SMALL ANIMALS/ EXOTIC

Sensitivity, positive predictive value, and interobserver variability of computed tomography in the diagnosis of bullae associated with spontaneous pneumothorax in dogs: 19 cases (2003–2012)

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Objective—To determine the sensitivity, positive predictive value, and interobserver variability of CT in the detection of bullae associated with spontaneous pneumothorax in dogs.

Design—Retrospective case series.

Animals—19 dogs with spontaneous pneumothorax caused by rupture of bullae.

Procedures—Dogs that had CT for spontaneous pneumothorax caused by rupture of bullae confirmed at surgery (median sternotomy) or necropsy were included. Patient signalment, CT protocols, and bulla location, size, and number were obtained from the medical records. Computed tomographic images were reviewed by 3 board-certified radiologists who reported on the location, size, and number of bullae as well as the subjective severity of pneumothorax.

Results—Sensitivities of the 3 readers for bulla detection were 42.3%, 57.7%, and 57.7%, with positive predictive values of 52.4%, 14.2%, and 8.4%, respectively, with the latter 2 readers having a high rate of false-positive diagnoses. There was good interobserver agreement (κ = 0.640) for correct identification of bullae. Increasing size of the bulla was significantly associated with a correct CT diagnosis in 1 reader but not in the other 2 readers. Correct diagnosis was not associated with slice thickness, ventilation protocol, or degree of pneumothorax.

Conclusions and Clinical Relevance—Sensitivity and positive predictive value of CT for bulla detection were low. Results suggested that CT is potentially an ineffective preoperative diagnostic technique in dogs with spontaneous pneumothorax caused by bulla rupture because lesions can be missed or incorrectly diagnosed. Bulla size may affect visibility on CT. (*J Am Vet Med Assoc* 2013;243:244–251)

The most common cause of spontaneous pneumothorax in dogs is rupture of subpleural bullae or blebs.[1–5] Pulmonary blebs are an accumulation of air within the layers of the visceral pleura, whereas bullae are caused by disruption of intra-alveolar septa and subsequent accumulation of air in the lung tissue.[2] This air collection may be contained by connective tissue in the lung or the visceral pleura. Determining whether a lesion is a bulla or bleb is not always possible by means of gross or even histologic evaluation, so for the purposes of the study reported here, these lesions will be collectively referred to as bullae.

Surgical intervention is considered superior to conservative management in dogs with spontaneous pneumothorax secondary to ruptured bullae.[2–5] Median sternotomy is the method that is currently recommended because it allows for exploration of all lung lobes.[2,3,6] If bullae can be identified prior to surgery as confined to 1 hemithorax, other surgical approaches such as lateral thoracotomy, which allows for easier lung lobectomy, could be performed.[6] Less invasive surgical alternatives to median sternotomy have been described in dogs, including thoracoscopic or video-assisted thoracoscopic techniques.[7–10] Although full exploration of the thorax can be accomplished thoracoscopically, knowledge of lesion location prior to surgery could aid in the appropriate placement of operative portals or allow for a unilateral procedure.[9,10]

Although thoracic radiography is effective for detection of pneumothorax, it has poor sensitivity for identifying bullae.[1–3] In human medicine, CT is routinely used for assessment and management in patients with spontaneous pneumothorax, and sensitivity of bulla detection is reportedly up to 91.8%.[11–14] One study[1] in 12 dogs that compared CT with thoracic radiography found that almost 2.5 times as many bullae were identified by means of CT as by means of radiography. Although CT

Abbreviations

HU	Hounsfield unit
PPV	Positive predictive value

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findings did have good agreement with surgical findings on a per-lung lobe basis in that study[1] ($\kappa = 0.735$), additional lesions were found at surgery that were not seen via CT (3/10 dogs that underwent surgery had additional bullae). One possible reason for missing bullae on CT images could be the presence of pneumothorax.[1] With increasing severity of pneumothorax, there is more atelectasis of the lung tissue, and focal decreases in lung attenuation and vascular distortion, both hallmark features of pulmonary bullae, may be more difficult to visualize and distinguish from surrounding pleural air.[1,15,16] Ruptured bullae can appear as focal areas of alveolar consolidation[16] and may therefore be even more difficult to discern from collapsed lung tissue via CT. Other potential reasons include small bulla size and spatial resolution of the CT scan.

