Preventative pneumopexy in the management of concurrent right cranial and middle lung lobe torsion following right caudal lung lobectomy in a dog

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Abstract: A 4-year-old female neutered Welsh Springer Spaniel was presented with pneumothorax secondary to a migrating foreign body in the right caudal lung lobe. Within 24 hours following thoracic exploration and hilar lung lobectomy, the patient deteriorated. Computed tomography was consistent with lobar torsion. A second median sternotomy identified concurrent right cranial and middle lung lobe torsion. Hilar lobectomy of the affected lobes was performed. To prevent lobar torsion of the remaining lobe, a preventative accessory lobe pneumopexy was performed, potentially averting an additional surgical procedure and reducing total lung capacity to less than the reported minimum critical mass compatible with survival. No complications following accessory lung lobe pneumopexy were encountered in this single case. Although post-lobectomy lung lobe torsion appears to be rare in dogs, clinicians should be aware of this potentially life-threatening complication. This case report documents the first description of pneumopexy as a preventative procedure in a dog.
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TITLE OF CASE
Preventative pneumopexy in the management of concurrent right cranial and middle lung lobe torsion following right caudal lung lobectomy in a dog

SUMMARY
A 4-year-old female neutered Welsh Springer Spaniel was presented with pneumothorax secondary to a migrating foreign body in the right caudal lung lobe. Within 24 hours following thoracic exploration and hilar lung lobectomy, the patient deteriorated. Computed tomography was consistent with lobar torsion. A second median sternotomy identified concurrent right cranial and middle lung lobe torsion. Hilar lobectomy of the affected lobes was performed. To prevent lobar torsion of the remaining lobe, a preventative accessory lobe pneumopexy was performed, potentially averting an additional surgical procedure and reducing total lung capacity to less than the reported minimum critical mass compatible with survival. No complications following accessory lung lobe pneumopexy were encountered in this single case. Although post-lobectomy lung lobe torsion appears to be rare in dogs, clinicians should be aware of this potentially life-threatening complication. This case report documents the first description of pneumopexy as a preventative procedure in a dog.

BACKGROUND
Lung lobe torsion (LLT) is an uncommon but potentially fatal disease in dogs without surgical intervention.¹⁻³ It occurs following axial rotation at the bronchovascular pedicle, with resultant airway obstruction and vascular compromise of the affected lobe. LLT can occur spontaneously or secondary to predisposing conditions that either increase lung lobe mobility or alter spatial relationships within the thorax. Predisposing conditions include pleural effusion (commonly chylothorax), trauma, pneumonia, neoplasia, and following surgical manipulation.²⁻⁸ Although not currently a recognized predisposing factor in dogs, lung lobectomy with subsequent LLT has been reported sporadically in the literature.¹⁻⁹,¹⁰ In people, post-operative LLT occurs with an incidence of 0.089-0.3%,¹¹ most commonly following superior lung lobectomy.¹¹,¹² This case report describes the management of concurrent right cranial and middle LLT, subsequent to right caudal lung lobectomy in a dog. To the authors’ knowledge, this is the first description of preventative pneumopexy as a strategy to prevent further torsion of a remaining lung lobe in veterinary medicine.
A 4-year-old female neutered Welsh Springer Spaniel weighing 16.7 kg presented with pneumothorax following a 3-day history of lethargy and pyrexia, for which she was treated with oral amoxicillin trihydrate/clavulanic acid and meloxicam by the referring veterinarian. Twelve hours prior to referral, 2.5 litres of air was drained from the left hemithorax via thoracocentesis under general anaesthesia. A second thoracocentesis was performed seven hours later under sedation; 360 ml and 480 ml of air were drained from the right and left hemithoraces respectively.

