD ligation. The importance of complete TD system ligation was demonstrated in a case which underwent pericardectomy combined with TD ligation, but continued to have persistent chylothorax until a second TD ligation was performed to close a TD branch missed at the first surgery.[61]

Whenever possible, treatment should be directed at the underlying cause of chylothorax. Unfortunately the majority of chylothorax cases do not have an identified underlying cause and thus are classified as idiopathic chylothorax.[3,10,17] The gradual improvement in understanding of the possible underlying aetiologies of chylothorax may help to explain the more recent apparent increases in surgical success rates.[10,11,22,45,61,76]

2.2.2 Management

2.2.2.1 Medical management

Due to an incomplete understanding of the underlying aetiology of idiopathic chylothorax the treatment outcomes have been poor with medical therapy, often resulting in only palliative management.[1,3]

Medical management is often initially instituted for three to four weeks as some cases may spontaneously resolve, thereby avoiding the cost and risk of a surgical procedure that carries only a fair to good prognosis.[1-3,8] Medical management has the best chance of success in those patients where chylothorax is caused by TD trauma, or that have another identified medically manageable underlying cause.[2] Medical therapy often involves providing some form of pleural drainage to overcome the respiratory symptoms, feeding a low fat diet, and possibly using benzopyrones to try to reduce flow through the TD.[1,2,8,11,12,66,98-102]

The TD not only transports 60-70% of ingested fat via the lymphatics to the venous system, but also fat soluble vitamins such as vitamin K, a large amount of plasma protein, protein bound hormones and enzymes such as pancreatic amylase and lipase, electrolytes, antibodies and the majority of

newly formed lymphocytes into the venous system.[1,8] Repeated or long term drainage of chyle from the body may result in clinical problems associated with loss of these products.[2-5] Furthermore drainage does not address the risk of secondary changes such as restrictive fibrosing pleuritis which is a rare but potentially devastating consequence of chronic chylothorax.[6,7] The presence of chyle in the pleural cavity may also induce a thickening of the pericardium, resulting in restrictive pericarditis, which could then further increase the central venous pressure, thereby increasing TD outflow pressure and potentially worsening lymphatic flow from the TD into the cranial vena cava.[10,61,76]

Maintaining an animal on a low fat diet to minimise chyle flow through the TD has been suggested to help manage chylothorax,[1,12,100] however it has been found that low fat diets only reduce the lipid content of the effusion and do not actually reduce the volume of flow through the TD.[3,101] Medium-chain triglycerides have also been recommended for the management of chylothorax in dogs, due to their supposed ability to bypass the intestinal lymphatics by being absorbed directly into the portal system.[1,8,102] However it has been shown that they are actually absorbed into the intestinal lymphatics and are thus of little benefit in reducing the chylous effusion in dogs.[3]

Benzopyrones, such as rutin, have been recommended in animals for the management of chylothorax.[11,66,98,99] A number of case reports exist in which rutin is used to treat idiopathic chylothorax in cats,[98,99] however the author is unaware of any experimental studies to assess the efficacy of rutin for the treatment of chylothorax in dogs. In humans benzopyrones have been used for management of high protein oedemas such as lymphoedema, though they are slow in effect and do not have a persistent action after cessation of treatment.[99,103,104] Benzopyrones may have an effect through a variety of mechanisms such as increasing the number and proteolytic activity of macrophages in the lymph, thereby lowering the high protein level in the lymphoedema, and reducing lymph production through reducing vascular permeability.[99,103] Their probable effect is however mediated through decreasing the number of macromolecules leaking from the blood vessels into the interstitial spaces, therefore reducing the osmotic drag of fluids out of the vasculature. Also by increasing lymphatic contraction and lymphatic flow,

benzopyrones improve lymphatic drainage.[104] This latter finding is interesting as it would imply that benzopyrones could increase flow through the TD which is merely a conduit for the improved lymphatic drainage from other tissues. However the decrease in lymph formation, caused by a reduction in the osmotic gradient between the intravascular and interstitial spaces, or by a reduced vascular permeability, may offset any potential increase in lymph drainage from an oedematous site and therefore minimise any increase in lymph flow through the TD system. Analysis of the available human research data in 2003 found that due to the poor quality of the trials that had been performed, no conclusions could be drawn as to the efficacy of benzopyrones in reducing lymphoedema.[105] It should also be noted that no case reports of benzopyrones being used for the treatment of chylothorax in people could be found.

2.2.2.2 Surgical management

Surgical intervention should be considered for any chylothorax case which does not respond to appropriate medical therapy, is diagnosed as a non-responsive idiopathic case, has severe respiratory symptoms, or has an identified underlying primary cause which is amenable to surgical correction.[1,3,8,10-12,16]

A variety of surgical options exist for idiopathic cases including TD ligation,[3,8-16,39,61-65] cisterna chyli ablation,[11,47] pleuroperitoneal shunting,[5,6,106-108] pleurovenous shunting,[7] partial pericardectomy,[10,22,61,76,109] omental drainage[110] and pleurodesis.[3,5,101,112]

The most commonly performed surgical procedure is TD ligation, which is conventionally accomplished by a right 10th or 11th intercostal thoracotomy,[3,8,9,12,16,47,61,64] although approaches as far cranial as intercostal space eight have also been reported.[10,11] The TD branches may be individually identified and ligated,[1,3,8-12,16,39,64] or all of the tissues dorsal to the aorta may be ligated en bloc.[3,16,62-65] TD ligation is one of the few surgical treatments that can actually prevent the formation of chylous pleural effusion. Many other techniques simply facilitate removal of the effusion from the pleural cavity after its formation, or endeavour to ablate the pleural space in

which the chylous effusion may accumulate. Ligation of the TD promotes formation of intra-abdominal lymphaticovenous anastomoses which facilitate the passage of chyle into the abdominal venous system,[47,113] thereby avoiding passage through the thoracic cavity. Chylothorax resolves in 53%[12] to 59%[3] of cases undergoing TD ligation alone, however flow through the TD system will continue after TD ligation if even one small TD branch is not occluded.[9,16,61] It has been demonstrated that within a few hours of TD ligation, previously undetected lymphaticovenous communications have appeared to open due to an increase in intralymphatic pressure.[29] Failure to ligate all collateral branches of the caudal TD is the single most common cause of operative failure.[16] Due to the limited surgical approach commonly used, and the high degree of variability in TD branch location and number,[1,8,9,18,24-26] it is critical to accurately ascertain the exact location of all TD branches relative to the aorta at the surgical site. A variety of methods have been developed in an attempt to reduce the risk of missing TD branches during surgery, such as feeding a high fat meal before surgery,[8] preoperative staining of the TD with products such as methylene blue,[8,10,28,46,54,92] TD lymphography to aid with preoperative planning and post operative assessment,[3,9,20,28] use of CT lymphography to gain better topographical information,[17] cisterna chyli ablation[11,47] and en bloc ligation of all caudal mediastinal structures dorsal to the aorta.[3,16,62-65]
Improved identification of TD branches could help to facilitate ligation of all TD branches, which may improve the success rate of the ligation procedure,[9,17,18] and enable the use of less invasive surgical procedures such as thorascopic ligation.[15]
Although TD ligation is still the mainstay of surgical management of chylothorax,[1,3,8,9,39,65] it is now being combined with a variety of other surgical techniques to improve the efficacy of surgical management.[10,11,47,61,76]
When TD ligation is combined with pericardectomy it was found to greatly improve the success rate of the surgical procedure, with successful outcomes in excess of 90% being reported in canine chylothorax cases.[10,61,76] Improved success rates are thought to be due to a reduction in the restrictive nature of an inflamed or thickened pericardium on the heart, thereby reducing any potential elevation of the central venous pressure, which may impede the flow of chyle through any lymphaticovenous communications.[10,22,61,76,82] It is

impedance of chyle flow, and not complete obstruction, that results in chylothorax.[28] It should be noted that the case numbers for combined TD ligation and partial pericardectomy are still small, with a total of only 30 dogs having been reported.[10,22,61,76] As mentioned earlier, only one of eleven dogs which underwent ultrasonographic assessment of the pericardium[10,76] was confirmed to have pericardial thickening[76] and six were thought to have a subjective thickening of the pericardium,[10] which again emphasises that other factors must be important in many cases that develop chylothorax. The importance of complete TD system ligation in the treatment process, even when combined with pericardectomy, has been mentioned previously.[61] Cisterna chyli ablation combined with TD ligation[11,47] resulted in 88% of chylothorax cases successfully resolving.[11] This technique's relative success may have been the result of removing the driving force behind the dilation or development of intrathoracic collateral lymphatics. The ablation should have removed the origin of chyle entering the intrathoracic lymphatics,[47] and should have ensured the avoidance of any transient TD hypertension.[29] It is interesting to note that there was still a 12% surgical failure rate even with complete ablation of the source of chyle to the TD system. However it should be remembered that non-chylous lymph from the left side of the head and neck, left thoracic limb, and left hemithorax will continue to pass through the TD, and therefore may enter the pleural space as it does not traverse the cisterna chyli, but enters the TD system directly.[24] This could result in cases with a non-chylous pleural effusion as have been reported previously.[28] However to the author's knowledge only two chylothorax dogs have had this potential source of non-chylous lymph investigated, and neither of them displayed any anatomical lymphatic abnormalities or leakage of contrast medium into the pleural cavity.[22]

Chapter 3: MATERIALS AND METHODS

3.1 Study design

3.1.1 Animal selection

3.1.1.1 Initial assessment

Thirteen beagle dogs aged between 14 months and 8 years, and weighing 10.0 to 15.5 kg, were initially selected from the University of Pretoria Biomedical Research Centre (UPBRC). Within the 7 days preceding the start of the trial, all selected dogs had their microchip identification numbers verified, and data was recorded for each dog regarding age, sex, body weight, habitus, rectal temperature, respiratory rate and mucous membrane colour. A specific gravity (SG) and sediment examination was performed on a voided urine sample obtained from each dog.

A peripheral blood smear was obtained and assessed for blood parasites (specifically *Babesia canis and Ehrlichia canis*). A jugular blood sample was obtained for full haematology (haematocrit, red cell count, haemoglobin concentration, red cell distribution width, as well as white cell, absolute mature neutrophil, lymphocyte, monocyte, eosinophil, basophil and thrombocyte counts, and the presence of anisocytes, normoblasts, reticulocytes, spherocytes, lymphoblasts, monoblasts, active monocytes and toxic granulocytes). A total serum protein, albumin, globulin, and albumin/globulin ratio were also obtained from the blood sample.

Right lateral recumbent and DV thoracic radiographs were obtained, and assessed by the primary investigator for any detectable abnormalities which could affect the TD or increase the anaesthetic risk to the dog.

All dogs were found to be clinically healthy, and haematological, serological, urological and radiological findings were all within normal limits (Appendix 1). Within 24 hours of starting individual trials, each dog again had the habitus, rectal temperature, respiratory rate and mucous membrane colour

reassessed, and a peripheral blood smear was obtained and assessed for blood borne parasites.

3.1.1.2 Trial group selection

Ten dogs were randomly selected from the initial thirteen, and then randomly assigned to two groups of five dogs each.

After difficulty identifying the popliteal LN with US on the second trial dog, all remaining dogs underwent US assessment of the popliteal lymph nodes. Only those dogs with at least one popliteal LN detectable on US were selected, and randomly reallocated to the two groups of five for the trial (Appendices 2 & 3).

3.1.2 Pre-, intra- and post-trial management of dogs

All dogs on the day of initial assessment, and the individual dogs on the day before, until the day after their trial, were kennelled in the general ward of the Section of Small Animal Surgery (SSAS) of the Onderstepoort Veterinary Academic Hospital (OVAH), and were managed as per the standard protocol for the SSAS. Otherwise they were housed at the UPBRC kennels and managed according to the standard UPBRC protocol, as well as being monitored for any signs of pain or other adverse effects of the trial. For reasons unrelated to this study all dogs underwent neutering which was performed after having had their second lymphographic study performed.

3.1.3 Trial day management of dogs

On the trial day each dog was orally dosed with corn oil at 2 ml/kg, 3 hours 45 minutes and 2 hours before the scheduled start of the CT lymphography procedure. For the mesenteric trial group this equated to corn oil doses being given at 3 hours, and then again at 75 minutes, before the approximate time of mesenteric lymphatic vessel catheter placement. Oral corn oil was given to the mesenteric trial group to facilitate visualisation of the mesenteric lymphatics during surgery, and to the popliteal trial group to standardise the procedure.

The individual dogs were transferred from the SSAS kennels to the theatre induction room kennels 30 minutes before anaesthetic induction, then

transferred to the theatre induction room and induced at the appropriate time. From this point the two trial groups followed different paths.

3.1.3.1 Mesenteric lymphography trial group management

After induction dogs were transferred to a surgical theatre, had the mesenteric catheter inserted surgically and were then transferred to the CT suite of the Section of Diagnostic Imaging (SDIM). After the CT lymphography was performed the dogs were transferred back to a surgical theatre for removal of the mesenteric catheter. Once the surgery was completed and the dogs had recovered they were transferred back to the SSAS kennels.

3.1.3.2 Popliteal lymphography trial group management

After induction the dogs were transported to the CT suite and had US guided percutaneous popliteal CT lymphography performed, before transfer to the SDIM radiology suite for radiographs of the utilised stifle. After completion of radiographs they were allowed to recover before being transferred to the SSAS kennels.

3.1.4 Trial schedule

Half of the original group of ten dogs had contrast medium administered through a catheterised mesenteric lymphatic vessel and then 10 to 21 days later through percutaneous injection into a popliteal LN. The other group of five had the trial procedure performed in the opposite order.

3.1.5 Trial procedure

3.1.5.1 Anaesthesia

An intravenous catheter (Jelco, Medex, Lancashire, United Kingdom) was placed into a cephalic vein of each dog and Ringers lactate (Fresenius Kabi, Midrand, South Africa) was administered intravenously at 10 ml/kg/hour after induction until the time of recovery. The initial dog was premedicated 30 minutes before induction with morphine (morphine sulphate, Fresenius Kabi,

Midrand, South Africa) at 0.2 mg/kg subcutaneously and diazepam (Tranject, Merck Generics RSA (Pty) LTD, Modderfontein, South Africa) 0.2 mg/kg intravenously and carprofen (Rimadyl, Pfizer, Sandton, South Africa) 4 mg/kg subcutaneously. After 30 minutes it was then anaesthetised with propofol (Fresenius Kabi, Midrand, South Africa) at 4 mg/kg intravenously.
It was noted that the morphine induced vomiting in the initial patient and corn oil was present in the vomitus. Therefore in all subsequent dogs the carprofen was still administered subcutaneously 30 minutes before induction, but the morphine and diazepam were both given intravenously immediately before induction with propofol.
Endotracheal intubation was then performed and isoflurane (Isofor, Safe Line Pharmaceuticals, Johannesburg, South Africa) inhalation anaesthetic used to maintain general anaesthesia.

3.1.5.2 Mesenteric lymphography procedure

After induction, the ventral abdominal area was clipped and prepared in a routine manner for midline coeliotomy. The patient was then transferred to a surgical theatre and a routine ventral midline coeliotomy was performed. The caecum was identified and the ileum, caecum and ascending colon were elevated from the abdominal cavity to allow identification of the colic and mesenteric lymph nodes with their associated chyle filled lymphatics (Figure 1). A larger lymphatic was identified proximal to the LN and a 22 gauge intravenous catheter (Jelco, Medex, Lancashire, United Kingdom) inserted into the lymphatic vessel, directed towards the cisterna chyli. For the initial two dogs the catheter was sutured into place using 4-0 silk (Silk, Johnson and Johnson, Retreat, South Africa). Unfortunately the tissue drag of this suture material resulted in a number of the surrounding lymphatics being damaged which caused leakage of chyle. Therefore to avoid this complication all following cases had the catheter fixed into place using 5-0 nylon (Ethilon, Johnson and Johnson, Retreat, South Africa).

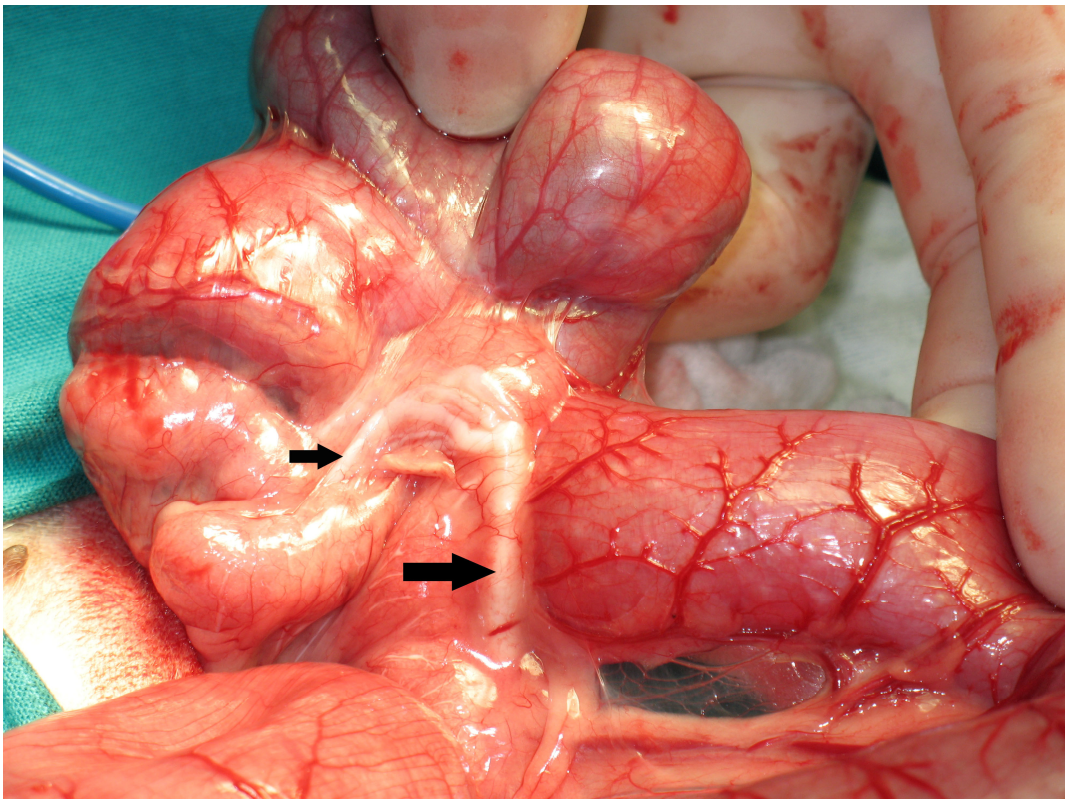

Figure 1. Chyle filled intestinal lymphatics (black arrows).

A low volume extension set (Brittan Healthcare, Isando, South Africa), with an attached stopper-injection port (In-stopper, Braun, Fourways, South Africa), was filled with contrast medium and then connected to the mesenteric catheter. The bayonet attachment of the extension set was sutured to the adjacent intestinal loop (Figure 2) before the catheter, extension set and associated intestinal loops were placed into the abdominal cavity.
The stopper-injection port, and a portion of the extension set were left projecting from the abdomen via the coeliotomy incision and the linea alba was temporarily closed with 3-0 nylon (Ethilon, Johnson and Johnson, Retreat, South Africa) in a simple continuous pattern.

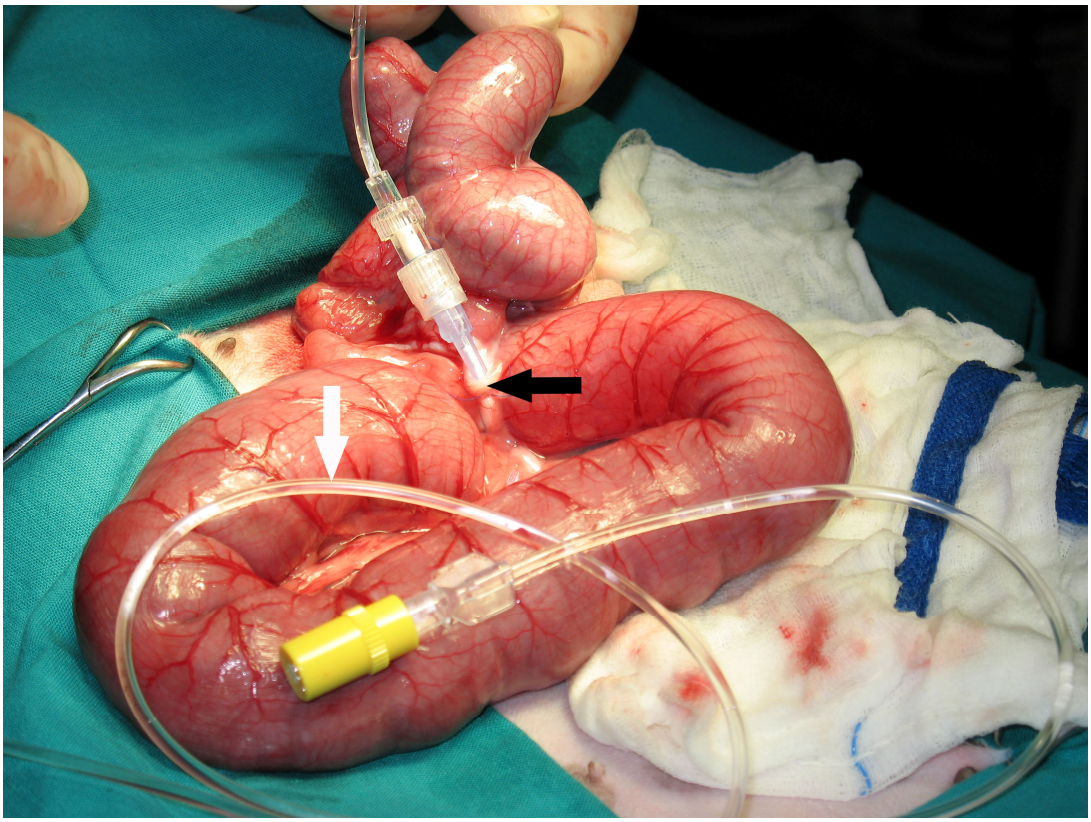

Figure 2. Catheter inserted into intestinal lymphatic (black arrow) with attached contrast medium filled extension tube (white arrow).

The skin was temporarily closed with 4-0 nylon (Ethilon, Johnson and Johnson, Retreat, South Africa) in a Ford interlocking or simple continuous suture pattern. The projecting end of the extension set was attached to the skin with a Chinese finger trap suture technique (Figure 3).
The patient was transferred to the CT suite and placed on the CT table in sternal recumbency with the pelvic limbs extended caudally. Iohexol 300 mgI/ml (Omnipaque, Nycomed Inc., New York, USA) was administered by hand at 1 ml/kg as a bolus over 1 minute, and the CT scan was initiated immediately after completing administration of the contrast medium.
Once the CT procedure was completed the patient was transferred back to a surgical theatre to have the lymphatic catheter and extension set removed, and the abdomen closed routinely. The dogs were then monitored in the OVAH over the next 24 to 36 hours for any signs of pain or other adverse effects, (Appendices 2 & 3) before being transferred back to the UPBRC where further monitoring occurred until 5 days post operatively.

