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SCIENCE TEXT

SMALL ANIMALS

ORIGINAL ARTICLE

Thoracic radiographic findings of canine spirocercosis in Australia

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Canine spirocercosis in Australia has been poorly described in the veterinary literature. The objectives of this multicentre retrospective case series were to increase the awareness of veterinarians (including teleradiology providers) regarding *Spirocerca lupi* in Australia and to describe the thoracic radiographic findings of dogs infected with *S. lupi* with comparison to other endemic regions. Fifty-nine dogs with a diagnosis of canine spirocercosis were recruited from veterinary practices located in subtropical and tropical Australia. Many (54/59; 92%) originated from Mount Isa, Queensland, due to proactive screening. Thoracic radiographs identified 42 oesophageal masses in 35/59 (59%) of affected dogs. Identification of oesophageal masses was nearly always facilitated by oesophageal gaseous distension after gastro-oesophageal endoscopy, sedation or anaesthesia (33/35, 94%). Oesophageal masses were most frequently centred at T8. Where the aorta was visualised, aortic enlargement was detected in 17/42 (40%) dogs. Spondylitis was frequently detected (32/59; 54%) and most frequently located at T8-11. Spondylosis deformans was less frequently detected (14/59; 24%) but in 7/14 (50%) studies it was present concurrently with spondylitis. Spondylitis had varied morphological features, some of which were contrary to previously reported definitions. Despite this, the radiographic appearance of spondylitis allowed relatively reliable differentiation from spondylosis deformans and added significant confidence to the radiographic diagnosis of spirocercosis. Pleural effusion (5/59; 8%) was the most frequent additional radiographic finding. In conclusion, thoracic radiographic findings of canine spirocercosis in Australia are similar to other endemic regions and *S. lupi* is present in multiple regions of Australia not previously reported.

Keywords canine; dogs; nematode; radiography; *Spirocerca lupi*; spondylitis

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Spirocerca lupi is a spirurid nematode parasite of carnivores with a worldwide distribution, typically in tropical and subtropical regions including South Africa, Kenya, Israel, Pakistan, Brazil, India, Greece, Turkey, southern United States and Asia.[1–8] *S. lupi* has also been increasingly reported in temperate countries such as Italy and Hungary.[9,10]

S. lupi has a complex indirect life cycle involving multiple species of coprophagous dung beetles (Scarabidae family) as intermediate hosts, paratenic hosts (e.g., rodents, lizards, poultry and rabbits) and dogs (*Canis familiaris*) as definitive hosts.[1,11] Dogs become infected by ingestion of the dung beetle (either directly or through coprophagia) or an infected paratenic host. The larvae migrate through the walls of the gastric and gastroepiploic arteries, then the caudal thoracic aorta, to eventually reach the caudal oesophagus for final development. Here, they stimulate the formation of nodules or masses. The cycle is completed when the female worm perforates the mucosa to lay eggs into the oesophageal lumen.[1,8] The prepatent period is usually 3–6 months, although adult *S. lupi* can persist in nodules within the dog for 2 years or longer.[1,8]

The diagnosis of canine spirocercosis is challenging. Firstly, clinical signs are often nonspecific, with vomiting and regurgitation being most frequently reported.[12–15] Sialadenosis can occur and may contribute to ptyalism and dysphagia.[16] Acute collapse secondary to aortic aneurysm rupture or aortic thromboembolism has been described.[17–19] Aberrant migration of *S. lupi* has also been reported to many organ systems, resulting in a variety of nonclassical presentations.[20–22] Secondly, faecal floatation has a low sensitivity of 42%–67% because it relies on egg shedding, which is intermittent.[23] Gastro-oesophageal endoscopy and visualisation of the characteristic caudal oesophageal masses is currently the gold standard for diagnosis with a sensitivity of up to 100% but requires general anaesthesia.[1,8] Thoracic radiography is often used as an initial screening test, with a reported sensitivity and specificity of 84% and 100% respectively.[24,25] Radiographic findings of canine spirocercosis have been well described.[2,13,14,24–27] The combination of a caudodorsal mediastinal mass and caudal thoracic vertebral spondylitis or an aortic aneurysm is considered to be pathognomonic.[13,26]

Veterinary literature of canine spirocercosis originating from Australia is particularly scarce, limited to mostly case reports.[28,29] Only one source briefly cites the prevalence of 17% in camp dogs within the Tanami Dessert region.[30] Therefore, the aims of this study are twofold: to describe in detail the thoracic radiographic findings of dogs diagnosed with spirocercosis in Australia with comparison to those reported in endemic regions; and to increase the awareness of veterinarians regarding the disease by providing the first comprehensive assessment of *S. lupi* in Australia. Our hypothesis is that the radiographic findings of dogs with canine spirocercosis in Australia would be similar to other regions. We also hypothesise that information regarding the location of the focal indentation in the craniodorsal oesophageal wall created by the right azygos vein will be particularly relevant when performing pneumo-oesophagraphy to increase the chances of diagnosing spirocercosis. This radiographic finding has been previously identified as a normal variant, but the exact location has not been described.[31] Thus, a supplementary aim of this study is to describe the exact location of this indentation.

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Methods

Selection and description of subjects

This was a multicentre retrospective cross-sectional study. Veterinarians in Australia were invited to take part in this research through email communication. A total of 46 veterinary practices were contacted, predominantly located in tropical and subtropical climate zones of Australia: regions with hot humid summers, warm humid summers, hot dry summers and mild winters (Figure 1). These locations were expected to be favourable for the survival and propagation of *S. lupi* and coprophagous dung beetles. The same email invitation was also forwarded to an Australian and New Zealand College of Veterinary Scientists (ANZCVS) staff member to invite a total of 2417 ANZCVS members across Australia. The deadline for veterinarians' response to the invitation was 30 May 2024.

All participating veterinarians retrospectively reviewed their practice records. Dogs that presented to any of the contacted veterinary practices or to any ANZCVS member were enrolled based on the following inclusion criteria: (1) antemortem or postmortem diagnosis of spirocercosis; and (2) have at least one thoracic radiograph performed at the time of diagnosis. An antemortem diagnosis of spirocercosis included cases that had a positive faecal flotation result (i.e., visualisation of *S. lupi* eggs), or a positive endoscopic result (i.e., visualisation of the typical caudal oesophageal nodule or mass, with or without visualisation of *S. lupi* worms), or a combination of both. A postmortem diagnosis of spirocercosis included histopathologically confirmed cases and cases where one or any combination of the following gross findings were observed (caudal oesophageal nodules/masses, aortic lesions typical of *S. lupi* including aneurysms[32], presence of *S. lupi* nematode anywhere in the dog).

For any dogs that had follow-up thoracic radiographs, these studies were also included only if the acquisition technique was similar. The most recent radiographic study was selected for comparison when any dog had multiple follow-up studies at different time points.

