Surgical management and outcome of dogs with primary spontaneous pneumothorax: 110 cases (2009–2019)

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OBJECTIVE
To describe surgical management and associated outcomes for dogs with primary spontaneous pneumothorax.

ANIMALS
110 client-owned dogs with primary spontaneous pneumothorax that underwent surgical management.

PROCEDURES
Medical records at 7 veterinary teaching hospitals were reviewed. Data collected included signalment, history, clinical signs, radiographic and CT findings, surgical methods, intraoperative and postoperative complications, outcomes, and histopathologic findings. Follow-up information was obtained by contacting the referring veterinarian or owner.

RESULTS
110 dogs were included, with a median follow-up time of 508 days (range, 3 to 2,377 days). Ninety-nine (90%) dogs underwent median sternotomy, 9 (8%) underwent intercostal thoracotomy, and 2 (2%) underwent thoracoscopy as the sole intervention. Bullous lesions were most commonly found in the left cranial lung lobe (51/156 [33%] lesions) and right cranial lung lobe (37/156 [24%] lesions). Of the 100 dogs followed up for > 30 days, 13 (13%) had a recurrence of pneumothorax, with median time between surgery and recurrence of 9 days. Recurrence was significantly more likely to occur ≤30 days after surgery, compared with >30 days after surgery. Recurrence >30 days after surgery was rare (3 [3%]). No risk factors for recurrence were identified.

CONCLUSIONS AND CLINICAL RELEVANCE
Lung lobectomy via median sternotomy resulted in resolution of pneumothorax in most dogs with primary spontaneous pneumothorax. Recurrence of pneumothorax was most common in the immediate postoperative period, which may have reflected failure to identify lesions during the initial thoracic exploration, rather than development of additional bullae. (J Am Vet Med Assoc 2021;258:1229–1235)

Spontaneous pneumothorax is the accumulation of air in the pleural space in the absence of a traumatic or iatrogenic cause. Spontaneous pneumothorax can be classified as primary or secondary, with PSP defined as pneumothorax without clinically apparent lung disease and secondary spontaneous pneumothorax defined as a complication of preexisting lung disease such as pneumonia, Dirofilaria infection, pulmonary abscess, or neoplasia.

The underlying etiology of PSP remains elusive and controversial; the primary histologic findings in dogs with PSP are pulmonary bullae and blebs or, occasionally, general bullous emphysema. Bullae and blebs occur when air accumulates inappropriately between the lung parenchyma and pleura (bullae) or between the layers of the visceral pleura (blebs); rupture of either bullae or blebs results in subsequent pneumothorax. In rare cases, surgical exploration and histologic examination fail to identify pulmonary lesions in dogs with PSP. Also, although PSP is seen more commonly in large-breed or deep-chested dogs, particularly Siberian Huskies, no additional risk factors have been identified.

Currently, the recommended treatment for PSP in dogs is surgical exploration to identify and resect the causative lesions. In previous studies, bilateral lesions were identified in as many as 75% of dogs undergoing surgical exploration. Therefore, median sternotomy is the most commonly performed surgical approach because it allows for thorough visual evaluation of all lung lobes. More recently, thorascopic treatment of dogs with PSP has been reported; however, results have been mixed, suggesting that current thorascopic techniques may not allow for adequate identification of some pulmonary bullous lesions.
Reported recurrence rates following surgical management of PSP range from 0% to 25% with open surgical approaches to as high as 50% with thoracoscopic treatment alone. However, previous studies do not distinguish between short-term recurrence, which may reflect failure to identify all lesions during the initial surgery, and long-term recurrence, which likely reflects development of additional bullous lesions.

Many of the previous reports of PSP in dogs consist of low case numbers (12 to 64 dogs), involve variable or poorly described surgical approaches, and provide limited data regarding follow-up and outcome. In addition, many of these studies predate the widespread availability of CT. Although subject to its own limitations in regard to identification of pulmonary bullae, thoracic CT is currently commonly performed preoperatively for dogs with PSP and may affect surgical planning and outcome. Thus, the objective of the study reported here was to provide an updated description of surgical management and associated outcomes for dogs with PSP. We hypothesized that the long-term recurrence rate would be low with surgical management and that median sternotomy in particular would be associated with a low recurrence rate.