In the authors' experience, use of CT as a preoperative diagnostic technique in dogs with spontaneous pneumothorax caused by bulla rupture can be unrewarding, and there is potential for lesions to be missed (low sensitivity). The formation of air pockets with pneumothorax can make it challenging to differentiate between subpleural bullae and pleural air, with the potential for a false-positive CT diagnosis. Therefore, the purpose of the study reported here was to determine the sensitivity, PPV, and interobserver variability of CT in bulla detection, with use of surgical or necropsy findings as the gold standard. Additionally, we wanted to assess whether factors such as degree of pneumothorax, bulla size, or CT protocol had any influence on a correct diagnosis, with the hypothesis that a smaller lesion size and larger degree of pneumothorax would negatively influence lesion detection.

Materials and Methods

Case selection and medical records review—Searches of the diagnostic imaging databases (2000 to 2012) at the University of Pennsylvania Matthew J. Ryan Veterinary Hospital, North Carolina State University Randall B. Terry Jr Companion Animal Veterinary Medical Center, and University of California-Davis Veterinary Medical Teaching Hospital were performed to identify dogs with spontaneous pneumothorax that had thoracic CT. Dogs were included in the study only if the final diagnosis was spontaneous pneumothorax secondary to bulla rupture, confirmed by means of surgery or necropsy and histologic examination. Dogs were excluded if surgery other than a median sternotomy was performed (ie, lateral thoracotomy), given that median sternotomy is the currently recommended surgical method for complete exploration of the entire lung field.[2,3,6] Information obtained from the medical record included patient signalment, CT protocols, and surgery or necropsy reports.

Imaging procedures—In all dogs, thoracic CT was performed by use of general anesthesia, with various anesthesia protocols used, depending on the institution and anesthesia service. The CT machines and protocols also differed among institutions. Earlier CT scans were performed on single-slice third-generation helical units[a,b] and later scans on either 16- or 64-slice multidetector units.[c–f] For the single-slice CT protocols, there was generally a helical scan through the entire thorax with either medium-frequency (termed detail or soft tissue) or high-frequency (bone) algorithms, thicker slices (3 to 5 mm), and variable pitch (1 to 2). The helical scans were followed by an axial high-frequency (bone) algorithm, thin-slice (1- to 2-mm) series with variable pitch (2 to 5), which in several cases did not include the entire thorax. For the multidetector CT protocols, various reconstructions were performed, including medium-frequency (detail) or high-frequency (lung) algorithms with 2.5- to 5-mm slice thickness or high-frequency (bone) algorithm with 1- to 1.25-mm slice thickness; beam pitch was approximately 1. In all but 1 dog in the study, every CT scan included at least 1 thin-slice (1- to 2-mm), high-frequency (high-resolution) series through all or portions of the thorax. In several cases, pre- and post-IV contrast series were performed; however, considering that contrast would not aid in bulla detection, the radiologists participating in the study disregarded these series. The CT scans were performed with dogs in either dorsal or sternal recumbency, depending on the preference of the radiologist. To minimize motion associated with breathing, the CT scans were performed with either a breath-holding technique (hyperventilation followed by breath-holding at approximately 20 cm H_2O; 9 dogs) or by hyperventilation only with an expected period of apnea to follow (10 dogs).

Three board-certified radiologists (WM, AVC, and JNS) with 1 to 12 years of experience evaluated the CT scans independently on a diagnostic workstation.[g,h] They were able to manipulate the images as needed, including changing window width or window level or magnifying images, although the scans were generally evaluated in a lung window (eg, window width, approx 2,000 HU; window level, approx –500 HU). They were able to view all the images in any given study, including multiplanar reformatted images (ie, sagittal or dorsal reformats) if available; reformats had been created at the time of the original scan, at the discretion of the radiologist on duty, and were available for 15 of 19 patients. The readers were aware that all case animals had pneumothorax secondary to bulla rupture but were not aware of the final surgical or pathological findings in any case. The readers evaluated images for the presence of bullae, noting lesion location (ie, the affected lung lobe and, more specifically, on which images lesions were seen and whether lesions were subpleural or located in the more central lung field) and approximate lesion size (in mm). If > 1 bulla was seen, each lesion was recorded separately. Regarding the multiplanar reformatted images, readers indicated whether they felt these additional images helped in lesion detection (yes, no, or maybe). Readers also subjectively graded the degree of pneumothorax (mild, moderate, severe, or tension) in each hemithorax. If thoracocentesis or air drainage via a thoracic tube was performed between CT series in any dog, the readers graded the pneumothorax a second time, and this second grade was used for statistical analysis.

Assessment of surgery or necropsy reports—Details obtained from the reports included bulla location (ie, affected lobe and, if possible, the specific location within the affected lobe). Bulla number and size were also recorded (when specified).