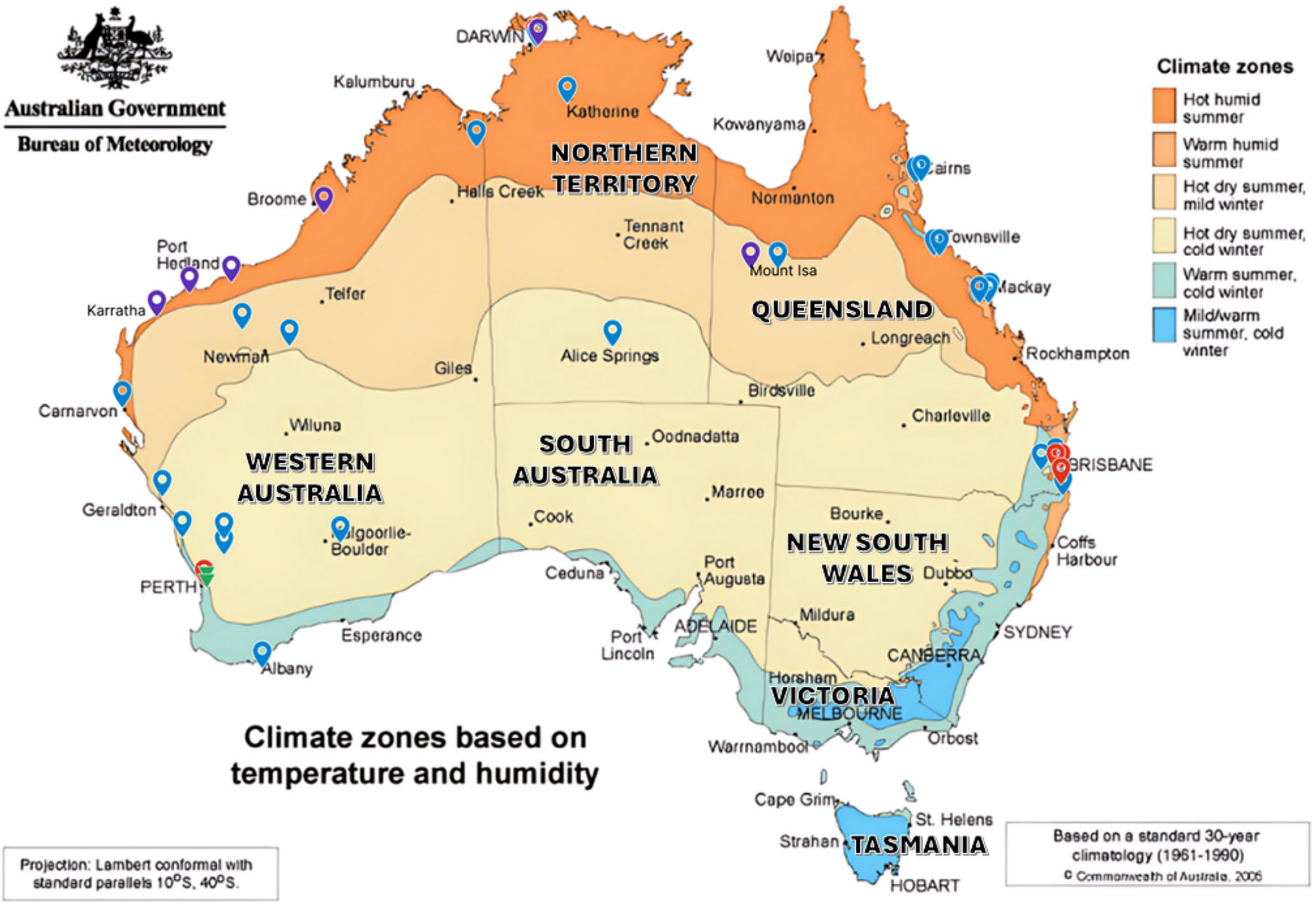

Figure 1. Map showing the Australian climate zones based on temperature and humidity, sourced and adapted with permission from the Australian Bureau of Meteorology, accessed 30 July 2024 from http://www.bom.gov.au/climate/maps/averages/climate-classification/. Markers on the map show approximate locations of the veterinary practices or ANZCVS Australian members contacted. Purple markers denote locations where cases of canine spirocercosis were diagnosed between October 2018 and May 2024. Green markers represent cases that were diagnosed and reported by veterinary referral centres; these dogs did not normally reside in these locations. Red markers denote locations that have reported cases of canine spirocercosis (date of diagnosis and case numbers not provided) but these were cases were not included in this study. Blue markers denote locations that either did not respond to the email survey or did not report any cases of canine spirocercosis.

Cases were excluded if no radiographs were received by 30 May 2024; if the radiographs were not of sufficient diagnostic quality; or if there was concurrent thoracic pathology that was likely unrelated but which precluded accurate interpretation of the mediastinum.

Data recording and analysis

Data collection, extraction and recording were performed by a veterinary radiology resident (P.T.) and a primary care veterinarian (G.T.). Data use was approved by each institution. Each patient had the following data recorded: signalment (age, breed, sex); reason for presentation and/or most recent clinical history; method of diagnosis (endoscopy, faecal flotation, gross postmortem examination, histopathology, improvement/resolution of associated clinical signs and oesophageal nodule[s] in response to specific treatment for spirocercosis); type of worming prophylaxis given before diagnosis; type of treatment administered after diagnosis (specified anthelmintic and/or other medications); and if available, relevant imaging, cytopathology and histopathology reports.

Radiographic acquisition technique was also recorded: type and number of projections performed; if sedation or anaesthesia was used (unsedated, sedated or anaesthetised); when gastro-oesophageal endoscopy was performed (before or after thoracic radiography). Photographs of any oesophageal lesion(s) for all patients diagnosed with endoscopy were extracted. If the same patients had any follow-up radiographic studies, these were compared with the initial radiographic study performed at the time of diagnosis. If follow-up gastro-oesophageal endoscopy was performed at the same time as the follow-up radiographs, photographs of the endoscopic examination were also extracted.

Image acquisition technical parameters for the institutions from which the thoracic radiographs were sourced are listed in Table S2. The radiographs were viewed using a cloud-based Digital Imaging and Communications in Medicine (DICOM) viewing and picture archiving and communication system (PACS) progressive web application (Keystone Omni, version 1.8.257.12830, Asteris). Objective measurements were performed using this web application. All studies were reviewed by the same resident (P.T.) and two board-certified (FANZCVS) veterinary radiologists (B.H. and Z.L.) with access to temporally matched endoscopic images. Decisions were reached by consensus for every radiographic feature.

For each study, three main regions were assessed based on the pathophysiology of canine spirocercosis: (1) oesophagus, (2) aorta and (3) spine.

Oesophagus. The degree of oesophageal gas distension was defined as none, focal or generalised. The presence of a focal dorsal indentation in the cranial thoracic oesophageal wall caused by the azygos vein and its location (with reference to the thoracic vertebrae) was recorded. The presence and number of any soft tissue nodule(s) and/or mass(es) within the region of the oesophagus that were later confirmed with endoscopy, advanced imaging or postmortem was recorded. Each lesion was assessed for the following features: size (maximal length and height in millimetres), location (centre and range with reference to the thoracic vertebrae), presence of any mineralisation. Size measurements were only performed if the margins of the mass(es) were well defined.

Aorta. The aorta was defined as either visualised or not visualised (i.e., if aortic margins were poorly defined or if the aorta was completely effaced). When visualised, the aorta was assessed for the presence of enlargement (yes/no; if yes, whether enlargement was focal or diffuse was also recorded) and mineralisation (yes/no).

Spine. The spine was assessed for the presence of spondylitis and/or spondylosis deformans. Spondylitis was defined as a linear or flat periosteal reaction affecting the ventral cortex of the vertebral body. Features of spondylitis recorded were opacity and margination: acute spondylitis was defined as faintly mineralised periosteal new bone with poorly defined margins; chronic spondylitis was defined as well mineralised periosteal new bone with well-defined margins. If spondylitis extended across the intervertebral disc space in a continuous manner with a flat ventral surface, it was described as bridging.

For the purposes of this study, any linear or flat periosteal reaction that ran parallel to the ventral cortex of the vertebral bodies creating the appearance of two lines was summarised as the 'double cortical sign'. Additionally, flat periosteal new bone with cranial and/or caudal triangular margins was named the 'skate sign' due to the shape being reminiscent of an ice skate blade.

Spondylosis deformans was recorded because it is a common thoracic spinal radiographic finding that needs to be differentiated from spondylitis. It was defined as curved osteophytes at the vertebral endplates. If the osteophytes were continuous across the intervertebral disc space, they were defined as bridging.

For the description of location for both spondylitis and spondylosis deformans, the thoracic spine was arbitrarily divided into three main segments: cranial (T1-4), middle (T5-T8) and caudal (T9-13).

Additional radiographic findings. Any other imaging findings were described and categorised based on anatomic location: airways, lungs, pleural space, mediastinum, cardiovascular, musculoskeletal, cranial abdomen.

For any dog that did not have complete thoracic radiographic studies, confirmation and interpretation of certain findings in some anatomical regions (particularly the lungs) was challenging. Only unequivocal and pertinent findings to this paper's objectives are reported below.

Statistics

Descriptive statistics were performed by the resident (P.T.) using a commercially available spreadsheet software programme (Microsoft Excel for Microsoft 365, Version 2406, Microsoft). Categorical data were expressed as frequencies, and continuous data were expressed as mean and median values (range minimum value to maximum value).

