Radiography is less sensitive relative to CT for detecting thoracic radiographic changes in dogs affected by blunt trauma secondary to a motor vehicle accident

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Abstract

Thoracic injuries caused by blunt trauma are commonly encountered emergencies in veterinary medicine. However, published studies are lacking that compare radiology to CT in blunt trauma caused by motor vehicle accidents in canine patients. The aim of this prospective diagnostic accuracy, methods comparison study were to estimate the sensitivity (Se) and specificity (Sp) of thoracic radiology relative to CT for detecting lung contusions, pneumothorax, pleural effusion, and rib fractures. The study further aimed to develop a severity scoring system for radiology and CT and to compare the findings between the two modalities. The hypothesis was that radiology would be less sensitive than CT at detecting these injuries and that radiology would underestimate the severity of lung contusions. Fifty-nine patients met the inclusion criteria. Radiology underestimated the presence of lung contusions (Se = 69%, 95% confidence interval) and overestimated the severity of the contusions relative to CT. There was high interobserver variability in evaluating lung contusion severity (coefficient of variation = 91%). Both the three-view thoracic and horizontal beam radiography had poor sensitivities for the detecting pneumothorax (Se = 19% and 63%, respectively) and pleural effusions (Se = 43% and 71%, respectively). Similarly, the sensitivity (56%) of radiographs for the detection of rib fractures was poor relative to CT. Findings from the current study indicated that thoracic radiography had low sensitivity for detecting lesions related to blunt thoracic trauma caused by motor vehicle accidents and supported the use of CT as an additional diagnostic imaging modality in these patients.

KEYWORDS

Canine, lung contusions, pleural effusion, pneumothorax, rib fractures

Abbreviations

CI - confidence interval
ECVDI - European College of Veterinary Diagnostic Imaging
MVA - motor vehicle accident
Se - sensitivity
Sp - specificity

1. INTRODUCTION

Thoracic injuries caused by blunt trauma are commonly encountered emergencies in veterinary medicine.[1] The use of CT as a first-line diagnostic tool in humans presenting with blunt trauma remains a controversial topic. Some authors believe that CT should be used as a first-line diagnostic tool in trauma patients or in patients that are intubated on presentation since it may decrease the risk of complications and improve patient outcome.[2-4] Others suggest that CT should be used to obtain additional information in patients with thoracic wall bruising or increased respiratory effort to complement radiology.[4, 5] A comparative study of human trauma cases reported that CT was able to identify up to 66% more thoracic injuries than radiology causing a change in treatment plan for up to 20% of patients.[5] Despite these disagreements in the literature on the value of CT as a first-line diagnostic tool in human trauma patients, it remains clear that the use of CT yields additional information in a certain patient subset compared to radiology.[4-6] Over the past 10-15 years, the use of CT examinations in patients with thoracic lesions has become more common in veterinary medicine.[7-9] However, no literature was found comparing conventional radiography to CT in dogs with blunt thoracic trauma secondary to motor vehicle accidents (MVA). Due to the increased availability of CT machines in large private veterinary hospitals and academic institutions, the value of CT in trauma patients requires investigation. The objective of this study was to estimate the sensitivity (Se) and specificity (Sp) of radiology relative to CT in patients affected by blunt thoracic trauma secondary to a MVA. The study further aimed to develop a severity scoring system for radiology and CT, and compare these findings between the two modalities. The hypothesis was that radiology would be less sensitive relative to CT for detecting common thoracic injuries due to blunt trauma secondary to MVA and that radiology would underestimate the severity of lung contusions compared to CT.

2. MATERIALS AND METHODS

The study was a prospective, diagnostic accuracy, methods comparison design. The study was approved by the institutional research and animal use and care committees and owner consent was obtained to enroll dogs into the study. All dogs presenting to our University's Veterinary Academic Hospital emergency service with a history of MVA between April 2011 and January 2015 were recruited. The following inclusion criteria had to be fulfilled: any dog involved in a MVA not more than 48 h previously with polypnea, dyspnea, or tachypnea (after shock stabilization), and/or any fractures. Patients presenting with severe respiratory distress requiring immediate thoracic interventional procedures (based on thoracic radiography) were excluded from the study. Dogs presenting with only skin lacerations without fractures or respiratory signs were excluded from study. Patient selection was initially determined by the emergency vet that stabilized the patients, with the final patient inclusion determined by an ECVDI-certified veterinary radiologist based on the specified parameters set out in the study protocol.