INVESTIGATIONS

At presentation to our facility, she was bright, alert and responsive. Physical examination revealed tachypnoea with a respiratory rate (RR) of 60 breaths per minute with no increased respiratory effort. Thoracic auscultation revealed muffled heart sounds bilaterally. Heart rate (HR) was 76 beats per minute, her mucous membranes were pink, with a capillary refill time of 1-2 seconds and the rectal temperature was within normal limits (38.8 °C). The remainder of the physical examination was unremarkable. Oxygen saturation (SPO₂) was 100% on pulse oximetry. Thoracic point of care ultrasound (T-POCUS) performed at the time of admission was negative for free fluid; glide sign was not assessed. Initial overnight management consisted of close monitoring of RR, effort and SPO₂. No oxygen supplementation was required during this period and the RR ranged from 22-31 breaths per minute with no increased respiratory effort for the first 10 hours after admission. Following this initial period, the patient’s RR and effort increased. Repeat T-POCUS demonstrated an absence of the glide sign (the shimmering effect caused by the pulmonary-parietal interface), consistent with a recurrent pneumothorax. Thoracentesis was performed and 250 ml of air was removed from each side of the thoracic cavity. Additionally, a small volume of flocculant pleural effusion was identified and aspirated. Analysis of pleural fluid revealed glucose and lactate levels of 5.6 mmol/L and 3.5 mmol/L respectively, compared to serum levels of 4.1 mmol/L and 0.9 mmol/L respectively. Cytologic examination performed by the clinician in charge of the case revealed neutrophilic inflammation consistent with an exudate and no evidence of intracellular etiological agents, in agreement with later cytological evaluation of the pleural fluid by a clinical pathologist. No bacteriological agents were isolated on bacterial culture and sensitivity testing. Abscessation with secondary lung perforation, pneumothorax and pyothorax was suspected at this time. Other differential diagnoses considered included an infected pneumatocele and a ruptured bulla with iatrogenic pyothorax secondary to repeated thoracentesis. Antibiosis consisting of Amoxicillin/clavulanic acid 20 mg/kg following 4 mg IV chlorphenamine every 8 hours and intravenous fluid therapy consisting of Lactated Ringers at 3 ml/kg/hr were continued intravenously. To narrow down the differential diagnosis, the patient was sedated with 0.2 mg/kg butorphanol and 1.5 ug/kg dexmedetomidine IV for thoracic computed tomographic (CT) imaging. Pre- and post-contrast studies revealed peripheral indentation of the lateral aspect of the right caudal lung lobe associated with a bronchiole, regional lung consolidation and pleural thickening. A moderate volume of free gas was identified in the pleural space, as well as a small volume of attenuating fluid ventrally. In addition, a small volume of free gas and a single enlarged sternal lymph node was observed in the mediastinum. The imaging diagnosis made was a suspected right caudal lung lobe perforation secondary to an undetected foreign body associated with secondary focal haemorrhage/pneumonia, pleuritis, pleural effusion, pneumothorax and pneumomediastinum (Figure 1). Following discussion with the owner,
surgical management was advised. A routine midline median sternotomy was performed. A small puncture hole and air leakage was identified on the lateral surface of the right caudal lung lobe. Right caudal lung lobectomy was performed with a TX60 mm staple at the level of the hilus. Lymphadenectomy of the enlarged sternal lymph node was additionally performed and a blade of grass encased in fibrous tissue was identified. No further foreign material was found on thoracic exploration. The thorax was closed routinely and a left sided 14-gauge Mila chest tube was placed in standard fashion to aid post-operative management. Samples of mediastinum, lymph node and the lung lobe were submitted for bacterial culture/sensitivity and histopathology. No bacterial isolates were identified and histopathological analysis was consistent with changes resulting from migrating foreign material as identified at surgery. The patient recovered and remained in the intensive care unit for close monitoring. Initial therapeutic management consisted of continued antibiotic and analgesia (constant rate infusion of fentanyl (4 mcg/kg/hr) and ketamine (3 mcg/kg/min)), which was deescalated to methadone at 0.1mg/kg intravenously every 4 hours, approximately 12 hours following surgery, and 10mg/kg intravenous paracetamol every 12 hours, in addition to instillation of bupivacaine via the chest drain at 1 mg/kg every 8 hours). Regular RR, effort and SPO2 monitoring was performed. Over the first 12 hours, average fluid production from the chest drain was 1.7 ml/kg/hr with a packed cell volume (PCV) of 9%; peripheral venous PCV at the same time was 40% with total solids (TS) of 42 g/l. The patient was eating and stable at this time with a mild increase in respiratory effort and a RR of 20 breaths per minute. Over the course of the next 6 hours, T- POCUS identified a markedly enlarged consolidated lung lobe which had a peripheral hypoechoic band and extensive central areas of scattered emphysema in the right thorax (figure 2). There was slight consolidation and comet tail artefact throughout the left thorax. Bilateral large volume of pleural effusion was also observed. The changes in the right lung lobe were suspicious of a lung lobe torsion. It was not possible to determine whether the abnormal lung lobe was the right cranial lung lobe or right middle lung lobe on ultrasound. This was accompanied by a deterioration in the patient’s clinical status with increased RR and effort. A total of 140 ml of grossly haemorrhagic pleural effusion was drained via the chest drain. Analysis of the thoracic fluid revealed a PCV of 14%, TS 25 g/l with a corresponding drop in peripheral venous PCV to 27%, TS 32 g/l. Coagulation parameters were within reference ranges (cit-aPTT 92s; RR 72-102 and cit-PT 13s; RR 11-17) and her blood type was determined as DEA (dog erythrocyte antigen) 1 negative. A bag of DEA 1 negative canine packed red blood cell transfusion was initiated. Repeat pre- and post-contrast thoracic CT showed a marked enlargement of the right cranial lung lobe, generalised vesicular pattern, abrupt interruption of the lobar bronchus and lack of contrast enhancement in the post-contrast images. These findings were consistent with lobar torsion. The right middle lung lobe had ill-marginated ground glass attenuation and patchy areas of consolidation. In addition, there was secondary dorsal and medial displacement and the lobar bronchus was partially collapsed. There was a minimal focal increase in the lung attenuation of the left cranial lung lobe and left caudal lung lobe. Post-contrast, the rest of the lung lobes including the right middle lung lobe showed normal vascularization. Pleural effusion was also identified. An imaging diagnosis of right cranial lung lobe torsion was made (figures 3 and 4). The changes in the right middle lung lobe and the lobar bronchus were suggestive of lobar pathology such as pneumonia and/ or atelectasis; LLT was considered as a possible diagnosis due to the abrupt ending of the main lobar bronchus. The changes in the left lung lobes were secondary to atelectasis.
DIFFERENTIAL DIAGNOSIS