Materials and Methods

Case selection

Medical records of 7 academic institutions (North Carolina State University, University of Florida, University of Georgia, University of Minnesota, Ontario Veterinary College, Atlantic Veterinary College, and Western College of Veterinary Medicine) were searched to identify dogs that underwent surgery for treatment of PSP between March 2009 and October 2019. Dogs were considered to have PSP if they had radiographic evidence of pneumothorax with no history of trauma and if bullae, blebs, or bullous emphysema (ie, bullous lesions) were identified visually at the time of surgery, during histologic examination of resected pulmonary tissue, or both. Dogs in which pulmonary neoplasia, abscess, or granulomatous disease was identified and dogs with evidence of trauma were excluded from the study.

Information collected from medical records included signalment (age, weight, breed, and sex), history, preoperative diagnostic and imaging findings, surgical treatment, intra- and postoperative complications, cost and duration of hospitalization, histologic findings, and outcome. Data collected from the operative report included surgical approach, location and appearance of gross lesions, location and extent of lung lobectomy, and complications. Postoperative complications were classified as mild, moderate, or severe on the basis of a previously established grading system. Recurrence was defined as development of pneumothorax any time during the follow-up period. Short-term recurrence was defined as recurrence ≤ 30 days after surgery on the basis of previous recommendations. Long-term recurrence was defined as recurrence > 30 days after surgery. Follow-up information was obtained through review of the medical records and by contacting the referring veterinarian or owner at the time of the present study.

Statistical analysis

Time to last follow-up was calculated as the time from hospital discharge to the date of last known contact with the referring veterinarian or owner. All continuous variables were tested with the Shapiro-Wilk test to determine whether they were normally distributed. Continuous variables were reported as mean and SD or as median and range, depending on whether they were or were not normally distributed. Categorical variables were reported as count and percentage. Sensitivities were calculated for preoperative imaging modalities with a true-positive finding defined as identification of pneumothorax or ≥ 1 bullous lesion and a false-negative finding defined as failure to identify pneumothorax or a bullous lesion. Logistic regression analysis was used to test whether signalment, body weight, duration of clinical signs, imaging findings, number and location of lesions, surgical approach and procedures, or leaking of lesions was associated with recurrence of pneumothorax. Variables with a value of P < 0.2 in univariable analyses were included in the multivariable analysis. Survival times for dogs with and without a recurrence of pneumothorax were compared with the Kaplan-Meier method, and potential effects of signalment, body weight, duration of clinical signs, imaging findings, number and location of lesions, surgical approach and procedures, and leaking of lesions at the time of intraoperative testing on survival time were analyzed with a Cox proportional hazards model; dogs alive at the time of last follow-up were censored. Dogs with ≤ 30 days of follow-up time were excluded from analyses of recurrence and survival. For all analyses, a value of P < 0.05 was considered significant. All statistical analyses were performed with standard software.

Results

Signalment and clinical signs

One hundred ten dogs met the inclusion criteria. Dogs consisted of Siberian Huskies (16 [14.5%]); mixed-breed dogs (14 [13%]); Golden Retrievers and Labrador Retrievers (11 [10%] each); goldendoodles (5 [4.5%]); Boxers and German Shepherd Dogs (4 [3.5%] each); Border Collies, Great Danes, and labradoodles (3 [3%] each); Afghan Hounds, Gordon Setters, Great Pyrenees, Irish Wolfhounds, Jack Russell Terriers, Miniature Poodles, Newfoundland, Old English Sheepdogs, and Standard Poodles (2 [2%] each); and 18 additional breeds (1 [1%] each). Mean ± SD age at the time of initial examination was 7.1 ± 2.7 years, and median weight was 28.8 kg (63.4 lb; range, 3.9 to 84.3 kg [8.6 to 185.5 lb]). There were 66 (60%) neutered males, 38 (34.5%) spayed females, 3
(3%) sexually intact males, and 3 (3%) sexually intact females. Median duration of clinical signs prior to initial examination was 4 days (range, 0 to 32 days). The most common clinical signs were increased respiratory rate and effort, dyspnea, coughing, lethargy, and hypo- or anorexia.