All patients underwent a helical thoracic CT examination using a dual slice scanner (Siemens Emotion Duo with sliding gantry; Siemens Medical Systems, Forchheim, Germany) within 24 hours of admission to the hospital but not within four hours of the traumatic incident. Dogs were typically positioned in sternal recumbency, but this varied depending on clinical presentation and body wall injuries. Patients were restrained using positional aids and Velcro straps or by confining the awake patient in a clinically supportive device (Vetmousetrap™, Champaign-Urbana, USA). Imaging was performed without general anesthesia but many patients were administered pain medication and/or sedation to prevent excessive motion. A non-breath hold thoracic survey CT examination was performed extending from C4 to L4 and was repeated if there was excessive motion. Technique settings included 3 mm thick slices in a soft tissue algorithm (window width = 400 Hounsfield units (HU), window level = 40 HU), a pitch of 1.95, tube rotation time 0.8 s, 130 kV and 60 mAs.

The CT-images were reconstructed into 1.5 mm intervals in the appropriate multiplanar lung (window width = 1200 HU, window level = −600 HU), soft tissue (window width = 400 HU, window level = 40 HU) and bone (window width = 1500 HU, window level = 450 HU) algorithms and analyzed at a dedicated CT-work station using a Digital Imaging and Communication in Medicine (DICOM)-system (Somaris/5 syngo CT 2006A, Siemens, Germany). The CT data were evaluated by an European College of Veterinary Diagnostic Imaging (ECVDI)-certified veterinary radiologist (R.M.K.). These data served as the gold standard benchmark to which the radiologic findings were compared. Lung lobes were assigned from L1 to L7 (where L1 represented the *pars cranialis* of the left cranial lung lobe; L2 the *pars caudalis* of the left cranial lung lobe; L3 the left caudal lung lobe; L4 the right cranial lung lobe; L5 the right middle lung lobe; L6 the right caudal lung lobe, and L7 represented the accessory lung lobe). The presence of presumed lung contusions, pneumothorax, pleural effusion, and rib fractures were recorded. Less common blunt-trauma related lesions were also documented if present. In particular, lung consolidation secondary to extensive diaphragmatic ruptures were ascribed to atelectasis. Pulmonic changes believed to be due to hemorrhage or contusions, or secondary to atelectasis, were given a subjective severity score for each lobe (absent (0), mild (1) interstitial/ground glass pattern (2), or alveolar pattern (3)). A pulmonary contusion/collapse trauma index was calculated as follows: For each lobe, a region of interest, avoiding major bronchi and air filled cavitary lesions, was traced along the periphery of the respective lung lobe, and the HU determined. This was done on a transverse slice taken at the level where the lobe was believed to be most severely affected. The degree of lung aeration was calculated by dividing the HU by −713 (normal expiratory lung HU[10]) converting it to a percentage by multiplying the value by a 100, and subtracting this from a 100 to give a contusion or non-aeration (eg, lung collapse secondary to pneumothorax) percentage. This was multiplied by the severity score (0-3) to give an estimated contusion percentage of the whole lobe. This was multiplied again by the percentage the lobe made up of the total aeration volume of the lung.[11] The totals of the seven lobes were added together to give a composite pulmonary trauma index that represented a semi-objective estimation of the total degree of lung lobe contusion or collapse.[12]

Digital radiographs were acquired for all included dogs using a standardized protocol (Apelum Baccara 90/20, Italy) using a Fuji CR console system (Fujifilm Medical Systems, Stamford, USA). Three-view thoracic dorsoventral, right lateral recumbency, and left lateral recumbency, as well as a thoracic ventrodorsal horizontal beam view in right lateral recumbency or left lateral recumbency (where patient injury prevented ventrodorsal right lateral recumbency horizontal beam view) were obtained for each patient. Imaging settings were based on a long-scale thoracic radiography technique chart constructed by the hospital's radiology department. Radiographic imaging was performed within 1 h of the CT examination.

The thoracic radiographs were evaluated and data recorded in tables by three observers consisting of a first-year diagnostic imaging resident (S.C.D.), an ECVDI-certified veterinary radiologist with four years’ experience (C.L.R.), and an ECVDI-certified veterinary radiologist with 30 years’ experience (R.M.K.). Images were evaluated at a dedicated workstation using DICOM capable software (Interview 2D 1.2.0.43, Petersaurach, Germany) on a 3 megapixel black-and-white medical grade monitor, with adjustable brightness, contrast and magnification (Lumimed MM30, Heeyoung, Singil-Dong, South Korea). All observers were blinded to case information. Each observer performed the image analysis independently to assess interobserver variability. Prior to starting the study, all observers interpreted a number of images unrelated to the study to obtain consensus on the employed grading systems. A majority ruling for each abnormality was compared relative to CT findings. Three-view thoracic radiographs were evaluated prior to horizontal beam radiographs, which were assessed independently. Three-view thoracic radiographs were evaluated for the presence of lung contusions, pneumothorax, pleural effusion, and rib fractures. The presence of less common trauma-related lesions was also assessed. The horizontal beam radiographs were evaluated for the presence of pneumothorax and pleural effusion.