Results

Patient findings

Fifty-nine dogs met the inclusion criteria (Figure 2). The cases were diagnosed between October 2018 and May 2024. The mean and

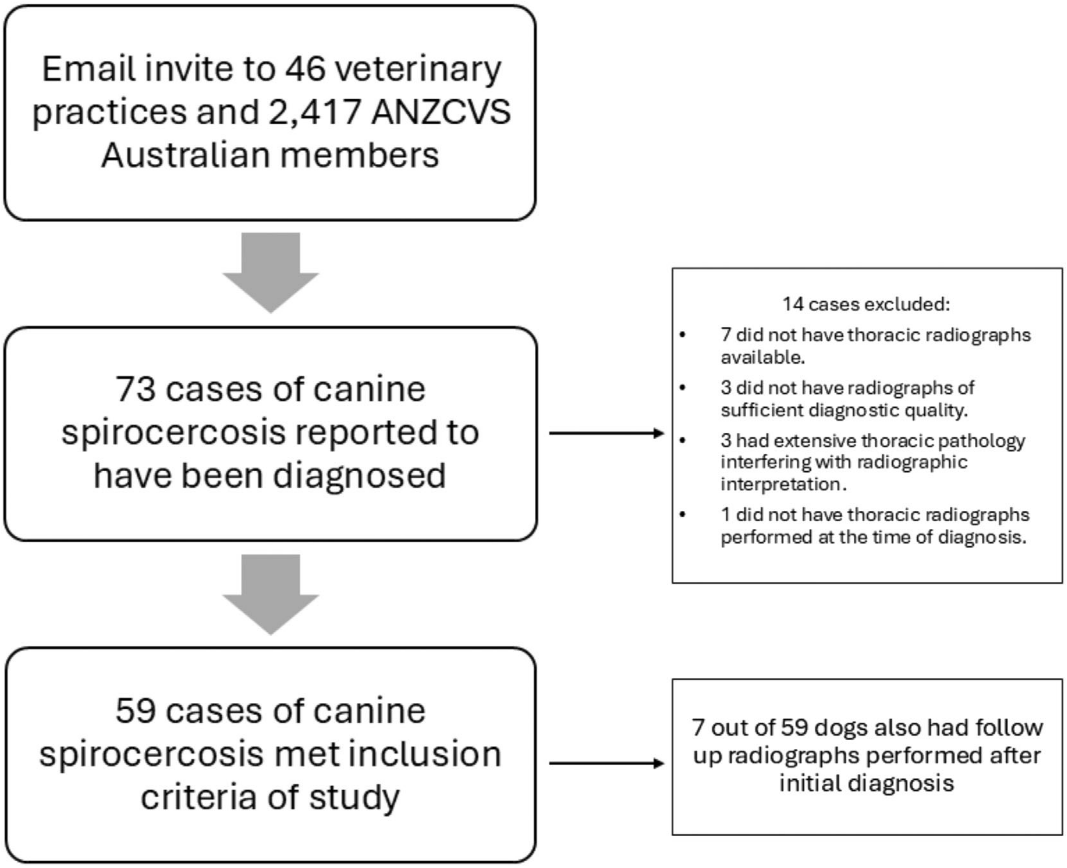

Figure 2. Flowchart showing how cases were recruited, including the reasons for exclusion.

median age were 4.5 years and 2.8 years, respectively (6 months to 14 years). There were 30 males (23 entire, 7 neutered) and 29 females (21 entire, 8 neutered). Many dogs were crossbreeds (26/59; 44%), with 22/26 of them being crossed with either a medium or large breed dog. This was followed by Labrador Retrievers (7/59; 12%) and Australian Cattle Dogs (7/59; 12%). Five (5/7) of the Labrador Retrievers were reported by their owners to have coprophagic tendencies. See Supplementary File S1 for the full list of breeds. The majority (54/59; 92%) were from Mount Isa (Queensland), with two dogs from South Hedland (Western Australia), and one dog each from Broome (Western Australia), Karratha (Western Australia) and Durack (Northern Territory). Figure 1 above shows the geographical distribution of cases in our study population.

Thirty-five dogs presented for being unwell (35/59; 59%). Of the dogs that were unwell, 30/34 (88%) presented for acute (<2 weeks duration) signs and 4/34 (12%) presented for chronic (>2 weeks duration) signs. Table 1 shows the clinical signs and physical examination findings recorded. Vomiting and regurgitation were common (19/59; 32%) and neuromuscular signs were observed in 9/59 (15%) dogs. Of note, the two patients that were presented for acute collapse were the same two patients that had mucous membrane pallor and muffled heart sounds. The remaining dogs (24/59; 41%) had subclinical disease and presented for the following reasons: routine desexing (9/59; 15%), elective procedures (6/59; 10%), other dog(s) in the household had been diagnosed with spirocercosis (5/59; 8%) and wound management (4/59; 7%). Four dogs had comorbidities: dirofilariasis (2/4), diabetes mellitus (1/4), myasthenia gravis (1/4).

Fifty-seven (57/59; 97%) dogs had gastro-oesophageal endoscopy performed and most were diagnosed with gastro-oesophageal endoscopy alone (53/59; 90%). Four dogs had other diagnostics in addition to endoscopy to confirm the diagnosis: gross postmortem, faecal flotation (Figure 3A), endoscopic biopsy and histopathology, computed tomography and histopathology. One dog was diagnosed using a combination of thoracic radiography and subsequent response to treatment for spirocercosis. The final dog was diagnosed with gross postmortem alone (Figure 3B,C). Of the three (3/59) dogs that had faecal flotation performed, only one was positive for *S. lupi*; this dog was the same one as described previously. Only two dogs were diagnosed at specialist referral centres, with the remaining (57/59; 97%) diagnosed at their respective primary care practices.

Only 2/59 (3%) dogs were up to date with worming prophylaxis at the time of diagnosis: one was treated with topical imidacloprid 10%/moxidectin 2.5% (Advocate®, Elanco) and the other did not have the prophylactic treatment specified by the owner or in the clinical record. Most dogs (46/59; 78%) received antiparasitic treatment at the time of diagnosis. Information regarding the type of antiparasitic treatment is available in File S1. The owners of ten dogs declined treatment, and one dog was euthanased during exploratory thoracotomy.

TABLE 1. **Reported clinical signs and physical examination findings in 59 dogs diagnosed with canine spirocercosis in Australia**

Clinical signs/physical exam findings	Number of dogs[a]
Subclinical disease	24
Vomiting	13
Inappetence	11
Lethargy or weakness	7
Pyrexia	7
Regurgitation	6
Dysphagia	5
Ptyalism	5
Weight loss	4
Odynophagia	3
Peripheral limb lameness/swelling	3
Neck pain/swelling	3
Food aversion	2
Coughing	2
Acute collapse	2
Pelvic limb mono- or paraparesis	2
Pale mucous membranes	2
Muffled heart sounds	2
Bilateral mandibular salivary gland enlargement (sialadenosis)	1
Submandibular lymphadenomegaly	1
Systemic hypertension	1
Masticatory muscle atrophy[b]	1
Tongue oedema	1
Acute bilateral cortical blindness, hyphaema and glaucoma	1

[a] Some dogs were reported to have multiple clinical signs and/or examination findings.
[b] This dog was also diagnosed with myasthaenia gravis.

Radiographic findings

Table 2 summarises the variation in acquisition technique. Tables 3 and 4 summarise the main radiographic findings recorded. All radiographic findings are provided in the Supplementary Material.

Twenty-one (21/59; 36%) dogs had an oesophageal mass and spondylitis. Only eight (8/59; 14%) dogs had oesophageal mass(es), spondylitis and aortic enlargement concurrently. Five (5/59; 8%) dogs had no radiographic findings.

Variations in acquisition technique. Thirty-two (32/59; 54%) dogs were anaesthetised for thoracic radiography: 29/32 had radiographs performed post-gastro-oesophageal endoscopy and 3/32 before endoscopy. Thirteen (13/59; 22%) dogs were unsedated and 4/59 (7%) were sedated.

