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Thoracic CT incidental pulmonary bullae in dogs: Characterization, interobserver variability, and general anesthesia risks

Won Suk Kim[1] | Michael Ward[2] | Elizabeth Huynh[3] | Lynn Griffin[4] | Jin Heo[3] | Arathi Vinayak[1]

[1]Department of Surgical Oncology, VCA West Coast Specialty and Emergency Animal Hospital, Fountain Valley, California, USA

[2]Sydney School of Veterinary Science, The University of Sydney, Camden, New South Wales, Australia

[3]Department of Diagnostic Imaging, VCA West Coast Specialty and Emergency Animal Hospital, Fountain Valley, California, USA

[4]Department of Diagnostic Imaging, Colorado State University College of Veterinary Medicine, Fort Collins, Colorado, USA

Correspondence
Won Suk Kim, 18300 Euclid Street, Fountain Valley, CA 92708, USA.
Email: wonkim846@gmail.com

Abstract

Ruptures of pulmonary blebs and bullae are the most common cause of spontaneous pneumothorax in dogs. Incidental bullae/blebs have been documented in otherwise healthy people, however information for veterinary patients is currently lacking. Objectives of this retrospective, observer agreement, analytical study were to characterize incidental bullae in thoracic CT studies of dogs, assess interobserver variability for characterizing the bullae, and assess anesthesia risks. Inclusion criteria were dogs presenting for non-pneumothorax related reasons that had a thoracic CT at a single specialty and emergency hospital from 2012 to 2021 and had a bulla listed in the CT report. Medical records for dogs meeting inclusion criteria were reviewed to collect data on signalment, weight, total number of general anesthesia procedures 2 years prior and 2 years following the CT scan, and adverse anesthesia events. In addition, the CT images were reviewed by three American College of Veterinary Radiology-certified veterinary radiologists to collect data on the location, size, number of bullae and thickness of the bulla wall. A total of 1119 dogs met initial inclusion criteria and 74 dogs were included in analyses. There was no sex predilection for incidental pulmonary bullae. Bullae were more commonly found in older (median age 11.3 years), large breed dogs (median weight 20.7 kg). A solitary bulla of less than 1 cm was the most common finding with no apparent predilection for a particular lung lobe. There was strong correlation among the three radiologists for bulla location, size, and number, but weak correlations for bulla wall thickness. No adverse anesthesia events were found following CT anesthesia or following repetitive anesthesia procedures.

KEYWORDS
anesthesia, blebs, bullae, computed tomography, incidental, lung, pulmonary, thorax

1 | INTRODUCTION

Rupture of pulmonary blebs and bullae is reported to be the most common cause of spontaneous pneumothorax in dogs.[1–3] The pathophysiologic changes associated with spontaneous pneumothorax include atelectasis, ventilation/perfusion mismatch, arterial hypoxemia, and myocardial dysfunction.[4,5] These changes lead to clinical signs including dyspnea, tachypnea, coughing, anorexia, and collapse.[4,6] Accurate and rapid diagnosis and treatment of the ruptured bullae or blebs is imperative to address this life-threatening condition. Treatment of choice is surgery to remove the affected lung lobe via median sternotomy.[1,6,7]

Blebs are accumulation of air within the layers of the visceral pleura, most commonly located at the lung apices.[1,3] Bullae are air-filled spaces within the pulmonary parenchyma secondary to disruption in the intra-alveolar septa. These disruptions can be in the form of dilatation, destruction, and confluence of the surrounding alveoli.[7] Bullae are confined to the internal layer of the visceral pleura and the connective tissue septa within the lung and are further classified into three types histopathologically.[1] Type 1 bullae are thin with a narrow connection to the lung parenchyma; Type 2 bullae arise from the subpleural parenchyma and are connected to the rest of lung parenchyma by a neck of emphysematous lung; Type 3 bullae are large and extend deep into the pulmonary parenchyma.[1] The cause of blebs or bullae formation is unknown. Multiple previous studies have defined blebs as thin-walled air containing spaces of less than 1 cm in size.[8–10] A bulla is defined as an air-filled space with a thin wall of less than or equal to 1 mm within the lung.[8] The use of the term "bleb" has been discouraged as the distinction between bullae and blebs is arbitrary and has little clinical significance.[10]