TREATMENT
A median sternotomy (1 day following initial median sternotomy) was performed at the previous surgical site. The severely congested and torsed right middle and cranial lobes were identified at surgery (figure 5). Lung lobectomy was performed at the hilus of each lobe with a V30 stapler. The remaining right accessory lobe was observed for normal ventilation and viability. This lobe was considered at high risk of subsequent torsion due to the large amount of space created within the thorax. A pneumopexy between the accessory lung lobe apex and the thoracic wall at intercostal space 11 was performed via excoriation, by very lightly scoring the corresponding visceral and parietal pleura in a grid pattern, followed by a single 2 metric poliglecaprone-25 mattress suture to secure the lobe in place. Lavage and leak testing were undertaken and the thorax was routinely closed. The patient was closely monitored and managed in the intensive care unit in a similar manner as described following initial surgery.

OUTCOME AND FOLLOW-UP
Over the first 24 hours following the second surgery, an average of 1.6 ml/kg/hr serosanguinous fluid was aspirated from the thoracic drain (PCV 2%, TS 10 g/l). Vital parameters and SpO₂ remained within normal limits. Blood gas analysis did not reveal any disturbances: pH remained above 7.31 (RR 7.31-7.42) and PₐCO₂ remained within the reference range when sampled. Thoracic fluid production reduced over 48 hours and the chest drain was removed 3 days post operatively. The patient was discharged 4 days post-operatively, at which time the patient was stable, active and eating well with no observed increase in RR or effort. Regular correspondence with both the referring veterinarian and owner until 1-year post operatively confirmed the patient remained clinically well. No complications were encountered in this single case.

DISCUSSION
This case report describes the successful use of a preventative pneumopexy. We also describe an unusual presentation of concurrent right cranial and middle lung lobe torsion occurring within 24 hours of right caudal lung lobectomy with atypical CT findings.