Ten dogs (10/59; 17%) had projections with different acquisition techniques performed at the time of diagnosis. One (1/10) had sedated projections acquired then 24 h later had anaesthetised projections performed after orogastric tube placement. Seven (7/10) had both unsedated and anaesthetised post-gastro-oesophageal endoscopy projections performed, with time elapsed between studies ranging from 2.5 h to 3 days. Two (2/10) had anaesthetised pre- and post-gastro-oesophageal endoscopy projections performed. Three dogs with unsedated projections (3/7) and the two dogs with anaesthetised pre-endoscopy projections (2/2) all had an ‘indistinct soft tissue opacity’ described in the dorsal mid to caudal mediastinum within the region of the oesophagus. In all five dogs, the anaesthetised post-endoscopy projections had generalised oesophageal gaseous distension which allowed a final radiographic diagnosis of a caudal thoracic oesophageal mass.

One (1/10) dog had radiographs under sedation and then again under anaesthesia post-gastric intubation, performed 26 hours apart. In this case, the generalised oesophageal gaseous distension secondary to gastric intubation allowed better visualisation of the caudal oesophageal mass, enabling a more accurate estimation of size.

Oesophagus. A total of 42 oesophageal masses were detected in 35/59 (59%) studies, with a large proportion being visualised due to concurrent generalised or focal oesophageal gas distension (33/35; 94%) (Figure 4). Almost all the masses (41/42; 98%) were detected between the level of T7 and T10 and were most frequently centred at T8 (19/42; 45%). Three nodules (3/42; 7%) had mineralisation. The height and length of the oesophageal masses were measured on lateral projections in 58/59 dogs because one of the studies was only available in JPEG format. The mean and median length were 52 mm and 47 mm respectively (24–196 mm). The mean and median height were 33 mm and 28 mm respectively (15–101 mm).

Indentation of the dorsal oesophageal wall by the azygos vein (Figure 5) was detected in 28/59 (47%) studies: 27/28 had generalised oesophageal gas distension and 1/28 had focal gas distension. It was most frequently detected at the level of the T5 vertebra (16/28; 57%), with its location ranging between the level of T4 and T6.

Aorta. The aorta was visualised completely in 42/59 (71%) studies and visualised partially (ascending aorta and aortic arch only) in 2/59 dogs (3%). Aortic enlargement (Figure 4A,B) was detected in 17/42 (40%) studies in which the aorta was visualised: 15/17 had diffuse enlargement and 2/17 had focal enlargement (both between the ascending aorta and proximal descending aorta). In one dog that had a 3-view study, the descending portion had marginally undulating margins only appreciated on the DV projection without enlargement detected on any other projection. However, the DV projection in this study was mildly rotated. Aortic mineralisation was not detected in any dog.

Spine. Spondylitis was detected in 32/59 (54%) dogs with a variety of morphological appearances (Figure 6). The periosteal new bone was centred on the vertebral body in all dogs.

Spondylitis was defined as acute in 11/32 dogs, chronic in 16/32 dogs and having mixed features in 5/32 dogs. The ‘double cortical line’ was more frequently detected in dogs with acute spondylitis (6/11) compared with dogs with chronic spondylitis (2/17). The ‘skate sign’ was more frequently detected in dogs with chronic spondylitis (11/17) compared with dogs with acute spondylitis (1/11).

Figure 3. Faecal floatation (A) of a dog infected with *S. lupi* showing a single oval-shaped, smoothly margined, embryonated egg (black arrow) at 100× magnification. Gross postmortem of a different dog that had an oesophageal nodule (B) with *S. lupi* nematodes in situ (white arrow) and an aortic aneurysm (C) that was incised open along the midsagittal plane. Photo credits: (A) University Avenue Veterinary Hospital; (B) and (C) Dr Scott Davis of Broome Veterinary Hospital.

In 15/32 (47%) dogs, the spondylitis was bridging or partially bridging the intervertebral disc space with vertebral endplate involvement; of these dogs, 9/15 had chronic spondylitis.

Multiple thoracic vertebral segments were often involved in the same dog, resulting in a total of 46 segments affected by spondylitis ranging from T5-L1. Most commonly, it was detected in the caudal thoracic segment (T9-13) (28/46; 61%), followed by the middle (T5-8) segment (17/46; 37%). The number of vertebrae affected ranged from 1 to 7 vertebrae in any one dog, with the most frequently affected thoracic vertebrae being T8-11. The mean and median age

TABLE 2. Variations in radiographic acquisition technique in 59 dogs diagnosed with canine spirocercosis in Australia

	Anaesthetised[a]	Sedated	Unsedated
3-view studies			
Left lateral, right lateral, ventrodorsal	1	2	0
Left lateral, right lateral, dorsoventral	5	2	1
2-view studies			
Left lateral, right lateral	9	0	3
Right lateral, dorsoventral	3	0	1
1-view studies			
Left lateral	18	0	0
Right lateral	6	0	8
Total	**42**	**4**	**13**

[a] 10 dogs from this group had variations in acquisition technique for different projections within a study: 7 had unsedated and anaesthetised post-gastro-oesophageal endoscopy projections; 2 had anaesthetised pre- and post-gastro-oesophageal endoscopy projections; 1 had sedated and anaesthetised postgastric tube placement projections. They were counted in this group as it was the anaesthetised projections that allowed radiographic diagnosis of an oesophageal mass and hence, spirocercosis.

TABLE 3. Oesophageal and aortic findings at time of diagnosis in 59 dogs diagnosed with spirocercosis in Australia

Radiographic finding	Frequency of finding	Total
Oesophageal mass(es)		
Detected		
With generalised oesophageal gas distension	27	35 dogs
With focal oesophageal gas distension	6	
No oesophageal distension	2	
Not detected		
With generalised oesophageal gas distension	10	24 dogs
With focal oesophageal gas distension	6	
No oesophageal distension	8	
Centre location		
T1-3	1	42 nodules detected in 35 dogs
T4-7	16	
T8-13	25	
Mineralisation		
Yes	3	
No	39	
Aortic enlargement		
Diffuse	15	17 dogs
Focal	2	

TABLE 4. Clinical and radiographic features of spirocercosis-associated spondylitis and spondylosis deformans in 59 dogs from Australia

Clinical / radiographic feature	Spondylitis	Spondylosis deformans
Age (years)		
Mean	4.4	8.4
Median	2.4	9.4
Range	0.5–14.0	2.0–14.0
Bridging		
Yes	10	3
Partially	5	4
Chronicity		
Acute	11	N/A
Chronic	16	
Mixed	5	
Skate sign	14	N/A
Double cortical line	13	N/A
Total detected (dogs)	32	14
Location		
T1-4 (cranial)	1[a]	1
T5-8 (middle)	14	11
T9-13 (caudal)	30	9
Lumbar	1[b]	6
Total vertebral segments affected[c]	46	27

[a] T4 spondylitis.
[b] L1 spondylitis.
[c] Multiple vertebral segments were affected in some dogs.

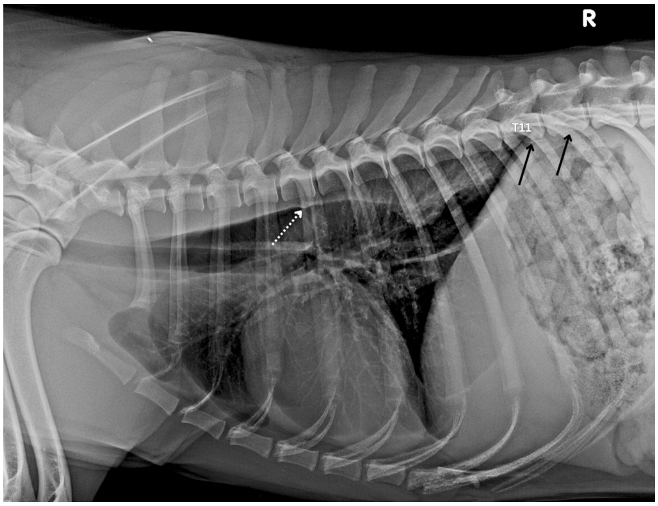

Figure 5. Post-gastro-oesophageal endoscopy anaesthetised right lateral projection of the thorax showing generalised oesophageal gas distention and the dorsal indentation created by the azygos vein (broken line white arrow). T11 vertebra is labelled, and spondylitis is also detected (black arrows). Radiographs credit: Mount Isa Veterinary Surgery.

for patients that had spondylitis were 4.4 and 2.4 years respectively (range 6 months to 14 years).

Spondylosis deformans was detected in 14/59 (24%) dogs (Figure 6) and was either partially or completely bridging in 7/14 (50%) dogs. Additionally, spondylosis deformans was present concurrently with spondylitis in 8/14 (57%). The mean and median age for patients that had spondylosis deformans were 8.4 years and 9.4 years respectively (range 2 to 14 years).