Statistical analysis—The readers' findings were compared with the surgery and necropsy reports, noting whether readers correctly identified the bullae. Only subpleural bullae were included in the statistical analysis, considering that these would be the clinically relevant lesions and lesions located centrally in the lung parenchyma would not be found at surgery. If a reader identified the correct bulla but incorrectly identified the lobe (which can occur when lesions are located along the boundaries between lung lobes), this was still considered a correct diagnosis for identifying the lesion. If the surgery or necropsy reports did not specify lesion size and therefore comparing the size to that noted by the readers was not possible, it was considered a correct diagnosis if the readers identified the affected area. In cases in which comparison to the precise location within a lobe was not possible, it was considered a correct diagnosis if the readers identified the affected lobe correctly. In cases in which multiple bullae were present but the actual number was not specified in the surgery or necropsy reports, it was considered a correct diagnosis if the readers identified the affected lobe with or without the specific affected area in that lobe.

For each reader, sensitivity and PPV were calculated, and interobserver variability for the detection of the actual bullae confirmed at surgery or necropsy was assessed with κ statistics.[i] For each reader, multivariate logistic regression was used to assess whether a correct diagnosis was associated with degree of pneumothorax, size of the bullae, CT slice thickness, or ventilation protocol used during the acquisition of the CT images. The degree of pneumothorax used for the analysis was based on the subjective ratings given by each reader for the hemithorax ipsilateral to the bulla lesion. If all readers graded the pneumothorax similarly, then this grade was used; if there were differing grades, then the grade used was that given by 2 of the 3 readers. For slice thickness, only the thinnest available slice for any particular case was used in the analysis (ie, slice thickness of the high-resolution series) because the assumption was that these images would be the best at detecting lesions. Values of $P < 0.05$ were considered significant.

Results

Patient population—Nineteen dogs were included in the study. The most commonly affected breeds were Golden Retriever (n = 4) and Husky (3). Other breeds included German Shepherd Dog (n = 2), Border Collie (2), and Labrador Retriever, Akita, Samoyed, Whippet, English Setter, Irish Setter, Miniature Poodle, and mix (1 each). There were 10 neutered males and 9 neutered females. Ages ranged from 3 to 14 years (median, 8 years).

Surgery and necropsy results—Eighteen dogs had median sternotomy performed immediately after the CT. One dog had bilateral thoracoscopy after CT, and no actively leaking lesion was found. Because of refractory pneumothorax after surgery, the patient was euthanized 2 days later, and necropsy was performed; results of the necropsy were used in the statistical analysis.

Fifteen of the 19 dogs had a single affected lung lobe. In 14 of those 15, there was a single bulla in that lobe. The other dog had an unspecified number of bullae in that 1 lobe, noted as several on the surgery report, but this was counted as only 1 lesion for the statistical analysis. Four of the 19 dogs had multiple affected lung lobes; 2 dogs had 2 affected lobes, and 2 had 3 affected lobes. One of the dogs with 2 affected lobes had 2 bullae in different areas of the same lobe, and these were counted as separate lesions. Therefore, the total number of confirmed subpleural lesions used for statistical analysis was 26.

The lung lobe distribution for the location of the bullae was as follows: right cranial lobe (n = 6), right middle lobe (4), right caudal lobe (2), accessory lobe (4), cranial segment of the left cranial lung lobe (7), caudal segment of the left cranial lung lobe (1), and left caudal lobe (1). In 6 of 26 bullae, the size was not noted in the surgery reports. In the 20 lesions with size description, size ranged from 0 mm (bullae only seen histologically) to 70 mm (mean, 15.03 mm; median, 10 mm). In multiple affected lobes, the precise lesion location in the lobe was not described (8/26 lesions), or if multiple bullae were seen, the exact lesion number was not recorded (7/26 lesions). In only 2 of the 19 reports were all 3 of these variables (size, exact location, and number) absent.

Results reported from CT—All 3 readers correctly identified 11 of 26 lesions (**Figure 1**). In 3 of those 11 correctly identified lesions, at least 1 reader diagnosed the incorrect lobe (ie, felt that lesion was in the sub-