A total radiologic lung contusion score, adapted from a previous human study and two other veterinary thoracic trauma studies, was calculated by grading the severity and extent of lung contusions and then determining the fractional contribution of that lung lobe to the overall lung capacity in canines.[1, 11-14] Severity scores were assigned as mild (1) when only an interstitial lung pattern was present, moderate (2) if there was an interstitial to early alveolar lung pattern, or severe (3) if there was an advanced alveolar lung pattern present. The extent of lung lobe involvement was scored as either less than one-third (1), one- to two-thirds, (2) or more than two-thirds (3). The severity by extent scores for each lobe (out of nine possible) were calculated by multiplying the severity score by the extent score. The total lung involvement was determined by multiplying each lung lobe's severity score by the fractional contribution of that lobe to the overall lung volume and adding all the affected lobes together.[11]

A qualified statistician (G.T.F.) performed statistical analyses. Quantitative data were described using scatter and box plots created within the ggplot2 package of R.[15, 16] Categorical data were described using proportions and mid-P exact confidence intervals (CI) determined using freeware (Epi Info, version 6.04, CDC, Atlanta, GA, USA). Inter-rater agreement (kappa) and 95% CI were calculated for data from the three radiologists using published formulas entered into a commercial spreadsheet program (Excel, Microsoft Office Professional 2010, Redmond, WA, USA).[17] Repeatability for quantitative data measured by the three radiologists was estimated by calculating the coefficient of variation. The correlation between data collected via evaluation of the three-view thoracic radiographic views and CT was estimated using Spearman's rho using commercial software (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, NY, USA). Sensitivity of radiographic detection of the thoracic lesions was estimated as the proportion of CT diagnosed lesions detected by radiography using the consensus radiographic diagnosis. Specificity was estimated as the proportion of cases without a particular CT detected lesion also identified free of that lesion based on the radiographic consensus. Kappa values of <0, ≤0.20, 0.21-0.40, 0.41-0.60, 0.61-0.80, and 0.81-1.00 were classified as no agreement, slight, fair, moderate, substantial, and almost perfect agreement, respectively.[18] Statistical significance was defined as $P < .05$.

3. RESULTS

Sixty-one dogs were enrolled in the study. Of these, 59 dogs met the inclusion criteria and had complete data. There were 12 Jack Russel Terriers, 10 Dachshunds and associated crossbreeds, six Labrador Retrievers, six mixed breeds, four Maltese Poodles, three Pekingese, three Fox Terriers, two Basset Hounds, two Boerboels, two Pugs, and one dog each of nine other breeds. The mean age was 32.6 months (median 17 and range 3-144 months) and weight was 10.4 kg (median 8 and range 1.8-41.4 kg). There were 22 intact males and 20 intact females, seven neutered males and 10 neutered females.

The time from accident to presentation was a mean of 3.4 hours (median 1 and range 0.25 - 24 hours).

All images were considered to be of acceptable quality for analysis. Presumed lung contusions were detected on CT in 35 (59%) dogs, while only 28 (47%) cases of lung contusions were also identified on the consensus radiographic diagnosis. Figure 1 illustrates an example of a false-negative radiographic study with presumed contusion evident on CT imaging. Overall, the detection of the presence of presumed lung contusions on radiographs (consensus of three observers) had fair to moderate Se (0.69) and a moderate Sp (0.83; Table 1). The interobserver agreement for detecting the presence of presumed lung contusions was substantial (Table 1).

Overall, radiology underestimated the presence of lung contusions for six of the seven individual lung lobes (Table 2). With the exception of L1, the severities of lung contusions, when present, were overestimated on radiographs. The overestimation of lung lobe severity scores was particularly noteworthy for L3 and L7, which differed from the CT-scores by 11% and 13%, respectively.

Overall, there was good correlation between radiologic findings and CT for determining severity of presumed lung contusions (Spearman's rho = 0.68; Figure 2). There was also good correlation between radiology (mean of three observers) and CT for L1, 2, and 4 (Table 3). The overall mean severity lung scores were higher for radiology than CT, with five of the seven lung lobes having higher mean lung scores on radiology (Table 3).