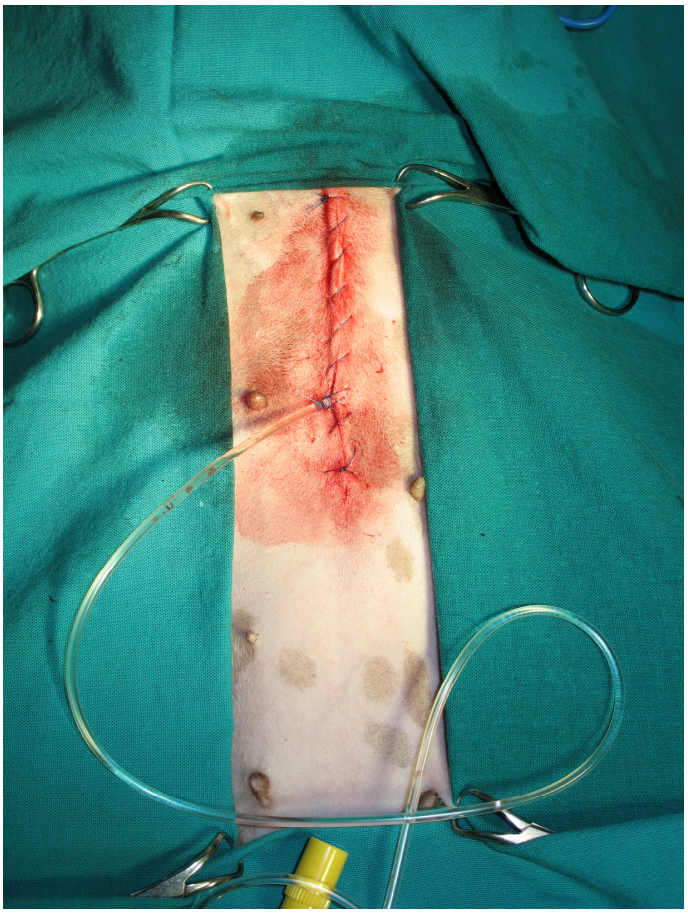

Figure 3. Temporary closure of coeliotomy incision with contrast medium filled extension tube projecting from the abdominal incision.

3.1.5.3 Popliteal lymphography procedure

After induction the popliteal area of both pelvic limbs was clipped and surgically prepared in a routine manner in the theatre induction room.
The patient was then transferred to the CT suite, placed head first into the CT gantry in sternal recumbency, with the pelvic limbs tied in a caudally extended position. A small foam pad was placed under the medial aspect of the selected stifle so as to elevate the area and facilitate ultrasonography and needle placement at the site (Figures 4 & 5).

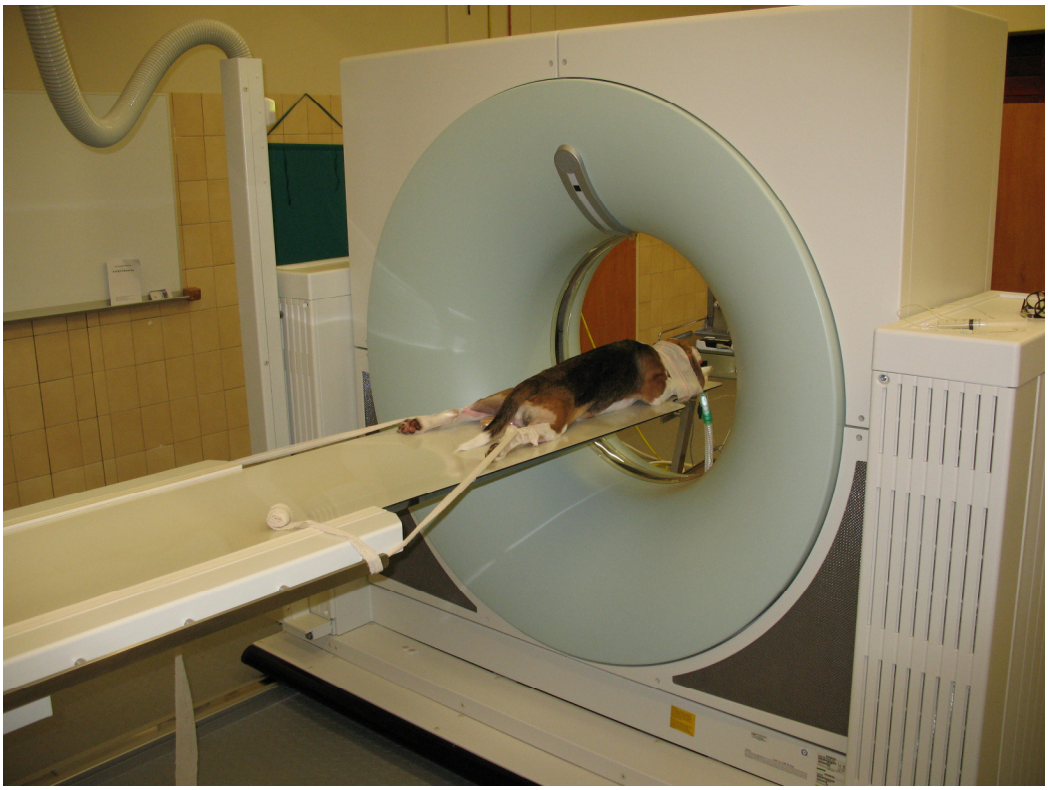

Figure 4. Patient positioning for the computed tomographic lymphography procedure.

The left popliteal area was used initially, however if a LN was not visualised in the preliminary US, or difficulty occurred with injection, then the right popliteal LN was utilised. Ultrasound was performed using a Siemens Sonoline Omnia (Siemens AG, Erlangen, Germany) ultrasound imaging system with a 9 MHz linear array transducer. The popliteal LN was identified as an ovoid structure slightly hypoechoic to the surrounding muscle, with a hyperechoic capsule and hilar area. Caudolateral, sagittal and parasagittal images were taken of the LN to aid identification. Initially a 23 or 25 gauge butterfly needle was introduced adjacent to the transducer head and advanced into the LN with US guidance.

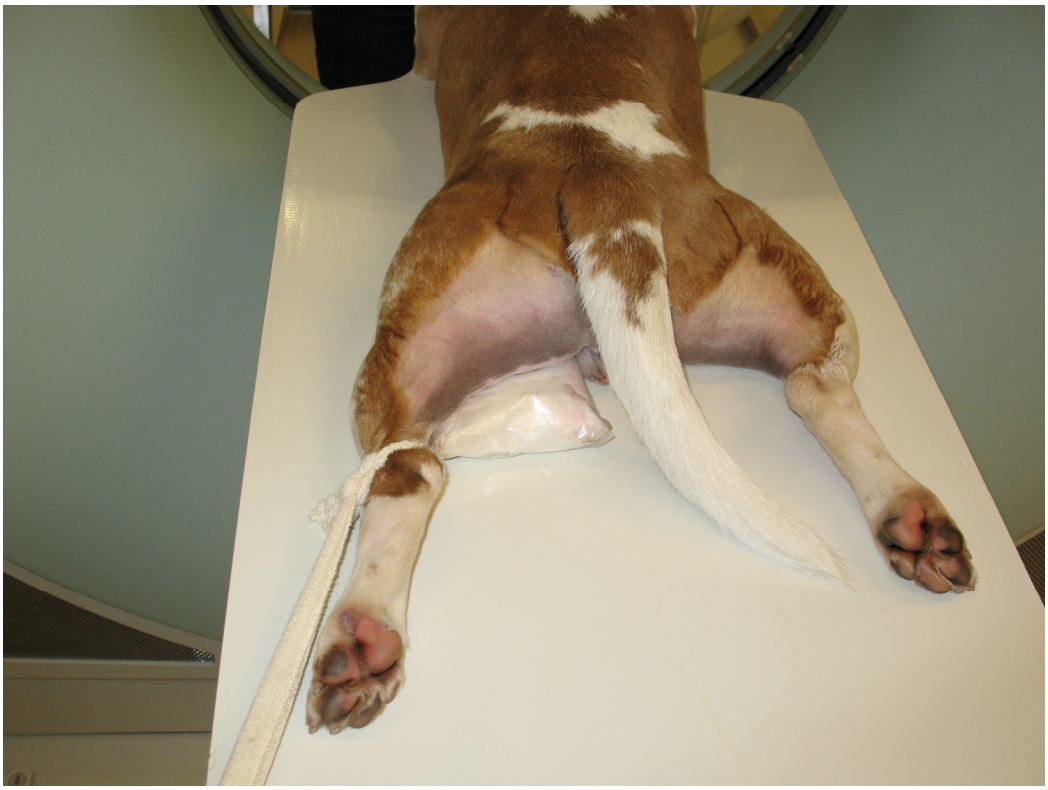

Figure 5. Limb preparation and positioning for ultrasound guided percutaneous injection of contrast medium into the popliteal lymph node.

Under constant ultrasonographic observation, Iohexol 300 mgI/ml was administered at 1 ml/kg of body weight, at a rate of 100 ml/hour. Administration was achieved either with a Braun Perfusor compact S syringe driver (B. Braun Melsungen AG, Melsungen, Germany) or by hand whenever the syringe driver failed (Figures 6 & 7). The needle position was adjusted as required to minimise extravasation of contrast medium seen ultrasonographically and if any extravasation was noted then the estimated volume of lost contrast medium was added to the total volume injected and the extra volume recorded (Appendices 2 & 3).

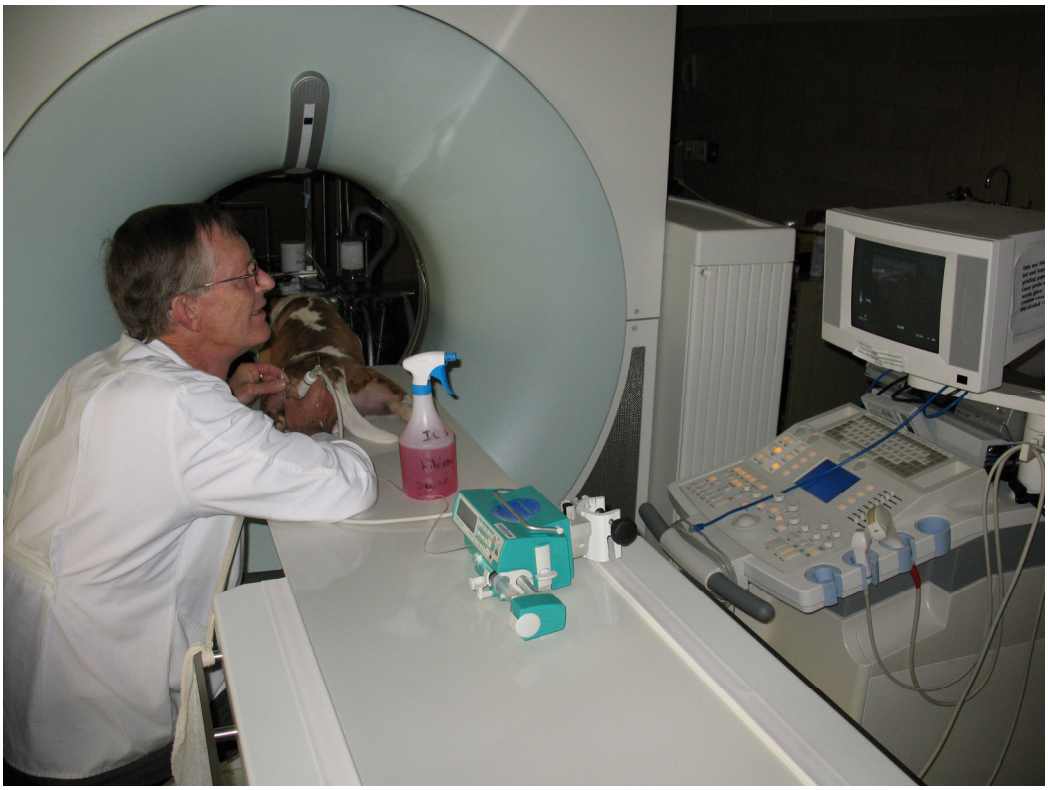

Figure 6. Ultrasound guided percutaneous injection of contrast medium into the left popliteal lymph node.

Due to difficulty in manipulating the butterfly needle on the first two popliteal cases it was elected to change over to a standard 23 gauge hypodermic needle attached the contrast medium filled low volume extension set. After four of the popliteal cases were completed, the needle was changed to a 25 gauge hypodermic needle in an attempt to reduce the volume of contrast medium extravasation that occurred during the injection procedure in some cases.

The CT procedure was initiated immediately after completing injection of the contrast medium. Once the CT was completed all popliteal cases had a mediolateral and craniocaudal radiograph of the injected stifle taken to document the presence of any extravasation of contrast medium.

The dogs were monitored in the OVAH for any pain, or other adverse effects of the procedure, for 24-36 hours (Appendices 2 & 3) before transfer back to the UPBRC where further monitoring occurred until 5 days post operatively.

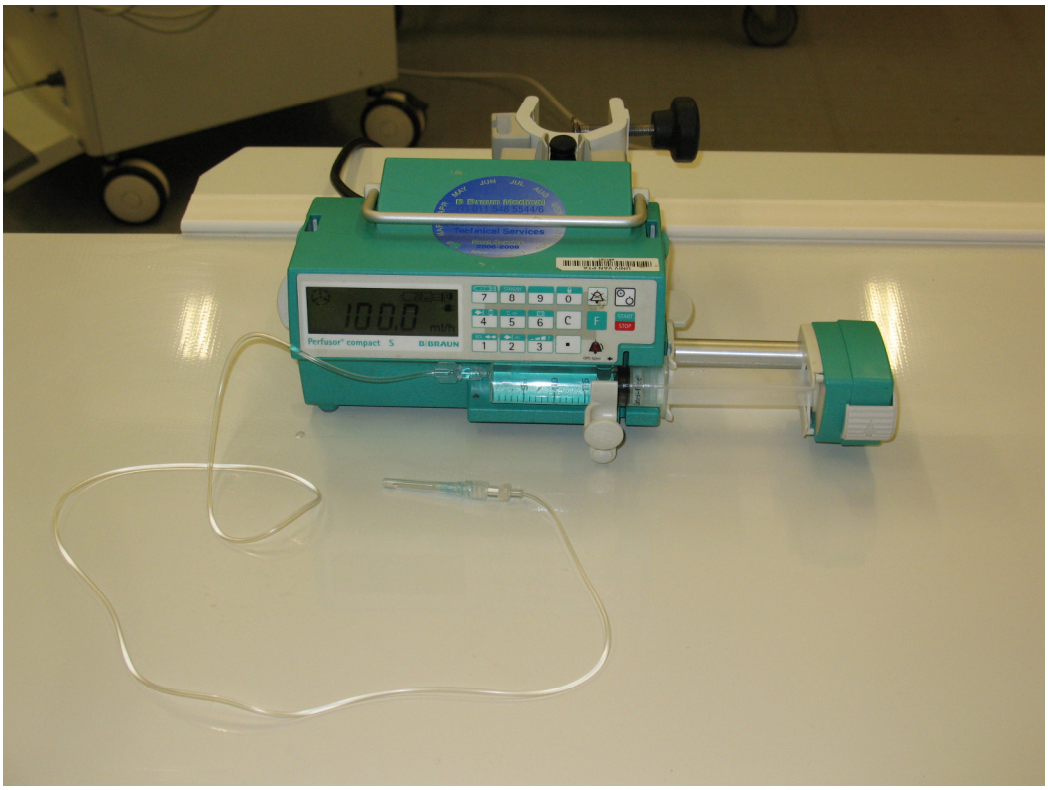

Figure 7. Infusion pump and contrast medium filled syringe and extension set ready for percutaneous injection of contrast medium into the popliteal lymph node.

3.1.5.4 Computed tomography procedure

The CT procedures were performed using the Siemens Emotion Duo dual slice CT scanner (Siemens AG, Erlangen, Germany) of the OVAH.

Dogs were placed in sternal recumbency, head first into the gantry, with their pelvic limbs tied caudally in an extended position (Figure 4). A lateral topogram was taken in a craniocaudal direction to include vertebrae C6 to Cd3. While the dog was prepared and injected with contrast medium, the appropriate CT fields were set for the individual on the topogram.

A B70s sharp kernel and spinal window (W=1500, C=450) were utilised for both CT modalities.

All data was stored on the CT computer for further processing before final data analysis.

3.1.5.4.1 Helical computed tomography procedure

Helical CT scans were initiated within 10 seconds of completing contrast medium administration, allowing time for removal of materials away from the CT gantry and for staff to exit the room. The helical CT scan was taken in a caudocranial direction, from mid-vertebral body L2 to mid-vertebral body T8 using 3mm slices with 50% overlap and a pitch of 1.55. Exposure was set utilising the Siemens CARE dose® algorithm to minimise radiation exposure. To prevent any significant thoracic respiratory movement from the patient, a lead shielded staff member was present in the CT room to adjust the degree of anaesthetic reservoir bag pressure, thereby maintaining a forced inspiratory breath hold for the duration of the thoracic helical CT scan.

3.1.5.4.2 Sequential computed tomography procedure

The sequential CT scan was initiated on average 21 seconds after completion of the helical CT scan, in a craniocaudal direction. The mid-point of each vertebral body L1 to T9 had been set visually on the lateral topogram image, and the slice orientation adjusted such that it was perpendicular to the long axis of the vertebral body. The topogram image size was maximised to try to improve the accuracy of the proposed slice placement, however superimposed structures often made this process difficult. Dual 1mm sequential slices were taken at each selected site and a breath holding sequence was not utilised for the sequential scans. Standard exposures were used for each sequential dual slice exposure.

3.1.5.5 Pain assessment procedure

Both percutaneous popliteal and mesenteric lymphatic lymphography cases were assessed by one individual in the OVAH for the first 24 to 36 hours after the procedure for any signs of pain or discomfort. Once the dog was transferred to the UPBRC this task was undertaken by the dog handler at that facility until 5 days post operatively. The dogs were observed for any signs of clinical discomfort including depressed habitus, vocalisation, hunched appearance or lameness, reluctance to exercise, or pain on palpation of the surgical site or popliteal injection site.

3.1.6 Data collection

Each contrast medium administration technique was attempted in ten dogs; however only seven individuals successfully completed both the popliteal and mesenteric contrast administration procedures (Appendix 4).

For interpretation of the images all T8-L2 helical CT scans were reconstructed to 1mm slices. For each helical CT scan the mid-vertebral body slice of vertebrae T9 to L1 was assessed to be the CT slice midway between the most cranial and most caudal edges of the pedicle for each vertebra (Appendix 5). This slice was then used by two interpreters to collect data at vertebrae T9, T10, T11, T12, T13, and L1 on each individual T8-L2 helical CT scan slice.

For the sequential CT scan the slice location on the vertebral bodies had been individually set for vertebrae T9 to L1 on the topogram as described in the CT technique section. Since a dual slice CT machine was used, two slices existed for each mid-vertebral body site; therefore the slice which optimised visualisation of the maximum number of TD branches was used for each vertebra (Figures 8 & 9).

A bone window (W=1500, C=450) was used for all data collection on both the helical and sequential CT series, so as to minimise the risk of beam averaging which is more prominent in a soft tissue window (W=350, C=40) (Figures 10 & 11).

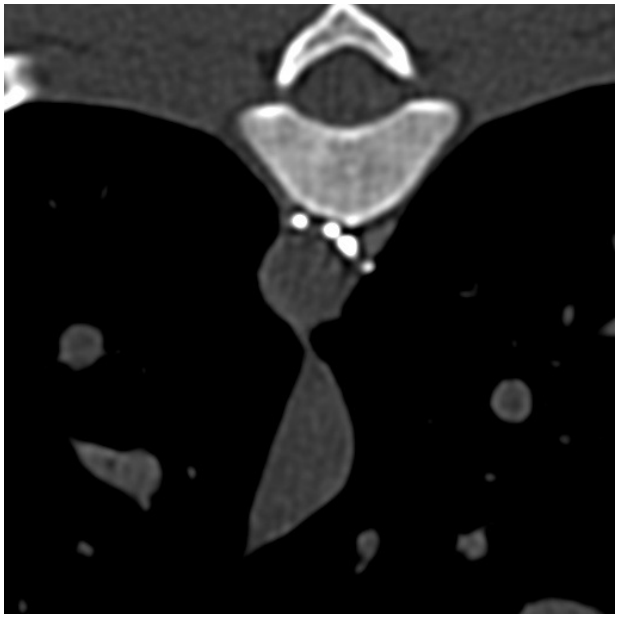

Figure 8. CT8133. Popliteal administration of contrast medium. Sequential computed tomography slice 1 from the T9 vertebral site. Note four thoracic duct branches are visible.

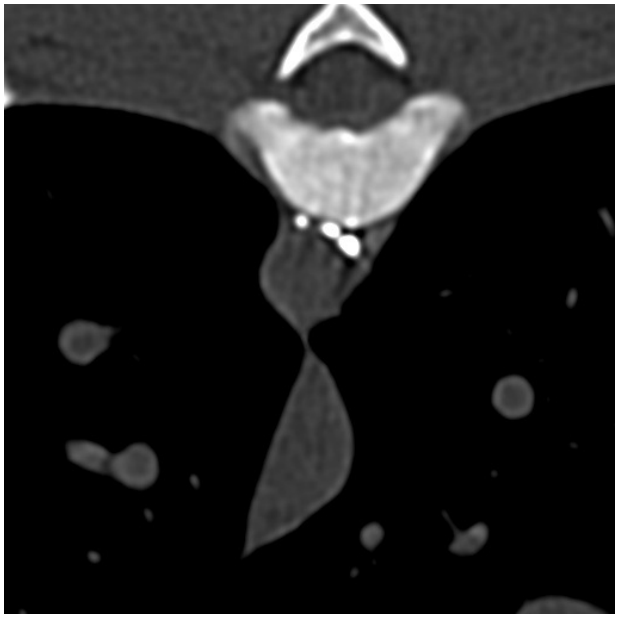

Figure 9. CT8113. Popliteal administration of contrast medium. Sequential computed tomography slice 2 from the T9 vertebral site. Note only three thoracic duct branches are visible.

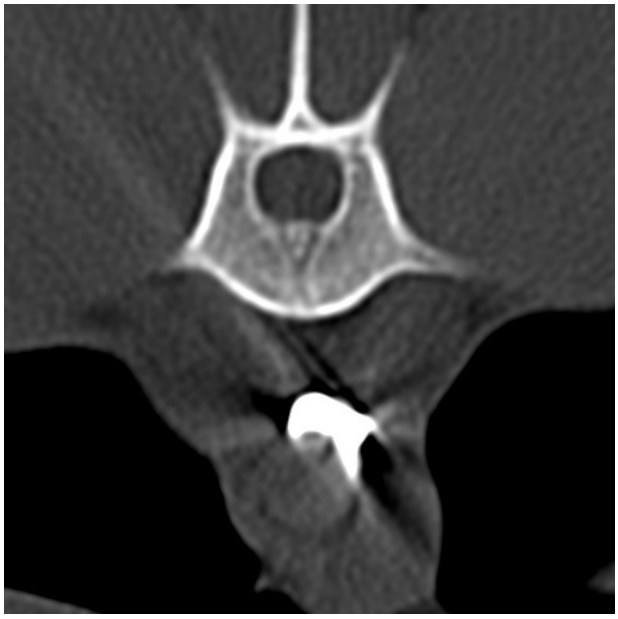

Figure 10. CT0886. Mesenteric administration of contrast medium. Bone window, using helical computed tomography of the L1 vertebral site.