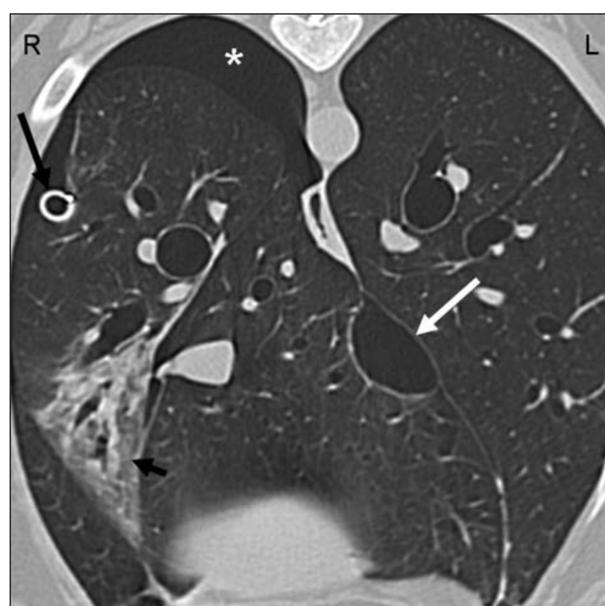

Figure 1—Transverse CT image of the thorax obtained in sternal recumbency in a dog with a single bulla in the accessory lung lobe (white arrow) that was correctly diagnosed by 3 image readers. Notice the focal ovoid hypoattenuating area in the lung lobe, with a thin hyperattenuating rim and distortion of the adjacent vessels. There is pneumothorax in the ipsilateral hemithorax (white asterisk), and a thoracic tube is in place (long black arrow). There is a small area of alveolar pattern in the ventral aspect of the right caudal lung lobe (short black arrow), attributed to positional atelectasis secondary to anesthesia. R = Right. L = Left. Window width, 2,120 HU; window level, –524 HU.

pleural aspect of the adjacent lobe). All readers did not have the correct diagnosis in 8 of 26 lesions. For the remaining 7 lesions, at least 1 reader had the correct diagnosis for 6 lesions and 2 readers had the correct diagnosis for 1 lesion (**Figure 2**).

The mean and median diameters of the confirmed bullae (size was available in 8 lesions) seen by all 3 readers were larger, compared with those bullae (size available in 12 lesions) that were seen by either none of the readers or only 1 or 2 of the readers (those seen by all readers [range, 5 to 70 mm; mean, 23.4 mm; median, 18.8 mm] vs those seen by none or only some of the readers [range, 0 to 30 mm; mean, 9.4 mm; median, 5.75 mm]).

In all dogs, at least 1 reader had ≥ 1 bulla listed that was not confirmed at surgery or necropsy (false-positive results; **Figure 3**). In 3 of those dogs, there were 5 false-positive subpleural bullae described by all of the readers. In 14 dogs, some of the bullae described were centrally located, and in 1 dog, all 3 of the readers noted the same central bulla.

In 15 of 19 dogs, multiplanar reformatted images were available. In general, the readers did not report that reformatted images were particularly helpful. One reader found them helpful in 3 dogs but only had correct bulla identification in 1 of those cases. Another reader felt that the reformatted images may have been helpful in 1 dog and did have the correct diagnosis in that case. The third reader found them helpful in 6 dogs and maybe helpful in 5 dogs but had the correct diagnosis in only 5 of those cases.

Eighteen of the 19 dogs had bilateral pneumothorax; the other dog had unilateral pneumothorax ipsilateral to the affected lung lobe. In the readers' grading of the pneumothorax ipsilateral to the lesion, the scores were as follows: mild (n = 11), moderate (14), and severe (1). The dog with unilateral pneumothorax initially had a tension pneumothorax (**Figure 4**), but after drainage of some of the air via a thoracic tube that was in place, the pneumothorax grade was then rated as moderate. Five other dogs had air drained prior to or between scout images or full scans, and in 2 of those dogs, this helped decrease the grade of pneumothorax. In the other 13 dogs, it was not known from the records whether air drainage was performed immediately prior to the CT. Fourteen of 19 dogs had thoracic tubes in place at the time of the CT (11 unilateral and 3 bilateral), but whether continuous suction was maintained during the scan could not be ascertained from the record.

Statistical analysis—Sensitivity of subpleural bulla detection for the 3 readers was 42.3%, 57.7%, and 57.7%, with PPVs of 52.4%, 14.2%, and 8.4%, respectively. There was good interobserver agreement (κ = 0.640) for correct identification of the confirmed bullae. Increasing size of the bulla was significantly associated with a correct CT diagnosis for 1 reader ($P = 0.038$) but not for the other 2 readers ($P = 0.077$ and 0.083). For the 3 readers, correct diagnosis was not associated with