In humans, the reported accuracy of radiographic detection of bullae or blebs ranges from 10% to 60.5%, and in dogs, from 0% to 50%.[3,6] CT provides a more accurate means of diagnosing bullae in humans with reported sensitivity ranging from 91.8% to 97%.[11,12] In dogs, however, the current reported sensitivity ranges from 42.3% to 69.2%.[8,13] Studies assessing interobserver variability report strong agreement among radiologists interpreting bullae via CT images; however, the sample sizes of these veterinary CT studies have been small with only 15 and 19 dogs with spontaneous pneumothorax.[13,14] While there were imaging-related publications in a subset of dogs with bullae-associated pneumothorax,[3,13,14] no publications on the subset of dogs with incidental pulmonary bullae/blebs without pneumothorax were found. In humans, incidental bullae/blebs are documented in otherwise healthy people. In a Dutch publication, incidental bullae on CT imaging were noted to be in a third of the adult population.[15] In dogs, epidemiologic data regarding bullae are limited. Deep-chested, large-breed dogs are commonly affected by primary spontaneous pneumothorax[1,4,6] and a higher incidence of primary spontaneous pneumothorax has been noted in Siberian Huskies compared to other breeds in some studies.[4,6,16] Consequences of incidental pulmonary bullae have also yet to be characterized in dogs. In a human study involving 46 pilots diagnosed with pulmonary bullae, it was reported that none of the pilots had evidence of rupture of these lesions during a mean follow-up of 424.4 days.[17] Although information regarding the recurrence of spontaneous pneumothorax following surgery in dogs exists,[18,19] data on anesthesia and spontaneous rupture risks associated with incidental pulmonary bullae are not available.

Objectives of this study were to characterize incidental bullae in thoracic CT studies of dogs, assess interobserver variability for characterizing the bullae, and assess anesthesia risks. Our hypotheses were that (1) there would be no sex or breed predilection for incidental bullae; (2) bullae would be more common in geriatric dogs, with a higher incidence of bullae in the caudal lungs as these lobes have greater lung tissue mass[20–22]; (3) there would be strong agreement among radiologists in terms of the number, location, size, and thickness of incidental bullae wall based on CT images; and (4) patients with incidental bullae would not have evidence of an adverse anesthesia event.

2 | MATERIAL AND METHODS

2.1 | Selection and description of subjects

This study was a retrospective, observer agreement, analytical design. Medical records and CT images of all dogs that underwent a thoracic CT scan for non-pneumothorax related reasons at VCA West Coast Specialty and Emergency Hospital between September 2012 to June 2021 were reviewed for this study. IACUC approval was not needed as this study involved patients undergoing anesthesia and CT for reasons unrelated to incidental pulmonary bullae. Approvals from the medical director and the senior group vice president of the hospital were obtained. Subject inclusion decision was made by an American College of Veterinary Surgeon—board certified surgeon (A.V.). Dogs were included in this study if they underwent a thoracic CT scan, had medical records of the time of the CT scan, had accessible CT images and were diagnosed with pulmonary bullae with a wall thickness of less than 1 mm on a CT radiology report by an American College of Veterinary Radiology (ACVR)—certified veterinary radiologist. As part of the inclusion criteria, all CT studies of the thorax were performed using the same multidetector (64 slice) CT scanner (Aquilion Prime, Toshiba Medial Systems, Tokyo, Japan) with helical acquisition. Transverse pre-contrast images were reconstructed in 2 mm slice thickness lung reconstruction algorithm (1600 WW, −550 WL) (Figure 1). Nonionic, iodinated positive contrast medium (2.2 ml/kg; Omnipaque™ [iohexol] 350 mgI/ml, GE Health Care, Princeton, NJ) was administered as an intravenous bolus for all patients using power injector (MEDRAD® Stellant [Bayer, NJ, USA]) at injection rates of 1 ml/kg for dogs less than 10 kg bodyweight and 2 ml/kg for dogs 10 kg or greater in body weight. Patients were excluded if the CT images were incomplete or inaccessible, if they had concurrent pneumothorax, or if they were wolf-hybrid dogs.

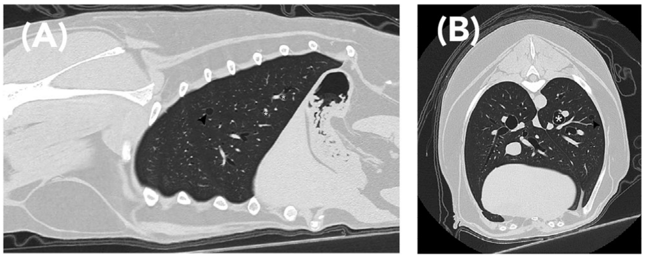

FIGURE 1 Transverse (A) and sagittal (B) plane lung window (1600 WW, −550 WL) computed tomographic images of a left caudal pulmonary bulla (black arrowhead) in an 11 year-old dog. Note the normal end-on bronchus (asterisk) on the transverse and sagittal plane images