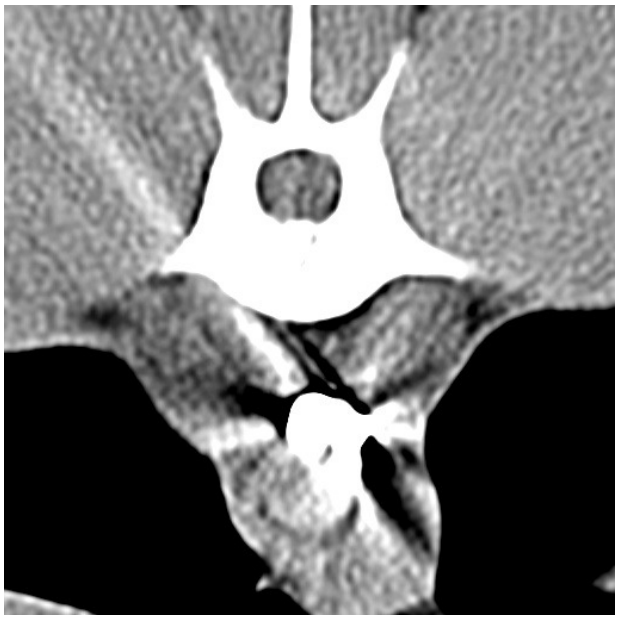

Figure 11. CT0886. Mesenteric administration of contrast medium. Soft tissue window, using helical computed tomography of the L1 vertebral site.

After initial assessment to ensure that more peripherally placed TD branches would not be missed (Figure 12), a standard two times magnification of the image was used (Figure 13) to facilitate more accurate data collection. Where possible any lymphatic branches that were assessed to be intra-abdominal were traced cranially to see if they perforated the diaphragm. If not then they were assumed to be either afferent lymphatics from the intestines (especially when mesenteric administration of the contrast medium had occurred), or aberrant efferent lymphatics that bypassed the TD system and were therefore not counted as TD branches.

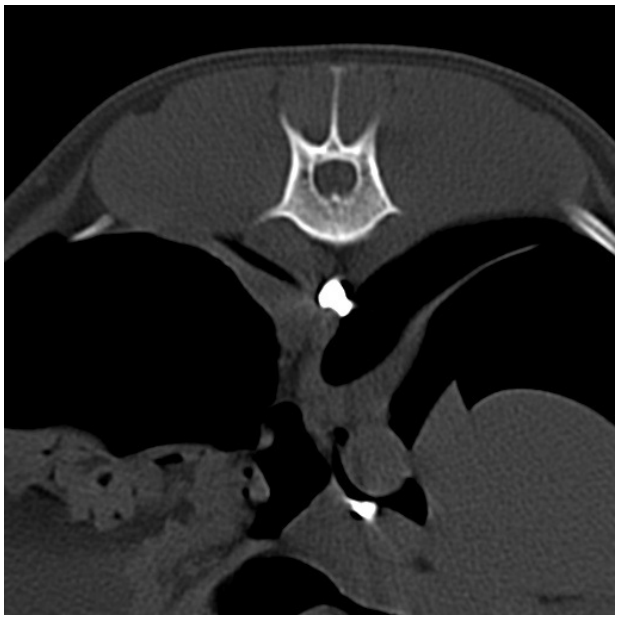

Figure 12. CT0893. Mesenteric administration of contrast medium. Full image of using helical computed tomography of the L1 vertebral site. Note two lymphatic branches can be visualised ventral to the L1 vertebra. This was the only case in which a lymphatic occurred outside of the magnified field. The ventral branch was assessed to be an intestinal lymphatic and therefore not counted as a TD branch.

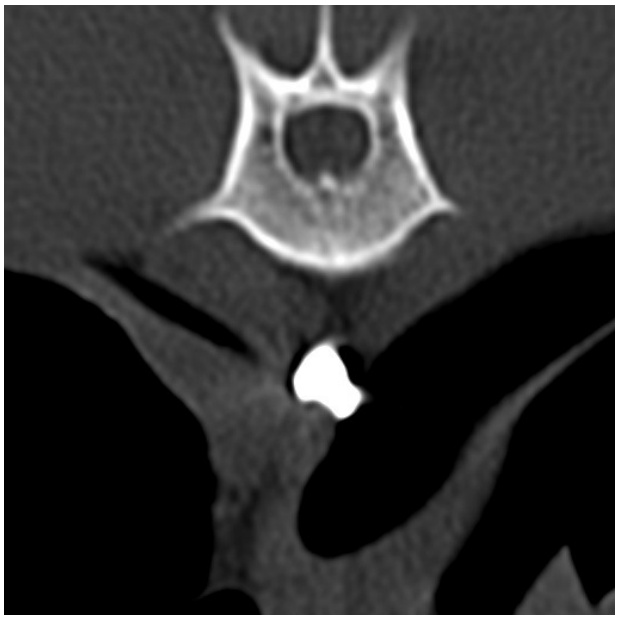

Figure 13. CT0893. Mesenteric administration of contrast medium. Two times magnification using helical computed tomography of the L1 vertebral site. Note that only one lymphatic can now be visualised ventral to the L1 vertebra.

A European board certified radiologist (RMK) and the primary investigator (IRM) assessed the CT scans independently and recorded the following data to the data capture form (Appendix 6):

- Number of TD branches
- Largest TD branch maximum and minimum diameter using the distance tool
- Largest TD branch maximum and mean Hounsfield units (HU), using the circular region of interest (ROI) tool, while ensuring that the maximum area within the TD branch was covered by the circular ROI.

The primary investigator also recorded the following data:

- Largest TD branch cross-sectional area assessed using the free hand ROI tool (Appendix 7)
- All TD branch positions relative to the aorta (Appendix 8).

To avoid potential bias both individuals interpreting the CT images were blinded as the trial group of each study, and were not able to match the two studies performed on any one dog. The primary investigator compared the number of TD branches each interpreter noted at each site and where

differences occurred the data were reviewed by the primary investigator, and adjusted accordingly (Figure 14), before all data were transferred into the data summary form (Appendix 7).

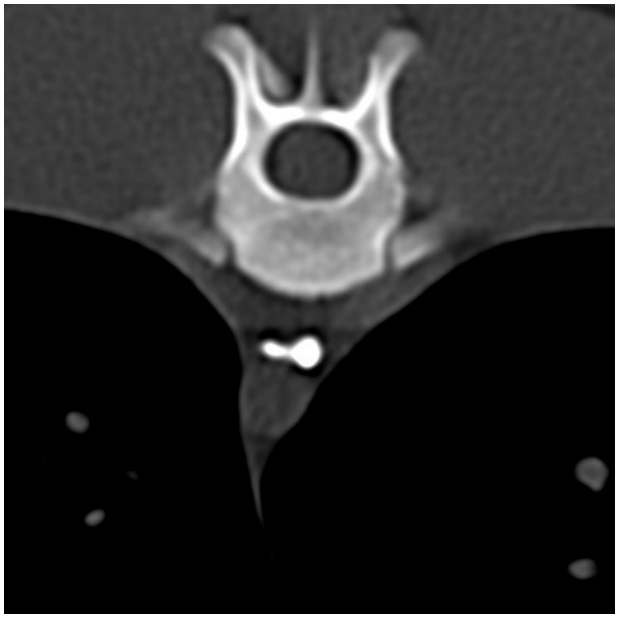

Figure 14. CT0894. Popliteal administration of contrast medium. Helical computed tomography of the T13 vertebral site. Observers differed in the number of thoracic duct branches counted at this site. After review of this image and the images before and after this slice, it was decided that two separate thoracic duct branches were present.

For assessment of the popliteal contrast medium spillage, the ultrasonographer (RMK) subjectively assessed the volume of spillage seen on the US image, and this volume was then added to the total contrast medium injection volume (Appendices 2, 3 & 9). Obviously the ultrasonographer was not blinded as to the needle size used for contrast medium administration. The primary investigator viewed the craniocaudal and mediolateral stifle radiographs, which were taken after performing the popliteal lymphography CT, and subjectively graded the visible contrast medium spillage between 0 (no spillage) and 5 (marked spillage) whilst being blinded as to the size of needle used to administer the contrast medium (Appendix 9, Figures 15 & 16).

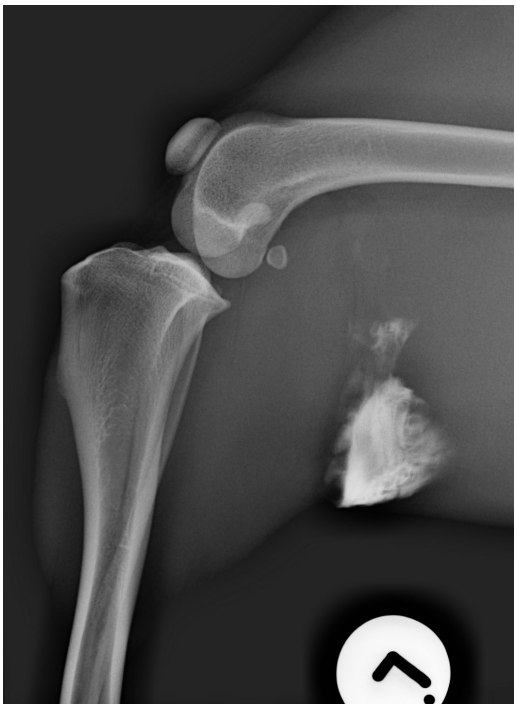

Figure 15. Case ID 211922. Mediolateral stifle radiograph showing grade 1 popliteal contrast medium spillage.

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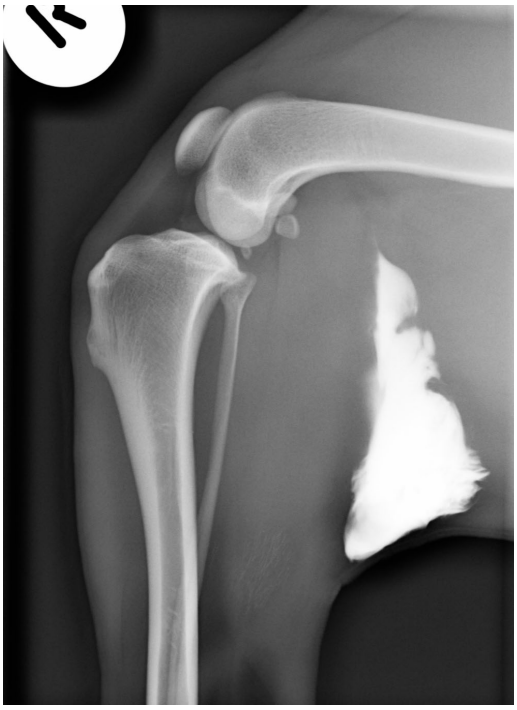


Figure 16. Case ID 211924. Mediolateral stifle radiograph showing grade 3 popliteal contrast medium spillage.

No specific assessment was done of the catheter site in the mesenteric administration cases, however where any abnormalities were detected they were recorded (Appendices 2 & 3).

Pain scores were assessed for each dog after having had a procedure and any significant failures in the standard analgesia protocol, and the corrective action taken, were recorded (Appendices 2 & 3).

3.2 Method of statistical analysis

The significance level was set at $\alpha = 0.05$ for all analyses. Data were analysed using Stata 10.1 statistical software (StataCorp, College Station, TX, U.S.A.).

3.2.1 Thoracic duct number

The effects of contrast medium administration method, CT modality, and vertebral site on the number of visible thoracic duct branches were estimated using a zero-truncated Poisson regression model. This approach was used because the outcome was a count variable and an outcome of zero was impossible, or at least was never observed. Clustering of observations within a dog was accounted for by modelling the dog as a fixed effect. An interaction term between method and modality was tested and retained in the model if significant at $P < 0.05$.

It should be noted that the count ratio (*CR*) estimated by a zero-truncated Poisson regression model will be consistently further from 1 than that estimated by a normal Poisson regression model and this should be kept in mind when interpreting the *CR* for number of TD branches.

3.2.2 Largest thoracic duct branch maximum diameter, cross-sectional area and mean Hounsfield units

As the largest TD branch maximum diameter, cross-sectional area and mean Hounsfield units were all continuous outcomes, the effects of method, modality and site were estimated using multiple linear regression, with the animal as a fixed effect and including the observer as an additional independent variable. Due to the largest TD branch maximum diameter and

cross-sectional area not being normally distributed, they were log transformed to achieve normality before fitting the statistical models.

3.3 Ethical considerations

All dogs received standard hospital treatment whilst in the OVAH. Analgesia consisting of morphine 0.2 mg/kg and carprofen 4 mg/kg were administered before each procedure, and where required individuals received further doses of morphine to manage any significant discomfort.

Each dog was exposed to two thoracoabdominal CT procedures, with an estimated equivalent radiation exposure of 20 millisievert (mSv). The maximum acceptable dose for an adult human is 50 mSv per annum.[114] Therefore it was recommended that these dogs not be used for any further CT studies for a period of 12 months after this trial.

All trial subjects were due to undergo neutering for reasons unrelated to this study.

The Animal Use and Care Committee of the Faculty of Veterinary Science, University of Pretoria, approved this study (reference AUCC – v022-08).

Chapter 4: RESULTS

4.1 Study population

4.1.1 Initial study population assessment

Thirteen dogs had an initial clinical examination, blood samples collected and thoracic radiographs taken to assess their suitability for inclusion in this trial (Appendix 1). No dogs were excluded on these initial findings, however one (ID 211917) was later excluded due to an idiopathic seizure during a follow up clinical examination and one (ID 211925) after an inability to detect a popliteal LN ultrasonographically before initiation into the trial (Appendices 2, 3 & 4). Therefore 11 dogs were included in the trial, of which ten underwent popliteal, and ten mesenteric administration of contrast medium. Seven individuals successfully completed both the popliteal and mesenteric CT lymphography studies.

4.1.2 Mesenteric lymphography study population

Five dogs had the mesenteric CT lymphography performed as an initial procedure of which four produced a successful lymphogram. The failed lymphogram (ID 211920) was due to a kink that developed in the mesenteric lymphatic vessel catheter, which prevented administration of the contrast medium (Appendices 2 & 4).

A further five dogs had mesenteric CT lymphography performed secondarily, 10 to 21 days after having had percutaneous popliteal lymphography performed. Four of these also produced successful mesenteric CT lymphograms. A single case failed (ID 211918) due to displacement of the catheter from the mesenteric lymphatic vessel, which resulted in deposition of the contrast medium into the peritoneal cavity (Appendices 3 & 4). Due to ethical considerations neither of the failed mesenteric lymphography dogs participated further in the study.

Mesenteric administration of contrast medium produced a successful lymphogram in 80% of cases on the first attempt.

4.1.3 Popliteal lymphography study population

Six dogs had percutaneous popliteal CT lymphography performed as their initial CT lymphography procedure, of which three produced a successful lymphogram on the first attempt. Two of the three dogs which failed this initial attempt went on to produce a successful percutaneous popliteal CT lymphogram when a second attempt was conducted 10 to 21 days later. One dog (ID 211919) failed to produce a successful lymphogram due to extravasation of contrast medium from the popliteal LN on the first attempt and then an inability to identify a popliteal LN on the second attempt (Appendices 2 & 4).

A further four dogs had percutaneous popliteal CT lymphography performed between 10 and 21 days after having had mesenteric CT lymphography performed. Three of these dogs produced a successful lymphogram on the first attempt. One dog (ID 211928) failed to have a successful percutaneous popliteal CT lymphogram performed after two separate attempts, due to an inability to identify a popliteal LN ultrasonographically (Appendices 3 & 4).

Due to ethical considerations percutaneous popliteal lymphography cases were limited to two separate attempts at contrast medium administration. Percutaneous popliteal CT lymphography produced a successful lymphogram in 60% of cases on the first attempt and 80% of cases after two attempts at contrast medium administration.

4.1.4 Combined final study population

Each administration technique was attempted in 10 dogs and was successful in eight. Seven dogs successfully completed both the percutaneous popliteal and mesenteric CT lymphographic studies. Three dogs initially had contrast medium administered via a mesenteric lymphatic catheter, and four initially had US guided percutaneous injection of contrast medium into a popliteal LN (Appendix 4).

4.2 Data acquisition

4.2.1 Mesenteric computed tomographic lymphography

With mesenteric CT lymphography, difficulties were encountered due to the extreme care needed while transporting and positioning the patient so as to minimise the risk of compromising the mesenteric lymphatic vessel catheter. These difficulties were reflected in part by the two mesenteric cases in which the CT scans had to be aborted. The first developed a kink in the mesenteric catheter (ID 211920) preventing administration of any contrast medium. This problem was not confirmed until after the repeat coeliotomy was performed to remove the catheter. The second failed case (ID 211918) was due to displacement of the mesenteric catheter from the mesenteric lymphatic vessel, which resulted in the full volume of contrast medium being deposited into the peritoneal cavity. This was also confirmed only on the follow up coeliotomy, but had been assumed to be the problem when initial CT slices showed the absence of any contrast medium in the TD system (Appendices 2 & 3) despite a full volume of contrast medium having been administered. In this latter case a slight reduction in resistance to contrast medium administration was noted (Appendix 3). Avoiding gross contamination of the surgical site, and an inability to monitor the administration site during contrast medium injection were also of concern.

Administration of contrast medium through the pre-placed mesenteric lymphatic vessel catheter was found to be very simple and contributed minimally (one minute) to the duration of the CT lymphography study.

The approximate time from the start of induction to completion of the diagnostic procedure for mesenteric CT lymphography was 113 minutes. This consisted of approximately 30 minutes to induce and prepare the patient for surgery, 30 minutes to perform the coeliotomy and place the mesenteric catheter, 5 minutes to transfer the dog from theatre to the CT suite, 16 minutes to position the dog, set the CT fields and administer the contrast medium, 2 minutes and 15 seconds to perform both the helical and sequential CT scans (Appendix 10), 10 minutes to transport and prepare the dog for

surgery, and approximately 20 minutes to perform the follow up coeliotomy with mesenteric catheter removal.

For mesenteric lymphography the average time from the start of the topogram to the start of the helical CT sequence was 15 minutes and 56 seconds, while the shortest time for the same period was 9 minutes and 14 seconds (Appendix 10). The majority of this time delay was due to the period taken to program the CT fields. The time required to organise and administer the contrast medium largely consisted of only the 1 minute period taken to inject the contrast medium as a bolus through the pre-placed mesenteric catheter. One mesenteric case (CT8125) accidentally received 350 mgI/ml Iohexol instead of 300 mgI/ml (Appendices 3 & 4), however this did not appear to result in any deleterious effects (Appendices 4 & 7) but actually resulted in significantly more TD branches being detected than when the same individual had a lymphogram performed with 300 mgI/ml via the popliteal administration route (CT8116).

4.2.2 Popliteal computed tomographic lymphography

The popliteal lymph nodes were more difficult to identify on US, and to inject with contrast medium, than was initially anticipated. Of eleven dogs in which ultrasonographic identification of the popliteal lymph nodes was attempted, one was excluded before initiation into the trial (ID 211925) due to an inability to identify a popliteal LN. Three others later failed due to having very small or unidentifiable popliteal lymph nodes (ID 211923, ID 211928, ID 211919), and one of the early cases failed due to extravasation of contrast medium despite the presence of clearly definable popliteal lymph nodes on US (ID 211927). Of the four failed percutaneous popliteal CT lymphography cases, two underwent successful popliteal contrast medium administration 10 to 21 days later (ID 211923, ID 211927), and two again failed to have an identifiable popliteal LN when reassessed at a later date (Appendices 2 & 3).

Ultrasound guided placement the needle into the popliteal LN was aided by positioning of the dog in sternal recumbency with both pelvic limbs extended caudally and the selected stifle abducted, and slightly elevated from the table on a small foam pad (Figures 4 & 5). Manipulation of the 23 gauge butterfly

needle was found to be difficult in the first two cases and was therefore changed to a standard 23 gauge hypodermic needle to allow easier manipulation of the needle. After some extravasation of contrast medium was noted in three cases with the 23 gauge needle, a 25 gauge needle was used for the remaining cases which appeared to reduce the volume of contrast medium extravasation seen on US. Extravasated contrast medium appeared as a hypoechoic pocket within the perinodal tissues. When Iohexol was injected correctly into the popliteal LN, the LN was seen to expand moderately in size and become significantly hyperechoic to the surrounding tissues (Appendices 2 & 3).

Leakage of contrast medium from the popliteal LN was noted radiographically in all of the percutaneous popliteal lymphography cases (Appendix 9, Figures 15 & 16).

The approximate time taken from the start of induction to completion of the diagnostic procedure for percutaneous popliteal CT lymphography was 61 minutes. This consisted of approximately 30 minutes to induce, prepare and transport the dog to the CT suite, 29 minutes to perform the US guided lymphography, and 2 minutes and 15 seconds to perform both the helical and sequential CT scans (Appendix 10).

The average time to perform US guided percutaneous popliteal lymphography was 29 minutes and 15 seconds, while the shortest was 22 minutes and 6 seconds. This consisted of the time required to perform the US, combined with the 6 to 9 minutes required to inject the contrast medium at 1.67 ml/min, and approximately 1 minute to move the US machine away from the CT gantry.

4.2.3 Helical computed tomographic lymphography

Helical CT scans were consistently initiated within 10 seconds of the completion of contrast medium injection for mesenteric CT lymphography cases. In the percutaneous popliteal CT lymphography cases, contrast medium injection to helical CT initiation was approximately 60 seconds due to the time required to move the US and syringe driver machinery away from the CT gantry. The average duration of a helical CT scan was 24 seconds with a

range of 22 seconds to 26 seconds (Appendix 10).This resulted in the average mid-helical scan time being 22 seconds after completion of contrast medium injection for the mesenteric administration cases, and 72 seconds for the popliteal administration cases.

Radiation exposure for the helical CT scans averaged at 35mAs at 130kV for 26 seconds giving a total of 910mAs (Appendix 11) when using the Siemens CARE dose® protocol.

4.2.4 Sequential computed tomographic lymphography

It was noted that setting of the mid-vertebral body site on the topogram was not always accurate in placing the slice site at the mid-vertebral body location, especially at the more cranial sites where superimposition of structures made identification of the vertebral body difficult (Figure 17).

Sequential CT scans were initiated on average 21 seconds after completion of the helical CT scan and therefore and average of 55 or 105 seconds from the completion of contrast medium injection for the mesenteric and popliteal administration techniques respectively. Six sequential CT scans of 1.5 seconds duration each were performed, however the total duration of the sequential scan series varied between 67 seconds and 129 seconds depending on the amount of extra time taken to allow for angulation of the CT gantry between each sequential CT scan plane. The average total time taken to complete the entire sequential CT sequence was 114 seconds (Appendix 10). Therefore the average time from completion of contrast medium injection to the mid-sequential scan time was 112 seconds for mesenteric administration cases and 162 seconds for popliteal contrast medium administration.

Radiation exposure for the sequential CT scans averaged was 77mAs at 130kV for 9 seconds giving a total of 696 mAs (Appendix 11).