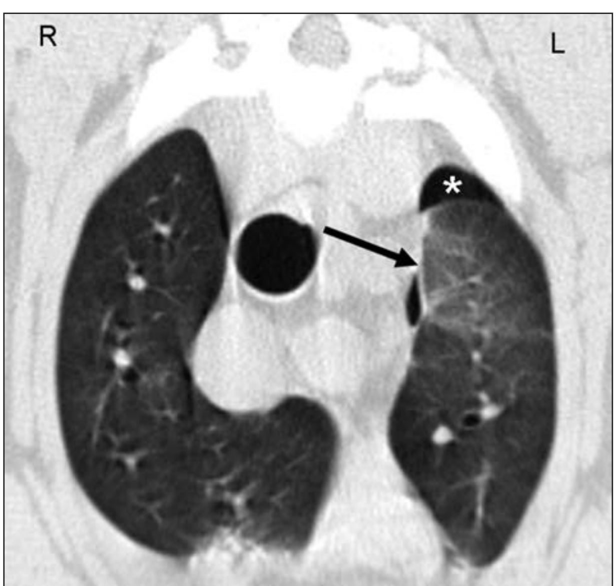

Figure 2—Transverse CT image of the thorax obtained in sternal recumbency in a dog with a single 20-mm ruptured bulla in the cranial segment of the left cranial lung lobe that was correctly identified by only 1 image reader. Notice the focal area of pulmonary pleural thickening along the dorsomedial aspect of the lobe (arrow) and regional interstitial pattern, which corresponded to the ruptured bulla found at surgery. The asterisk indicates the area of pneumothorax. Window width, 1,219 HU; window level, –456 HU. *See* Figure 1 for remainder of key.

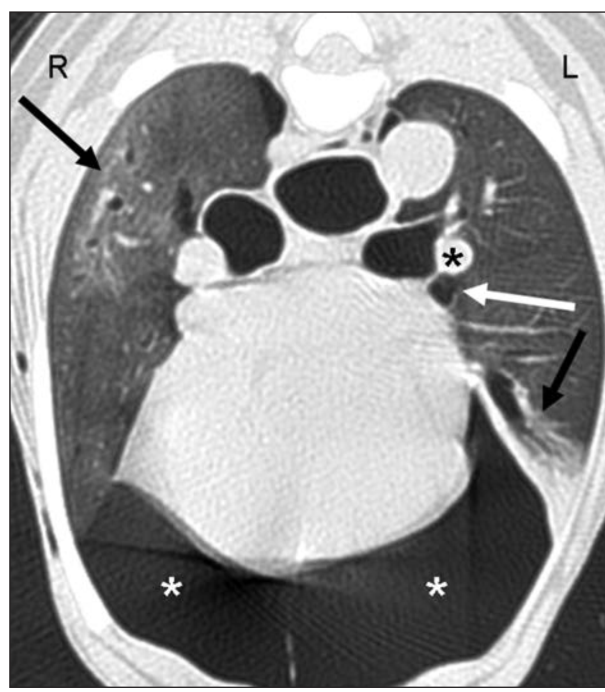

Figure 3—Transverse CT image of the thorax obtained in dorsal recumbency (image rotated 180° for easier orientation) in a dog in which a false-positive result for identification of a pulmonary bulla occurred. The white arrow indicates a round hypoattenuating structure adjacent to the left caudal lobar pulmonary artery (black asterisk) that was noted by 3 readers but was not found at surgery. Notice the bilateral pneumothorax (white asterisks), which is located ventrally in this image because the imaging was performed in dorsal recumbency. The black arrows indicate areas of interstitial to alveolar patterns, attributed to positional atelectasis from anesthesia and atelectasis secondary to moderate pneumothorax. This dog had a single bulla in the accessory lung lobe (not shown) that was correctly diagnosed by only 1 image reader. Window width, 1,556 HU; window level, –594 HU. *See* Figure 1 for remainder of key.

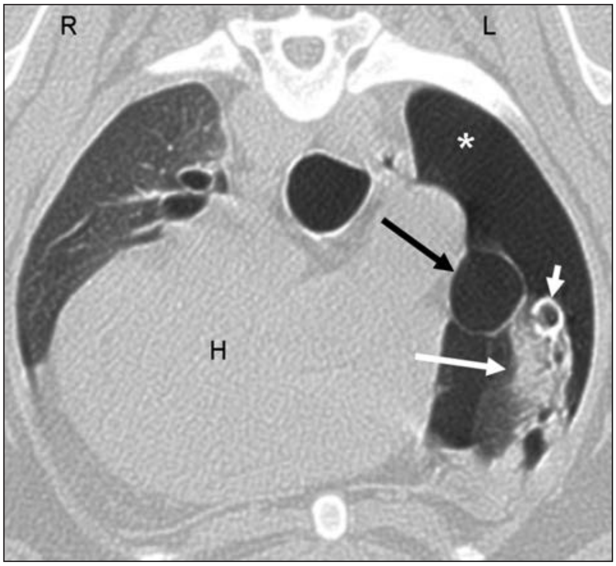

Figure 4—Transverse CT image of the thorax obtained in sternal recumbency in a dog with a single bulla in the cranial segment of the left cranial lung lobe (black arrow), which was seen by all image readers despite the presence of marked atelectasis of the adjacent lung (long white arrow). Notice the large volume of ipsilateral pneumothorax (asterisk) that was graded as tension pneumothorax because of a right mediastinal shift. The short white arrow indicates the thoracic tube in the left hemithorax. Window width, 1,949 HU; window level, –553 HU. H = Heart. *See* Figure 1 for remainder of key.

slice thickness (*P* = 0.778, 0.056, and 0.875), ventilation protocol (*P* = 0.529, 0.732, and 0.875), or degree of pneumothorax (*P* = 0.283, 0.329, and 0.425).