**Diagnostic imaging findings**

Point-of-care thoracic ultrasonography was performed in 16 (14.5%) dogs at the time of presentation, and pneumothorax was detected in all 16 (sensitivity, 100%). Eighty-three (75.5%) dogs underwent thoracic radiography, and pneumothorax was identified in all 83 (sensitivity, 100%). However, sensitivity of radiography for detection of ≥1 bullous lesion was only 23% (19/83). Eighty-nine (81%) dogs underwent thoracic CT; sensitivity of CT for detection of ≥1 bullous lesion was 71% (63/89). A total of 95 possible bullous lesions were identified on CT; of these, 36 (38%) were located in the left cranial lung lobe, with 28 (29.5%) in the cranial subsegment and 8 (8%) in the caudal subsegment; 20 (21%) were located in the right cranial lung lobe; 17 (18%) were located in the right middle lung lobe; 12 (12.5%) were located in the right caudal lung lobe; 9 (9.5%) were located in the left caudal lung lobe; and 1 (1%) was located in the accessory lung lobe. Forty-three of the 89 (48%) dogs that underwent CT were imaged in sternal recumbency, 6 (7%) were imaged in dorsal recumbency, and 21 (24%) were imaged in both sternal and dorsal recumbency or both sternal and lateral recumbency. For the remaining 19 (21%) dogs that underwent CT, positioning was not stated in the medical record.

**Surgical intervention**

Eight dogs (7%) underwent autologous blood pleurodesis 1 to 3 times without resolution of pneumothorax prior to surgical intervention. All dogs underwent thoracic exploration with 1 or multiple partial or complete lung lobectomies. Median number of bullous lesions per dog was 1 (range, 1 to 4), with 156 lesions identified in the 110 dogs. Lesions were found in all lung lobes. The most commonly affected lung lobes were the left cranial lung lobe, with 40 of the 156 (25.5%) lesions in the cranial subsegment and 11 of the 156 (7%) in the caudal subsegment, and the right cranial lung lobe, with 37 of the 156 (24%) lesions. The remaining lesions were distributed as follows: right middle lung lobe, 28 of 156 (18%) lesions; right caudal lung lobe, 16 of 156 (10%) lesions; accessory lung lobe, 14 of 156 (9%) lesions; and left caudal lung lobe, 10 of 156 (6.5%) lesions. Twenty-three of the 110 (21%) dogs had bilateral lesions identified during thoracic exploration. A median sternotomy was performed in 99 (90%) dogs, whereas 9 (8%) dogs underwent a single intercostal thoracotomy, and 2 (2%) dogs underwent thoracoscopic alone. The length of median sternotomy was recorded in 38 dogs and most commonly extended from the second sterna to the seventh sterna (14/38 [37%] dogs) or from the second sterna through the xyphoid (10/38 [26%] dogs). The manubrium was transected in only 2 of the 38 (5%) dogs. Sixteen of 110 (14.5%) dogs underwent thoracoscopic initially, with 14 of those 16 (87.5%) thoracoscopic procedures converted to an open thoracotomy. Reason for conversion from thoracoscopic to thoracotomy was not specified in the medical record for all dogs but was stated to be due to poor visualization of all lung lobes in 11 of 14 (78.5%) dogs. Of the 14 thoracoscopic procedures that underwent conversion, 11 (78.5%) were converted to a median sternotomy and 3 (21.5%) were converted to an intercostal thoracotomy.

A lobectomy, with complete removal of ≥1 lobe, was performed in 58 of the 110 (53%) dogs; a partial lobectomy, with partial removal of ≥1 lobe, was performed in 43 of the 110 (39%) dogs, and a combination of lobectomy and partial lobectomy (involving separate lobes) was performed in 6 of the 110 (5%) dogs. The procedural details were not reported in the medical record for 2 dogs, and 1 dog was euthanized intraoperatively. Lobectomy was performed most commonly with a thoracoabdominal stapler (88 dogs); additional instruments used for lobectomy included an endovascular gastrostominal stapler (7), pretied ligature loop (3), and a vessel-sealing device (1). Staple height was 2.5 mm in 70 dogs for which that information was recorded in the medical record and was 3.5 mm in 16 dogs, with multiple staple heights used in some instances. Closure of the sternum was accomplished with orthopedic wire in all cases.

Intraoperative complications included hypoxemia (n = 9), arrhythmia (9), continued air leakage from a lung lobectomy site following stapling that required oversewing (5), iatrogenic laceration of a lung lobe (3), hemorrhage due to laceration of the internal thoracic artery requiring a packed RBC transfusion (2), malfunction of a stapling device (1), regurgitation (1), severe hypoxemia (oxygen saturation of hemoglobin as measured by pulse oximetry < 80% for a prolonged period; 1), and euthanasia owing to extent of disease (1). Sixty-seven of 110 (61%) dogs had bullae and 5 of 110 (4%) dogs had blebs identified by means of histologic examination of removed tissue. The remaining dogs had emphysematous or atelectic changes without evidence of other underlying pulmonary disease.