2.2 | Data recording and analysis

Medical records were reviewed by a surgical oncology intern (W.K.). The data collected from medical records included signalment, weight, date of CT, total number of general anesthesia procedures 2 years prior and 2 years following the CT scan, adverse anesthesia events following CT scan, number of general anesthesia procedures for radiation therapy when applicable, subsequent adverse anesthesia events (not radiation therapy associated), and treatments for those adverse anesthesia events. For the purposes of this study, general anesthesia procedure was defined as induction of general anesthesia in a patient; adverse anesthesia event was defined as a complication due to anesthesia procedure. In addition, concurrent pulmonary disease was also recorded and categorized as either inflammatory/infectious, neoplastic-primary, neoplastic-metastatic, or free of concurrent pulmonary disease.

The CT images were reviewed by three ACVR-certified veterinary radiologists with varying levels of experience from 3 years to 10 years post-residency (observer 1– 3 years; observer 2– 5 years; and observer 3 – 10 years). Pre-, postcontrast medium, and delayed (5 min) postcontrast images were acquired and viewed at the reviewer's discretion. Multiplanar images in a lung window (window width = 1600, window level = −500) were viewed and analyzed on an image analysis workstations (eFilm Workstation, IBM Watson Health, Durham, NC). Assessments of the size, location, and number of bullae, and thickness of the bullae wall were recorded by the radiologists based on independent review. The radiologists were only aware of the signalment of the patient and the date of the study while reviewing the images. Size was defined as the widest recorded diameter in centimeters. Each bulla was categorized into three size groups: <1 cm in diameter, 1–2 cm in diameter, and >2 cm in diameter. The location of the bulla was noted as right cranial, right middle, right caudal, right accessory, left cranial segment of the cranial lobe, left caudal segment of the cranial lobe, or left caudal lung lobe. In our population of dogs with pulmonary bullae, some of the wall thicknesses were observed to be thicker, though still having a thin wall of less than or equal to 1 mm. Thickness of the bullae wall was evaluated subjectively by each radiologist and recorded as thin or thick based on their assessment. For the purpose of the study, the term "solitary" refers to the sum of one bulla per dog, and the term "single" refers to one bulla per lobe. The term "multiple" was used to describe either many bullae in a single lobe or many bullae in multiple lobes. Bullae were defined as abnormal thin-walled, air-filled spaces within the lung lobes, regardless of size.

2.3 | Statistics

Statistical analysis was performed by a statistician (M.W.) using commercially available software (IBM SPSS Statistics for Windows, version 28.0, IBM Corp., Armonk, N.Y., USA). The Shapiro–Wilk test was used to test for normality. The Spearman rank correlation test was used to analyze the correlation between the number of bullae per patient noted by each of the three radiologists. All radiologists assessed all patients, so the correlation between their assessment per patient was the outcome of interest in this study, rather than patient effect. The number of bullae noted in each of the seven lung lobes by each radiologist was further analyzed using Spearman rank correlation, as was the size of the bullae noted by the radiologists (<1 cm, 1–2 cm, >2 cm). Spearman rank correlation interpretations were based on the following : 0-0.19 "very weak" • 0.20-0.39 "weak" • 0.40-0.59 "moderate" • 0.60-0.79 "strong" • 0.80-0.99 "very strong.[23] Perfect correlation between the radiologists was considered a value of 1.0. As the presence and characteristics of the pulmonary bullae were not confirmed intra-operatively in these asymptomatic patients, inputs from the two radiologists with the strongest correlation were deemed to be the most accurate representation of a patient's bulla characteristic. Chi-square test was used for further analysis and to answer questions such as: whether bullae tend to be solitary or multiple, the most common size of bullae, and commonly affected lung lobes. Values of $P < 0.05$ were considered significant. Kruskal-Wallis 1-way ANOVA was performed on each type of concurrent pulmonary diseases (inflammatory, neoplastic-primary, neoplastic-metastatic, or no concurrent pulmonary disease) to determine if the type of concurrent disease affected the number of bullae that was present. Adverse anesthesia events associated with each anesthesia procedure was tabulated.