Discussion

Although prior reports[2,3,8] have suggested that CT may be a useful preoperative diagnostic technique in dogs with spontaneous pneumothorax caused by bulla rupture, results of the present study raised questions about its effectiveness in these cases. Similar to results of the previous study[1] comparing CT and radiography for bulla detection, bullae may be missed via CT. In addition to the low sensitivity found in the present study, the PPV was particularly low for 2 of the readers, reflecting a large number of false-positive results. This differed from the previous study,[1] in which there was only 1 false-positive result (1/10 dogs that underwent surgery). Considering that either missing a bulla or falsely diagnosing a bulla via CT may have clinical relevance with respect to the surgical approach, the authors still recommend performing full exploratory surgery of the thorax regardless of CT results. It is also important to note that the prevalence of multiple bullae in dogs reportedly ranges from 37% to 83.3%[1–3] and, for the presence of bilateral bullae, ranges from 26% to 58.3%.[1–3] Therefore, even if only 1 bulla is identified via CT, the possibility of additional missed bullae exists. In the present study, there were fewer dogs with multiple (4/19) and bilateral (3/19) bullae than in other studies. Of those cases, all 3 readers did not correctly identify all of the bullae in 2 of the 4 dogs, and in the other 2 dogs, only 1 or 2 of the readers identified all of the bullae.

The interobserver variability in the present study was good, which indicated that at least in some cases, all readers were able to identify the correct bullae, whereas in other cases, all readers had similar difficulty in identifying the bullae. This fits with our clinical impression that CT seems helpful for bulla detection in some cases but not others.

The sensitivity range of 42.3% to 57.7% was lower than has been reported in human medicine (88% to 91.8%),[11–14] although in 1 study[17] regarding children, sensitivity for bulla detection was only 59%. In the previous study[1] regarding dogs, 13 of 17 affected lobes were identified on CT, and there was good agreement with the surgical findings on a per–lung lobe basis (κ = 0.735). Although these results are better than in the present study, they still do not approach the generally higher sensitivities found in human medicine. Also, in 30% of dogs that underwent surgery in that study,[1] additional lesions found at surgery were not detected via CT. The reason for the lower sensitivity results in the present study, compared with the previous study,[1] was not apparent. The previous study[1] did not include thorough lesion description (eg, bulla size) or degree of pneumothorax (except to report that 11 of 12 dogs had various degrees of pneumothorax, from mild to severe) that may have allowed for comparison of the results. Those authors also did not try to identify reasons for their false-negative results, except for suspecting that pneumothorax played a role.[1]

There are multiple potential reasons for false-negative results, and we attempted to identify factors associated with a missed diagnosis, including bulla size, slice thickness, ventilation protocol, and degree of pneumothorax. Results of the multivariate logistic regression analysis indicated that increasing size of the bulla was significantly associated with a correct CT diagnosis for 1 reader (*P* = 0.038) but not the other 2 readers (*P* = 0.077 and 0.083). These results were somewhat surprising, as it would be expected that larger bullae would be easier to identify via CT, and for example, several of the missed bullae were 10 to 20 mm in diameter; also, the mean and median bulla size was larger for those bullae seen by all 3 readers, compared with those bullae seen by none or only 1 or 2 of the readers. The low sample size may have contributed to these findings. Given the lack of significance for lesion size and visibility as assessed via CT by 2 of the readers, other factors must play a role in missing bullae.

Differences in slice thickness were not significantly associated with bulla detection. This result was not unexpected, given that with the exception of 3 dogs, the CT protocols included at least 1 series with thin slices (1 to 1.25 mm). However, in several dogs, in which none or only some of the bullae were seen by the readers, less than ideal high-resolution protocols were used, which may have affected results of statistical analysis. In 2 dogs, the high-resolution series did not include the entirety of the affected lung lobes because only sections of the thorax were imaged with thin slices (at the discretion of the radiologist, on the basis of review of the lower-resolution scans of the thorax). In another dog with a 3-mm bulla, the pitch used for the high-resolution series (which included a 1 $\times$ 5-mm slice [pitch, 5] through the entire thorax and a 1 X 3-mm slice [pitch, 3] through only a portion of the thorax) could have affected the visibility of the bulla, given that spatial and contrast resolution decreases with increasing pitch. The effect that a CT-processing algorithm might have had on bulla detection was not evaluated because all but 1 dog had at least 1 high-frequency algorithm series performed. A high-frequency algorithm will increase image sharpness and is the recommended algorithm for assessing structures with inherently high object contrast, such as the lungs.[18]