**Postoperative management and complications**

Median hospitalization time was 5 days (range, 2 to 13 days), which included a median postoperative hospitalization time of 3.2 days (range, 1 to 13 days). Mean cost of hospitalization was $6,336.89 ± 1,626.88. Median duration of indwelling thoracic tube maintenance following surgery was 2 days (range, 0.5 to 9 days). Mild postoperative complications that were reported included hyporexia (3 dogs); incisional infection treated topically, cough, hypoxia, and pyrexia (2
dogs each); and arrhythmia, seroma at the thoracic drain site, incisional seroma, delayed incisional healing, pleural effusion, and a single episode of collapse (1 dog each). Moderate postoperative complications included incisional infection requiring systemic antimicrobial administration in 1 dog and pneumonia in 1 dog. Severe postoperative complications occurring ≤ 30 days after surgery included recurrence of pneumothorax in 10 dogs, incisional dehiscence or infection requiring surgical intervention in 2 dogs, hemorrhage from the internal thoracic artery requiring surgical intervention in 1 dog, lung lobe torsion in 1 dog, and development of septic abdomen in 1 dog. Two dogs died suddenly at home after discharge with no necropsy performed. In total, 9 of the 110 (8%) dogs experienced incisional complications; all incisional complications occurred in dogs that underwent a median sternotomy.

Recurrence and long-term outcome

Median follow-up time was 508 days (range, 3 to 2,377 days). Ten dogs were lost to follow-up or had follow-up times of ≤30 days after discharge. Pneumothorax recurred in 13 of the 100 (13%) dogs followed up for >30 days. Median time from surgery to recurrence was 9 days (range, 0 to 421 days), with dogs significantly (P = 0.007) more likely to have a recurrence ≤30 days after surgery, compared with >30 days after surgery. Of the 10 recurrences that occurred ≤30 days after surgery, 5 were detected prior to hospital discharge. Only 3 recurrences occurred >30 days after surgery (71, 103, and 421 days). Signalment, body weight, duration of clinical signs, imaging findings, number and location of lesions, surgical approach, partial versus complete lobectomy, and whether the lesion was leaking air during intraoperative testing were not found in multivariable modeling to be associated with recurrence of pneumothorax. Recurrence prior to initial discharge was significantly associated with a longer hospitalization time (P = 0.002) but not with a higher hospitalization cost (P = 0.128). Of the 9 dogs that underwent an intercostal thoracotomy and were followed up for >30 days, 3 had recurrence of pneumothorax (in all 3, pneumothorax recurred ≤30 days after surgery), whereas 10 (11%) of the 90 dogs that underwent a median sternotomy and were followed up for >30 days had a recurrence; however, these proportions were not significantly (P = 0.067) different. Length of the median sternotomy was recorded for only 2 dogs that had a recurrence of pneumothorax and extended from the third through the seventh sternebra in 1 dog and from the second sternebra through the xyphoid in the other.

Of the 13 dogs in which pneumothorax recurred, 6 underwent a second surgery for treatment of recurrent pneumothorax, including 1 dog that underwent autologous blood pleurodesis, which did not resolve the pneumothorax, prior to the second surgery. Four of those 6 dogs underwent additional partial or complete lung lobectomy for removal of additional bullous lesions. Additional lesions were found in the accessory (2) and left cranial (2) lung lobes. One of these dogs was euthanized after the second surgery because of a second recurrence of pneumothorax while still hospitalized; the remaining 3 survived to discharge. A fifth dog was euthanized during the second surgery because of the extent of bullous lesions. Details of the second surgery were not known for the sixth dog. Of the 7 dogs with recurrence in which a second surgery was not pursued, 5 were euthanized and 1 died while still hospitalized. The seventh dog was discharged to the care of the referring veterinarian with a thoracic tube in place and was still alive at the time of last follow-up (469 days).

In total, 10 of the 110 (9%) dogs were lost to follow-up ≤30 days after discharge. Of the 100 dogs followed up for >30 days, 7 died or were euthanized because of recurrence of pneumothorax, and 17 died or were euthanized for reasons unrelated to pneumothorax. One year after discharge, 91 of the 100 (91%) dogs were alive or had died for reasons unrelated to pneumothorax; 2-year and 5-year survival rates were 90%. Median survival time for dogs without a recurrence was 77 months and was significantly (P < 0.001) longer than the median survival time for dogs that had a recurrence (5.5 months; Figure 1).