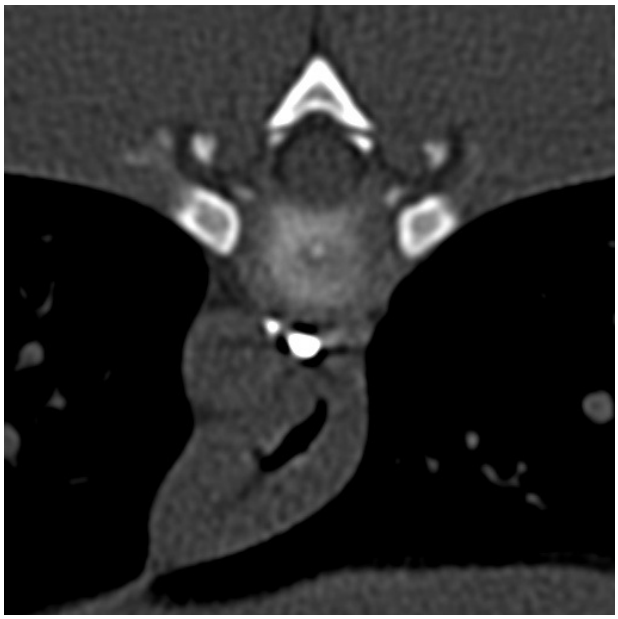


Figure 17. CT8124. Popliteal administration of contrast medium. Sequential computed tomography slice 2 of the T9 vertebral site. Note this slice passes through the intervertebral disc space and not through the mid-vertebral body.

4.2.5 Computed tomographic lymphography artefacts

Streak artefact was not uncommonly seen, especially in images of the more caudal vertebral sites, however it never posed a problem for interpretation of the CT images. The images acquired after mesenteric administration of contrast medium tended to have more streak artefact present (Figures 18 & 19), the severity of which was often greatest when mesenteric administration was combined with the helical CT modality. However the sequential CT modality appeared to result in more images with less severe streak artefact than helical CT.

The lack of motion artefact on the sequential images, despite the thoracic movement not being stopped, was most likely a result of the relatively slow and minor thoracic movements that occurred with the animal under general anaesthetic, combined with the short duration of the each sequential scan slice.

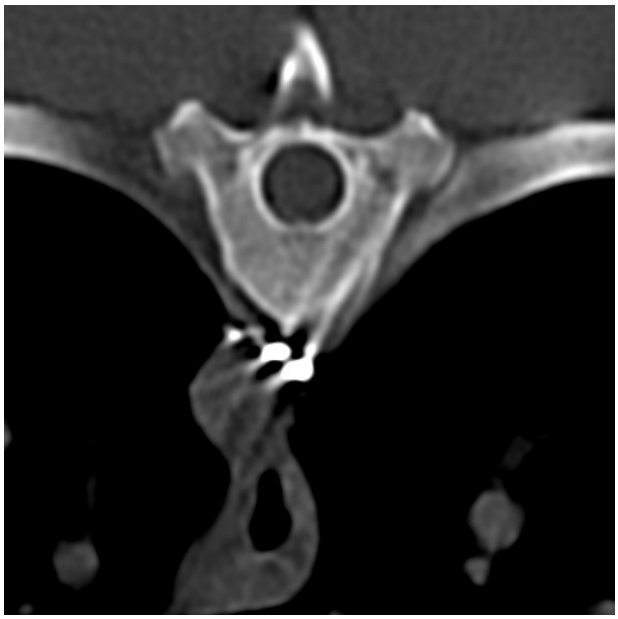


Figure 18. Patient ID 211921 - CT0886. Mesenteric administration of contrast medium. Helical computed tomography of the T9 vertebral site. The largest thoracic duct branch mean Hounsfield units was 3032. Note the prominent streak artefact.

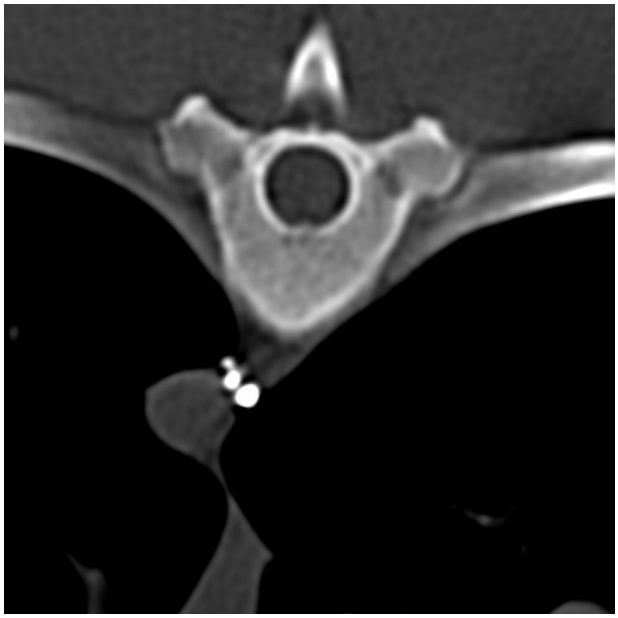


Figure 19. Patient ID 211921 - CT8103. Popliteal administration of contrast medium. Helical computed tomography of the T9 vertebral site. The largest thoracic duct branch mean Hounsfield units was 3060. Note the lack of significant streak artefact.

4.2.6 Pain assessment

Two of the mesenteric lymphatic lymphography cases (ID 211922, ID 211928) displayed significant discomfort for up to 24 hours after the diagnostic procedure which required extra analgesia above the standard protocol (Appendix 2). None of the percutaneous popliteal lymphography cases displayed detectable signs of pain or discomfort as a result of the lymphography over the five day observation period after the procedure.

4.2.7 Contrast medium spillage assessment

Contrast medium spillage was assessed through ultrasonographic monitoring of the area, and by performing radiographs of the popliteal area after the percutaneous popliteal CT lymphography had been performed.

Ultrasound monitoring performed at the time of popliteal contrast medium administration revealed that only one of the lymph nodes injected did not have notable contrast medium leakage (ID 211929) (Appendix 3). Radiographically all popliteal lymphography cases were assessed to have had contrast medium spillage between grades 1 and 4, when using a subjective scale of 0 to 5 (Appendix 9, Figures 15 & 16). The subjective findings of the ultrasonographic and radiographic assessment of popliteal contrast medium spillage did not necessarily match (Appendices 2 & 3). The spillage was predictably contained within the fascial planes surrounding the fat filled popliteal space, and thus it was difficult to fully distinguish spilled contrast medium from that still within the popliteal LN on radiographs.

While the time between contrast medium administration and popliteal radiography was not recorded, it should have remained reasonably constant between dogs as they were all radiographed immediately after completion of their CT. However this may still have impacted upon the findings due to the rate of contrast medium removal from the area over time. For the two lymph nodes in which a full volume of contrast medium was injected with a 23 gauge needle the average radiographic contrast medium spillage grade was 3.5, while for the four in which a 25 gauge needle was used the average was 2.0 (Appendix 9). Although the numbers are limited this result appears to support the clinical assessment made on US during contrast medium administration

that it was easier to minimise contrast medium spillage when the finer gauge needle was used.

Two of the cases receiving contrast medium administration via a catheterised mesenteric lymphatic were noted to have a small amount of contrast medium extravasated at the catheter site (ID 211923, ID 211929), while one was noted to have a significant amount extravasated (ID 211926) (Appendices 2 & 3). The mesenteric catheter site was not routinely assessed for spillage of contrast medium on the CT.

4.3 Data analysis

The interaction terms between method and modality were not significant in the models for the number of TD branches detected (P=0.373), mean HU (P=0.271), largest TD branch maximum width (P=0.370), or the largest TD branch cross-sectional area (P=0.519) and were therefore not included in the final models.

4.3.1 Thoracic duct number

The numbers of visible TD branches, by contrast medium administration method, CT modality and mid-vertebral site, are shown in Table 1. The results of the zero-truncated Poisson regression model are shown in Table 2.

4.3.1.1 Effect of contrast medium administration method

The number of TD branches detected did not differ significantly between percutaneous popliteal or mesenteric lymphatic lymphography (P=0.256). Although not statistically significant the *CR* indicated that percutaneous popliteal lymphography detected slightly fewer TD branches than the mesenteric lymphatic lymphography (CR=0.830) (Table 2, Graph 1).

4.3.1.2 Effect of computed tomography modality

The number of TD branches detected did not differ significantly between sequential or helical CT scanning modalities (*P*=0.417).

Although not statistically significant the *CR* indicated that helical CT detected slightly fewer TD branches than sequential CT (*CR*=0.876) (Table 2, Graph 2) despite helical CT consistently being performed before the sequential CT.

4.3.1.3 Effect of vertebral site

The T9 and T10 vertebral sites did not have a significantly different number of TD branches (*P*=0.074), however the number of TD branches reduced significantly as the TD system was followed caudally from T11 to L1 (*P*<0.05), with a slight rise in the number of TD branch numbers in the L1 segment (Table 2, Graphs 1 & 2) which was possibly due to actual early branching, inclusion of the cranial portion of the cisterna chyli (Figure 20), or inclusion of intra-abdominal lymphatic branches (Figure 21).

4.3.1.4 Variation between observers

Whenever variations in the number of TD branches occurred between observers the images were individually reassessed by the primary investigator and adjusted accordingly to produce a single data set, therefore statistical assessment of variability between observers could not be performed.

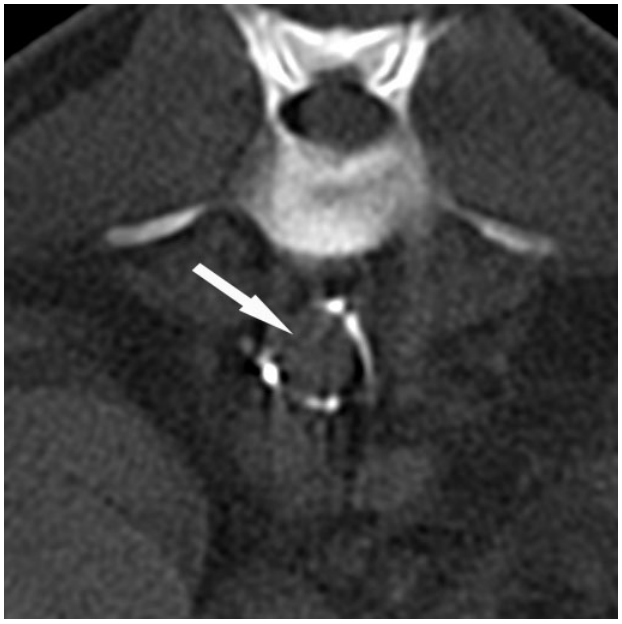


Figure 20. CT892. Popliteal administration of contrast medium. Sequential computed tomography of the L1 vertebral site. Note the position of apparent TD branches circumferentially around the aorta.

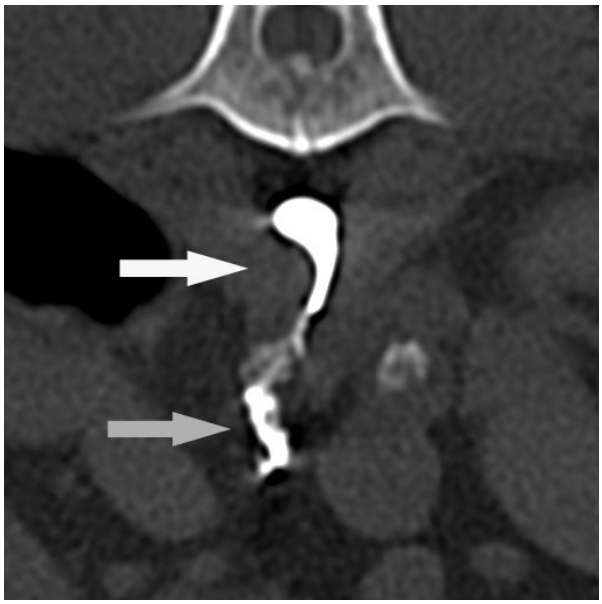


Figure 21. CT892. Popliteal administration of contrast medium. Helical computed tomography of the L1 vertebral site. Note the comma shaped TD branch to the right of the aorta (white arrow) and the second apparent TD branch lying ventral to the aorta (grey arrow).

Table 1. The number of thoracic duct branches visible using computed tomographic lymphography in dogs, by contrast medium administration method, computed tomographic modality and mid-vertebral body site.

Mid-vertebral body site	Number of visible thoracic duct branches															
	Mesenteric								Popliteal							
	Helical				Sequential				Helical				Sequential			
	Mean	SD	M	Ran	Mean	SD	M	Ran	Mean	SD	M	Ran	Mean	SD	M	Ran
T9	2.57	0.98	3	1-4	3.29	1.11	4	1-4	2.57	0.54	3	2-3	2.71	0.76	3	2-4
T10	2.14	0.90	2	1-3	2.43	0.98	2	1-4	2.00	1.00	2	1-3	2.00	0.58	2	1-3
T11	2.00	1.00	2	1-4	1.86	1.46	1	1-5	1.71	0.76	2	1-3	1.43	0.54	1	1-2
T12	1.43	0.54	1	1-2	1.57	0.79	1	1-3	1.43	0.54	1	1-2	1.14	0.38	1	1-2
T13	1.14	0.38	1	1-2	1.14	0.38	1	1-2	1.14	0.38	1	1-2	1.14	0.38	1	1-2
L1	1.00	0.00	1	1	1.57	0.79	1	1-3	1.29	0.49	1	1-2	1.57	1.13	1	1-4

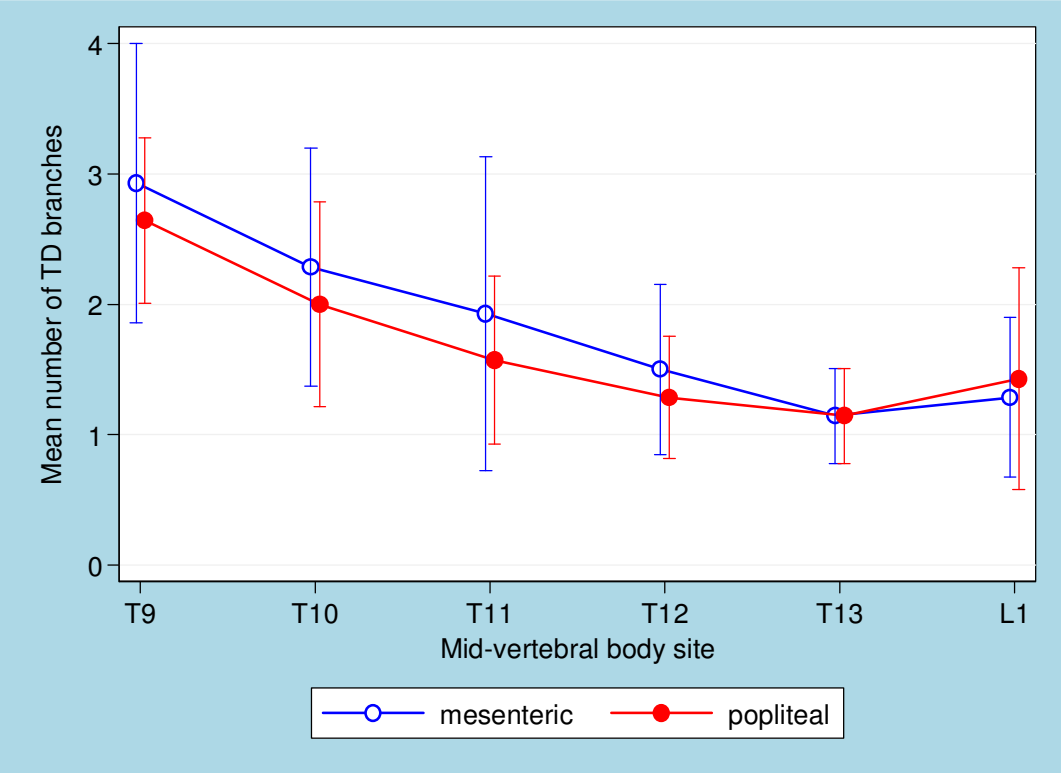
T9-T13 = Thoracic vertebrae 9 to 13
L1 = Lumbar vertebra 1
SD = Standard deviation
M = Median
Ran = Range

Table 2. Effect of contrast medium administration method, computed tomography modality and mid-vertebral body site on number of thoracic duct branches visible using computed tomographic lymphography in dogs: results of a zero-truncated Poisson regression model.

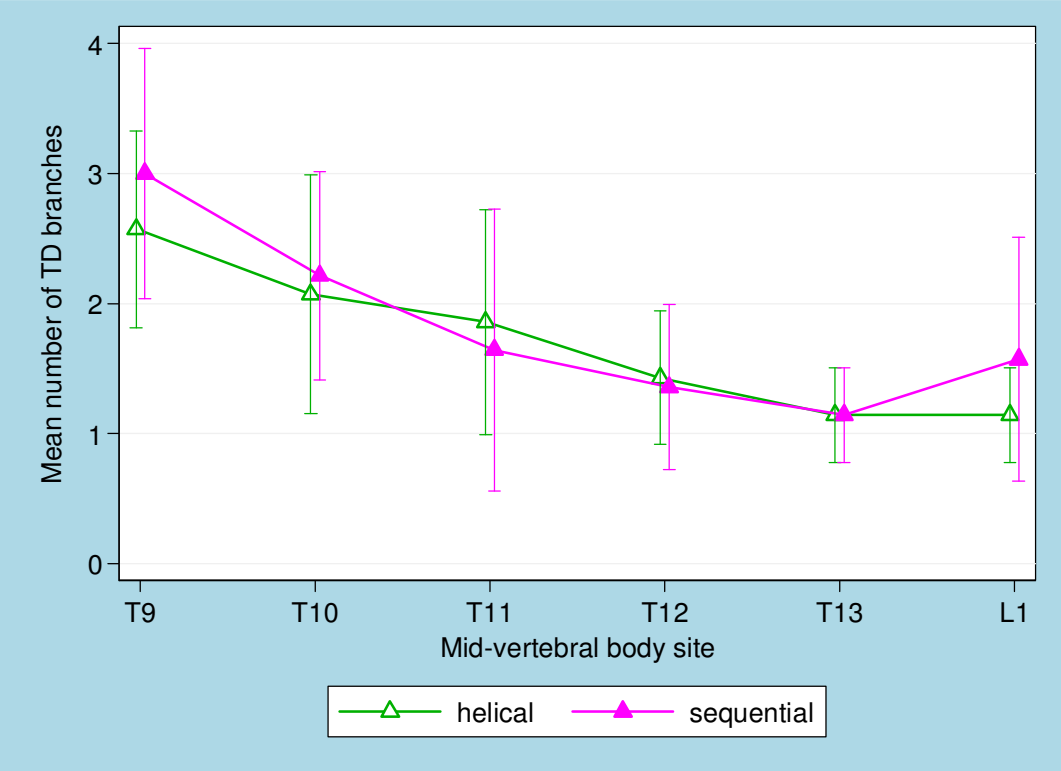
Variable		*CR*	95% CI (*CR*)	*P*-value
Method	Popliteal *vs*. mesenteric	0.830	0.603, 1.144	0.256
Modality	Helical *vs*. sequential	0.876	0.636, 1.206	0.417
Mid-vertebral body site	T9	1*	–	–
	T10	0.692	0.462, 1.036	0.074
	T11	0.485	0.303, 0.775	0.002
	T12	0.275	0.149, 0.508	<0.001
	T13	0.107	0.040, 0.289	<0.001
	L1	0.252	0.133, 0.479	<0.001
Dog	(7 categories)	–	–	0.007

* Reference level

Graph 1. Effect of contrast medium administration method and mid-vertebral body site on the number of thoracic duct branches visible using computed tomographic lymphography in dogs. Mean and one standard deviation.



Graph 2. Effect of computed tomography modality and mid-vertebral body site on the number of thoracic duct branches visible using computed tomographic lymphography in dogs. Mean and one standard deviation.



4.3.2 Mean Hounsfield units of the largest thoracic duct branch

The mean HU of the largest TD branch, by contrast medium administration method, CT modality and mid-vertebral site, are shown in Table 3. The results of the multiple linear regression model are shown in Table 4.

4.3.2.1 Effect of contrast medium administration method

Percutaneous popliteal lymphography resulted in a significantly lower largest TD branch mean HU than mesenteric lymphatic lymphography (P<0.001) (Table 4).

4.3.2.2 Effect of computed tomography modality

Sequential CT resulted in a significantly lower largest TD branch mean HU than helical CT (P<0.001) (Table 4).

4.3.2.3 Effect of vertebral site

There was no significant difference in the largest TD branch mean HU between T9 to T11, however there was a significant decline in the mean HU from T12 to L1 (Table 4).

Percutaneous popliteal LN administration started with, and maintained a significantly lower largest TD branch mean HU compared to mesenteric administration. Both contrast medium administration methods did however show a similar rate of decline in the mean HU from T9 to L1 (Table 3 & Graph 3).

Helical CT maintained a virtually constant largest TD branch HU mean from T9 to L1, while in comparison sequential CT had a slightly lower HU mean at T9 to T11 but then had a significant decline in the mean HU from T12 to L1 (Table 3 & Graph 4).

4.3.2.4 Variation between observers

Observer variation was not found to be statistically significant when measuring the mean HU of the largest TD branch (P=0.161) (Table 4).

Table 3. Hounsfield units of the largest thoracic duct branch using computed tomographic lymphography in dogs, by contrast medium administration method, computed tomography modality and mid-vertebral body site. Mean Hounsfield units and standard deviation.

Mid-vertebral body site	Hounsfield units							
	Mesenteric				Popliteal			
	Helical		Sequential		Helical		Sequential	
	HU	SD	HU	SD	HU	SD	HU	SD
T9	3029	321	3005	93	2721	336	2626	406
T10	3023	66	2912	278	2685	557	2495	584
T11	3026	50	2819	328	2707	611	2661	375
T12	3032	53	2834	372	2590	586	2210	615
T13	3051	44	2576	642	2643	535	1980	972
L1	3057	19	2391	643	535	268	972	760

T9-T13 = Thoracic vertebrae 9 to 13

L1 = Lumbar vertebra 1

HU = Mean Hounsfield units

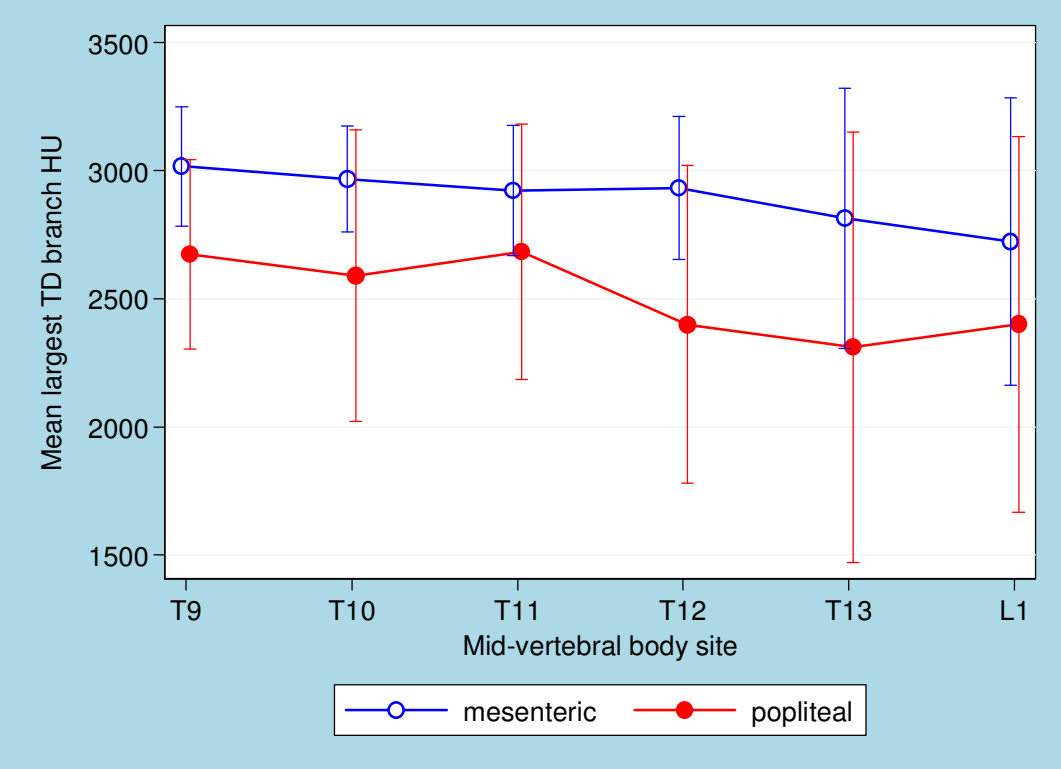
SD = Standard deviation

Table 4. Effect of contrast medium administration method, computed tomography modality, mid-vertebral body site and observer on the mean Hounsfield units of the largest thoracic duct branch, using computed tomographic lymphography in dogs: Results of a multiple linear regression model.