Although the precise mechanism leading to lung lobe torsion is frequently unknown, it is thought that any pathology within the thoracic cavity which either alters spatial relationships and/or mobility of lung lobes could predispose to torsion. Thus, right caudal lung lobectomy was likely a contributing factor in the development of subsequent right cranial and middle LLT in this case through creation of potential space within the thorax. Ongoing pleural effusion following initial surgery, though relatively small in volume, could also have played a role. Pleural effusion may lead to some increased mobility of lobes and can additionally cause a degree of atelectasis, also identified on imaging in this case, further increasing instability facilitating torsion. Furthermore, iatrogenic damage such as inadvertent...
transection or stretching of pulmonary ligaments during thoracic surgical exploration may have occurred and further compounded this effect.

LLT following ipsilateral lobectomy is uncommon in veterinary medicine, occurring between 5 and 180 days\textsuperscript{2,9,10} following surgery in cases reported. In human medicine, LLT following lung lobectomy is a recognised complication,\textsuperscript{11,12} occurring immediately and up to 3-weeks post-operatively.\textsuperscript{14,15} LLT was identified approximately 24 hours post operatively in this case. Clinicians should therefore be aware of the potential for this complication to occur in the immediate post-operative period. Torsion of more than one lung lobe concurrently is also rare, only being reported sporadically in the literature,\textsuperscript{2,16,17} however an ipsilateral torsion of more than one lung lobe concurrently has not previously been described as a complication following lung lobectomy.

The preferred surgical approach for lung lobectomy is intercostal thoracotomy due to reduced post-operative morbidity\textsuperscript{18} but median sternotomy was deemed more appropriate to allow better visualisation and to facilitate thorough thoracic exploration in this case. Lung lobectomy is the treatment of choice for LLT in dogs and cats.\textsuperscript{1,2,10} Despite past perceptions of high complication rates and mortality associated with this procedure, recent studies have demonstrated excellent survival rate between 92-100\%.\textsuperscript{1,2,19}

Dogs can survive 50\% resection of their lung mass but are unlikely to tolerate removal of a larger critical mass.\textsuperscript{20} The right lung dominates and occupies over 50\% of the total lung mass. Therefore, whilst total left pneumonectomy can be successful, right pneumonectomy is not recommended and is more likely to be fatal unless the underlying disease process necessitating pneumonectomy is slowly progressive,\textsuperscript{20,21} potentially allowing time for physiological adaptation and regeneration of remaining lung tissue prior to surgery.\textsuperscript{22}

Following successive lung lobectomy of the right caudal, middle and cranial lung lobes over a 24-hour period in the case described here, we regarded the remaining accessory lobe to be at risk of subsequent torsion due to the large space created in the thorax and the potential for ongoing pulmonary effusion. This led us to undertake a protective pexy procedure owing to concerns around reduction of lung capacity to less than the critical mass compatible with survival. In humans, pneumopexy of remaining lobes is described as a key technique to prevent future torsion\textsuperscript{11,12,23–25} and is undertaken routinely in the many cases following lung lobectomy.\textsuperscript{26} Pneumopexy is commonly performed by tacking remaining adjacent lung lobes together,\textsuperscript{27} although other techniques are described.\textsuperscript{12,23,28} In the absence of remaining lobes in this case, we selected and area of the thoracic wall to secure the accessory lobe to, where it reached easily without tension during either inspiration or expiration. No apparent complications were encountered in this single case report however there is a theoretical risk of bullae formation, pneumothorax or emphysematous disease secondary to needle penetration of the pulmonary parenchyma. Other techniques circumventing parenchymal penetration could be considered such as use of fibrin adhesives and synthetic polymeric sealants, as have been reported in human medicine.\textsuperscript{28,29} Further studies are recommended to establish the clinical benefit, criteria to define at risk animals, optimal surgical technique and complications of preventative pneumopexy in veterinary medicine.