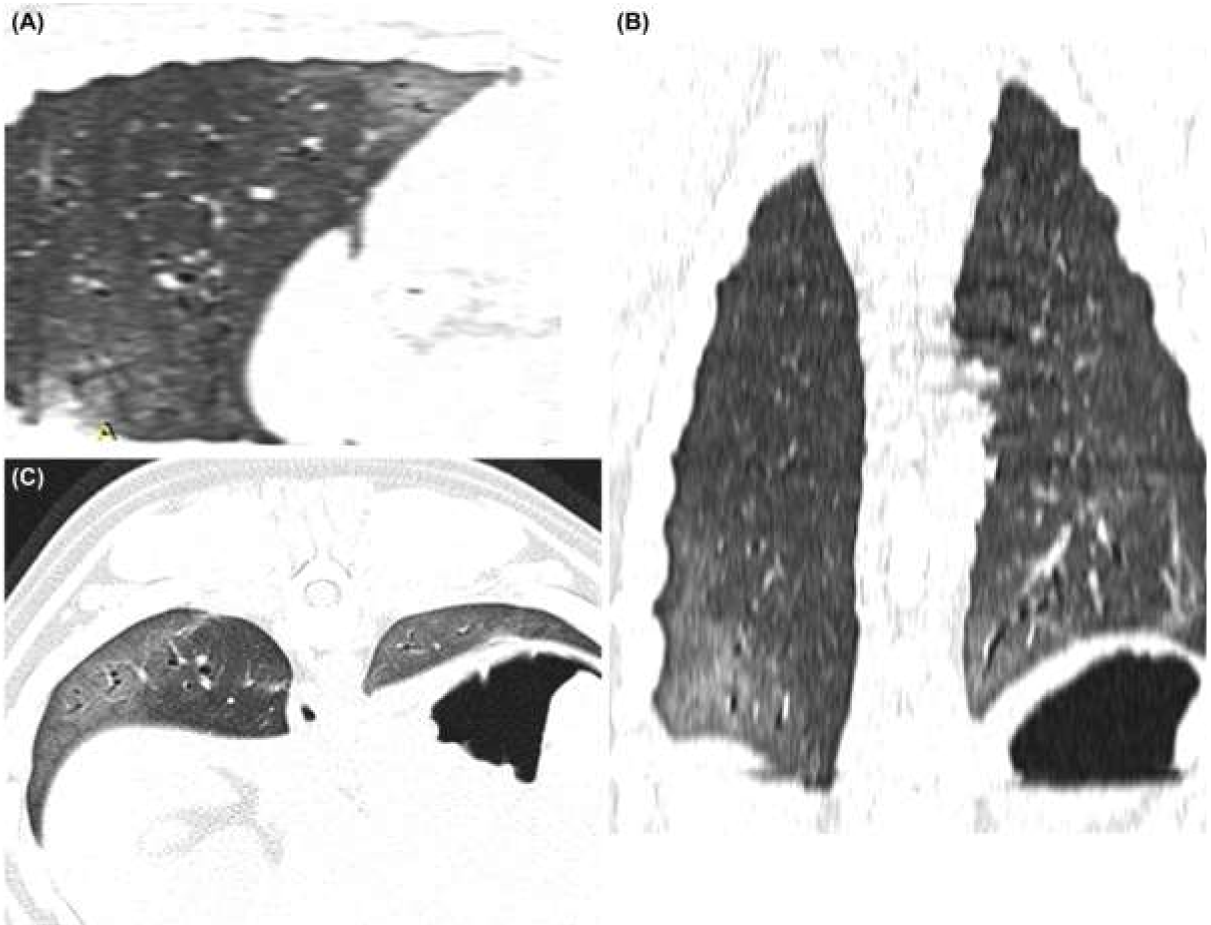

FIGURE 1 Sagittal (A), dorsal (B) , and transverse (C) plane computed tomographic(CT)-images obtained in sternal recumbency of a three-year-old spayed female Labrador Retriever that presented with blunt trauma of which lung contusions were undetectable on radiographs but clearly evident on CT. The CT lung contusion score was low (2.88%). Right is to the left on the relevant CT images. WW 1500; WL -400

TABLE 1 Interobserver repeatability of consensus detection of common thoracic pathology using three-view thoracic radiographic views and sensitivity and specificity calculated relative to computed tomography (CT) in 59 dogs diagnosed with blunt trauma from a single veterinary teaching hospital

Lesion	n	Kappa (95% CI)	Sensitivity* (95% CI)	Specificity* (95% CI)
Lung contusion	35	0.64 (0.49, 0.79)	0.69 (0.52, 0.82)	0.83 (0.65, 0.94)
Pneumothorax	16	0.47 (0.32, 0.62)	0.19 (0.05, 0.43)	1.0 (0.93, 1.0)
Pleural effusion	7	0.38 (0.23, 0.53)	0.43 (0.12, 0.78)	0.96 (0.88, 0.99)
Rib fractures (left)	5	0.33 (0.18, 0.47)	0.60 (0.18, 0.93)	0.96 (0.88, 0.99)
Rib fractures (right)	7	0.22 (0.07, 0.37)	0.43 (0.12, 0.78)	1.0 (0.94, 1.0)
Rib fractures (any)	9	0.30 (0.16, 0.45)	0.56 (0.24, 0.84)	0.96 (0.87, 0.99)

CI = confidence interval.

* Estimated for the consensus radiographic diagnosis relative to CT as the gold standard.