3 | RESULTS

3.1 | Description of sampled animals

A total of 1119 patients had a thoracic CT scan during the selected time frame. Of the 1119 patients, 87 patients had pulmonary bullae diagnosed in an ACVR—boarded radiologist's report. Four of 87 patients were excluded due to the diagnosis of spontaneous pneumothorax. Eight cases were excluded due to incomplete records or CT images and one case was excluded as the patient was a wolf hybrid, resulting in a final sample of 74 patients for analyses. Of the 74 dogs that were included in our study, there were 35 spayed females, 34 neutered males, one intact female, and four intact males. Weight was not normally distributed, but age was normally distributed. The median weight was 20.7 kg with an interquartile range of 7 kg to 30 kg. The median age was 11.3 years (135.5 months) with an interquartile range of 10 years (120 months) to 13 years (156 months). A variety of breeds were noted. The most common pure breed affected was the Golden Retriever, representing 8% of the cases. Breeds most commonly included in this study were: Mix breed dog (8), Golden Retriever (6), Labrador Retriever (4), Pitbull mix (4), Boxer (4), Bassett Hound (3), and German Shepherd (2). There were no Siberian Huskies in the sample population.

3.2 | Clinical findings in dogs with presence of incidental pulmonary bullae

Of the 74 dogs with incidental pulmonary bullae, 18 dogs had respiratory clinical signs at presentation. The respiratory signs noted included:

TABLE 1 Correlations summary. Observer 1 versus Observer 3 had the highest correlation in total number of bullae seen for all 74 patients with correlation statistic of 0.822, 95% CI [0.727, 0.886]. Left caudal lung lobe had the highest correlation in the number of bullae seen with correlation statistic of 0.933, 95% CI [0.894, 0.958] and right cranial lung lobe had the lowest correlation in the number of bullae seen with correlation statistic of 0.832, 95% CI [0.742-0.893]. Correlation in bullae sizes were strong with correlation statistic of 0.8 and greater. Thick and thin showed weak to moderate correlation across all three radiologists

	Observer 1 versus Observer 2 (Correlation Coefficient, 95% CI[])	Observer 1 versus Observer 3 (Correlation Coefficient, 95% CI[])	Observer 2 versus Observer 3 (Correlation Coefficient, 95% CI[])
Total	0.748, [0.623, 0.836]	0.822, [0.727, 0.886]	0.770, [0.653, 0.851]
R. Cranial	0.780, [0.667, 0.858]	0.832, [0.742, 0.893]	0.747, [0.621, 0.835]
R. Middle	0.528, [0.334, 0.678]	0.862, [0.786, 0.912]	0.399, [0.181, 0.580]
R. Caudal	0.824, [0.730, 0.887)	0.882, [0.817, 0.925]	0.755, [0.633, 0.841]
R. Accessory	0.826, [0.733, 0.888]	0.847, [0.764, 0.902]	0.659, [0.502, 0.774]
L. Cranial seg of Cranial	0.742, [0.614, 0.832]	0.904, [0.850, 0.940]	0.656, [0.498, 0.772]
L. Caudal seg of Cranial	0.667, [0.512, 0.779]	0.856, [0.777, 0.908]	0.634, [0.468, 0.756]
L. Caudal	0.730, [0.598, 0.824]	0.933, [0.894, 0.958]	0.761, [0.641, 0.845]
<1 cm	0.810, [0.711, 0.878]	0.802, [0.698, 0.872]	0.778, [0.665, 0.857]
1-2 cm	0.693, [0.548, 0.798]	0.870, [0.798, 0.917]	0.743, [0.615, 0.832]
>2 cm	0.653, [0.493, 0.770]	0.811, [0.711, 0.878]	0.811, [0.711, 0.878]
Thick	0.196, [−0.041, 0.412]	0.513, [0.316, 0.667]	0.456, [0.247, 0.624]
Thin	0.558, [0.372, 0.701]	0.568, [0.384, 0.708]	0.565, [0.381, 0.706]

coughing (13), stridor (2), sneezing (1), wheezing (1), and increased respiratory noise (1). Of the 18 dogs with respiratory signs, eight dogs had no concurrent pulmonary disease on CT, six dogs had primary pulmonary neoplastic disease, three had metastatic pulmonary neoplastic disease, and one had inflammatory pulmonary disease.

3.3 | Results of statistical analyses

The total number of bullae noted between observers was strongly correlated. The correlation statistics (Spearman rank correlation) were all > 0.7; observer 1 vs. observer 2: 0.748, observer 1 vs. observer 3: 0.822, and observer 2 vs. observer 3: 0.770, and all were significant with $P < 0.001$. Overall, observer 2 observed a greater median number (2.0) of bullae than observer 3 (1.5) and observer 1 (1.0), and the difference was significant ($P < 0.001$). Observer 2 observed more bullae than either observer 1 or observer 3, but no significant difference was noted between observer 1 and observer 3. Correlations were generally strong amongst the radiologists except for thin vs. thick bullae wall evaluations. Correlation between observer 1 and observer 3 was the strongest, but comparable for total number, size, and location between observer 1 and observer 2, and between observer 2and observer 3, except for location for right middle and left cranial lung lobe caudal segment (Table 1). Agreement between observer 1 and observer 3 for location was the strongest for left caudal lung with correlation statistic of 0.933 followed by left cranial segment of the cranial lung lobe with that of 0.904. The weakest agreement in location was for the right cranial lung lobe with correlation statistic of 0.832. For size, the strong correlation was for 1–2 cm bullae with correlation statistic of 0.87 (Figure 2).