Additional radiographic findings. Five dogs (5/59; 8%) had pleural effusion detected (Figure 7). The cause of pleural effusion was confirmed by thoracocentesis in 4/5 of these dogs: three were diagnosed with haemothorax and one had haemorrhagic pyothorax. One patient had repeat thoracic radiographs four days after the initial study, which showed resolution of previously identified pleural effusion.

Three dogs (3/59; 5%) had tracheal and/or stem bronchial displacement secondary to oesophageal masses. Two dogs (2/59; 3%) had ventrally distributed alveolar lung patterns; both were unsedated studies.

All other additional findings are listed in Table S2.

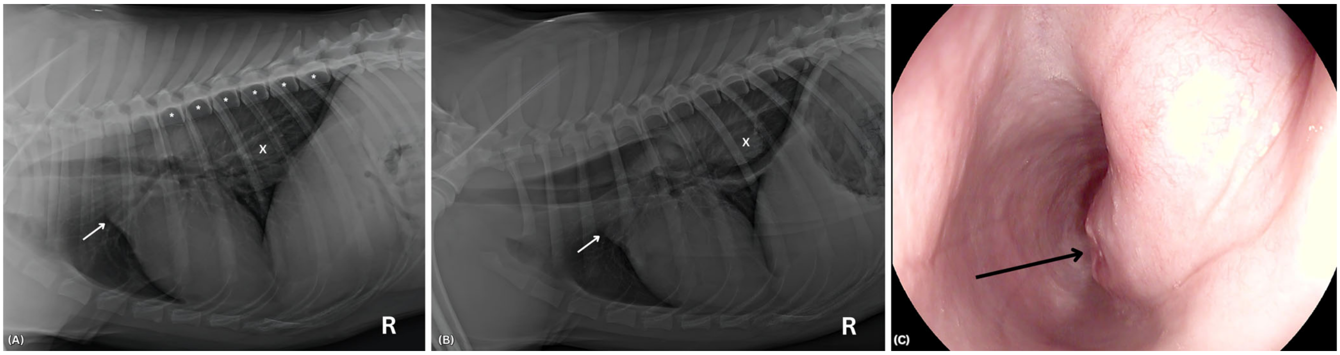

Figure 4. Unsedated (A) and post-gastro-oesophageal endoscopy anaesthetised (B) right lateral projections of the thorax; endoscopic image of oesophageal nodule (C) in the same patient. In (A), there is an ill-defined soft tissue opacity structure in the caudodorsal mediastinum ('X') that was confirmed to be the caudal oesophageal nodule. Note the ventral faintly mineralised spondylitis from T6-11 (asterisks on image A) visible on both projections. Better visualised in (B), the aortic arch has mild focal bulging past the cranial margins of the cardiac silhouette (white arrows). Image (C) shows the classic broad-based oesophageal nodule with the operculum (black arrow) through which the female worm will deposit eggs into the lumen.[20] Radiographs and photo credit: Mount Isa Veterinary Surgery.

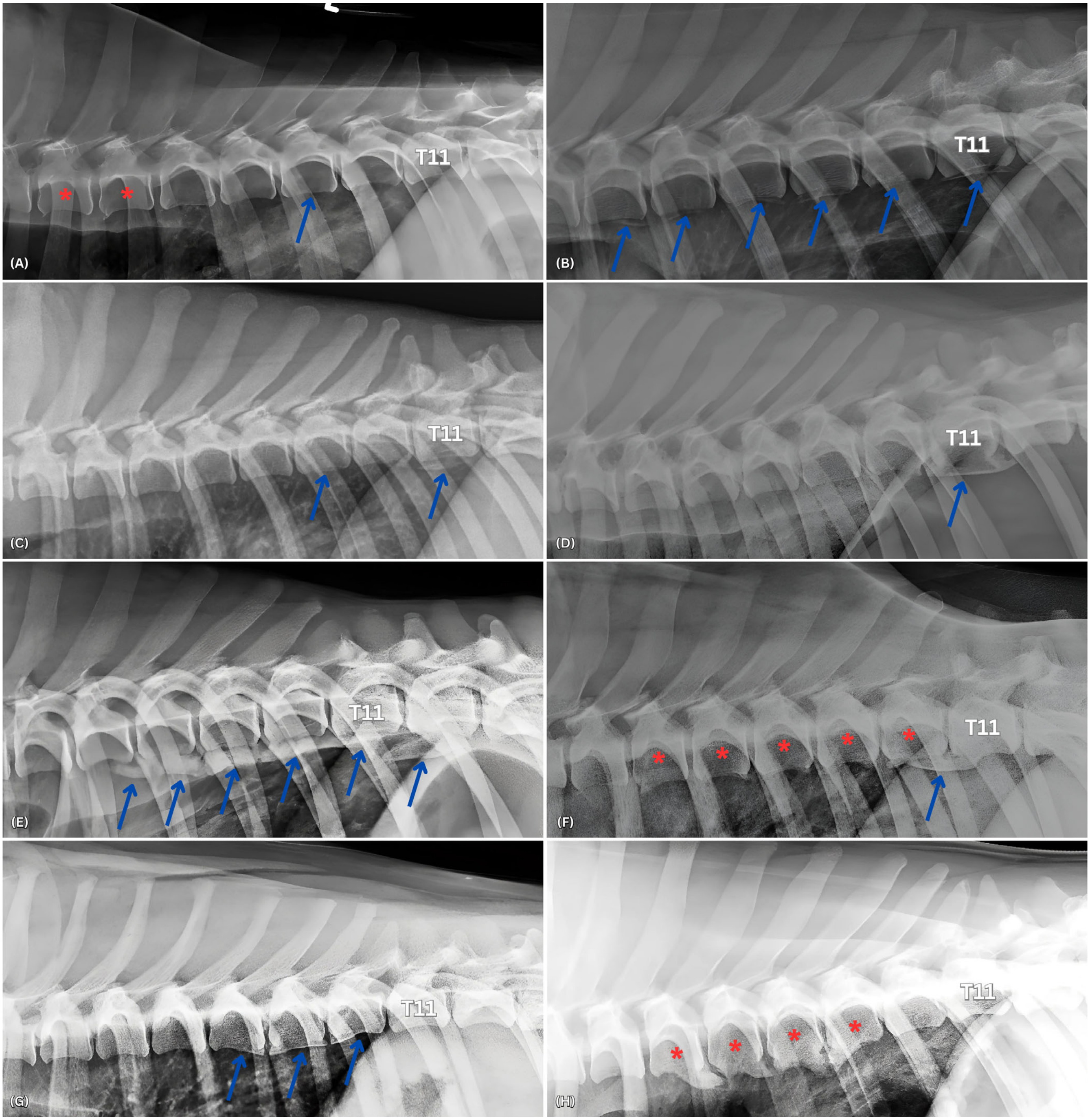

Figure 6. **Cropped lateral radiographs with window and levelling optimised for the thoracic spine showing the morphological variation in spondylitis (blue arrows) and vertebrae affected by spondylosis deformans (red asterisks); T11 vertebra labelled for reference. (A) shows ventral flattening of the T9 vertebral body, especially when compared with the normal concave ventral margin of the other thoracic vertebral bodies. (B) shows faintly mineralised, hazy linear spondylitis; described as the 'double cortical line'. (C) shows spondylitis at T9 and a 'skate sign' at T11. (D) shows a different appearance of the 'skate sign'. (E) shows extensive spondylitis at T7-11 and a skate sign at T12. (F) shows mineralised spondylitis bridging across T10-T11 intervertebral disc space. (G) shows another variation of the 'skate sign'. (H) shows proliferative, curved new bone involving both the vertebral body and endplate with partial bridging; this was described as spondylosis deformans in this study, but spondylitis has been known to mimic this appearance.[37] Radiographs credit: Mount Isa Veterinary Surgery.**

Longitudinal data. Seven (7/59; 12%) dogs had follow-up radiographs acquired, with one dog having two studies performed at different follow-up time points. Based on the most recent radiographic studies for these dogs, mean and median follow-up time were 11.7 months and 8 months respectively (range 4 months to 2.9 years). Of these dogs, six (6/7) were treated with ivermectin and