TABLE 2 The radiologic consensus prevalence and mean severity scores determined for each affected lung lobe relative to the prevalence and severity scores of computed tomography (CT) determined by a single observer in 59 dogs diagnosed with blunt trauma from a single veterinary teaching hospital

	Radiographic findings for lung contusion			CT findings for lung contusion		
Lobe	**Frequency**	**Prevalence (%)**	**Mean severity score (%)**	**Frequency**	**Prevalence (%)**	**Mean severity score (%)**
L1	19	32	27	17	29	28
L2	13	22	28	16	27	29
L3	9	15	49	12	20	38
L4	15	25	29	17	29	27
L5	9	15	40	12	20	25
L6	9	15	33	15	25	20
L7	4	7	41	13	22	28

L1 = *Pars cranialis* left cranial lung lobe; L2 = *Pars caudalis* left cranial lung lobe; L3 = Left caudal lung lobe; L4 = Right cranial lung lobe; L5 = Right middle lung lobe; L6 = Right caudal lung lobe; L7 = Accessory lung lobe

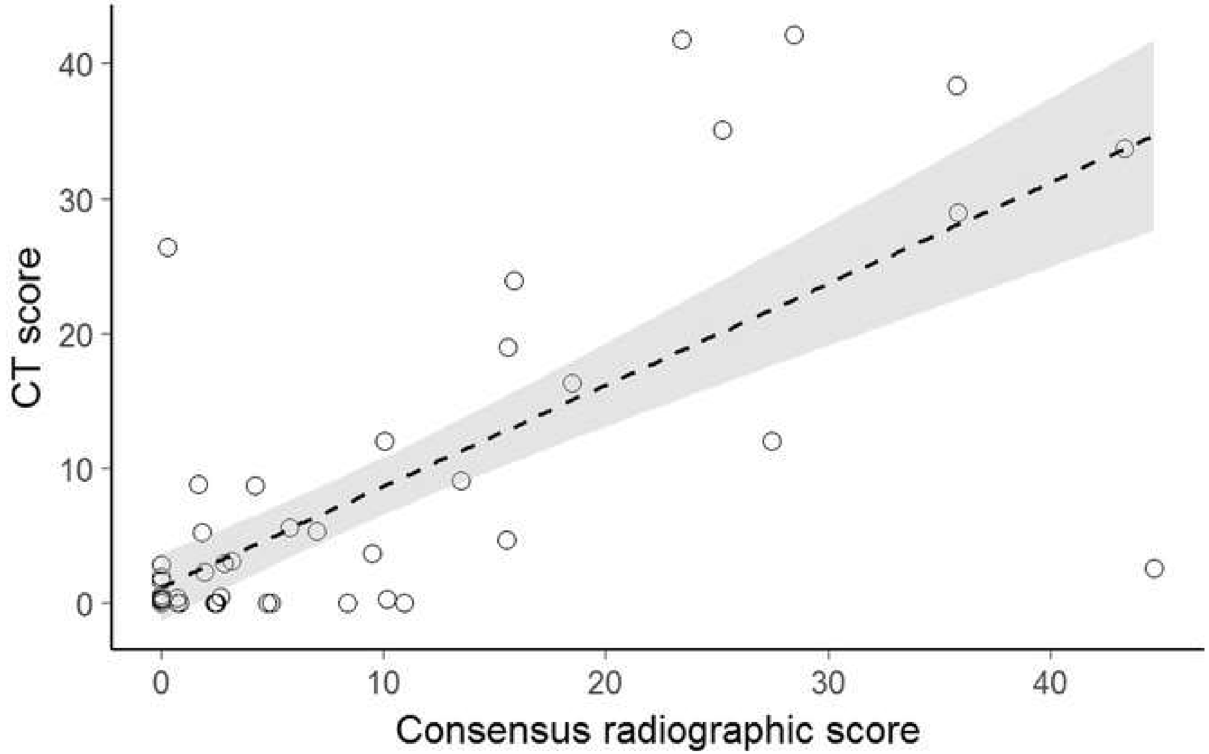

FIGURE 2 Consensus radiographic overall severity scores (lung contusion) was positively correlated with the analogous scores calculated from computed tomography (CT); ϱ=0.681, P<0.001)

TABLE 3 Interobserver repeatability of thoracic radiographic individual and overall lung lobe scores and correlation to similar scores calculated based on computed tomography (CT) examinations in 59 dogs diagnosed with blunt trauma from a single veterinary teaching hospital