Figure 1—Kaplan-Meier estimates of survival times for 100 dogs with PSP that underwent surgical management and did (n = 13; dashed line) or did not (87; solid line) have a recurrence of pneumothorax following surgery. None of the dogs without a recurrence of pneumothorax died as a result of PSP. Median survival time was significantly (P < 0.001) longer for dogs that did not have a recurrence (77 months) than for dogs that did (5.5 months).

Discussion

Results of the present study suggested that median sternotomy was the most common surgical treatment for dogs with PSP and resulted in resolution of pneumothorax in most affected dogs. Recurrence of pneumothorax was most common in the immediate postoperative period, which may have reflected failure to identify lesions during the initial thoracic exploration, rather than development of additional...
bullae. The long-term (ie, > 30 days after discharge) recurrence rate was low (3/100 [3%]).

In humans, PSP occurs most commonly in tall young-adult males, with smoking identified as a key risk factor. Previous studies in dogs have failed to identify risk factors for development of PSP, although middle-aged, large-breed, deep-chested dogs with no history of respiratory disease are most commonly affected, which was consistent with our study’s population. Siberian Huskies were overrepresented in a previous study and were also the most common breed in the present study. Given the association between smoking and PSP in people, dogs residing in a smoking household may also be at higher risk for PSP. However, owing to the retrospective nature of the present study, we were not able to assess this factor.

Thoracic radiography and CT are commonly used to diagnose pneumothorax and identify pulmonary bullae and blebs. The sensitivity of radiography for identification of pulmonary bullae was low in the present study and in a previous study, but radiography remains a useful tool for the initial diagnosis of pneumothorax and ruling out underlying primary lung disease. The use of point-of-care thoracic ultrasonography is increasing in veterinary medicine. This technique may be used to identify pneumothorax at the time of initial presentation, but has been shown to have limitations in identification of pneumothorax and in evaluation of the lung parenchyma in dogs and cats with traumatic pneumothorax. To the authors’ knowledge, there are no reports evaluating the accuracy of point-of-care thoracic ultrasonography as a diagnostic tool for the identification of nontraumatic pneumothorax in dogs or the accuracy of thoracic ultrasonography for identifying pulmonary bullae in dogs. Although the number of dogs undergoing point-of-care thoracic ultrasonography in the present study was small (16), the sensitivity of 100% for detecting pneumothorax suggested that this technique may be a useful tool in initial evaluation of dogs suspected to have PSP. Further study is warranted to determine the utility of thoracic ultrasonography in identifying pulmonary bullae.

Owing to the limitations of radiography in identifying pulmonary bullae, thoracic CT is often performed to aid in lesion identification and surgical planning. The sensitivity of CT in dogs is higher than that of radiography, but lower than the sensitivity reported for people. In the present study, the sensitivity of CT for identification of ≥1 bullous lesion was 71% (65/89). This was similar to previously reported sensitivities, which range from 42% to 75%. Because we collected data pertaining to whether CT identified ≥1 bullous lesion in each dog and did not ascertain whether CT accurately identified the location of all lesions in a given patient, the sensitivity reported in our study may overestimate the true sensitivity of CT for pulmonary bullae in dogs. Reasons for the discrepancy in CT accuracy for bulla identification between species may relate to CT image quality as well as to patient size, because the accuracy of CT in children with PSP is reported to be substantially lower than that reported for adults. In addition, CT images in the present study were obtained with dogs positioned in various recumbencies, including 21 dogs in which images were obtained in 2 positions. Positioning of dogs in multiple recumbencies during CT acquisition has been theorized to improve visualization of bullous lesions, but further study is needed to determine whether patient positioning affects CT identification of bullous lesions in dogs. The potential for CT to fail to identify bullous lesions and the preponderance of median sternotomy as the surgical approach of choice for PSP call into question the utility of preoperative CT for management of PSP in dogs. Preoperative CT, however, may help rule out other nonbullous causes of PSP and guide surgical exploration of the thorax when a bulla is identified on CT images in an area that may be difficult to access surgically (eg, on the dorsal aspect of the accessory lobe).