Inputs from the two radiologists with the strongest correlations were used to further characterize the bullae in terms of number, location, and size. As there were generally weak correlations in the thin versus thick assessment of the bullae wall, further analysis was not continued. The maximum responses from either observer 1 or observer 3 were selected to represent the bullae characteristic for each of the 74 patients.

Overall, there were 18 patients with multiple bullae and 56 patients with a solitary bulla. A patient was three times more likely to have a solitary bulla compared to multiple bullae. For each lung lobe with bullae, a single bulla was more common than multiple bullae (111 cases vs. 35 cases; Table 2).

In regards to size, <1 cm was most common (87.4%), followed by 1–2 cm (11.3%), and then >2 cm (1.3%). There was no significant association between size and location ($P = 0.8452$; Table 3). Incidence of multiple bullae in left caudal lung lobe was 29.7%, right caudal lung lobe was 25.6%, left cranial segment of the cranial lung lobe was 25%, right accessory lung lobe was 23.1%, right middle lung lobe was 18.2%, left caudal segment of the cranial lung lobe was 13.9%, and right cranial lung lobe was 8.7%. There was no significant association between multiple bullae and location ($P = 0.466$). There was no statistical difference between the incidence of multiple bullae in the left lung lobes (22.6%) and right lung lobes (19.8%; $P = 0.6456$). Bullae < 1 cm was by far the most common size in solitary (82.3%) and multiple cases (89.5%), and there was no significant difference in the size distribution of solitary vs. multiple bullae cases ($P = 0.4741$; Table 4).

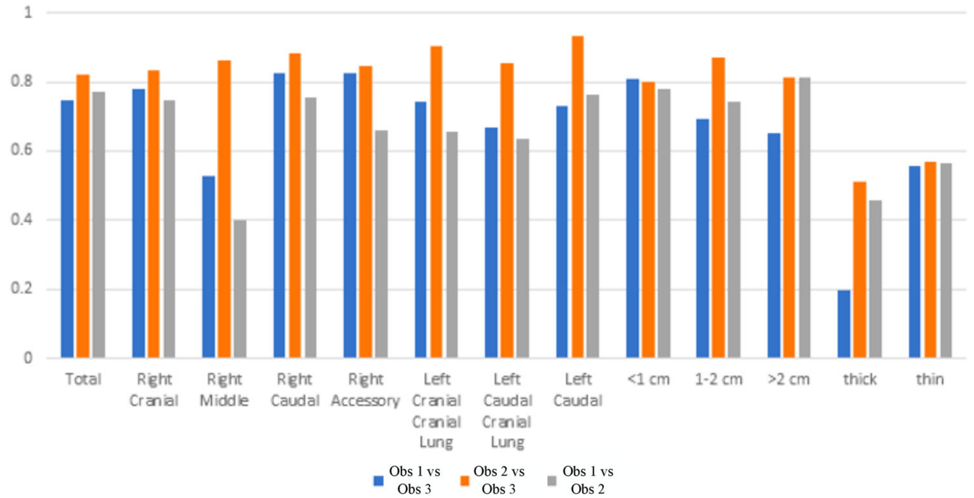

FIGURE 2 Graphic representation of correlation summary. Observer 1 versus Observer 3 had the highest correlation in total number of bullae seen for all 74 patients with correlation statistic of 0.822, 95% CI [0.727, 0.886]. Left caudal lung lobe had the highest correlation in the number of bullae seen with correlation statistic of 0.933, 95% CI [0.894, 0.958] and right cranial lung lobe had the lowest correlation in the number of bullae seen with correlation statistic of 0.832, 95% CI [0.742-0.893]. Correlation in bullae sizes were strong with correlation statistic of 0.8 and greater. Thick and thin showed weak to moderate correlation across all three radiologists [Color figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Single versus multiple bullae in each of the lung lobes. Percentage of multiple bullae for each lung lobe was statistically non-significant