	Mean (sd) radiologist lung score			Mean (sd)	Mean (sd) of all	Mean (sd)	Spearman's rho
Lobe[α]	A (RES 1)	B (RAD 4)	C (RAD 30)	COV	radiologists	CT score	(P value)*
L1	14.1 (24.5)	7.3 (13.9)	5.3 (12.1)	99% (50%)	8.9 (15.1)	7.9 (18.9)	0.696 (P<0.001)
L2	7.2 (19.3)	6.8 (13.7)	6.4 (18.1)	107% (49%)	6.8 (13.8)	7.8 (22.0)	0.701 (P<0.001)
L3	10.0 (28.2)	11.1 (21.4)	6.2 (21.6)	126% (59%)	9.1 (21.7)	7.7 (24.6)	0.400 (P=0.002)
L4	14.1 (26.9)	5.1 (12.6)	5.6 (14.2)	104% (57%)	8.3 (16.4)	7.8 (19.0)	0.609 (P<0.001)
L5	9.6 (24.5)	6.2 (17.3)	4.3 (11.3)	109% (58%)	6.7 (16.6)	5.1 (16.1)	0.560 (P<0.001)
L6	10.4 (26.7)	6.6 (14.2)	2.3 (6.8)	107% (49%)	6.4 (14.0)	5.0 (15.4)	0.443 (P<0.001)
L7	6.6 (23.0)	2.8 (8.4)	1.7 (13.0)	137% (47%)	3.7 (12.7)	6.2 (18.3)	0.527 (P<0.001)
Overall	10.8 (18.3)	7.1 (10.4)	4.6 (8.7)	91% (54%)	7.5 (11.6)	6.8 (11.8)	0.681 (P<0.001)

sd = standard deviation. COV = coefficient of variation calculated as the standard deviation divided by the mean x 100

*Correlation between mean radiology score and CT score for all dogs

[α]L1 = *Pars cranialis* left cranial lung lobe; L2 = *Pars caudalis* left cranial lung lobe; L3 = Left caudal lung lobe; L4 = Right cranial lung lobe; L5 = Right middle lung lobe; L6 = Right caudal lung lobe; L7 = Accessory lung lobe

The coefficient of variation was high for lung severity scores with high interobserver variability across all lung lobes (Table 3 and Figure 3). Lobes 3 and 7 were the poorest, with both medians representing the largest values.

Sixteen patients (27%) with pneumothorax were detected on CT but only four patients (7%) were positive on the consensus three-view thoracic radiographic views. Figure 4 illustrates examples of false-negative radiographic studies with pneumothorax evident on CT. The interobserver agreement was moderate (Table 1). Pneumothorax was detected in 10 (17%) patients on consensus horizontal beam radiography. Figure 5 illustrates examples of false-negative horizontal beam radiographs with pneumothorax evident on CT. The overall Se of detecting pneumothorax on horizontal beam radiography was fair to moderate (Se = 0.63; Sp = 0.95). The interobserver agreement for detecting pneumothorax on horizontal beam radiographs was fair ($\kappa = 0.39$).

Seven patients (12%) had pleural effusion evident on CT but only three (5%) were identified on consensus radiographs. Figure 6 illustrates examples of false-negative radiographs with pleural effusion visible on CT. The interobserver agreement for detecting pleural effusion on the three-view thoracic radiographic views was fair (Table 1). Pleural effusion was detected in five of the seven patients on HB-radiography. The overall sensitivity of detecting pleural effusion on HB radiography was fair to moderate, whilst the overall specificity was moderate to good (Se = 0.71; Sp = 0.90). The interobserver agreement for detecting pleural effusion on HB was moderate ($\kappa = 0.56$).