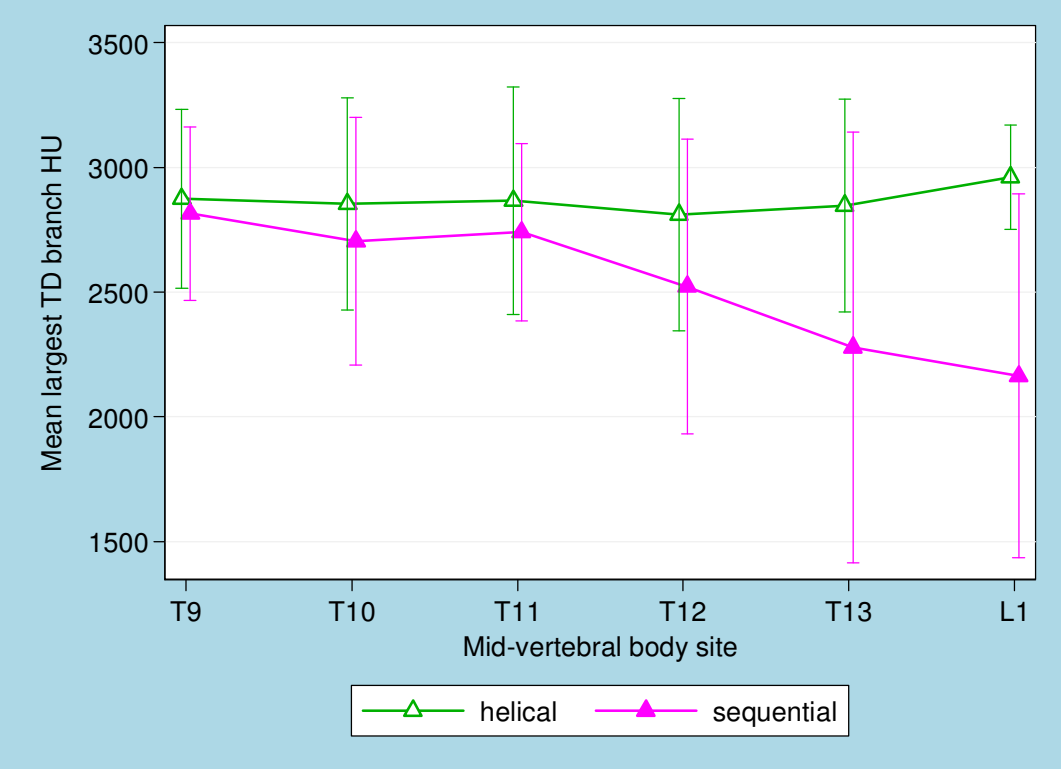
Variable		*b*	95% CI (*b*)	*P*-value
Method	Popliteal vs. mesenteric	–386.244	–0.309, –0.157	<0.001
Modality	Sequential vs. helical	–331.804	–0.240, –0.088	<0.001
Observer	2 vs. 1	-66.054	–0.061, 0.091	0.161
Mid-vertebral body site	T9	1*	–	–
	T10	-66.518	-226.846, 93.810	0.415
	T11	-41.857	-202.185, 118.471	0.608
	T12	-178.768	-339.096, -18.440	0.029
	T13	-282.607	-442.935, -122.279	0.001
	L1	-283.018	-443.346, -122.690	0.001
Dog	(7 categories)	–	–	<0.001

* Reference level

Graph 3. Effect of contrast medium administration technique and mid-vertebral body site location on the mean Hounsfield units of the largest thoracic duct branch using computed tomographic lymphography in dogs. Mean and one standard deviation.



Graph 4. Effect of computed tomography modality and mid-vertebral body site location on the mean Hounsfield units of the largest thoracic duct branch using computed tomographic lymphography in dogs. Mean and one standard deviation.



4.3.3 Maximum diameter of the largest thoracic duct branch

The maximum diameter of the largest TD branches, by contrast medium administration method, CT modality and mid-vertebral site, are shown in Table 5. The results of the multiple linear regression model are shown in Table 6.

4.3.3.1 Effect of contrast medium administration method

Percutaneous popliteal lymphography resulted in a significantly smaller largest TD branch maximum diameter than mesenteric lymphography (P<0.001) (Table 6).

4.3.3.2 Effect of computed tomography modality

Sequential CT resulted in a significantly smaller largest TD branch maximum diameter than helical CT (P<0.001) (Table 6).

4.3.1.3 Effect of vertebral site

No statistically significant difference could be found in the largest TD branch maximum diameter from T9 to T12. However there was a trend for the diameter to increase as the vertebral sites were followed caudally from T9 to T11. At the T12 vertebral site there was a tendency for the largest TD branch maximum diameter to be at its narrowest. At the T13 and L1 sites the largest TD branch maximum diameter was found to be significantly greater than at T9 (P<0.05) (Tables 5 & 6, Graphs 5 & 6).

4.3.3.4 Variation between observers

Observer variation was not found to be statistically significant (P=0.706) when measuring the maximum diameter of the largest TD branch (Table 6).

Table 5. Effect of contrast medium administration method, computed tomography modality and mid-vertebral body site on $\log_e$ (largest thoracic duct branch maximum diameter) using computed tomographic lymphography in dogs: Mean maximum thoracic duct diameter (mm) and standard deviation.

Mid-vertebral body site	Method and modality							
	Mesenteric				Popliteal			
	Helical		Sequential		Helical		Sequential	
	mm	SD	mm	SD	mm	SD	mm	SD
T9	3.54	1.07	3.51	1.36	2.59	0.78	2.54	0.69
T10	4.31	1.28	2.88	0.85	3.36	1.23	2.73	0.67
T11	3.83	1.51	3.73	1.20	3.04	1.20	3.16	1.35
T12	3.35	1.08	2.91	0.73	2.26	0.66	2.72	1.18
T13	4.01	0.81	3.85	1.14	3.00	0.73	3.12	1.36
L1	6.72	0.67	4.19	1.80	6.62	2.59	3.96	3.13

T9-T13 = Thoracic vertebrae 9 to 13

L1 = Lumbar vertebra 1

mm = Mean maximum thoracic duct diameter in mm

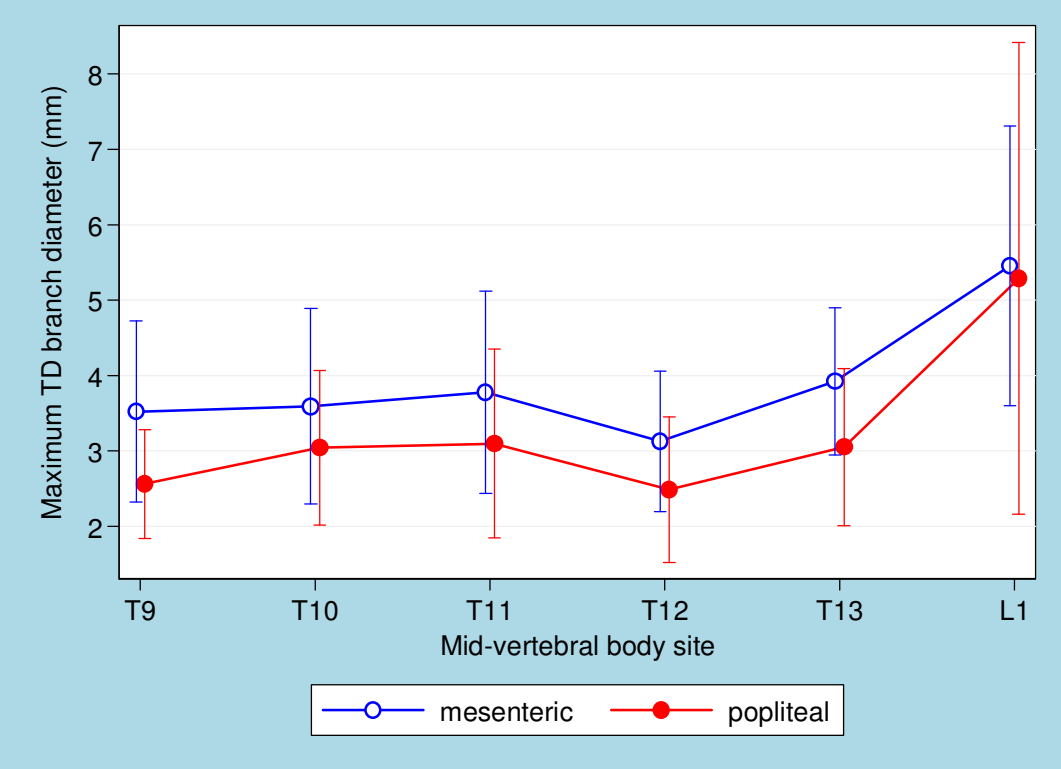
SD = Standard deviation

Table 6. Effect of contrast medium administration method, computed tomography modality, mid-vertebral body site and observer on $\log_e$ (largest thoracic duct branch maximum diameter) using computed tomographic lymphography in dogs: Results of a multiple linear regression model.

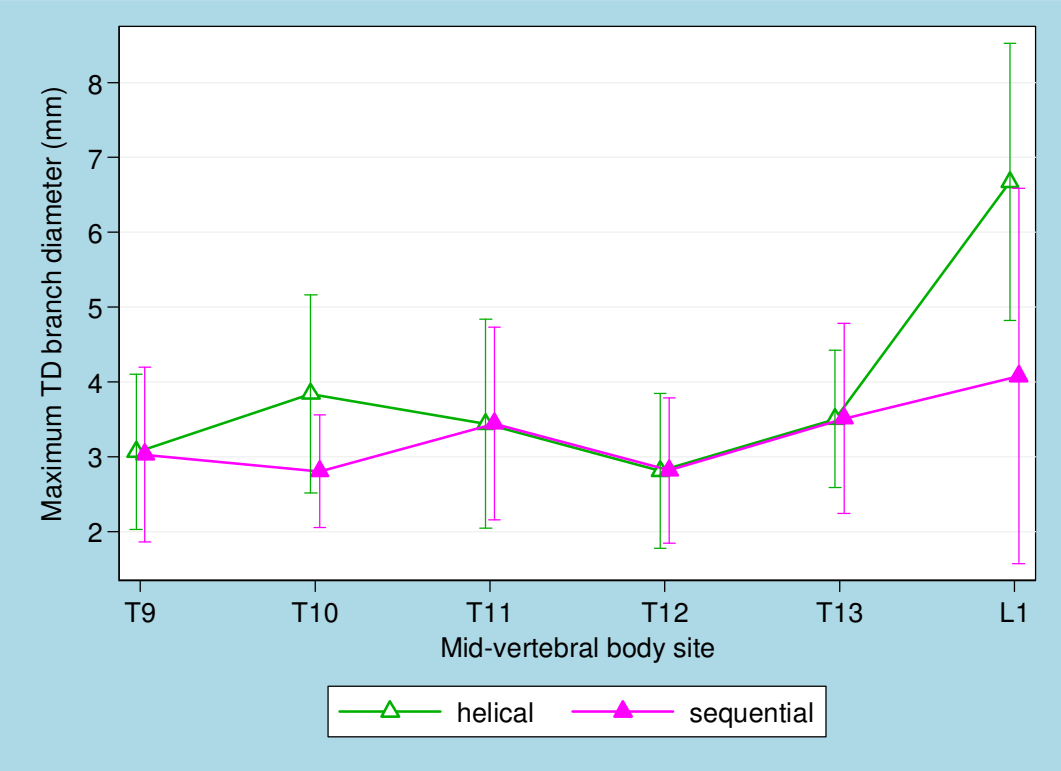
Variable		*b*	95% CI (*b*)	*P*-value
Method	Popliteal *vs.* mesenteric	–0.233	–0.309, –0.157	<0.001
Modality	Sequential *vs.* helical	–0.164	–0.240, –0.088	<0.001
Observer	2 vs. 1	0.015	–0.061, 0.091	0.706
Mid-vertebral body site	T9	1*	–	–
	T10	0.791	-0.521, 0.210	0.236
	T11	0.108	-0.023, 0.239	0.106
	T12	-0.916	-0.223, 0.040	0.171
	T13	0.145	0.013, 0.278	0.032
	L1	0.481	0.350, 0.612	<0.001
Dog	(7 categories)	–	–	<0.001

* Reference level

Graph 5. Effect of contrast medium administration method and mid-vertebral body site location on the largest thoracic duct branch maximum diameter using computed tomographic lymphography in dogs. Mean and one standard deviation.



Graph 6. Effect of computed tomography and mid-vertebral body site location on the largest thoracic duct branch maximum diameter using computed tomographic lymphography in dogs. Mean and one standard deviation.



4.3.4 Cross-sectional area of the largest thoracic duct branch

The cross-sectional area of the largest TD branches, by contrast medium administration method, CT modality and mid-vertebral site, are shown in Table 7. The results of the multiple linear regression model are shown in Table 8.

4.3.4.1 Effect of contrast medium administration method

Percutaneous popliteal lymphography resulted in significantly smaller largest TD branch cross-sectional area than mesenteric lymphography (P<0.001) (Table 8).

4.3.4.2 Effect of computed tomography modality

Sequential CT resulted in a significantly smaller largest TD branch cross-sectional area than mesenteric lymphography (P<0.001) (Table 8).

4.3.4.3 Effect of vertebral site

While not statistically significant the largest TD branch cross-sectional area showed a tendency to be slightly smaller at the T12 vertebral site, otherwise there was an overall trend for the cross-sectional area to increase as the vertebral sites were followed caudally from T9 to T13. The largest TD branch cross-sectional area was found to be significantly larger at the L1 site (P<0.001) (Tables 7 & 8, Graphs 7 & 8).

4.3.4.4 Variation between observers

A single observer assessed the largest TD branch cross-sectional area, so variability between observers could not be assessed.

Table 7. Effect of contrast medium administration method, computed tomography modality and mid-vertebral body site on $\log_e$ (largest thoracic duct branch cross-sectional area) using computed tomographic lymphography in dogs: Mean cross-sectional area (mm^2) and standard deviation.

Mid-vertebral body site	Method and modality							
	Mesenteric				Popliteal			
	Helical		Sequential		Helical		Sequential	
	mm^2	SD	mm^2	SD	mm^2	SD	mm^2	SD
T9	0.86	0.30	0.63	0.28	0.49	0.22	0.40	0.15
T10	1.04	0.50	0.50	0.23	0.64	0.36	0.36	0.10
T11	0.86	0.45	0.84	0.42	0.53	0.28	0.59	0.28
T12	0.81	0.41	0.61	0.24	0.43	0.27	0.47	0.29
T13	1.19	0.33	0.93	0.52	0.69	0.36	0.57	0.45
L1	2.63	0.36	1.04	0.60	2.06	1.10	0.94	1.15

T9-T13 = Thoracic vertebrae 9 to 13

L1 = Lumbar vertebra 1

mm^2 = Mean cross-sectional area in mm^2

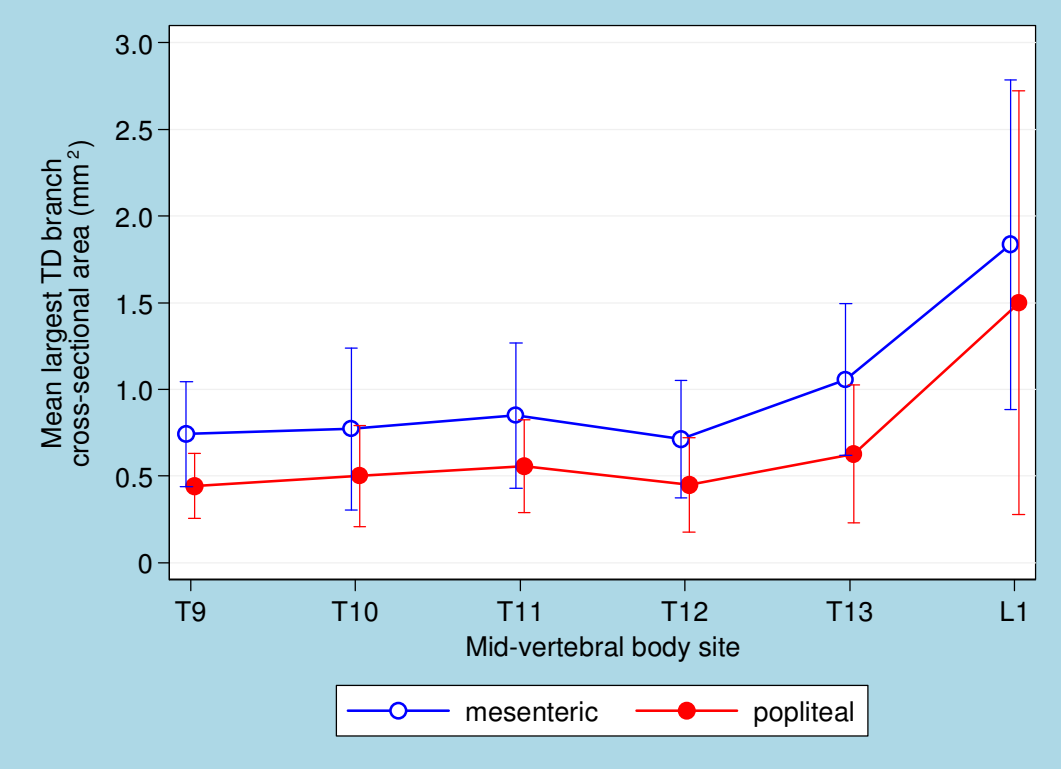
SD = Standard deviation

Table 8. Effect of contrast medium administration method, computed tomography modality and mid-vertebral body site on log_e (largest thoracic duct branch cross-sectional area) using computed tomographic lymphography in dogs: Results of a multiple linear regression model.

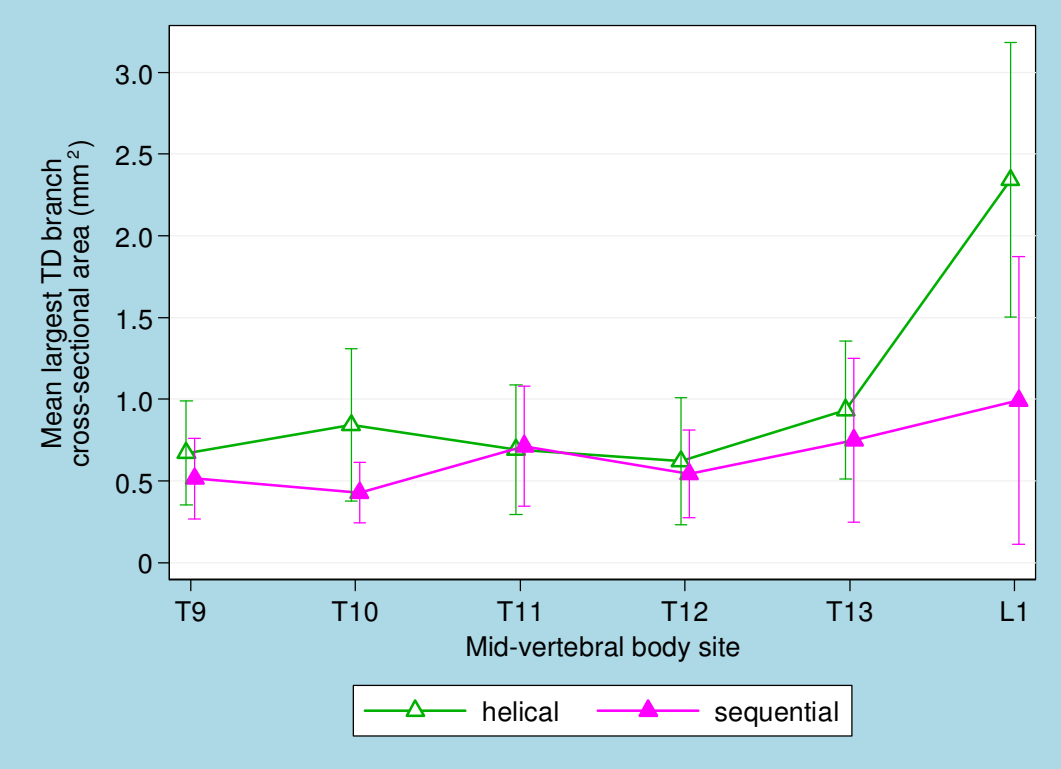
Variable		*b*	95% CI (*b*)	*P*-value
Method	Popliteal vs. mesenteric	-0.524	-0.700, -0.348	<0.001
Modality	Sequential vs. helical	-0.412	-0.588, -0.237	<0.001
Mid-vertebral body site	T9	1*	–	–
	T10	-0.003	-0.308, 0.302	0.985
	T11	0.134	-0.170, 0.439	0.385
	T12	-0.082	-0.387, 0.223	0.596
	T13	0.251	-0.053, 0.556	0.105
	L1	0.783	0.478, 1.087	<0.001
Dog	(7 categories)	–	–	<0.001

* Reference level

Graph 7. Effect of contrast medium administration method and mid-vertebral body site location on the largest thoracic duct branch cross-sectional area using computed tomographic lymphography in dogs. Mean and one standard deviation.



Graph 8. Effect of computed tomography modality and mid-vertebral body site location on the largest thoracic duct branch cross-sectional area using computed tomographic lymphography in dogs. Mean and one standard deviation.



4.3.5 Position of thoracic duct branches relative to the aorta

The TD branch positions relative to the aorta using a clock's face analogy are shown in Table 9, with 12 o'clock being dorsal and 3 o'clock being right lateral.

4.3.5.1 Effect of contrast medium administration method and computed tomography modality

All contrast medium administration method and CT modality data was combined to assess TD branch position, therefore no comparative data was assessed.

4.3.5.2 Thoracic duct branch position

The TD branch position was recorded for the T9 to L1 vertebral sites (Table 9) however the TD branch position analysis was limited to the cumulative results for the surgically important T10 to T12 vertebral segment.

In the T10 to T12 segment the number of TD branches ranged between one and five but only one dog (ID 211925) had a single TD branch through the entire segment which ran between the 1 to 2 o'clock positions. All of the TD branches lay dorsally between the 10 and 3 o'clock positions relative to the aorta, with 87% lying to the right of the aorta and 13% to the left in the assessed segment (Table 9, Graph 9).