	Multiple	Single	Percentage of Multiple bullae	Proportion test, null = 24%
R. Cranial	2	20	9.1%	0.1080
R. Middle	3	7	30.0%	0.6569
R. Caudal	10	24	29.4%	0.2940
R. Accessory	3	10	23.1%	0.9394
L. Cranial seg of Cranial	4	15	21.1%	0.7672
L. Caudal seg of Cranial	3	10	23.1%	0.9394
L. Caudal	10	25	28.6%	0.5240
Total	35	111	24%	

TABLE 3 Sizes of all bullae. < 1 cm bullae were the most common, comprising 87.4% of all bullae, followed by 1-2 cm (11.3%) and > 2 cm (1.3%)

Sizes	R. Cranial	R. Middle	R. Caudal	R. Acc.	L. Cr. seg Cranial	L. Cau. seg Cranial	L. Caudal	Total # of bullae	Percentage (%)
<1 cm	23	12	57	16	20	14	60	202	87.4
1-2 cm	3	2	9	1	4	2	5	26	11.3
>2 cm	0	0	2	0	1	0	0	3	1.3
Total	26	14	68	17	25	16	65	231	100

Concurrent pulmonary diseases were categorized as infectious/inflammatory, neoplastic-primary, neoplastic-metastatic, or no concurrent pulmonary disease strictly based on CT imaging findings. Overall 67.6% (50/74) of the dogs were free of concurrent pulmonary diseases. Of the 32.4% (24/74) of dogs with concurrent pulmonary disease, 20.8% (5/24) dogs had infectious/inflammatory disease, 54.2% (13/24) had a primary neoplastic disease, and 25% (6/24) had metastatic neoplastic diseases noted on their thoracic CT. Kruskal–Wallis one-way ANOVA of each category of concurrent pulmonary diseases revealed no significant difference in the number of pulmonary bullae with or without concurrent pulmonary disease. Patients with concurrent inflammatory disease had on average 2.96 bullae ($P = 0.155$), primary neoplastic disease had an average of 2.91 bullae ($P = 0.263$), metastatic neoplastic disease had an average of

TABLE 4 Single versus multiple bullae of varying sizes. A) < 1 cm bulla was the most common for single bulla comprising 82.3% of all single bulla. B) < 1 cm bulla was also the most common for multiple bullae comprising 89.5% multiple bullae

A)		
Single	**Number of bullae**	**Percentage**
<1 cm	116	82.3%
1-2 cm	22	15.6%
>2 cm	3	2.1%
Total	141	
B)		
Multiple	**Number of bullae**	**Percentage**
< 1 cm	34	89.5%
1-2 cm	3	7.9%
>2 cm	1	2.6%
Total	38	

TABLE 5 Count of anesthesia procedures for 2 years after CT anesthesia. 38 dogs had anesthesia procedures following incidental bullae diagnosis

Number of Dogs with anesthesia procedures 2 years following CT	# of anesthesia procedures
36	0
18	1
7	2
6	3
2	4
1	5
2	6
1	9
1	10
74	Grand Total

2.96 bullae (P = 0.816), and patients with no concurrent pulmonary disease had an average of 2.97 bullae (P = 0.304).

Of the 74 dogs, 34 dogs (46%) had previous general anesthesia procedure in the 2 years prior to the CT scan. There were 18 dogs that had one anesthesia procedure, seven had two anesthesia procedures, six had three anesthesia procedures, two had five anesthesia procedures, and one had seven anesthesia procedures in the 2 years prior to the CT scan. There were no reported adverse anesthesia events associated with the CT scan for the 74 dogs. Of the 74 dogs, 36 dogs had no reported general anesthesia procedures in the 2 years following the CT scan. There were 18 dogs that had one anesthesia procedure, seven had two anesthesia procedures, six had three anesthesia procedures, two had four anesthesia procedures, and one had five anesthesia procedures, two had six anesthesia procedures, one had nine anesthesia procedures, and one had 10 anesthesia procedures in the 2 years following to the CT scan (Table 5). There were no reported adverse

TABLE 6 Count of consecutive anesthesia procedures for radiation therapy following CT anesthesia

Number of Dogs with RT consecutive anesthesia procedures	# of anesthesia procedures
3	2
6	3
2	4
1	5
2	6
1	8
1	10
58	No RT anesthesia procedures
74	Grand total

anesthesia events associated with these procedures for the 38 dogs. Of the 38 dogs that had a general anesthesia procedure following CT scan, 16 dogs had consecutive anesthesia for radiation therapy (RT). There were three dogs that had two consecutive RT anesthesia procedures, six dogs had three consecutive RT anesthesia procedures, two dogs had four consecutive RT anesthesia procedures, one dog had five consecutive RT anesthesia procedures, two dogs had six consecutive RT anesthesia procedures, one dog had eight consecutive RT anesthesia procedures, and one had 10 consecutive RT anesthesia procedures (Table 6). There were no reported adverse anesthesia events associated with consecutive anesthesia procedures.