Previous studies have established that surgery is associated with a better outcome than nonsurgical treatment and is therefore considered the standard of care for dogs with PSP. Given the limitations of preoperative imaging to accurately identify all bullous lesions in dogs with PSP and the prevalence of bilateral disease, median sternotomy is the recommended approach for surgical treatment of PSP in dogs. This was supported by the findings in the present study that 3 of 9 dogs that underwent an intercostal thoracotomy and were followed up for >30 days had a recurrence of pneumothorax and that 23 (21%) dogs had bilateral disease. Median sternotomy has historically been thought to be associated with higher morbidity rates and prolonged recovery, compared with intercostal thoracotomy; however, only 9 dogs underwent an intercostal thoracotomy, with 2 dogs requiring surgical intervention because of incisional dehiscence or infection. This supported findings of a previous study in which a higher rate of incisional complications was associated with median sternotomy than with intercostal thoracotomy. In the present study, however, only 9 dogs underwent an intercostal thoracotomy, precluding any meaningful comparison of incisional complication rates between median sternotomy and intercostal thoracotomy. In addition, a recent study found no difference in short-term postoperative pain and outcomes between dogs undergoing median sternotomy and those undergoing intercostal thoracotomy for lung lobectomy. Although the potential for incisional complications should be a consideration when choosing a surgical approach, our findings suggested that the complication rate for dogs undergoing median sternotomy may be lower than previously reported. Furthermore, given that most incisional complications were mild or moderate, the benefits of minimizing incisional complications should be carefully weighed against the risk of increasing the likelihood of pneumothorax recurrence. In the present study, the recurrence rate for
dogs undergoing an intercostal thoracotomy (3/8) was not significantly different from that for dogs undergoing a median sternotomy (10/90), but this may have been due to a type II error given the low number of dogs undergoing intercostal thoracotomy.

Pneumothorax has been reported in previous studies\textsuperscript{2,4} to recur in 0% to 25% of dogs with PSP treated surgically. The present study represented the largest multi-institutional retrospective analysis of surgically managed PSP; thus, the recurrence rate of 13% (13/100) reported in this study may likely be more representative of PSP recurrence than rates reported in previous studies. Risk factors for recurrence have not previously been evaluated in dogs with PSP. In the present study, none of the evaluated factors (signalment [age, weight, breed, and sex], duration of clinical signs, preoperative imaging results, surgical approach, partial versus complete lobectomy, number of lesions, unilateral versus bilateral disease, and results of intraoperative leakage testing) were found to be associated with an increased risk of recurrence. Our hypothesis that the long-term recurrence rate in dogs with PSP would be low was supported by the fact that only 3 of the 13 recurrences occurred > 30 days after surgery, with the remaining 10 occurring ≤ 30 days after surgery. These findings were similar to those of a previous study\textsuperscript{3} in which 2 of 3 dogs experiencing a recurrence did so within 2 weeks after surgery. Excluding recurrence of pneumothorax, additional severe postoperative complications were rare in the present study, but complications such as incisional infection, hemorrhage, and potential lung lobe torsion should be discussed with owners preoperatively.

Because most deaths associated with PSP are due to persistence or recurrence of pneumothorax, reducing recurrence rates via thorough thoracic exploration and resection of all bullous lesions is critical for successful management of PSP. In the present study, 23 of 110 (21%) dogs had bilateral lesions, suggesting that a unilateral surgical approach such as a single intercostal thoracotomy is inadequate to ensure resolution of PSP in many dogs.

Although median sternotomy has traditionally been recommended for surgical management of PSP, thoracoscopic treatment has also been evaluated owing to potential advantages, including decreased postoperative morbidity rates.\textsuperscript{17–19} Limited numbers of dogs undergoing intercostal thoracotomy and thoracoscopic treatment of PSP precluded meaningful comparison of outcomes among surgical techniques in the present study. Although thoracoscopy allows for bilateral visualization of the pleural surfaces, our findings suggested that evaluation of the entire pulmonary surface is difficult via thoracoscopy, which may necessitate intraoperative conversion to a thoracotomy. In 2 dogs in the present study that had a recurrence ≤ 30 days after surgery, additional bullous lesions were found in the accessory lung lobe, a region that is difficult to thoroughly evaluate, particularly via thoracoscopy. Similarly, many surgeons attempt to avoid dividing the manubrium and xiphoid when performing a median sternotomy to provide additional stabilization of the osteotomy site postoperatively. Failing to divide the xiphoid may severely limit the surgeon’s ability to visualize the entirety of the accessory lung lobe, particularly in deep-chested dogs. The length or extent of median sternotomies performed in our study could not be assessed owing to the study’s retrospective nature. It is possible that short-term recurrences in dogs that underwent a median sternotomy may have been due to a limited osteotomy that impaired thorough visualization of all pulmonary surfaces, particularly that of the accessory lung lobe.