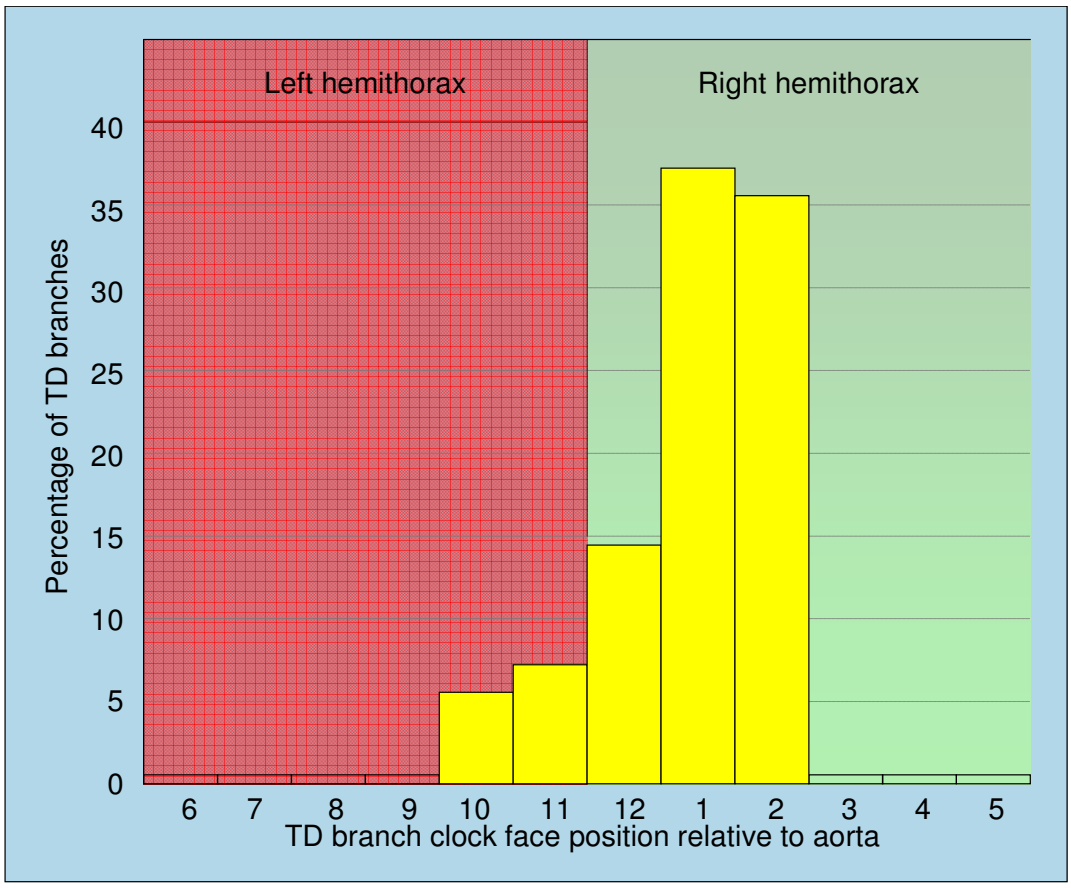
4.3.4.3 Variation between observers

A single observer assessed the TD branch location relative to the aorta, so variability between observers could not be assessed.

Table 9. Cumulative results for the thoracic duct position relative to the aorta using a clock face analogy for mid- vertebral body sites when assessed using computed tomographic lymphography in dogs: Percentage of thoracic duct branches at each clock face position relative to the aorta.

Vertebral site	Clock face position of TD branch relative to the aorta											
	12.00 12.59	01.00 01.59	02.00 02.59	03.00 03.59	04.00 04.59	05.00 05.59	06.00 06.59	07.00 07.59	08.00 08.59	09.00 09.59	10.00 10.59	11.00 11.59
T9	18.0	18.0	33.3	12.8	0	0	0	0	0	0	0	18.0
T10	9.7	35.6	32.3	0	0	0	0	0	0	0	6.5	16.1
T11	15.8	31.6	42.1	0	0	0	0	0	0	0	5.3	5.3
T12	16.7	44.4	33.3	0	0	0	0	0	0	0	5.6	0
T13	23.5	35.3	29.4	5.9	0	0	5.9	0	0	0	0	0
L1	37.5	20.8	16.7	4.2	0	4.2	0	4.2	8.3	0	8.3	0
T9-L1	19.5	28.9	30.9	4.7	0	0.7	0.7	0.7	1.3	0	4.0	8.7
T10-T12	14.2	37.2	35.9	0	0	0	0	0	0	0	5.8	7.1

Graph 9. Thoracic duct branch location relative to the aorta for the T10 to T12 vertebral segment using a clocks face analogy.



Chapter 5: DISCUSSION

5.1 Introduction

Seven dogs underwent CT lymphography of the canine caudal TD system with contrast medium administered through a catheterised mesenteric lymphatic vessel, and on a separate occasion by US guided percutaneous injection of contrast medium into a popliteal LN. For both contrast medium administration methods the CT was initially performed using the helical modality and was then immediately repeated using the sequential modality. The impact of both contrast medium administration methods and CT modalities were evaluated for their ability to detect and assess TD branches, as well as their suitability for clinical application. Potential areas for further research were identified.

5.2 Data collection method

Both contrast medium administration techniques and CT modalities resulted in excellent quality lymphograms for interpretation. Use of the CT bone window allowed clear definition of the TD branch borders which facilitated more accurate assessment than was possible in the soft tissue window (Figures 10 & 11). Mild streak artefact was not an uncommon finding however it was never severe enough to interfere with interpretation (Figure 18). The mesenteric administration technique appeared to have more streak artefacts, which maybe due to the fact that it had a significantly higher concentration of contrast medium found within the TD branches which would have resulted in a greater disparity in radiographic attenuation of adjacent structures. However streak artefact did not always occur in the cases with the highest concentration of contrast medium within the TD branches (Figures 17 & 18). Also it actually appeared to be more common at the more caudal vertebral sites despite them having a significantly lower mean HU. The sequential CT modality appeared to produce more images with minor streak artefact than helical CT, which is surprising considering that the TD branches had a significantly higher mean HU with helical CT (Tables 3 & 4, Graph 4). This

reduction in the amount of expected streak artefact with helical CT may have been a result of the tube current modulation that occurred when the Siemens CARE dose® algorithm was utilised with the helical CT (Appendix 11), as this resulted in a lower mAs being used at each individual slice site. The author could not however explain all of the disparities in the appearance of streak artefacts on the images.

Sequential CT may have had a slight advantage over helical CT when assessing the number of TD branches, as the dual slice CT machine provided two images of each site and the single image with the greatest number of TD branches was selected for assessment (Figures 8 & 9). By comparison helical CT was restricted to the single image selected as the mid-vertebral body slice (Appendix 5); however this potential disadvantage may have been partially mitigated as the slices immediately cranial and caudal to the helical slice site could be assessed to aid interpretation.

Setting the sequential slice orientation perpendicular to the individual vertebral body long axis would have altered the slice profile through the TD branches, when compared to the uniplanar approach used for helical CT. However this did not appear to cause a problem, probably due to the fact that the TD branches do not simply run parallel to the vertebral bodies, but are highly variable in their orientation and therefore both CT modalities actually sliced the TD branches at various angles relative to the TD branch long axis. Due to an apparent lack of any benefit with multiplanar CT slices, the extra time taken to orient the CT fields on the topogram and more importantly the considerable increase in scan time while waiting for the CT gantry to tilt between sequential CT slices, it is recommended that sequential CT be performed on a uniplanar basis as was used for the helical CT. This would be particularly important in a clinical case where anaesthetic time may be critical in a respiratory compromised patient, and it may avoid any potential bias in research cases.

The differing methods for selecting the mid-vertebral body slice location for the two CT modalities resulted in the sequential CT slice being much less accurately set at the mid-vertebral body site. In some cases the sequential slices were located over vertebral end plates or intervertebral disc spaces (Figure 17). This was particularly prominent for the more cranial vertebrae where superimposition of structures over the vertebral bodies made accurate

identification of the sites difficult on the topogram. Although this did not appear to result in a significant difference in number of TD branches, it may still present a problem for research purposes.

Variation between observers for the number of TD branches was not analysed, however there appeared to be minimal variation with only 22 data points out of a possible 168 being different. Of these differences only three data points differed by more than one counted TD branch. Review of the data points where observers differed in the number of counted TD branches revealed that most were due to a difference in interpretation as to whether two TD branches had fully separated or not on the assigned CT slice (Figure 14).

Assessment of the largest TD branch maximum diameter proved to be quite simple and reproducible with no significant variation between observers detected (P=0.706) (Table 6). While not significant, the slightly higher variation between observers seen for the mean HU (P=0.161) (Table 4) was probably due to differences in the largest TD branch area assessed with the circular ROI tool. This may have been overcome if the freehand ROI tool had been used to assess the entire largest TD branch area, as was done by a single observer when assessing the largest TD branch cross-sectional area.

5.3 Contrast medium administration method

Both US guided percutaneous popliteal LN and mesenteric lymphatic vessel lymphography resulted in excellent visualisation of TD branches at the assessed sites.

There was no significant difference between the two administration techniques in the number of TD branches detected (P=0.256) (Table 1), however the *CR* of 0.83 may indicate that there is a slight trend for mesenteric lymphography to detect more TD branches. This potential trend should however be interpreted with some caution, as the zero-truncation performed on the Poisson regression model for the number of TD branches tends to shift the *CR* away from 1. The raw data actually equated to popliteal lymphography detecting 93% of the number of TD branches identified with mesenteric lymphography, though this difference was not found to be statistically significant in this study.

The rapid bolus of contrast medium into a mesenteric lymphatic caused a significantly greater dilation of the assessed TD branches (largest TD branch maximum diameter and cross-sectional area (P<0.001)) (Tables 5 & 7, Graphs 5 & 7) and resulted in a higher concentration of contrast medium within the assessed duct (largest TD branch mean HU (P<0.001)) (Table 3, Graph 3). This appears to indicate that administration of contrast medium as a bolus into a mesenteric lymphatic vessel does deliver the radiographic contrast medium into the TD system at a higher concentration, and under greater pressure than percutaneous popliteal lymphography. These findings may be due to percutaneous popliteal lymphography having used a more peripheral administration site, and a significantly slower rate of contrast medium administration. Administration of contrast medium into a LN rather than directly into a lymphatic may have affected the rate of pressure increase within the TD. Also the extra 50 second delay that occurred between the completion of contrast medium administration and initiation of the CT with popliteal lymphography, while the US equipment was moved away from the CT gantry, may also have played an important role. These latter two factors may have had a significant impact upon the degree of TD dilation in particular, and certainly it would have been ideal to standardise the time between completion of contrast medium injection and initiation of the CT, if a true comparison of the effect on TD branch dilation was required. Conversely delaying initiation of the CT for the mesenteric administration technique by an extra 50 seconds, such that it matched that of the popliteal administration technique, would not have then been a realistic assessment of the two administration techniques when used in a clinical setting. As mentioned previously, mesenteric lymphatic vessel lymphography usually has the diagnostic imaging initiated immediately after completing injection of the contrast medium.[1,9,10,17,18]

Analysis of the effect of vertebral site on the mean HU proved that no time delay is required after completing the injection of contrast medium before the initiation of the CT for either contrast medium administration technique. This supports the findings of previous popliteal[21,54] and mesenteric[1,9,10,18,19,28] TD lymphography reports. However it should be noted that in this study, and the single other TD lymphography study in which contrast medium is administered

into a popliteal LN,[21] the period of contrast medium administration exceeded 5 minutes due to the significantly slower rates of administration possible through a LN. In fact with both mesenteric and popliteal administration techniques the mean HU was found to actually be higher in the more cranial vertebral sites (Table 3, Graph 3), which would imply that the main bolus of contrast medium had already passed through the more caudal portion of the TD system at the time of assessment. When the mean HU for the two CT scan modalities are compared (Table 3, Graph 4), it can be seen that the contrast medium concentration remains high throughout the helical CT scan, but then steadily declines after the T11 vertebral site of the sequential CT scan. The average time mid-point for the sequential scan equates to between the T11 and T12 vertebral sites, therefore it can be estimated that the drop off in contrast medium concentration seems to occur approximately 2 to 2 minutes and 30 seconds after administration of contrast medium for both techniques. This closely matches the finding in a previous popliteal contrast medium administration study[21] where it was found that when images were taken more than 2 minutes after the completion of contrast medium injection, the resultant lymphograms were not as clear. It should be noted that a large number of factors can influence the flow rates of lymph through the TD system.[31] Due to contrast medium concentration drop off rates not being one of the primary factors investigated in this study a large number of variables were not kept constant when estimating this value. Therefore the stated figure should be interpreted only as a guide, until such time as more specific studies can be performed. The apparently rapid drop off in intraductal contrast medium concentration does however bring into question some TD contrast studies where the time from contrast medium injection until performance of the diagnostic imaging ranged from 5 minutes up to 30 minutes.[17,22] The estimated time after injection until there is a drop in the mean HU should not be confused with the duration of TD branch dilation that occurs after contrast medium administration. This study is not capable of assessing the time line for the TD branch dilation after contrast medium injection, as a progressive series of CT scans at the same sites would be needed to assess this.

The popliteal LN injection rate of 1.67 ml/minute used in this study differed from the 2 ml/minute used in a previous study[21] due to limitations with the

available infusion pumps. However both studies found that these relatively high rates of infusion into the popliteal LN were not problematic, and did not appear to cause any pain, discomfort, or other complication in dogs when Iohexol was administered at a dose of 1 ml/kg. This dose rate is similar to that previously reported for mesenteric lymphatic vessel lymphography,[1,9,10,15,18,28,46,47] however it should be noted that this is a significantly higher dose than that reported for percutaneous mesenteric LN lymphography.[22]

Although many previous studies report diluting radiographic contrast agents before use to reduce their viscosity,[1,10,11,15,28] problems were not encountered when Iohexol 300 mgI/ml was used at room temperature through either a 22 gauge catheter into a mesenteric lymphatic, or a 25 gauge needle into a popliteal LN.

For mesenteric lymphatic vessel lymphography, catheter placement was reasonably easy to perform via a routine midline coeliotomy, as long as the orally ingested oils had rendered the lymphatic vessels visible. In this study, oral oil doses were given approximately 3 hours and again 75 minutes before the lymphatic catheter was placed. One dog vomited immediately after the second dose of oil and it was found to have poorly visible mesenteric lymphatics at the time of surgery. This may suggest that for optimal visualisation of the mesenteric lymphatic vessels oral doses of oil should not be given more than 75 minutes before surgery. This lies within the range of previous recommendations of oral oil doses being given from between 30 minutes to 5 hours before anaesthesia.[1,9,13,18-20] Further research may help to minimise the unnecessary time delay caused by allowing excessively long periods for oral oil dosing before surgery. Injection of Evans blue or methylene blue into an intestinal LN may be considered as an alternative method of facilitating visualisation of intestinal lymphatics.[14,47,53]

When suturing the mesenteric lymphatic catheter in place, the tissue drag associated with using silk suture material resulted in rupture of lymphatics in some early cases. For later cases 5-0 nylon was used instead which minimised tissue drag and prevented lymphatic rupture from occurring (Appendices 2 & 3).

Extreme care was required while moving dogs from the surgical theatre to the CT suite, and during the positioning of dogs for the CT, so as to avoid loss of the implanted mesenteric vessel catheter. Despite the care taken, two dogs (20%) had their catheters become non-functional due either to kinking or displacement of the mesenteric lymphatic vessel catheter (Appendix 4). The reason for mesenteric lymphographic failure could only be ascertained during the follow up coeliotomy, due to an inability to accurately monitor the site of the lymphatic catheter during the CT procedure. Otherwise once in the CT suite the mesenteric lymphography technique was relatively simple and quick to perform, although the dogs then needed to be returned to a surgical theatre to have the implanted lymphatic vessel catheter removed.

Many of the dogs in this study did not have palpable popliteal lymph nodes, which was an unexpected finding. An earlier study[21] performed on similar sized dogs did not report problems in popliteal LN palpation or blind percutaneous injection, although they did suggest US guidance may prove to be an improvement over their technique. Another difficulty was the unexpected challenge in identifying a popliteal LN with US in some individuals. Four of eleven dogs (36.4%) failed to have a popliteal LN initially detected on US. After a delay of between 10 to 21 days, two of the three dogs reassessed (66.6%) failed to have a popliteal LN detected on US (Appendices 2 & 3).

Eight dogs underwent US guided percutaneous popliteal lymphography, of which one failed (12.5%) due to extravasation of the contrast medium, and two dogs required a second attempt 10-21 days later before a successful lymphogram was achieved (Appendix 4). The single dog which failed due to extra-nodal contrast medium leakage occurred early on in the trial process and was mainly a result of inexperience with the procedure. In later cases the administration needle was changed from a 23 gauge butterfly needle to a 25 gauge hypodermic needle which simplified manipulation of the administration apparatus during contrast medium administration. The reduction in needle size also appeared to minimise extra-nodal contrast medium loss, although an inadequate number of dogs were assessed to confirm this finding. Ultrasound guided percutaneous administration of contrast medium into a popliteal LN produced a successful TD lymphogram in 80% of cases, which was identical

to the result achieved by mesenteric lymphatic vessel administration in this study. However this success rate was less than that achieved in previous TD lymphography studies where the contrast medium was administered percutaneously into a LN. One administered contrast medium blindly into a popliteal LN,[21] while the other used US guidance to inject contrast medium into a mesenteric LN,[22] and achieved TD lymphograms in 100% of dogs.
The success rate of popliteal lymphography could have been improved if early US assessment of the popliteal LN had been consistently performed before attempting to undertake the popliteal lymphography procedure. It is therefore recommended that potential US guided percutaneous popliteal lymphography cases should have ultrasonographic assessment of their popliteal lymph nodes before the initiation of the lymphography procedure. Where a popliteal LN can not be identified the patient should have the contrast medium administered by another method. The popliteal LN could also be reassessed at a later date for popliteal lymphography, however it appears as thought there is only about 1/3rd of these cases in which LN identification is achieved on the follow up US.
Ultrasound guidance facilitated confident needle placement within the LN, which may be critical in dogs with poorly or non-palpable popliteal lymph nodes as often occurred in this study. It also allowed early detection and correction of contrast medium extravasation, which is of particular importance for experimental studies where any spilled contrast medium may be significant, and the volume may need to be corrected.
The total time taken to perform percutaneous popliteal CT lymphography was approximately half that taken for the mesenteric procedure. The average time saving of 52 minutes was largely due to circumventing the need to surgically implant and remove a lymphatic vessel catheter. However the popliteal cases occupied the CT suite for nearly twice the time that the mesenteric lymphography cases did. This was largely due to the period required to perform the popliteal LN US, the slower contrast medium administration rate, and the extra time needed to move the US equipment away from the CT gantry (Appendix 10). This may have a cost implication where the CT suite and diagnostic imaging staff are charged at an hourly rate instead of a flat

procedural rate as is used at the OVAH; or if the additional time required results in a reduced case through put for the CT facility.

The cost of performing the percutaneous popliteal CT lymphographic procedure was just 29% of the cost to perform the mesenteric procedure, largely through avoiding the need to perform any surgical procedures.

None of the percutaneous popliteal lymphography cases displayed any notable discomfort after the procedure, while two (20%) of the mesenteric lymphography cases developed post operative discomfort of a level which required extra analgesia above the standard protocol.

The consistent hyperechoic appearance of the popliteal LN seen after injection with Iohexol was an unexpected phenomenon and to the author's knowledge has not been reported previously. A reason for this finding was not ascertained by this study.

This is the first study in which percutaneous popliteal lymphography has been performed under US guidance, and it was found that 100% of the successful popliteal lymphography cases suffered an estimated 0.5 to 5ml of perinodal contrast medium extravasation on US (Appendices 2 & 3). The US monitoring enabled correction of needle placement or abortion of the procedure if a LN could not be identified or injected appropriately.

Conventional radiographs combined with popliteal administration of contrast medium may result in detection of fewer TD branches when compared to CT, due to the smaller size of TD branches and the lower concentration of contrast medium found with popliteal administration. CT is superior to conventional radiographs in detecting both smaller objects and lower concentrations of contrast medium.[17,55,56]

While concerns have been expressed over the ability of popliteal lymphography in delineating as many TD branches as mesenteric lymphatic lymphography,[21] the study performed here did not detect any statistically significant difference between the two contrast medium administration methods in detecting TD branches.

5.4 Computed tomography modality

Both helical and sequential CT resulted in excellent visualisation of the TD system at the assessed sites, with no significant difference detected in the quality of the images from either CT modality.

A statistically significant difference was not found between the two CT modalities in the number of TD branches detected (P=0.417) (Table 2), although helical CT did produce significantly larger TD branches (largest TD branch maximum width (P<0.001) (Table 5 & Graph 6), cross-sectional area (P<0.001) (Table 7 & Graph 8)) with a significantly higher mean HU (P<0.001) (Table 3 & Graph 4).

With helical CT resulting in larger TD branches which contained a higher concentration of contrast medium, its failure to detect a greater number of TD branches is surprising. In fact when the *CR* is assessed, it would appear that helical CT may have detected slightly fewer TD branches (*CR*=0.876) than sequential CT (Table 2 & Graph 2), although as mentioned earlier, due to the use of a zero-truncated Poisson regression model the *CR* should be interpreted with some caution. When the raw data are compared helical CT detected 95% of the number of TD branches that sequential CT detected, however this difference was not statistically significant in this study.

Sequential CT scans were consistently performed after completion of the helical CT scans and were initiated on average 45 seconds after the initiation of the helical CT. This may have placed the sequential CT scans at a potential disadvantage due to the longer delay since administration of the contrast medium, which would have allowed a reduction of the pressure within the thoracic duct system and dilution of the contrast medium. This is supported by the sequential CT findings of a significantly smaller TD branch size and lower concentration of radiographic contrast medium. However as mentioned above, sequential CT was found to be at least equivalent, if not slightly superior to helical CT in detecting TD branches, despite the apparent disadvantages of smaller TD branch size and lower contrast medium concentration. Therefore it would appear that a variety of factors may be influencing the comparison of CT modalities when assessing the TD system.

These could include:

- Selection of the single image with the most visible TD branches from two sequential slices taken by the dual slice CT machine
- Altering the TD branch slice profile by tilting of the gantry to be perpendicular to the long axis of the vertebral body for the sequential CT
- The effect on the TD system of the increased intrapleural pressures that occurred when a forced inspiratory breath hold was used to minimise thoracic respiratory movement for the helical CT
- The effect of the extra 45 second delay that occurred after contrast medium administration, before initiation of the sequential CT. Particularly the influence on contrast medium concentration and viscosity, and intraductal pressures.

As mentioned previously selecting the single sequential CT slice with the greatest number of visible TD branches and tilting of the CT gantry do not appear to have had a significant impact on the study, other than the latter resulting in the sequential CT scans taking an average of 91 seconds longer than the helical CT scans (Appendix 10). However in future studies both of these factors should be reassessed and standardised when a comparison between sequential and helical CT is performed. Since there did not appear to be any advantage with using gantry tilt, for clinical chylothorax cases a uniplanar scan would be recommended as this will help to minimise the time that these potentially respiratory compromised patients will spend under anaesthetic.