4 | DISCUSSION

The goal of this study was to characterize incidental pulmonary bullae in terms of the signalment of those affected, common size, commonly affected lung lobe, and whether solitary bulla or multiple bullae were more common. In addition, we aimed to provide information on interobserver variability in diagnosing incidental pulmonary bullae on CT and on anesthesia risks associated with pulmonary bullae in the dog. We accepted the hypothesis that bullae are more common in geriatric dogs, but rejected the hypothesis that the caudal lungs have a higher incidence of bullae. We accepted our hypothesis that there is strong agreement among radiologists in regards to number, location, and size based on CT images. There was poor agreement among the radiologists with regards to wall thickness. We accepted our hypothesis that patients with incidental bullae would not have evidence of an adverse anesthesia event as no evidence of an association between incidental bullae and adverse anesthesia events was found.

In a recent human paper, researchers found that approximately one third of Dutch adults, with no previously diagnosed pulmonary disorders, had pulmonary blebs or bullae noted on a postmortem CT (PMCT). Of the 130 individuals, 44 individuals were noted to have incidental pulmonary blebs/bullae with equal representation from the different age groups.[15] The authors questioned the implications of this finding for diving medicine, as pulmonary bullae are considered contraindications for diving. Although implications for diving may not be pertinent for dogs, incidental bullae in dogs could have implications in medical treatments such as hyperbaric oxygen therapy (HBOT). As rupture of pulmonary bullae is the most common cause of spontaneous pneumothorax in dogs[1–3] and pneumothorax is the one absolute contraindication for HBOT,[24] knowledge of the characteristics of pulmonary bullae in dogs and risks associated with the disease is valuable for better understanding of the disease process and its potential complications.

Based on the current study, incidental bullae appear to be more common in older, larger breeds of dogs with no gender predilections. Neuter status could not be evaluated as very few animals were intact. Approximately 24.3% (18/74) of the dogs presented with respiratory signs with coughing listed as the most common clinical sign at the time of presentation (13/18). Interestingly, most dogs (10/18) presenting with respiratory signs had other concurrent pulmonary disease to account for these signs.

In veterinary medicine, diagnosis of pulmonary bullae is a challenge as the sensitivity of CT in detecting bullae in veterinary medicine is low.[13] A recent study evaluating the use of CT for the diagnosis of pulmonary bullae reported sensitivity ranging from 57% to 69%[14] compared to up to 97% in humans.[11] The proposed causes for the low sensitivity in veterinary medicine include the smaller size of the patients and the use of anesthesia for CT scans.[14] Anesthesia used for CT scans in veterinary patients can result in atelectasis of the lungs and can lead to lung tissue attenuation, further hindering the ability to recognize bullous lesions.[3,14] Despite these limitations, interobserver agreement between radiologists reviewing thoracic CT for bullae in pneumothorax cases has historically been strong with reported k-values of 0.64[13] and 0.67,[14] with k value of 1 representing perfect agreement, in two smaller studies with sample sizes of 19 and 15 dogs, respectively. The correlation statistics (Spearman rank correlation) were all > 0.7 between the three radiologists and considered to be strong agreement.

Prevalence of multiple bullae was reported to be between 37% to 83.3% and bilateral bullae were reported in 26%–58.3% of the dogs in previous studies.[1,3,6] In our study, a solitary bulla was more common than multiple bullae. For dogs with multiple bullae, a single bulla in a lobe was more common than multiple bullae in a lobe. There was no significant difference in the presence of multiple bullae between the lung lobes. Each hemithorax were equally likely to have multiple bullae. Bullae less than 1 cm was the most common. There was no significant difference in the size distribution of solitary versus multiple bullae cases and there was no significant association between size and location. A vast majority of the dogs in this study were free of concurrent pulmonary diseases. Among the 32.4% of dogs with concurrent pulmonary disease, a solitary mass in the lungs consistent with a primary lung tumor was the most common. The type of concurrent pulmonary disease was unrelated to the number of bullae.