Ultrasound has been reported to be a useful imaging modality to diagnose a LLT. The presence of a hypoechoic peripheral halo and central emphysema in an enlarged lung lobe is suggestive of a lung lobe torsion.\textsuperscript{30} Recent studies also suggest CT as an accurate imaging modality in obtaining a definitive diagnosis of LLT compared to radiography and
ultrasound\textsuperscript{2,9,10}. CT changes include abnormal abrupt curtailing of the lobar bronchus, abnormal lobar positioning, poorly enhancing consolidation with increased volume, pleural effusion and contralateral mediastinal shift.\textsuperscript{30} A recently published study also identified the presence of a peripheral soft tissue attenuating band surrounding the emphysematous torsed lung.\textsuperscript{31} This change is also identified in our images in the right cranial lung lobe but not the right middle lung lobe (figure 1). The CT features of double LLT has not previously been described.

In this case report, a typical pattern of lung lobe torsion was observed in the right cranial lung lobe. By contrast, the right middle lung lobe only showed a partial collapse or partial abrupt interruption of the lobar bronchus, and some patchy areas of ground glass attenuation and consolidation. Other CT findings such as, vesicular pattern, lack of contrast enhancement or abnormal position of the torsed lobe were not observed. Lack of a vesicular pattern and/or preservation the vasculature cannot completely exclude a lung lobe torsion,\textsuperscript{2,10,29} however the changes associated with the lobar bronchus of the right middle lung lobe were mainly attributed to lobar compression due to the enlarged left cranial lung lobe in this case. Another explanation for this partial collapse may be a partial torsion of this lung lobe or hyperacute LLT which may be consistent with the rest of the pulmonary changes.

\textbf{LEARNING POINTS/TAKE HOME MESSAGES}

- Although post-lobectomy lung lobe torsion appears to be rare in dogs, clinicians should be aware of this potentially life-threatening complication in the immediate post-operative period.
- This case report documents the first description of pneumopexy as a preventative procedure in a dog.
- Feasibility of this procedure is demonstrated but further studies should be conducted to establish whether fixation of at-risk lung lobes reduces post lobectomy lung lobe torsion.

\textbf{CONFLICT OF INTEREST STATEMENT}

The authors declare there are no conflicts of interest

\textbf{ETHICS STATEMENT}

The legal and ethical requirements and institutional guidelines have been met with regards to the humane treatment of animals as described in this case report

\textbf{REFERENCES}


18. Bleakley S, Phipps K, Petrovsky B, Monnet E. Median sternotomy versus intercostal


FIGURE/VIDEO CAPTIONS

FIGURE 1. CT transverse image at the level of the 10th intercostal space; lung window. Note the focal area of consolidation and the defect at the lateral surface of the right caudal lung lobe and visceral pleura compatible with the perforation site (white arrowheads),
adjacent visceral pleural thickening (white arrows) and secondary pneumothorax (white asterisk).

**FIGURE 2.** Sagittal ultrasound image of the abnormal lung lobe following deterioration in the right thorax showing a hypoechoic peripheral band (white circle) and scattered central emphysema (white arrow).

**FIGURE 3.** Dorsal reconstruction CT image (A and B) of the thorax at the level of the tracheal bifurcation; lung window and post contrast soft tissue window respectively. Transverse CT image of the thorax (C) at the level of the 5th intercostal space post contrast soft tissue window. Note abrupt ending of the main lobar bronchus of the right cranial lung lobe (A) (white circle). Vesicular pattern and lack of contrast enhancement is seen in the right cranial lung lobe (B) (white arrow). Note the soft tissue band surrounding the torsed right cranial lung lobe (black arrow) in B. Note pleural effusion at the ventral aspect of the thoracic space (C) (white asterisk) and secondary mediastinal shift to the left (C) (white double asterisk). R: Right

**FIGURE 4.** Transverse thoracic CT images at the level of the 8th (A) and 7th intercostal space (B): lung window. Note the absence of vesicular pattern in the right middle lung lobe (A) (asterisk) and the accessory lung lobe (double asterisk); subtle ground glass attenuation is observed at the ventral aspect of the right middle lung lobe (white arrow). The white arrow in B denotes a partial collapse of the main lobar bronchus of the right middle lung lobe (B). R: Right

**FIGURE 5.** Intraoperative image identifying torsed right cranial (RCr) and right middle (RM) lung lobes

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