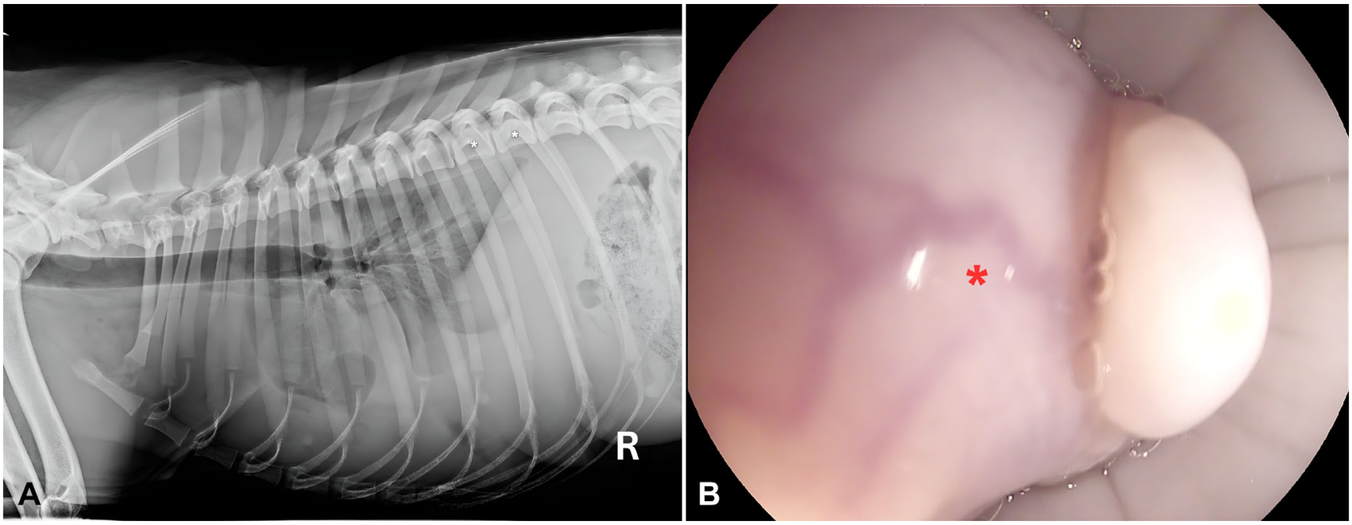

Figure 7. Unsedated right lateral projection of the thorax (A) showing large volume pleural effusion and thoracocentesis confirmed the effusion was haemorrhage, suspected secondary to rupture of an aortic aneurysm. T9 and T10 vertebrae (white asterisks) have a 'double cortical line'. Endoscopy of the same dog (B) shows a very large oesophageal nodule (red asterisk). Radiographs and photo credit: Mount Isa Veterinary Surgery.

one dog with Advocate®. All dogs were anaesthetised for the follow-up studies.

Oesophageal masses were identified in the initial radiographic study of 5/7 dogs. In the follow-up studies, the masses had completely resolved in 4/5 dogs, with four months being the earliest time to resolution. In the last dog, the nodules had decreased in height and length (Figure 8). In 2/5 dogs, the oesophageal masses developed mineralisation in the follow-up study. In one dog (1/5), the oesophageal mass developed gas cavitations.

One dog (1/7) developed aortic enlargement. In another dog (1/7), the aorta was not visualised in the initial study (being effaced by an oesophageal mass) but at follow-up, the aorta was visualised completely and found to be enlarged.

One dog (1/7) had acute vertebral spondylitis detected at the initial study, which then became chronic and bridging at the follow-up study. Finally, one dog (1/7) developed a caudal heart base mass.

Discussion

Radiographic findings of canine spirocercosis in Australia were comparable to other descriptions from endemic regions. Oesophageal nodules/masses were more frequently identified when there was generalised or focal oesophageal gas distension and almost half (45%) were centred on T8, similar to a South African study.[13] This is not surprising as pneumo-oesophagography used in conjunction with thoracic radiographs increases the sensitivity of oesophageal nodule or mass detection to 97%.[33] In the two studies where oesophageal masses were detected without oesophageal gas distension, both masses measured >5 cm in length and >3.5 cm in height. However, the total detection rate with radiography for our population was still significantly lower (59%) compared with endoscopy (90%). This is likely because not all of them had oesophageal gas to provide negative contrast and soft tissue masses located on the lateral walls of the oesophagus may be missed when only lateral projections are acquired. It has previously been shown that survey dorsoventral/ventrodorsal projections could detect 86% of caudodorsal mediastinal masses in dogs, compared with 50% on the lateral projections.[25]

The frequency of mass mineralisation was low (7%), similar to Dvir et al.[13] Mineralisation has been reported to indicate malignant transformation, but differentials may include osseous metaplasia and mineralised chondroid foci.[13,34] *S. lupi*-induced oesophageal nodules initially resemble a granulation tissue response but then transition to become predominantly fibroblastic.[35] These lesions have the potential to progress to neoplasia, such as into an oesophageal sarcoma.[35] Histopathology was not performed for the majority of oesophageal masses, so any neoplastic transformation could not be confirmed.

Diffuse aortic enlargement was more common than focal aortic enlargement. This is interesting because aortic aneurysms typically cause focal enlargement.[27] Aortic lesions secondary to *S. lupi* are mostly located in the intima layer and include aneurysm formation, thrombosis and extensive scarring 4–6 months after infection.[27] The damage can be severe and involve multiple aneurysms along the length of the aorta.[32] This could potentially explain the discrepancy but could not be confirmed as postmortem was not performed on all dogs. Other differentials for generalised aortic enlargement include phasic variation in vessel size and systemic hypertension.[36] Aortic mineralisation was not detected in any study, likely because thoracic radiographs have low sensitivity for detecting aortic mineralisation relative to CT.[27]

Spondylitis was detected radiographically in 54% of dogs in our study, located between T4 and L1 and most frequently affected T8-T11 vertebrae. The prevalence of spirocercosis-associated spondylitis has ranged from 0% to 87%, likely dependent on how it was diagnosed, but the caudal thoracic location in our population is consistent with most reports.[2–4,13,20,24,37] Spondylitis is defined as a periosteal reaction of the vertebral body without involvement of the