Understanding the risks of anesthesia and long-term ramifications of pulmonary bullae in dogs are crucial pieces of information that have not been looked at in dogs to the best of the authors' knowledge. Recurrence rate of spontaneous pneumothorax in dogs following surgery is reported to be low with rates ranging from 0% to 25%, but the percentage of pulmonary bullae that rupture and lead to spontaneous pneumothorax is unknown.[1,6,18,25] Furthermore, implications of bullae in anesthesia safety in dogs have not been evaluated. In humans, a study following up on incidental bullae diagnosed found that there was no evidence of rupture of these lesions on a low-dose chest CT follow-up after a mean of 424.4 days. The authors of this study also noted that only 5 cases showed changes in size and these findings led the authors to conclude that preventive treatments were not necessary.[17] In our study, there were no reported adverse anesthesia events associated with CT scan for the 74 dogs. Of the 74 dogs, 38 dogs had anesthesia procedures 2 years following the CT scan with 16 of those dogs having repeat consecutive anesthesia procedures for radiation therapy, all with no reported adverse anesthesia events. As there were no adverse anesthesia events, odds ratio could not be calculated. There was no evidence of an association between incidental bullae and adverse anesthesia events. While a study dedicated to long-term follow-up and ramifications of incidental bullae is needed in veterinary medicine, our study suggests that preventative treatment of these bullae may not be needed in asymptomatic patients.

Limitations of this study include those related to the retrospective nature of this study. Due to a change in the medical record system during the study time frame, some of the medical records were incomplete. Information regarding adverse anesthesia events and anesthesia protocol during the CT was absent in some of the medical records, leading them to be excluded. Without surgical intervention or necropsy, we were unable to compare the radiologists' interpretations to a gold standard. As dogs with incidental pulmonary bullae were asymptomatic, surgical intervention to confirm bullae characteristics was not warranted. Thus, histopathology of these lesions compared to those of dogs with spontaneous pneumothorax due to ruptured bullae was not possible to determine if they were of similar etiology. Based on our review of the literature, none of the published veterinary studies using CT to evaluate pulmonary bullae have objective measurements of wall thickness to know if they are truly < 1 mm. This is a limitation of the current study as well. In general, wall thickness has been a subjective assessment made by veterinary radiologists using a < 1 mm wall thickness definition derived from human medicine. A study evaluating the accuracy of wall measurements in micrometers/millimeters on CT relative to histopathologic wall thickness confirming that bullae in veterinary medicine are indeed less than 1 mm is warranted. These may be the reason for the poor agreement among the radiologists in bullae wall thickness measurement. Another limitation is that nearly half of the study population (36/74) did not have medical records pertaining to anesthesia in the 2 year follow-up period after diagnosis of incidental bullae; however of the 38 dogs with long term follow-up and anesthesia procedures, adverse anesthesia events were not noted.

In conclusion, there was no sex predilection for incidental pulmonary bullae in this sample of dogs. Bullae were more commonly found in older, large-breed dogs. Solitary bulla less than 1 cm was the most common size with no apparent predilection for a particular lung lobe. In dogs with multiple bullae, bullae of less than 1 cm were still the most common size. No adverse anesthesia events were noted following CT anesthesia in patients with incidental pulmonary bulla. This was true even in patients that underwent repeat anesthesia procedures. 51% of the dogs underwent additional anesthesia procedures in the 2-year follow-up period after CT and none experienced adverse anesthesia events. Majority of dogs with incidental pulmonary bulla were free of concurrent pulmonary diseases and most of the dogs presenting with respiratory signs had concurrent pulmonary disease. In the subset of dogs with concurrent pulmonary disease, the type of concurrent pulmonary disease was unrelated to the number of bullae. The authors conclude that presence of incidental pulmonary bullae should not deter pursuance of diagnostics or treatment involving general anesthesia procedures.

LIST OF AUTHOR CONTRIBUTIONS

Category 1

(a) Conception and Design: Vinayak
(b) Acquisition of Data: Huynh, Heo, Griffin, Kim, Vinayak
(c) Analysis and Interpretation of Data: Ward, Kim, Vinayak

Category 2

(a) Drafting the Article: Kim, Vinayak
(b) Revising Article for Intellectual Content: Kim, Ward, Vinayak, Huynh, Heo, Griffin

Category 3

(a) Final Approval of the Completed Article: Kim, Ward, Vinayak, Huynh, Heo, Griffin

Category 4

(a) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved: Kim, Ward, Vinayak, Huynh, Heo, Griffin

CONFLICT OF INTEREST

The authors declare no conflict of interest.

PREVIOUS PRESENTATION OR PUBLICATION DISCLOSURE

None

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ORCID

Won Suk Kim https://orcid.org/0000-0002-8534-8836
Lynn Griffin https://orcid.org/0000-0002-0074-8233

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