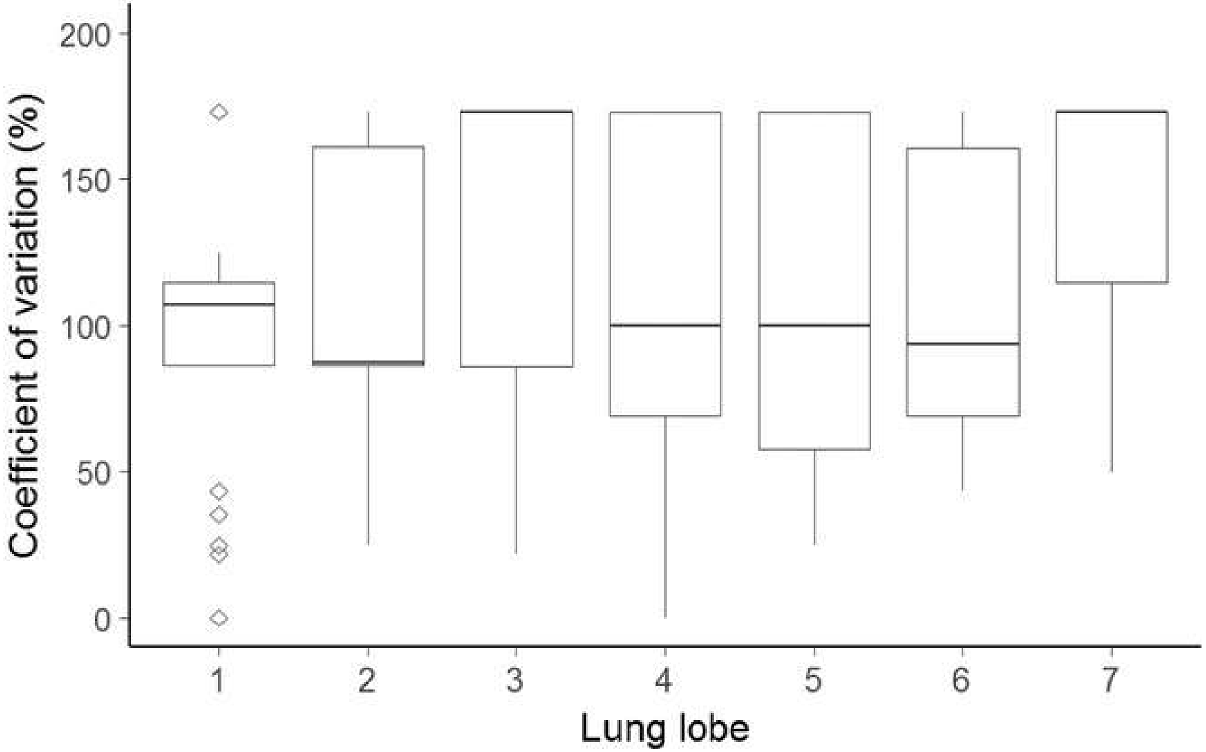

FIGURE 3. The effect of consensus lung lobe contusion severity score on the repeatability of radiography derived total lung score as measured by the coefficient of variation

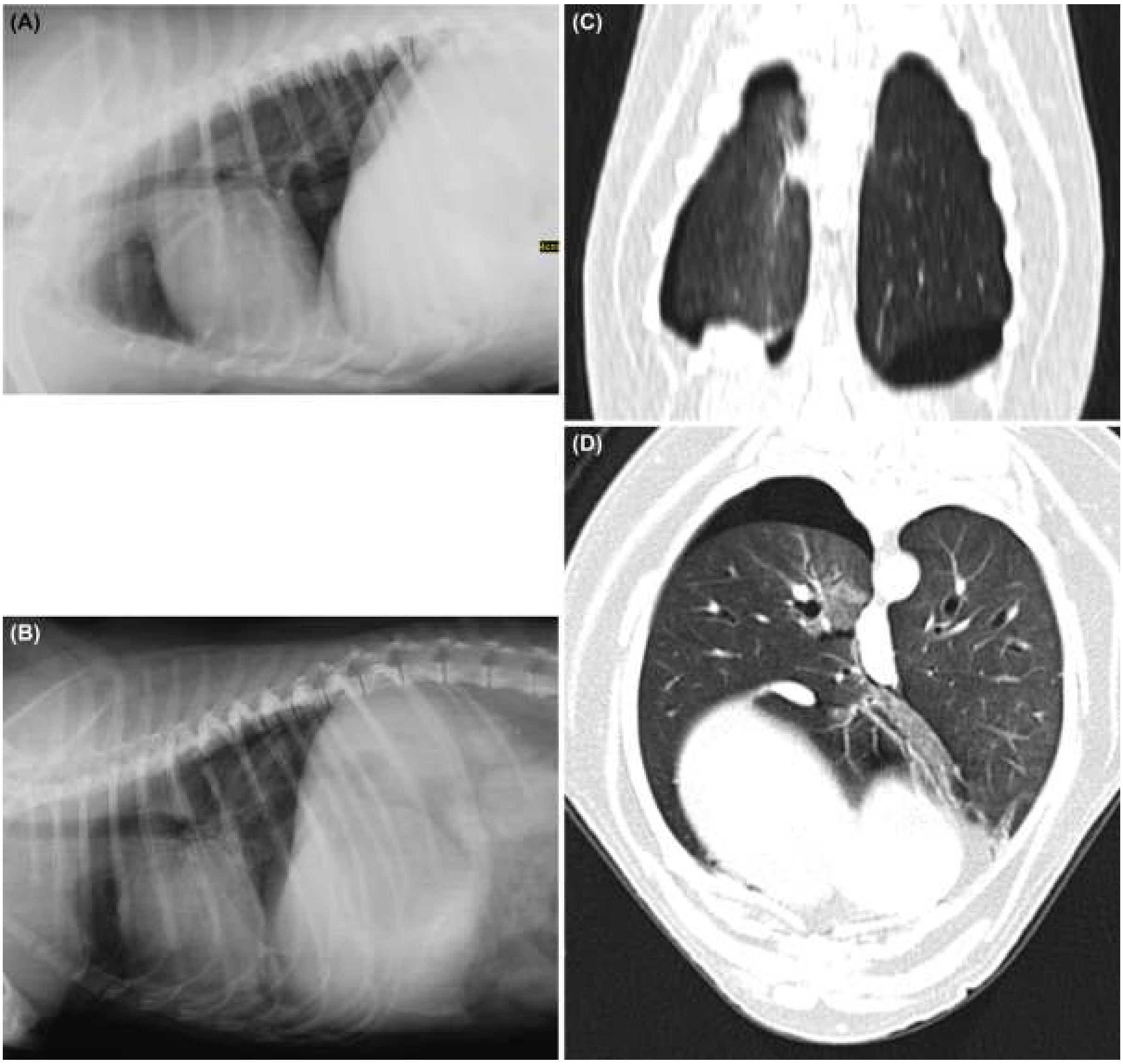

FIGURE 4. Left lateral recumbency and right lateral recumbency radiographs with corresponding dorsal and transverse CT images, respectively, of an 8-year-old spayed female Pug (A and D), and an 8-year-old spayed female small crossbreed (B and C) obtained in left lateral and sternal recumbencies, respectively, that presented with trauma where pneumothorax was undetectable on radiographs but evident on CT. Also note the mild presumed lung contusions evident on both CT images, which are not visible on the radiographs. Right is to the left on the relevant CT images. Window width 1500; window level −400