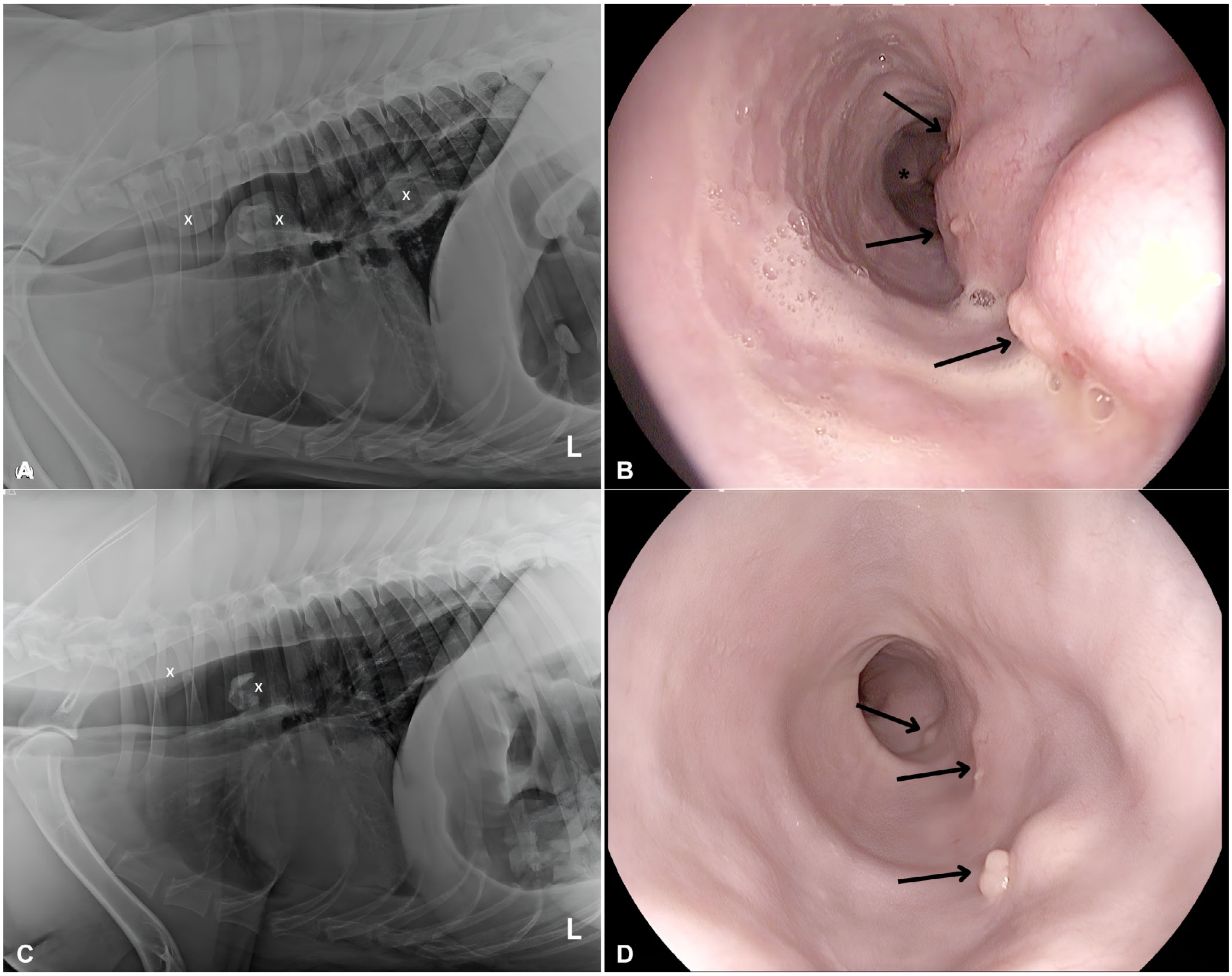

Figure 8. **Postendoscopy anaesthetised left lateral projections of the thorax of a dog at time of diagnosis (A) and at 11 months follow-up (C) with visible oesophageal nodules ('X'); endoscopic images of the same dog showing the oesophageal nodules (black arrows) at time of diagnosis (B) and at 11 months follow-up (D). In (B), the gastro-oesophageal junction is also visualised (asterisk). Comparing (A) and (C), note the reduced size of the cranial and middle nodules, the progressive mineralisation of the middle nodule and resolution of the caudal nodule. This corresponds to the images (B) and (D), noting the caudal nodule is still present endoscopically but now too small to be visible radiographically. Radiographs and photo credit: Mount Isa Veterinary Surgery.**

intervertebral disc space or the vertebral end plates.[26] It is not specific to *S. lupi* infection and can be a result of other infectious aetiologies such as migrating grass awns.[38,39] Conversely, spondylosis is defined as benign, typically age-related osteophytosis at the vertebral end plates ventrally and laterally thought to be secondary to degeneration of annulus fibrosus fibers.[40] Our data reflect this as the mean and median ages of dogs with spondylosis deformans were at least twice as high as dogs that had spondylitis.

Besides that, our study demonstrated that spirocercosis-associated spondylitis has a wide variety of radiographic appearances. Almost half of the dogs with radiographic spondylitis had periosteal new bone that bridged across the intervertebral space, contrary to its definition in veterinary literature.[26] Of additional interest, the 'double cortical line' was more frequently identified in acute spondylitis and the 'skate sign' was more frequently detected in chronic cases. Neither of these signs were associated with spondylosis deformans and were considered reliable radiographic signs of spondylitis.

Thoracic spondylosis deformans was detected in 24% of dogs in our population, and in more than half of those dogs it was detected concurrently with spondylitis. In some of our patients, spondylitis bridged the intervertebral disc space and was differentiated from classic spondylosis by its flat ventral margin and continuity with spondylitis on adjacent vertebrae. In several patients with spondylitis, the adjacent endplates had lesions more typical of characteristic spondylosis, with curved endplate osteophytes (Figure 6H). In these patients, it was not possible to definitively determine whether this was true spondylosis or a variant of spondylitis. These results emphasise the challenges of being able to differentiate between the radiographic appearance of spondylitis and spondylosis. Despite this, differentiation between these two lesions remains imperative due to the implications for ongoing case management.[26]

Kirberger et al.[26] described and compared histopathologic findings of vertebral segments affected by spirocercosis-associated spondylitis and spondylosis deformans. In that study, spondylitis was diagnosed radiographically and showed similar variation in radiographic appearance to the results of our study. However, Kirberger et al.[26] also reported that although 8/10 dogs with radiographic spondylitis had at least one section associated with histologic lesions, only three of these dogs had compelling evidence of inflammation in the adjacent connective tissue. Importantly, it was revealed that in the absence of local inflammation, mature spondylitis (including bridging spondylitis) could not be differentiated from spondylosis with histopathology alone.[26] This is significant as it further supports the notion that the radiographic appearance of new bone ventral to the vertebral body plays a vital role in helping to consider spirocercosis as a differential, particularly in young and middle-aged dogs in endemic areas.

Most additional radiographic findings were supportive of several well-reported complications of spirocercosis such as airway displacement secondary to oesophageal mass and haemothorax secondary to aortic aneurysm rupture.[1,8,18] Pleural effusion was identified in 8% of dogs, confirmed to be either haemothorax or haemorrhagic pyothorax. The one dog that did have a postmortem examination confirmed that the haemothorax was secondary to rupture of an aortic aneurysm. In the two dogs that had unsedated radiographs showing a ventrally distributed alveolar lung pattern, aspiration pneumonia was considered a differential which has also been reported as a complication of spirocercosis.[1,8] Hypertrophic osteopathy, typically a complication of malignant spirocercosis, was not reported in our cohort of dogs despite some of them presenting with peripheral limb lameness or swelling.[34] This could be an underestimation as this condition was not specifically investigated and it is not known if any of these patients had radiographs performed of the affected limbs.

Seven dogs had follow-up studies resulting in limited longitudinal data. There was a reduction in the size and number of oesophageal nodules or complete resolution of the nodules. This is consistent with other papers tracking treatment response, with time to nodule resolution (not necessarily complete) ranging from approximately 1 to 18 months.[32,41–46] In two dogs, the oesophageal nodules became mineralised, but malignant transformation or dystrophic mineralisation could not be confirmed, as histopathology was not performed in these patients.

Gastro-oesophageal endoscopy was again proven to be the most reliable method of diagnosis in this study, with 90% of our population being diagnosed with endoscopy alone. It remains the gold standard for spirocercosis.[1,8] Faecal flotation was only positive in one of the three dogs in this study, but the true frequency of a positive faecal flotation result may actually be higher if more dogs in our population had this test performed.

No sex predilection was found in our cohort, which is consistent with most other reports.[2,3,15] The mean and median age of our population were both >1 year of age, which is expected as dogs ≤1 year of age are less likely to be infected by *S. lupi*.[2,3,15,47,48] This is most likely due to the nematode's long prepatent period.[1] Only one dog in our cohort was 6 months of age when diagnosed; this patient presented with multifocal neurological signs and did not have any oesophageal masses. It is known that dogs less than 6 months of age may be infected but likely too young to have developed oesophageal nodules or associated clinical signs.[1] Figure 9 shows the radiographic, endoscopic and histopathologic findings for this case.

Majority of dogs in our study population were either medium or large mixed breeds, Labrador Retrievers and Australian Cattle dogs. It has been shown by other large-scale studies that large breed dogs are more likely to have *S. lupi*, with German Shepherd dogs and Labrador Retrievers being overrepresented.[1,2,13,20,49] Furthermore, previous studies have shown that hunting, stray and urban dogs were also at higher risk of infection, indicating that lifestyle plays an important role in exposure to intermediate and paratenic hosts.[3,8,50,51] It is likely that the dogs in our population have a lifestyle that revolves around outdoor activity, including travel to the locations reported in this paper.

Only 5 cases (8.5%) were from the tropical regions of Western Australia and Northern Territory. Fifty-four dogs (91.5%) were from Mount Isa, Queensland. This finding is because one of the authors (G.T.) routinely screens dogs using a combination of thoracic radiography and gastro-oesophageal endoscopy. Proactive screening performed by G.T. has revealed over 300 cases in Mount Isa over the past 3–4 years. As there are no previously published data on the incidence of canine spirocercosis in Australia, it is unclear whether this large number of cases diagnosed is the usual incidence of canine spirocercosis, or if this is more than typically expected, which would suggest a disease hotspot.