The ventilation protocol used during the acquisition of the CT images (positive-pressure ventilation breath-holding vs apnea induced by hyperventilation) also was not associated with bulla detection in this study. In theory, positive-pressure ventilation during the scan could increase bulla visibility, given that in humans undergoing video-assisted thoracic surgery, more bullae are detected during periods with positive end-expiratory pressure and high-frequency jet ventilation.[19] In addition, studies[20,21] have found that bullae can decrease in size during expiratory CT scans, compared with inspiratory scans, which could potentially affect their visibility. Conversely, if a bulla is completely ruptured, positive-pressure ventilation may simply lead to increased air leakage from the bulla into the pleural space. In thoracic radiography, obtaining radiographs at expiration can reportedly improve bulla visibility because of increased contrast between a cavitated lesion and the surrounding less aerated lung parenchyma (which would be more radiopaque than at inspiration).[22] Computed tomographic images obtained during a hyperventilation-induced apnea technique would be more expiratory, yet we still found no significant difference in bullae detection with this protocol.

Pneumothorax was also not significantly associated with bulla detection. There were similar numbers of dogs with pneumothorax grades of mild and moderate, but only in 1 dog was pneumothorax graded as severe. Therefore, although mild to moderate grades of pneumothorax were not associated with bulla detection, it is still possible that severe pneumothorax or tension pneumothorax could inhibit bulla identification, as discussed in prior reports.[1,15,16] It is hypothesized that with increasing severity of pneumothorax and subsequent increasing atelectasis of the lung, bullae would be more difficult to distinguish from adjacent pleural air.[1,15,16] This was the reason for repeating scans after air evacuation in 6 dogs that initially had severe or tension pneumothorax. In 2 of those dogs, air evacuation did lessen the pneumothorax grade, although readers had mixed opinions as to whether the lesser grade was associated with successful bulla detection (all readers had the correct diagnosis in these 2 cases). Although the association between severe pneumothorax or tension pneumothorax and bulla detection could not be determined, other causes of missed diagnosis of bullae besides atelectasis must play a role. For example, 1 dog in the study, with a 15-mm bulla, had a large amount of regional pleural air and marked lung collapse in the area of the bulla (Figure 4), yet the bulla was easily identifiable and seen by all readers. Regardless of this particular result, the authors still recommend attempting to evacuate as much free air as possible prior to scanning or use of continuous suction in patients with thoracic tubes in place.

A ruptured bulla may appear as a focal area of alveolar consolidation[16] and could be difficult to distinguish from collapsed lung tissue. In 2 of the study dogs, 1 author (JAR) had the opportunity to view the affected lung lobes during exploratory thoracotomy and, knowing the specific locations and appearances of the bullae, retrospectively evaluated the CT scans. One of the dogs had 3 bullae, and readers found only 1 of these lesions. One of the missed bullae was observed to be ruptured at the time of surgery, yet no focal alveolar pattern was seen in the affected area via CT. The other bulla, which was intact at surgery, was in an area of atelectatic lung, which may have been a reason readers missed that lesion. For the second dog, which had a single 20-mm ruptured bulla, the affected area appeared as a region of pulmonary pleural thickening with adjacent interstitial pattern, and only 1 reader identified this as the correct area (Figure 2). On the basis of these 2 cases, it appears that ruptured bullae can have various appearances.

Regarding bulla rupture, many of the surgical reports (15/19) were lacking in information about whether a bulla was ruptured or intact at the time of surgery. Although it is assumed that a bulla must be ruptured to cause pneumothorax, results of a study[23] examining bulla surfaces via electron microscopy suggest that air leakage can occur through an intact bulla wall. Ruptured bullae are more difficult to detect via CT; if many of the dogs in the present study had ruptured bullae, this could potentially explain why the sensitivity of detection was low. This could also potentially explain the differences in the present study versus the previous study[1] in terms of sensitivity, such that more bullae may have been intact in that cohort of dogs.

Regarding multiplanar reformatted images, readers generally did not find them useful in bulla identification, although this was not assessed statistically. This may be attributable to the fact that unless reformatted images are created with an isotropic or near isotropic voxel (ie, voxel size is the same in all 3 spatial planes), stairstep artifacts may contribute to difficulty in identifying lesions.[24] Also, motion associated with breathing can contribute to artifacts on reformatted images, in addition to its effect on the original scan. In a study[17] in children with ruptured bullae, the authors noted that coronal reformats did provide additional information, but results were often limited by streak artifacts from the shoulders in the primary area of interest (lung apices). Readers also did not find multiplanar reformatted images helpful in some instances because the lesion was easily seen on the transverse images and the reformats did not offer any additional information.