In the present study, we did not find an association between type of lung lobectomy for treatment of PSP (partial vs complete) and outcome (recurrence vs no recurrence). Owing to the retrospective nature of this study, we could not determine whether the decision to perform a partial or complete lobectomy was based on surgeon preference, the anatomic location of bullous lesions, or both. The fact that partial lung lobectomy was not associated with higher recurrence rates aligned with current histologic evidence that bullous lesions associated with PSP are discrete lesions.\textsuperscript{2} This also supported the assertion that partial lung lobectomy is likely sufficient for PSP resolution when a single peripheral bullous lesion is amenable to excision via partial lung lobectomy. Conversely, a hilar lesion, multiple bullous lesions in the same lobe, or grossly visible diffuse emphysematous changes within a lobe would suggest that complete lung lobectomy is warranted.

Although most dogs with PSP are large-breed dogs, conformation within this subset of dogs can vary and may affect the ability to visualize the entire pulmonary surface. For example, thoracic exploration may be especially difficult in very large, deep-chested dogs, as evidenced by the fact that 2 of 3 Great Danes in the present study experienced a recurrence of pneumothorax within 5 days after surgery. Understanding the typical distribution of lesions in dogs may help to optimize intraoperative identification of lesions, especially if no lesions are identified on preoperative images. In humans, bullae occur almost exclusively above the carina.\textsuperscript{12} Although bullae were found throughout all lung lobes in the present study, 88 of the 156 (56%) lesions were found in the right cranial and left cranial lung lobes. In dogs that underwent a second thoracic surgery following recurrence, additional bullae were found in the left cranial lung lobe in 2 dogs and in the accessory lung lobe in 2 dogs, suggesting that these are 2 locations in which bullae may be more frequently missed during surgical exploration. Although lesion distribution in dogs may not be as predictable as in humans, our findings suggested that certain segments of lung may be more likely to have bullae or may be more difficult to visualize, and this should be considered during initial surgical intervention. This is particularly important when considering that owners of only 6 of 13 dogs elected to proceed with a second surgical intervention in the face of recurrence.
Given the limitations of preoperative bulla identification via diagnostic imaging, the short time to recurrence, and the fact that an additional bullous lesion was found in at least 5 of the 6 dogs undergoing a second surgery following short-term recurrence, results of the present study suggested that short-term recurrence of pneumothorax in dogs with PSP is likely due to failure to identify causative lesions during the initial thoracic exploration rather than to rapid development of additional lesions. For the purposes of this study, short-term recurrence was defined as recurrence ≤ 30 days after surgery, and long-term recurrence was defined as recurrence > 30 days after surgery. Although this cutoff was somewhat arbitrary, our goal was to separate cases that more likely reflected a missed lesion during initial treatment from those suggestive of true recurrence of bullous lesions. Following this logic, short-term recurrence should more appropriately be referred to as persistence of PSP, rather than recurrence of PSP. Because the long-term recurrence rate of PSP in this study was low (3%), we assert that dogs in which all causative lesions are correctly localized and resected at initial surgical treatment have a good long-term prognosis and median survival time, with a true recurrence rate lower than previously reported.4 Because the present study was limited by its retrospective nature and limited follow-up, a prospective study with longer follow-up would help clarify long-term outcome in dogs with PSP managed surgically.

In conclusion, surgical resection of bullae resulted in resolution of pneumothorax in most dogs with PSP. The widespread distribution of lesions and limited accuracy of preoperative CT illustrated the need for complete exploration of all pulmonary surfaces, particularly the cranial and accessory lung lobes. This may be most effectively achieved via median sternotomy. Surgical complications were uncommon, with recurrence of pneumothorax comprising the most common life-threatening complication. Recurrence was most likely to occur ≤ 30 days after surgery, suggesting that it likely represented persistence of lesions missed during the initial surgery and that a second surgery to evaluate for additional bullous lesions should be considered. Dogs without a recurrence of pneumothorax within the first 30 days after surgery could be expected to have a good long-term prognosis.

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Footnotes
a. JMP, SAS Institute Inc, Cary, NC.

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