The effect of increased intrapleural pressures, as occurs with a forced inspiratory breath hold, and any delay in performing the CT after administration of the contrast medium are interrelated. They can both influence TD dilation through altering the extra- and intraductal pressures respectively. Helical CT had an advantage over sequential CT as it was initiated immediately after contrast medium injection and therefore would have had greater intraductal pressures, which is supported by the finding that helical CT had a significantly greater largest TD branch size (Tables 6 & 8, Graphs 6 & 8). Conversely the increased intrapleural pressures that occurred with the forced inspiratory breath hold should have placed helical CT at a

disadvantage by reducing the size of the TD branches through the Starling resistor effect. While this was not found in this study, the result may indicate that the difference in pressure gradients between intra- and extraductal pressures may not have been proportional. There was only moderate lung inflation and hence a moderate increase in intrapleural pressure, while the rapid intralymphatic bolus of contrast medium would have caused significant increases in intraluminal duct pressures. This result may however support that a more rapid contrast medium administration rate, and possibly administering contrast closer to the origin of the TD system, can result in a greater TD branch size, although it does not necessarily result in a greater number of TD branches detected. Although no significant interaction term was found between the administration methods or CT modalities, non-breath hold mesenteric sequential CT (highest intraductal pressure with normal intrathoracic pressure) resulted in the greatest number of TD branches being identified (80), while popliteal sequential (70), mesenteric helical (72) and popliteal helical (71) CT lymphography all resulted in lower numbers of TD branches identified (Appendix 7). While no significant difference was detected in this study, the count ratios for the number of TD branches identified (Table 2) also seem to support that both extra- and intraductal pressures are important. Both sequential CT (no increased extraductal pressure) (CR = 0.876) and mesenteric administration of contrast medium (maximum intraductal pressure) (CR = 0.830) appear to detect slightly greater numbers of TD branches. The use of a forced inspiratory breath hold during helical CT could be avoided through the use of muscle relaxants to minimise thoracic respiratory movements, although extreme care must be taken particularly in an already respiratory compromised patient.

Because the sequential CT was performed after completion of the helical CT a longer time had lapsed since the administration of the contrast medium, therefore allowing greater dilution of the contrast medium. That the lower mean HU for sequential CT is due to the time delay is supported by the fact that the mean HU appears to stay reasonably constant throughout the duration of the helical CT but then declines significantly during the second half of the sequential CT (Table 3, Graph 4). As discussed previously this drop appears to occur approximately 2 minutes after completion of the contrast

administration. Due to the dilution of the contrast medium which occurs over time, the viscosity would be reduced and this could aid flow into and through TD branches due to the reduced resistance to flow. This may be another factor which could help to explain the slight superiority of sequential CT over helical CT. The potential importance of contrast medium viscosity is highlighted by the following two formulae[32] which are used for calculating the flow, and resistance to flow, of a fluid passing through a tube. The greater impact of increased contrast medium viscosity, particularly on smaller TD branches can be seen.

$$\text{Flow} = \frac{\Delta P \times \pi r^4}{L \times V \times 8} = \text{Poiseuille's law}$$

$$\text{Resistance} = \frac{V \times L}{\pi r^4}$$

ΔP = Pressure gradient.

r = Radius of the tube.

L = Length of the tube.

V = Fluid viscosity.

8 = Constant of proportionality.

Use of a hyperosmolar contrast medium could damage the TD wall and initiate adherence of leucocytes to the TD wall, thereby reducing the functional radius of the TD branches and increasing resistance to flow. Certainly the effect of increased leucocyte adherence has been demonstrated in blood vessels, and its effect is greatest in small blood vessels.[33] The significance of contrast medium viscosity is however thrown into doubt when it is seen that popliteal lymphography also resulted in a significantly lower mean HU but still appeared to detect slightly fewer TD branches. Also when one dog (ID 211923) was accidentally given 350 mgI/ml Iohexol instead of 300 mgI/ml (Appendix 3), it appears as if the lymphogram taken with the more concentrated and viscous contrast medium (CT8125) actually resulted in considerably more TD branches being detected than when the same individual had a lymphogram performed with the less concentrated contrast medium via the popliteal route (CT8116) (Appendix 7). This latter finding should however be interpreted with caution as no statistical significance could be attributed, and CT8125 was the mesenteric administration study. Therefore

the effect of the contrast medium viscosity may not be as simple as it first appears. The case of CT8125 could be a result of the 350 mgI/ml Iohexol being more hyperosmolar than the 300 mgI/ml, therefore drawing more fluid into the TD resulting in an increased intraductal pressure, especially when combined with the already higher intraductal pressure achieved through mesenteric lymphatic vessel administration of the contrast medium. The TD branch diameters and cross-sectional areas were greater when the higher concentration of contrast medium was used. However CT8125 was a mesenteric administration study and this trial found that mesenteric administration of contrast medium results in a significantly larger largest TD branch size compared to popliteal administration. The variation in TD branch size did however appeared to be greater in this specific case than the other cases examined in this trial. Interestingly the maximum mean HU was 3071 for CT8125, as it was for all of the other cases where 300 mgI/ml contrast medium was used, indicating that this was the maximum HU value achievable with the CT algorithm used. Unfortunately due to the limited nature of the data available in this study it is impossible to further clarify the importance of contrast viscosity and osmolality on the number of TD branches that can be detected.

Placing dogs in sternal recumbency for the CT scans allowed a more normal physiological position to be maintained throughout the CT procedure, thereby minimising cardiovascular changes[57,58] that could impact upon chyle flow within the TD system. This positioning also minimised any cardiorespiratory changes which may affect anaesthetic safety, particularly in a compromised patient such as one with chylothorax. This positioning facilitated easy access to the popliteal area for percutaneous popliteal administration of contrast medium, however it also resulted in the mesenteric cases lying on the contrast medium administration apparatus and their coeliotomy incision.

The radiation risk to staff was higher with helical CT due to the need for an individual to be present within the CT suite to manage the controlled breath hold; however this could be overcome through using other means to minimise thoracic movement, such as the use of muscle relaxants as previously discussed. Use of the Siemens CARE dose® protocol for the helical CT allowed the mAs to be minimised, however the total scan mAs was still

approximately 30% higher for helical CT compared to the sequential CT (Appendix 11). Unfortunately the CT dose index data for this trial was lost during data transfer and therefore the patient radiation exposure could not be calculated and further compared for the two CT modalities.
Considering that surgical ligation of the TD is most commonly performed through the right 10th or 11th intercostal space,[3,8,9,12,16,45,61,64] the area that needs to undergo CT to allow accurate location of all the TD branches at the surgical site is actually quite narrow when compared to the area examined in this study. The narrower surgically relevant area could further reduce any difference between the two CT modalities in patient radiation exposure. If multiple sequential CT slices are required of the surgical area then helical CT may potentially result in a lower patient radiation exposure. Helical CT allows high quality secondary reconstructions to be made, such as three dimensional reconstructions, which can often be useful in surgical planning.

5.5 Vertebral site, and thoracic duct number and location

There was a general trend for the number of TD branches to reduce in a craniocaudal direction from the T9 to L1 vertebral sites. The L1 site was found to occasionally have an increased number of TD branches, which often appeared as poorly defined branches positioned circumferentially around the aorta (Figure 20), or as isolated branches closely associated with the main TD branch. In one dog it appeared that the extra lymphatic branch may have been a very cranial afferent abdominal lymphatic vessel entering either the caudal TD or cranial cisterna chyli, or possibly an abnormal efferent lymphatic vessel bypassing the normal route of the TD (Figure 21). In this case (CT0892) the TD branch was included in the count due to its close association with the main TD branch. Also because the contrast medium had been administered through the popliteal LN it was probably at a lower intraluminal pressure and therefore less likely to cause back flow down any afferent lymphatic vessels. This differed from the only other case (CT0893) (Figure 12) where an apparent intra-abdominal branch was not included in the TD branch

count as it was not visibly associated with the TD, and the contrast medium had been administered through a mesenteric lymphatic. Because of these two factors this vessel was classified as an afferent intestinal lymphatic (Figure 12). However as there are no valvular structures at the entry point of the afferent lymphatics into the cisterna chyli,[24-26] both of the branches discussed above could represent back flow into an afferent lymphatic from the cisterna chyli, due to an increased pressure within the cisterna chyli; although this is more likely in the case with mesenteric contrast medium administration as this technique appears to generate a greater intralymphatic pressure.

As most of the additional lymphatic branches noted at the L1 site did not continue cranially into the T13 site, the majority probably result from individual variability in the point of transition from the cisterna chyli into TD[24] as was discussed earlier. This is particularly true for the cases with poorly defined branches positioned circumferentially around the aorta (Figure 20).

The most commonly reported intercostal approach for TD ligation is via the right 10th or 11th intercostal space[3,8,9,12,16,45,61,64] although approaches as far cranial as intercostal spaces eight[10] and nine[11] have been reported. This conventional approach is taken as the TD system has fewer branches more caudally, and it is reported to be classically located on the right dorsal border of the aorta from L1 to T6,[1,8,9,16,24] thereby facilitating access from the right side. The limited surgical access means that TD branch position relative to the aorta can be of critical importance when considering surgical ligation of the TD system. A high degree of variability in the TD anatomy and position has been recorded[1,8,9,18,24,27] and this is supported by the results reported here. Due to the caudal inclination of the ribs and the surgical exposure achieved through a 10th or 11th intercostal thoracotomy, the T10 to T12 segment of the TD system will normally be exposed surgically and therefore becomes critical when assessing TD position. For this segment 87% of TD branches were found to lie to the right of the aorta, while 13% lay to the left and would therefore not have been visible from a right sided thoracotomy. However 100% of TD branches lay between the 10 o'clock and 3 o'clock positions (Table 9 & Graph 9) relative to the aorta, which may support the approach of en bloc ligation of all tissues dorsal to the aorta[16,64,65] as long as all tissues on the lateral aspects of the aorta are included.

The TD branch positional information becomes even more critical when less invasive techniques such as thorascopic TD ligation[15] are used, especially when you consider that one dog in the study reported here had up to five TD branches present in the T10 to T12 segment, spread between the 10 o'clock and 3 o'clock positions relative to the aorta (Table 9).

5.6 Future studies

Some areas regarding TD lymphography identified during this study that could warrant further investigation are:

- The minimum time required between oral dosing of oil and the placement of a mesenteric lymphatic catheter that still optimises visualisation of lymphatics during surgery, but minimised the time delay before starting surgery
- Methods of maximising the number of TD branches identified:
    - The effect of the rate, duration and volume of contrast medium administration
    - The effect of contrast medium concentration, osmolality and viscosity
    - The effect of increased TD dilation and methods to achieve this
    - The effect of intrapleural pressure gradients, and specifically the effect of mechanical ventilation or a positive pressure breath hold
    - The ideal period after contrast medium administration to perform diagnostic imaging, and the impact of time on both contrast medium concentration and TD branch dilation
    - Methods of getting, or identifying, contrast medium in normally non-patent TD branches.
- The comparability of percutaneous injection of contrast medium into a mesenteric LN, with the popliteal LN and mesenteric lymphatic vessel administration methods
- Identify the reason for the hyperechoic appearance of the popliteal LN on US after injection with Iohexol.

Chapter 6: CONCLUSION

The following conclusions were deduced from this study regarding US guided percutaneous popliteal LN, and mesenteric lymphatic vessel administration of contrast medium for TD lymphography:

- Both administration techniques:
  - Resulted in excellent quality lymphograms of the TD system
  - No significant difference existed in the number of TD branches detected.
- Mesenteric lymphatic vessel administration:
  - Requires either preoperative oral oil dosing, or intraoperative injection of a dye, to aid visualisation and catheterisation of a mesenteric lymphatic vessel
  - Required approximately twice the total time to perform the diagnostic procedure due to the time needed for surgical catheter implantation and removal
  - Required extreme care when moving the patient so as not to compromise the lymphatic vessel catheter
  - Resulted in the largest TD branch being of greater size, and containing a higher concentration of contrast medium. Probably both were due the contrast medium being administered as a rapid bolus directly into a lymphatic vessel, at a site closer to the TD origin.
- US guided percutaneous popliteal LN administration:
  - Required an initial careful assessment of the popliteal LN on US to ensure a LN was detectable. Approximately 1/3rd of cases did not have a detectable popliteal LN. If a popliteal LN is not detected then another method of contrast medium administration is recommended as approximately 2/3^{rds} will still not have a detectable LN on US 10-21 days after the initial assessment
  - Required approximately twice the time in the CT suite due to the time needed to identify the popliteal LN, and then slowly inject the contrast medium into the LN

- Had a relatively short learning curve with regards to finding a popliteal LN and successfully performing the lymphography
- Resulted in a largest TD branch of smaller size, which contained a lower concentration of contrast medium. This was probably due to the considerably slower rate of contrast medium administration and that it was administered into a LN, at a more peripheral site
- Required approximately half of the total diagnostic time, resulted in less patient risk and post diagnostic pain, and incurred only 29% of the total diagnostic costs.

The following conclusions were deduced from this study regarding the use of forced inspiratory breath holding helical CT and normal respiratory cycle sequential CT for TD lymphography:

- Both CT modalities:
  - Resulted in excellent quality lymphograms of the TD system
  - No significant difference existed in the number of TD branches detected.
- Normal respiratory cycle sequential CT:
  - Required more time to perform due to the extra time taken to program and perform gantry tilting, which allowed the sequential CT slice to be kept perpendicular to the vertebral body long axis. No advantage was found with this multiplanar approach and it is therefore recommended that a uniplanar approach, as was used for helical CT, be utilised in the future.
- Forced inspiratory breath holding helical CT:
  - Required a forced inspiratory breath hold to minimise thoracic respiratory movement due to the helical CT scan duration. Muscle relaxants could be used to achieve the same purpose, and may minimise increases in intrapleural pressure
  - Resulted in an increased staff radiation exposure risk due to the need to maintain a forced inspiratory breath hold
  - Resulted in the largest TD branch being of larger size and containing a higher concentration of contrast medium. Both of these findings were probably as a result of the helical CT being

consistently performed before the sequential CT and therefore closer to the time of contrast medium administration

- Increased intrapleural pressures due to forced inspiration which may have exerted a Starling resistor effect on TD branches thereby reducing their chance of dilation
- Enabled three dimensional reconstructions of the TD system, which would facilitate easier surgical planning.

This trial concludes that US guided percutaneous popliteal lymphography is an acceptable alternative to mesenteric lymphatic vessel lymphography when using either helical or sequential CT; pending the availability of suitably trained staff, appropriate US and CT equipment, and there being an ultrasonographically detectable popliteal LN in the patient. It is faster to perform the diagnostic procedure, causes less patient risk and discomfort, and incurs less than 1/3rd of the diagnostic costs.

If possible:

- Avoid increasing intrapleural pressures during the lymphography, thereby minimising any Starling resistor effect on the intrathoracic lymphatic vessels
- Imaging should be performed within 2 minutes of completing the injection of contrast medium so as to optimise the intraductal contrast medium concentration. Imaging immediately after contrast medium administration may also help to take advantage of any ductal dilation that occurs due to the volume of contrast medium injected, or its osmotic effect.

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Appendix 1

Initial patient assessment									
Patient number	Animal identification	Sex	Age	Weight (kg)	Urine specific gravity	Urine sediment	Clinical findings	Radiographic findings	Blood results
211917	4010674C42	F	8yr	11.0	1.036	WNL	Previous abdominal surgery.	Caudal cervical spondylosis.	WNL
211918	400D0D5325	F	8yr1m	10.8	1.030	WNL	Previous left cranial cruciate ligament surgery.	WNL	WNL
211919	4062095172	F	8yr	13.0	1.028	WNL	WNL	WNL	WNL
211920	985140000110276	M	1yr8m	13.6	1.050	WNL	WNL	WNL	WNL
211921	985140000106840	M	1yr8m	13.3	1.056	WNL	WNL	WNL	WNL
211922	978000000681198	M	1yr3m	12.8	1.040	WNL	WNL	WNL	WNL
211923	4058744B03	F	8yr	10.5	1.065	WNL	WNL	WNL	WNL

Patient number	Animal identification	Sex	Age	Weight (kg)	Urine specific gravity	Urine sediment	Clinical findings	Radiographic findings	Blood results
211924	985140000119747	F	1yr8m	10.0	1.058	WNL	WNL	WNL	WNL
211925	500853063F	F	8yr	12.0	1.060	WNL	Previous right cruciate ligament surgery. Umbilical hernia.	WNL	WNL
211926	4017670028	F	8yr1m	10.2	1.042	WNL	Kerato-conjunctivitis sicca.	WNL	WNL
211927	978000000679816	F	1yr4m	11.3	1.054	WNL	WNL	Microchip over left heart base.	WNL
211928	400B261E3B	MN	8yr1m	15.2	1.032	WNL	WNL	Microchip dorsolateral over T4.	WNL
211929	985140000121424	M	1yr8m	14.8	1.070	WNL	WNL	WNL	WNL

F = Female
M = Male
MN = Male neutered
WNL = Within normal limits
T4 = Thoracic vertebra 4

Appendix 2

Rotation 1 comments form			
Patient ID	WGT / Vol	OIL TIME	COMMENTS
211917 4010764C42	11.0		Had seizure with excitement before U/S. EXCLUDED.
211918 400D0D5325	11.0 P		L LN=4x6mm – 25G needle – estimated 2ml extravasated so +2ml. 100ml/hr – pump. US photo taken – note increased echogenicity of LN on injection of contrast (extravasated material is hypoechogenic). Also LN expands considerable/more visible with correct injection.
211919 4062095172	13.0 P	06.15 08.00	U/S = L LN very small – pad under medial stifle to elevate LN. Estimated 1ml spillage on U/S – added 1ml. No contrast on 1st CT – all extravasated. R=no LN visible on U/S, injected 2 ml but all extravasated. Aborted CT. 23G butterfly needle. SECOND ATTEMPT No LN identified on U/S.
211920 985140000110276	13.6 M	08.00 09.45	1st lymphatic blown – placed 2nd lymphatic - ++chyle leakage into retroperitoneal – difficult to ID lymphatics (did not cut peritoneum 1st to isolate lymphatic) – hit BV with silk – haematoma at catheter site) – resistance to contrast injection. No contrast administered. Aborted CT. Catheter kinked when removed.
211921 985140000106840	13.3 M	08.00 09.45	Vomited after pre-med including some oil. 1 min bolus - hand Contrast and CT went well.
211922 978000000681198	12.8 M	08.00 09.45	U/S = L LN visible, R LN not visible Surgery ok, contrast ok, CT went well 1 min bolus - hand. Painful to 24 hrs post Surgery – Morphine 4x doses at q4hrs.

211923 4058744B03	10.5 P	06.15 08.00	Vomited after pre-med. US = no visible LN on either – extravasation of all contrast on L. 100ml/hr by hand – pump pressure failure. 23G butterfly needle. SECOND ATTEMPT Repeat US – L=good – picture taken. 2ml extravasated -hypoechoic. Got hyperechoic appearance of LN on injection into LN. +2ml given. 100ml/hr – pump. 23G needle.
211924 985140000119747	10.0 P	06.15 08.00	US = Small L LN visible – extravasation 0.5ml – changed to R LN – inject 10ml – small amount extravasation at end of injection – extra 0.5ml given. Spillage on radiographs. 100ml/hr – pump. 23G needle.
211925 500853063	12.0		NO LN detected on US. EXCLUDED.
211926 4017670028	10.2 P	06.15 08.00	US = LN very small – contrast on US looked OK with 1ml extravasation (slight) – corrected needle whilst injecting. 100ml/hr – pump. 25G needle.
211927 978000000679816	11.3 P	06.15 08.00	US = good LN on both sides – extravasation 5ml on L so changed to R and injected 11.3ml (looked suspicious of 25% extravasation on US). No contrast in lymphatics on CT. 100ml/hr – pump. SECOND ATTEMPT US check LN looks good – 7/7. 6ml extravasated L-but good LN on US. R side 25G needle instead of 23G (1ml lost with initial use of 23G but then all ok with 25G on R) +1ml on R. On CT some contrast from L LN as well. 100ml/hour – hand.

211928 400B261E3B	15.2 M	08.00 09.45	Catheter ½ into duct then hit stop. Tied in with 5-0 nylon instead of silk – easier and less risk of duct trauma (tissue drag) – no trauma to surrounding lymphatics. Good result. Good CT. 1 min bolus - hand. Painful post surgery – Morphine every 2hrs for 3 doses then every 4 hrs over night.
211929 985140000121424	14.8 M	08.00 09.45	Ruptured 1x lymphatic adjacent to catheterised one with silk suture but OK. CT went well. Small amt of extravasation in abdomen. 1 min bolus – hand.

ID = Identification
CT = Computed tomography
P = Popliteal
M = Mesenteric
US = Ultrasound
R = Right
L = Left
LN = Lymph node
G = Gauge

Appendix 3

Rotation 2 comments form			
Patient ID	WGT / Vol	OIL TIME	COMMENTS
211917 4010764C42	11.0		EXCLUDED.
211918 400D0D5325	11.0 M	08.00 09.45	Poor fat uptake but catheter placed OK with difficulty. Lower resistance to contrast administration – slight. 1 min bolus – hand. No contrast in TD at start of CT so aborted. Catheter had fallen out of lymphatic during the move to CT – seen at follow up coeliotomy. Aborted CT. EXCLUDED.
211919 4062095172	13.0 M		EXCLUDED.
211920 985140000110276	13.6 P	06.15 08.00	Blown mesenteric last week. EXCLUDED.
211921 985140000106840	13.3 P	08.00 09.45	L=15x5mm-not palpable, v superficial-5mm from skin 1ml extravasation - +1ml contrast. 100ml/hr - hand (pump failure). 25G needle.
211922 978000000681198	12.8 P	06.15 08.00	L LN=good LN on u/s. 1ml extravasation – so +1ml. 100ml/hr - hand (pump failure - pressure). 25G needle.
211923 4058744B03	10.5 M	08.00 09.45	Catheter kept kinking due to position once placed into abdomen (wanted to lie vertical against ventral abdominal wall. WRONG CONTRAST – 350mgI/ml. 1 minute - hand. Good CT – Small amt extravasated.
211924 985140000119747	10.0 M	08.00 09.45	5-0 nylon. Morphine after general anaesthetic. CT went well. 1 minute – hand.

211925 500853063	12.0		EXCLUDED.
211926 4017670028	10.2 M	08.00 09.45	Vomited after pre-medication – poor fat in lymphatics. Placed close to ileocolic LN. Some bleeding. CT success but a lot of intra-abdominal extravasation. 1 minute – hand.
211927 978000000679816	11.3 M	08.00 09.45	Good lymphatics – Photo taken. Good catheter placement. 1 minute - hand. Good CT.
211928 400B261E3B	15.2 P	06.15 08.00	US = L LN= not visible, R LN= not visible – aborted without CT or contrast injection. SECOND ATTEMPT No popliteal LN visible – no contrast injected. EXCLUDED.
211929 985140000121424	14.8 P	06.15 08.00	L=16.7x3.5mm – 4ml extravasated – stopped. R=similar LN size – 2ml extravasated – add 2ml. 100ml/hr – pump. CT machine failure. SECOND ATTEMPT Very good LN on L. No visible extravasation on US. 50%-hyperechoic glow with injection of contrast. 100ml/min – pump. 25G needle.