The PPVs in the present study were low, and 2 of the readers had a larger number of false-positive results. This is an important finding for 2 reasons. First, even the reader with the lowest number of false-positive results had a low PPV (52.4%); coupling this with the low sensitivity result (42.3%) supported the hypothesis that CT can be an ineffective diagnostic test in these cases. Second, the poor results of the other 2 readers underscored one of the important limitations to this study.

Although readers were unaware of surgery or necropsy results, they were aware that all dogs had bullae. This led to expectation bias in that readers felt compelled to identify lesions and therefore overinterpreted the CT scans. On some level, this parallels a true clinical scenario in which a radiologist may feel compelled to identify some lesions in dogs with spontaneous pneumothorax. In a study of spontaneous pneumothorax by Puerto et al,[3] 94% of dogs that underwent surgery or necropsy had a clear etiology for the pneumothorax; 68% of dogs had bulla rupture, and the others had neoplasia (11%), migrating foreign body (5%), pleuritis only (5%), or pulmonary microabscess and pleuritis (3%). Therefore, in most cases of spontaneous pneumothorax, a radiologist expects to identify a lesion. However, the rate of false-positive results by 2 readers in the present study was much higher than would be expected in a true clinical case, therefore calling into question the validity of their results (ie, their higher sensitivity would be falsely increased because of increased likelihood of identifying bullae by chance). With retrospective assessment of the CT scans by 1 author (JAR), the false-positive results were generally caused by misinterpreting regions of free pleural air pockets adjacent to the lung as bullae. It is interesting to note that the reader with the lowest sensitivity and highest PPV was the most experienced radiologist and the reader with the lowest PPV was the least experienced. It was not surprising that the least experienced radiologist would be more concerned with missing lesions and was therefore more likely to misidentify a pleural air pocket as a bulla. Similar results were noted in a recent study[25] comparing thoracic radiography to CT for the detection of pulmonary nodules, in which less experienced readers often overinterpreted the findings. In several dogs in the present study, central bullae were described by one or all of the readers, and given that these lesions would not be visible during surgery, whether these were true- or false-positive results could not be determined. Regardless, these lesions were presumably clinically irrelevant in that they would not be the underlying cause for pneumothorax.

In addition to the lack of a control population, there were several other limitations to the present study. Because of the retrospective nature of the study, there were issues regarding the gold standard. Full exploration of the thorax via median sternotomy is currently the best surgical method for bullae detection.[2,3,6] All the dogs in the present study that had this surgery survived to discharge (ie, implying that the causative bullae were removed); the issues regarded the surgery reports, which were sometimes lacking in a complete and thorough description of lesion location and size. So, although readers were asked to note specific details about the lesions, comparison of their results to the gold standard in some cases was difficult. For example, even if the surgery report did not specifically identify where a lesion was located in an affected lung lobe, it was still considered a correct diagnosis if the reader identified a lesion in that lobe in general, although in fact it could not be determined whether this was a true- or false-positive result. Therefore, the number of correct diagnoses may have been overestimated, and sensitivity results may have been erroneously increased. However, even if sensitivities should have been lower, the final results were consistent with our hypothesis that CT can be unreliable in diagnosing bullae. Another limitation included the small number of cases, which lessened statistical power, although the number of cases was greater than in the previous study.[1]

Results of CT for the diagnosis of pulmonary bullae should be interpreted with caution. Full exploratory surgery of the thorax should be performed regardless of the CT findings. Although this could suggest that dogs with spontaneous pneumothorax should simply undergo exploratory surgery without preoperative CT, the authors would not discourage its use, considering that there are other etiologies of pneumothorax besides bulla rupture that may potentially be diagnosed via CT.

a. GE ProSpeed, General Electric Co, Milwaukee, Wis.
b. GE HiSpeed, General Electric Co, Milwaukee, Wis.
c. GE BrightSpeed, General Electric Co, Milwaukee, Wis.
d. GE LightSpeed, General Electric Co, Milwaukee, Wis.
e. Siemens Somatom Sensation 16 CT, Siemens Medical Systems, Malvern, Pa.
f. Siemens Somatom Sensation 64 CT, Siemens Medical Systems, Malvern, Pa.
g. Philips iSite Radiology 3.5.0, Royal Philips Electronics, Amsterdam, The Netherlands.
h. E-film workstation 3.4.0, Merge Healthcare, Chicago, Ill.
i. Stata/IC, version 11.2, StataCorp LP, College Station, Tex.

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