In our study population, the proportion of dogs that had subclinical spirocercosis (41%) was consistent with previous reports of between 4%–96%.[4,13,15] Interestingly, a small portion of the subclinical dogs from our study presented specifically because another dog in the same household had *S. lupi*, highlighting the role of owner education and awareness in early detection of disease. Moreover, only 3% of the dogs in our population had up-to-date worming prophylaxis at the time of diagnosis, which emphasises the importance of regular preventative treatment to minimise risk of *S. lupi* infection.[32,52] Dogs in our study were treated with a multitude of antiparasitic treatment regimens (see File S1). Discussion regarding the efficacy of different treatment protocols is beyond the scope of this study and the reader is referred elsewhere.[32,41,42,44–46]

Of the dogs that were unwell (58%), the type of clinical signs and physical examination findings as well as their distribution amongst the study population were largely consistent with other regions.[2,3,8,13–15,20,21,53] A key difference was that melena and hematemesis were not reported despite both being common in other studies. This could reflect a lack of ulcerated oesophageal nodules in our study population.[2] Besides that, the frequency of respiratory signs was low (3%) similar to a more recent paper[53], but this contrasts with other sources which report a frequency of respiratory signs between 14% and 60%.[2,3,13–15] Coughing in dogs with spirocercosis has previously been associated with aspiration pneumonia, airway displacement and pulmonary metastases.[13,34]

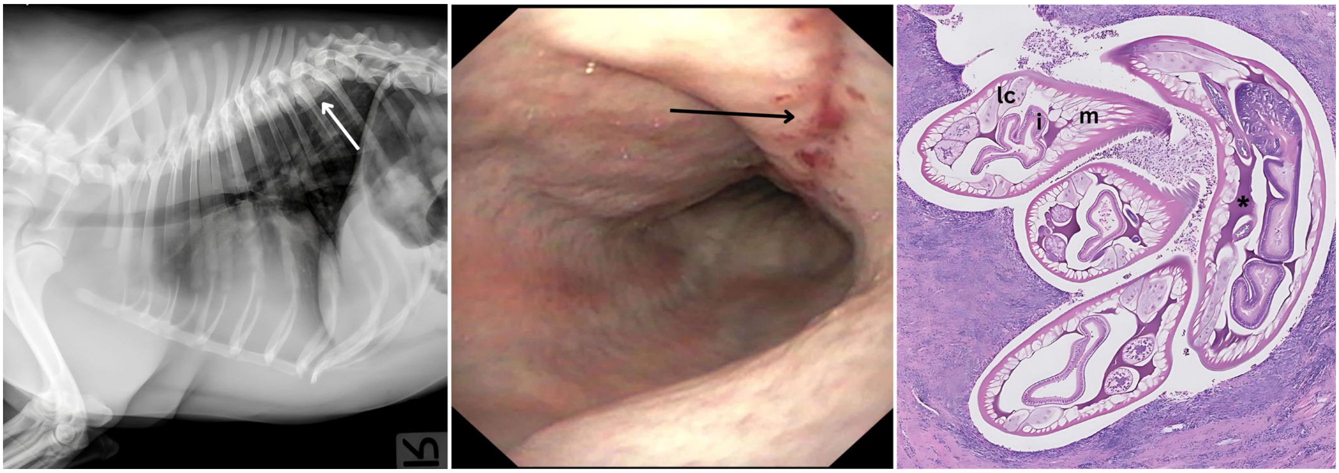

Figure 9. **Sedated right lateral thoracic radiograph (A) showing caudal thoracic spondylitis including the skate sign at T10 (white arrow); there are also incidental congenital thoracic vertebral malformations. (B) is a postmortem gastro-oesophageal endoscopy of the same patient showing focal mucosal haemorrhage (black arrow). (C) is a histological section through the caudal oesophagus where the gross haemorrhage was identified, and it contains multiple cross-sectional *S. lupi*. Note the large lateral hypodermal chords (lc), coelomyarian-polymyarian muscles (m), smooth cuticle, amphophilic to basophilic fluid in the pseudocoelom (*) and an intestine (i) composed of individual cuboidal cells each with a prominent brush border. Hematoxylin and Eosin stain, 2× magnification. Radiograph and photo credits: (A) and (B) Animalius; (C) Dr Audra Walsh of Vetnostics Pathology.**

Our study has likely underestimated the frequency of radiographic findings supportive of aspiration pneumonia and/or airway displacement as a large proportion of the radiographic studies were incomplete (i.e., only one- or two-views).

Our study has several limitations. Firstly, due to the retrospective nature, there was a lack of standardisation in radiographic acquisition technique and post-processing algorithms. The thorax was incompletely evaluated in many studies, which likely underestimated certain radiographic findings. If more studies in our cohort included dorsoventral or ventrodorsal projections, then there may have been increased detection of aortic enlargement and caudodorsal mediastinal masses on survey radiographs.[54] Secondly, not every patient in our study had postmortem examination and histopathology performed, so a definitive diagnosis could not be achieved for all radiographic findings described. The authors acknowledge that this has likely resulted in some findings being under-reported. Furthermore, certain findings such as aortic enlargement and oesophageal mass mineralisation have multiple differentials that may not actually be caused by spirocercosis. In the patients that did not have postmortem examinations, the authors also acknowledge that the association between spirocercosis and some of the radiographic findings with multiple differentials was merely speculative. Thirdly, a large selection bias was present because most cases came from one location, most likely because of the author's (G.T.) awareness of this disease in their geographic locale. In conclusion, our study is the first comprehensive review of spirocercosis in Australia. The results support our hypothesis that thoracic radiographic findings of canine spirocercosis in Australia are similar to those reported in other endemic regions. The diagnosis of spirocercosis remains challenging given the nonspecific clinical presentation, poor sensitivity of faecal flotation and large variations in the radiographic appearance of spondylitis. In light of this paper's findings, the authors suggest the following recommendations:

1. The thoracic projections that allow for the highest diagnostic yield of spirocercosis are a lateral projection (to allow for visualisation of spondylitis lesions) and a dorsoventral projection (for better detection of aortic aneurysms and oesophageal masses). However, plain thoracic radiographs alone may not be enough for diagnosis.
2. If spondylitis is identified on thoracic radiographs of a dog that lives in or has had a travel history to the regions described in this report, it should prompt further screening for spirocercosis.
3. Pneumo-oesophagraphy can significantly increase the chances of detecting oesophageal masses. It is accessible to practices that do not have access to endoscopy. This procedure is cost-effective and relatively simple to perform.
4. Gastro-oesophageal endoscopy should ideally be performed if there remains a high clinical suspicion for spirocercosis despite negative radiographic findings.

Finally, future studies are required to accurately estimate the prevalence and incidence of *S. lupi* in both dogs and intermediate hosts in Australia.

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Conflicts of interest and sources of funding

The authors declare no conflicts of interest or sources of funding for the work presented here.

Ethics statement

All cases in this study were retrospective and data were acquired during routine clinical work under the Veterinary Surgeons Act 1960. The clients from each participating veterinary hospital provided informed consent for treatment and use of the animal's data for research and educational purposes. All email communications with participating veterinarians were through publicly available published email addresses. For the veterinarians who were Australian ANZCVS members, the email invitation for this retrospective case series was forwarded to them by an ANZCVS staff member without the authors having access to any personal data of any of the veterinarians on the ANZCVS mailing list. Therefore, animal institutional care committee approval was not required.

Data availability statement

The data that supports the findings of this study are available in the supplementary material of this article.

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Supporting information

Additional Supporting Information may be found in the online version of this article at the publisher's web-site: http://onlinelibrary.wiley.com/doi/10.1111/avj.13447/suppinfo.

Supplementary File 1A. Clinical Data.
Supplementary File 1B. Radiographic Findings.
Supplementary File 1C. Dogs that had multiple acquisition techniques.
Supplementary File 1D. Dogs that had multiple radiographic studies.
Supplementary File 2. Image acquisition technical parameters for veterinary practices which provided the radiographs.
Supplementary File 3. Additional thoracic radiographic findings at time of diagnosis in 59 dogs diagnosed with spirocercosis.

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