See appendix 2 for abbreviations

Appendix 4

Computed tomographic lymphography success / failure				
Patient identification	Mesenteric CT number	Popliteal CT number	Study order	Comment
985140000106840 211921	☑=0886	☑=8103	M-P	
978000000681198 211922	☑=0893	☑=8107	M-P	
4058744B03 211923	☑=8125	☒=0887 ☑=8116	P-M	No LN detected 8125 = 350mgI/ml
985140000119747 211924	☑=8106	☑=0894	P-M	
4017670028 211926	☑=8104	☑=0892	P-M	
97800000067916 211927	☑=8127	☒=0888 ☑=8113	P-M	LN detected but missed
985140000121424 211929	☒=0000 ☑=0889	☑=8124	M-P	CT failure
4010674C42 211917				Seizure before trial
400D0D5325 211918	☒=0000	☑=8114	P-M	Mesenteric catheter pulled out
4062095172 211919		☒=0000 ☒=0000		No LN detected No LN detected
985140000110276 211920	☒=0000			Kinked mesenteric catheter
500853063F 211925		☒=0000		No LN detected initial examination
400B261E3B 211928	☑=0896	☒=0000 ☒=0000		No LN detected No LN detected

☑ = Successful CT lymphography
☒ = Failed CT lymphography
M = Mesenteric lymphography
P = Popliteal lymphography

Helical computed tomography slice used							
CT number	Vertebral site and CT slice number						
	T8	T9	T10	T11	T12	T13	L1
0886	11	26	43	57	75	94	115
0889	-	20	38	54	72	92	114
0892	-	01	17	35	54	74	95
0893	-	20	36	53	70	90	111
0894	-	09	25	39	56	70	93
8103	10	15	30	46	63	83	102
8104	09	24	39	56	74	94	114
8106	11	25	40	55	72	89	108
8107	-	12	28	44	61	81	101
8113	-	15	31	46	64	84	103
8116	-	01	16	32	49	67	87
8124	-	12	29	46	62	82	102
8125	09	25	39	55	72	90	109
8127	-	15	30	46	64	83	105

CT = Computed tomography
T8-T13 = Thoracic vertebrae 8 to 13
L1 = Lumbar vertebra 1

Appendix 6

Data capture form					
CT number					
Oil dosing times					
Contrast medium dose					
Contrast medium start					
CT start					
Site	TD No	Largest TD diameter Max - Min	Hounsfield units Min – Max - Mean	TD branch location	Comments
Helical B70S					
T9					
T10					
T11					
T12					
T13					
L1					
Sequential B70s					
T9					
T10					
T11					
T12					
T13					
L1					

CT = Computed tomography
TD = Thoracic duct
Min = Minimum
Max = Maximum
T9-T13 = Thoracic vertebrae 9 to 13
L1 = Lumbar vertebra 1

Appendix 7

Data for statistical analysis

ANIMAL NUMBER				1										
CT NUMBER				8103										
CONTRAST METHOD				POPLITEAL										
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	1	2	2	3	1	1	1	1	1	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	9.5	2.5	2.7	2.9	2.1	2.1	10.3	3.1	2.2	3.3	4.1	2.5
		HU	MINIMUM	3058	2182	1597	1935	2446	2306	3056	2978	2392	2732	1556	3064
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3069	3041	2962	3008	3036	3007	3069	3062	3019	3058	2915	3070
	RK	WIDTH	MAXIMUM	9.8	3.2	2.5	3.1	2.1	2.2	10.4	3.2	2.2	3.5	4	2.7
		HU	MINIMUM	1828	2880	1597	1935	2630	1549	2600	1761	1813	2732	2728	2480
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3002	2961	2961	3007	3032	2841	3064	2943	2916	3060	3048	3048
	IM	CROSS-SECTION AREA	mm^2	2.6	0.8	0.5	0.6	0.3	0.3	4.2	0.6	0.4	0.6	0.7	0.5

ANIMAL NUMBER				1									
CT NUMBER				0886									
CONTRAST METHOD				M ESENTERIC									
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				2	1	1	1	2	3	1	1	1	2	3	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	2.4	3.1	3.2	5.1	2.5	3.5	7.5	3.6	3.3	5.8	3.1	3.1
		HU	MINIMUM	1283	2038	1904	2625	1936	2281	3058	3055	2970	3060	1650	2341
			MAXIMUM	2125	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1794	2679	2906	3030	2938	3027	3069	3065	3057	3070	2930	3032
	RK	WIDTH	MAXIMUM	2.5	3.2	2.6	4.9	4.3	3.7	8.3	3.5	3.4	5.7	3.2	2.7
		HU	MINIMUM	1076	1034	1342	2482	2615	2281	2498	2976	3012	1972	1478	2563
			MAXIMUM	2125	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1761	2471	2875	3047	3050	3017	3055	3064	3060	2998	2889	3031
	IM	CROSS-SECTION AREA	mm^2	0.5	0.6	0.6	1.2	0.5	0.7	2.6	1.1	0.7	1.2	0.6	0.6

ANIMAL NUMBER				2											
CT NUMBER				8116											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	2	2	2	2	3	1	1	2	3	3	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	1.2	1.4	1.7	2	2.3	1.5	5	2.6	1.3	1.4	1.2	1.5
		HU	MINIMUM	904	1123	1043	1270	914	1319	1650	1570	1023	1013	1285	963
			MAXIMUM	1177	1462	2848	2927	2523	2860	2910	3071	1960	1507	2106	3071
			MEAN	1035	1315	2081	2124	1881	2054	2271	2605	1399	1294	1688	2323
	RK	WIDTH	MAXIMUM	1	1.8	1.8	1.9	2.1	1.5	5.1	2.5	1.4	1.5	1.3	1.6
		HU	MINIMUM	816	904	742	1270	1430	1319	1650	1977	1023	1013	694	963
			MAXIMUM	1177	1462	2848	2927	2523	2860	2910	3071	1960	1507	2106	3071
			MEAN	998	1151	1900	2124	1988	2075	2313	2756	1534	1330	1427	2322
	IM	CROSS-SECTION AREA	mm^2	0.1	0.1	0.2	0.3	0.2	0.2	1.6	0.4	0.1	0.1	0.1	0.2

ANIMAL NUMBER				2											
CT NUMBER				8125											
CONTRAST METHOD				M ESENTERIC											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	3	5	3	4	1	1	2	4	3	4
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	7.8	5.2	1.9	1.9	2.1	2.7	6.1	4.5	2.2	2.3	2.8	2.3
		HU	MINIMUM	2159	3055	2347	2711	2763	3056	3058	3054	1953	1385	3056	2084
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3040	3067	2939	3040	3049	3069	3068	3066	3012	2931	3068	3045
	RK	WIDTH	MAXIMUM	7	5.1	1.8	2.7	2.2	2.7	6.3	3.9	2.1	2.2	2.9	2.2
		HU	MINIMUM	2159	2944	1662	1744	2179	2501	2411	2816	1617	2251	1831	1499
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3007
			MEAN	3027	3066	2743	2924	2944	3052	3056	3062	2934	3020	2955	2855
	IM	CROSS-SECTION AREA	mm^2	1.9	1.4	0.4	0.3	0.4	0.5	2.3	1.4	0.4	0.4	0.5	0.9

Note: 350mg/ml Iohexol used.

ANIMAL NUMBER				3											
CT NUMBER				8113											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				2	1	1	2	2	4	1	1	2	2	2	2
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	2.7	3	3.9	2.6	2.6	2	4.7	3	2.4	3.1	3.9	4.1
		HU	MINIMUM	1266	1114	1175	2172	2933	2498	2656	2529	1897	1944	1454	1513
			MAXIMUM	1494	1616	2398	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1411	1414	1945	2966	3063	3005	3058	3044	2857	2890	2781	2495
	RK	WIDTH	MAXIMUM	2.8	3.2	3.9	2.7	2.7	2.2	4.8	2.9	2.4	3.1	3.8	4.1
		HU	MINIMUM	1312	1114	1614	1542	1929	1649	2003	1970	2047	1737	1352	1513
			MAXIMUM	1526	1616	2398	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1449	1413	2086	2730	2937	2681	2993	2944	2913	2634	1954	2409
	IM	CROSS-SECTION AREA	mm^2	0.4	0.3	0.6	0.6	0.4	0.3	1.3	0.7	0.5	0.6	1.1	0.9

ANIMAL NUMBER				3											
CT NUMBER				8127											
CONTRAST METHOD				M ESENTERIC											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	2	2	2	4	1	1	1	2	2	2
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	3.6	3.5	2.8	2.9	3	4.9	6.1	3.5	5.4	3.5	6.2	5.4
		HU	MINIMUM	1760	2324	3064	1822	3065	2953	3063	3047	3057	3052	3056	3060
			MAXIMUM	2428	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	2113	2805	3071	2890	3071	3056	3070	3064	3064	3064	3066	3968
	RK	WIDTH	MAXIMUM	3.6	3.6	3.1	3.1	2.9	4.6	7	3.5	5.5	3.2	5.1	5.5
		HU	MINIMUM	1612	1876	2080	1780	3065	2303	1817	2296	2297	3052	2506	1066
			MAXIMUM	2397	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1964	2705	2995	2978	2070	2979	3046	3035	3027	3064	3051	2580
	IM	CROSS-SECTION AREA	mm^2	0.7	0.9	0.7	0.6	0.5	0.6	2.6	1	1.5	0.8	1.8	1.4

ANIMAL NUMBER				4											
CT NUMBER				8124											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	1	1	2	2	1	1	1	2	1	2
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	1.6	2	0.8	2.1	3.9	2.8	5.2	1.8	1.8	2.1	3.9	2.6
		HU	MINIMUM	1148	1239	1102	1315	1236	2243	2211	1606	1586	2761	2593	2184
			MAXIMUM	1655	2277	1273	3064	2403	3071	3071	2035	2610	3071	3071	3071
			MEAN	1443	1804	1176	2427	1713	2997	2802	1806	2032	3050	3026	2963
	RK	WIDTH	MAXIMUM	1.8	1.7	0.8	2.2	3.7	2.8	4.9	1.9	1.9	2.1	3.9	2.4
		HU	MINIMUM	1148	1587	1127	1531	1155	2243	1480	1172	1586	2618	2552	1476
			MAXIMUM	1655	2277	1273	3064	2497	3071	3071	2035	2610	3071	3071	3071
			MEAN	1478	1937	1200	2569	1884	3001	2702	1586	2031	3026	3032	2743
	IM	CROSS-SECTION AREA	mm^2	0.2	0.3	0.1	0.3	0.4	0.6	1.2	0.2	0.2	0.4	0.7	0.5

ANIMAL NUMBER				4											
CT NUMBER				0889											
CONTRAST METHOD				M ESENTERIC											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	2	2	2	2	1	1	1	2	2	1	2
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	1.7	2.4	2.5	3.6	4.4	5.9	6	3	2.7	3.4	4.7	3.2
		HU	MINIMUM	1306	1173	1689	1385	3062	2412	3061	3056	3060	3056	3053	3047
			MAXIMUM	1557	1228	2109	3022	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1442	1204	1936	2166	3071	3025	3071	3066	3068	3064	3064	3058
	RK	WIDTH	MAXIMUM	1.7	2.4	2.2	3.6	4.3	6.2	6	2.8	2.6	3.1	4.5	3.5
		HU	MINIMUM	1306	1003	1639	1200	1976	2530	1636	1317	1682	3054	2170	2255
			MAXIMUM	1557	1258	2323	3022	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	1441	1177	2033	2114	3001	3042	3016	2902	2902	3065	3051	3022
	IM	CROSS-SECTION AREA	mm^2	0.2	0.2	0.4	1	1	1.2	2.1	0.7	0.5	0.7	1.1	0.7

ANIMAL NUMBER				5											
CT NUMBER				8107											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	1	1	3	3	1	1	1	1	3	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	3.9	5.3	3.7	5.6	2.2	2.7	5	3.5	3.3	5.1	1.8	1.8
		HU	MINIMUM	2886	3055	3057	2874	2471	1862	2135	3069	3036	3061	3053	3040
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3042	3066	3067	3063	3008	2626	2859	3071	3064	3067	3065	3061
	RK	WIDTH	MAXIMUM	4	5.5	3.5	5.5	2.3	2.6	5	3.3	3.2	5.4	1.9	1.9
		HU	MINIMUM	1752	2278	2736	2072	2286	1862	1931	1449	2331	2620	2348	1730
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	2579	3053	3060	3013	2980	2619	2866	2992	3028	3036	3012	2933
	IM	CROSS-SECTION AREA	mm^2	0.6	1.2	1	1	0.3	0.4	1.6	1.1	0.9	1	0.3	0.3

ANIMAL NUMBER				5											
CT NUMBER				0893											
CONTRAST METHOD				M ESENTERIC											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	1	1	3	3	1	1	1	1	3	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	5	5.7	3.8	5.9	2.4	2.9	6.7	4.7	3.9	6.2	2.8	3.2
		HU	MINIMUM	3063	3071	3062	3037	2742	3062	3063	3053	3052	3052	3052	3070
			MAXIMUM	3071	3071	3071	3071	3071	3067	3071	3071	3071	3071	3071	3071
			MEAN	3070	3071	3069	3066	3045	3067	3070	3066	3067	3063	3061	3071
	RK	WIDTH	MAXIMUM	5	5.6	4	5.5	2.6	2.5	6.6	4.1	3.8	6.4	3	3.2
		HU	MINIMUM	1836	2011	1393	3039	2317	1505	1461	3010	3061	1557	3045	3068
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	2957	2939	2945	3061	3020	2885	3019	3065	3066	3013	3064	3070
	IM	CROSS-SECTION AREA	mm^2	1.2	1.7	1.1	1.5	0.4	0.6	2.7	1.7	1.2	1.7	0.7	0.7

ANIMAL NUMBER				6											
CT NUMBER				0892											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				4	1	1	1	2	2	2	1	2	2	3	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	1	?	4.1	4.3	3.8	3.8	10.7	4.3	2.9	3.7	4	2.8
		HU	MINIMUM	1060	4.6	1377	1969	1386	1730	3060	3065	3069	2497	2170	2070
			MAXIMUM	1478	560	2509	2156	1902	2300	3071	3071	3071	3071	3071	3031
			MEAN	1318	477	2072	2275	1752	2030	3070	3070	3071	3003	2878	2932
	RK	WIDTH	MAXIMUM	2	?	4.2	5	3.4	3.7	10.8	4.3	3.1	3.6	4.1	2.8
		HU	MINIMUM	1108	281	1574	1545	1394	1426	1569	2121	1760	1192	2170	2354
			MAXIMUM	2270	569	2509	2516	2285	2369	3071	3071	3071	3071	3071	3071
			MEAN	1748	443	2101	2163	1892	2009	3017	3041	2981	2729	2889	2983
	IM	CROSS-SECTION AREA	mm^2	0.1	0.2	0.5	0.9	0.5	0.6	2.9	1.2	0.6	0.6	0.6	0.5

ANIMAL NUMBER				6											
CT NUMBER				8104											
CONTRAST METHOD				M ESENTERIC											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				2	1	1	1	4	4	1	2	2	2	2	3
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	4.8	3.2	3.8	3.6	2.1	2.1	7	4	3.6	3.3	5.4	3
		HU	MINIMUM	1347	1837	3056	1478	2018	2784	3058	3052	3050	2814	3062	2027
			MAXIMUM	3962	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	2249	2429	3069	2595	2800	3001	3068	3062	3061	3052	3068	2965
	RK	WIDTH	MAXIMUM	4.7	2.8	3.8	4	2	2.2	7.4	4	3.6	3.5	5.7	3
		HU	MINIMUM	2015	1555	2229	1740	1530	1967	2912	3052	2059	1522	2087	865
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	2472	2313	3005	2592	2579	2731	3068	3062	3007	2949	2923	2569
	IM	CROSS-SECTION AREA	mm^2	1.3	0.6	0.6	0.8	0.3	0.3	3.2	1	0.9	0.7	1	0.6

ANIMAL NUMBER				7											
CT NUMBER				0894											
CONTRAST METHOD				POPLITEAL											
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				1	1	1	1	1	2	2	2	1	1	1	2
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	6.5	3.6	2.2	2.1	2.5	2.9	5.4	2.8	1.9	2.3	4.6	2.7
		HU	MINIMUM	1623	2486	1308	3057	2407	2157	2635	1865	1981	3060	3065	1506
			MAXIMUM	3071	3071	2641	3071	3071	3071	3071	2772	3071	3071	3071	2609
			MEAN	2552	2805	2149	3067	2936	2926	3044	2074	2788	3069	3070	2057
	RK	WIDTH	MAXIMUM	7.7	4.2	2.3	2.2	2.5	2.8	5.4	2.8	1.7	2.4	4.6	2.7
		HU	MINIMUM	1259	2462	978	1364	1983	2157	1797	1050	1481	970	1426	1440
			MAXIMUM	3071	3071	2769	3071	3071	3071	3071	3036	3071	3071	3071	3071
			MEAN	1982	2845	2182	2716	2828	2891	2984	2008	2625	2654	2801	2751
	IM	CROSS-SECTION AREA	mm^2	2.6	1.1	0.4	0.4	0.4	0.4	1.6	0.6	0.3	0.4	1	0.5

ANIMAL NUMBER				7										
CT NUMBER				8106										
CONTRAST METHOD				M ESENTERIC										
CT MODALITY				SEQUENTIAL B70s						HELICAL B70s					
VERTEBRAL SITE				L1	T13	T12	T11	T10	T9	L1	T13	T12	T11	T10	T9
TD NUMBER				3	1	1	1	1	4	1	1	1	1	1	1
LARGEST TD BRANCH	IM	WIDTH	MAXIMUM	4.7	3.9	2.5	2.6	2.7	2.6	6.5	5.5	2.4	2.4	5.5	4.7
		HU	MINIMUM	3069	3061	3071	3062	3071	3065	3064	3061	3059	3039	3060	3059
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3071	3069	3071	3069	3071	3069	3070	3069	3066	3064	3069	3069
	RK	WIDTH	MAXIMUM	4.2	4.2	2.7	2.8	2.8	2.7	6.6	5.5	2.4	2.7	5.5	4.6
		HU	MINIMUM	3062	3060	1965	900	2767	2611	1900	3051	2629	1918	2829	3059
			MAXIMUM	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071	3071
			MEAN	3070	3068	3020	2894	3061	3054	3045	3065	3050	2950	3059	3068
	IM	CROSS-SECTION AREA	mm^2	1.5	1.1	0.5	0.5	0.4	0.5	2.9	1.4	0.5	0.5	1.6	1.1

CT = Computed tomography, TD = Thoracic duct, HU = Hounsfield units, T9-T13 = Thoracic vertebrae 9 to 13, L1 = Lumbar vertebra 1, IM = Ian Millward, RK = Robert Kirberger

Appendix 8

Thoracic duct position relative to aorta							
Patient number	CT number	Vertebral site					
		T9	T10	T11	T12	T13	L1
211921	0886	01.00 02.30 11.30	01.00 02.00	01.30	01.00	01.00	01.00 02.00
	8103	12.00 01.00 02.30	01.00 02.00	01.00 02.00	01.00	01.00	01.30
211922	0893	02.00 03.00 11.00	01.00 02.30 11.00	12.00 02.00	01.30	01.00	12.00
	8107	02.00 03.00 11.30	01.00 02.30 11.00	01.00	02.00	12.45	12.00
211923	8116	02.00 02.30 11.30	12.00 01.00 11.00	01.30 11.00	01.00 02.30	02.00 03.00	03.00
	8125	02.00 03.00 11.30	01.30 02.30 11.30	12.00 01.00 01.30	12.00 10.30	02.00	01.00
211925	0894	12.00 01.00	01.00	02.00	01.30	12.30	12.00 01.30 10.30
	8106	12.00 02.30 11.30	02.00	02.00	02.00	12.30	12.30
211926	0892	12.00	01.00	02.00	02.00	02.00	12.30 02.00 05.30 08.30
	8104	12.00 01.00 02.00 11.00	12.00 01.30 02.00 11.30	12.00	12.30	06.00 12.00	12.00 07.00 08.00 10.00
211927	8113	12.00 01.00 02.00 03.00	10.30 02.00	10.30 02.00	01.30	01.30	12.00 2.00
	8127	12.00 01.00 02.00 03.00	10.30 02.00	10.30 02.00	12.00 01.30	01.00	12.00 01.00
211929	0889	01.00	12.00 01.30	02.30	01.00 02.00	01.00 02.00	12.00
	8124	02.00 02.30	01.30 02.00	02.00	02.00	02.30	02.00

CT = Computed tomography
T9-T13 = Thoracic vertebrae 9 to 13
L1 = Lumbar vertebra 1

Appendix 9

Popliteal contrast spillage					
Patient identification	Lymph node used	Contrast volume injected (ml)	Ultrasound estimated spillage (ml)	Needle gauge	Radiographic spillage grade 0-5
211921	L	14.3	1.0	25	3
211922	L	13.8	1.0	25	1
211923	L	12.5	2.0	23	3
211924	L	0.5	0.5	23	1
	R	10.5	0.5	23	4
211926	L	11.2	1.0	25	2
211927	L	6.0	6.0	23	2
	R	12.3	0	25	1
211929	L	14.8	0	25	2

L = Left
R = Right

Appendix 10

Computed tomographic start times and intervals							
Animal ID	CT ID	Admin. method	Topogram start	Helical start	Helical end	Seq. start	Seq. end
211926	0892	P	10.06.57	10.44.02	10.44.25	10.44.54	10.46.16
	8104	M	11.36.56	11.57.55	11.58.21	11.58.45	12.00.54
211924	0894	P	09.52.14	10.22.17	10.22.38	10.23.01	10.25.04
	8106	M	11.40.57	12.00.49	12.01.13	12.01.38	12.03.10
211923	8116	P	10.06.57	10.29.03	10.29.23	10.29.41	10.30.48
	8125	M	11.45.12	12.06.03	12.06.27	12.06.48	12.08.20
211929	0889	M	11.47.36	11.57.44	11.58.08	11.58.29	11.59.41
	8124	P	12.52.46	13.29.12	13.29.36	13.29.52	13.31.11
211922	0893	M	11.36.31	12.05.19	12.05.43	12.06.02	12.07.34
	8107	P	10.34.50	10.57.35	10.58.00	10.58.16	10.59.39
211927	8113	P	10.14.51	10.49.12	10.49.36	10.49.52	10.51.16
	8127	M	11.03.09	11.12.23	11.12.47	11.13.11	11.15.03
211921	0886	M	11.45.36	11.56.24	11.56.49	11.57.16	11.58.59
	8103	P	10.05.05	10.28.12	10.28.36	10.28.54	10.29.56

ID = Identification
CT = Computed tomography
Admin. = Administration
Seq. = Sequential
P = Popliteal
M = Mesenteric

Appendix 11

Computed tomography exposure chart								
Vertebral site	Helical – CARE dose®				Sequential			
	mAs	kV	Duration (s)	Total mAs	mAs	kV	Duration (s)	Total mAs
T9	35	130	26	910	70	130	1.5	696
T10					72	130	1.5	
T11					84	130	1.5	
T12					75	130	1.5	
T13					76	130	1.5	
L1					87	130	1.5	

mAs = Milliampere-seconds
kV = Kilovolts
s = Seconds
T9-T13 = Thoracic vertebrae 9 to 13
L1 = Lumbar vertebra 1