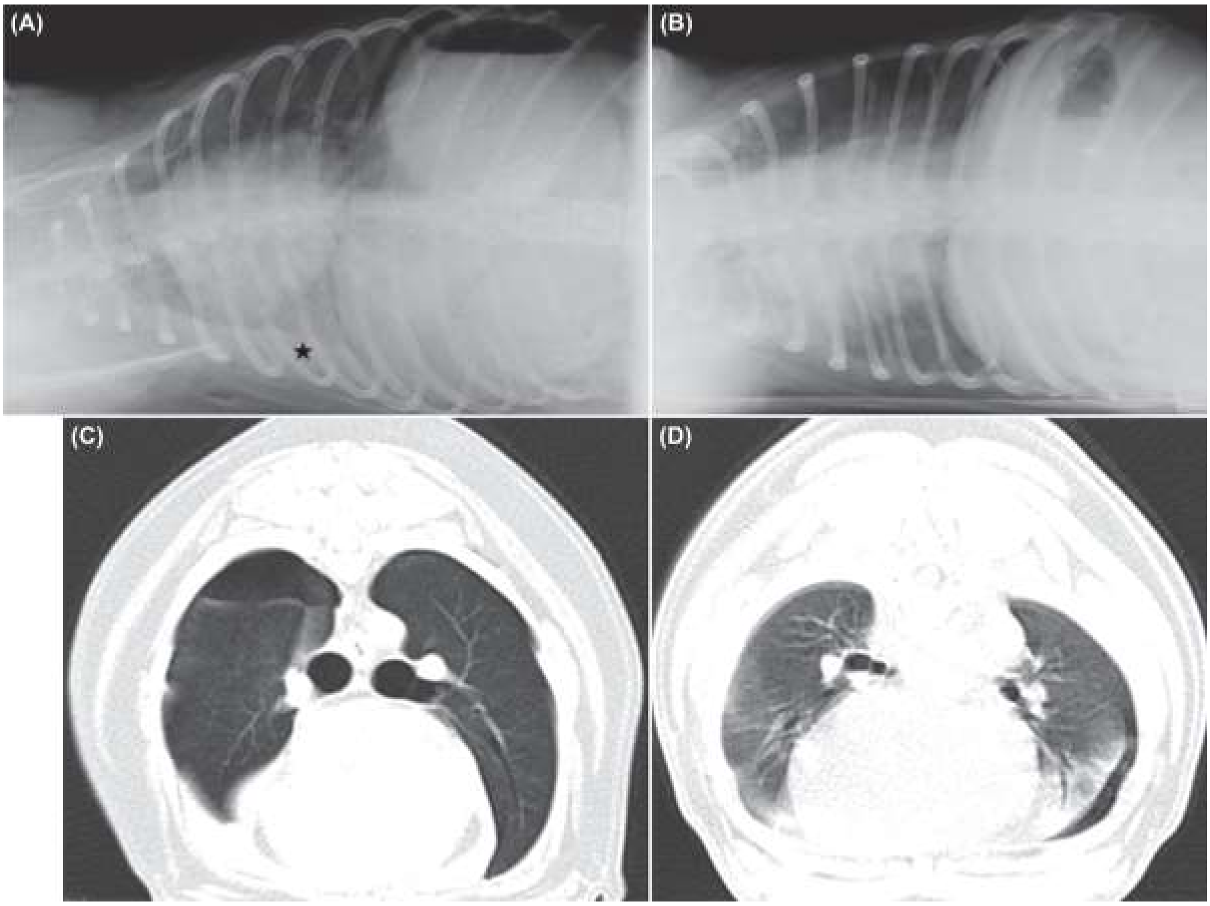

FIGURE 5. Horizontal beam radiographs in right lateral recumbency with corresponding transverse CT images both obtained in sternal recumbency of an 8-year-old spayed female small crossbreed (A and C) and an 8-month-old intact male Jack Russel Terrier (B and D) that presented with trauma where pneumothorax was undetectable on horizontal beam radiographs (and three-view thoracic radiographs) but evident on CT. A, also shows evidence of a pleural effusion (*) on the radiograph, which is also visible on the corresponding CT image on the right side. Mild, presumed lung contusions are noted on image (D). Right is to the left on the CT images. Window width 1500; Window level –400.

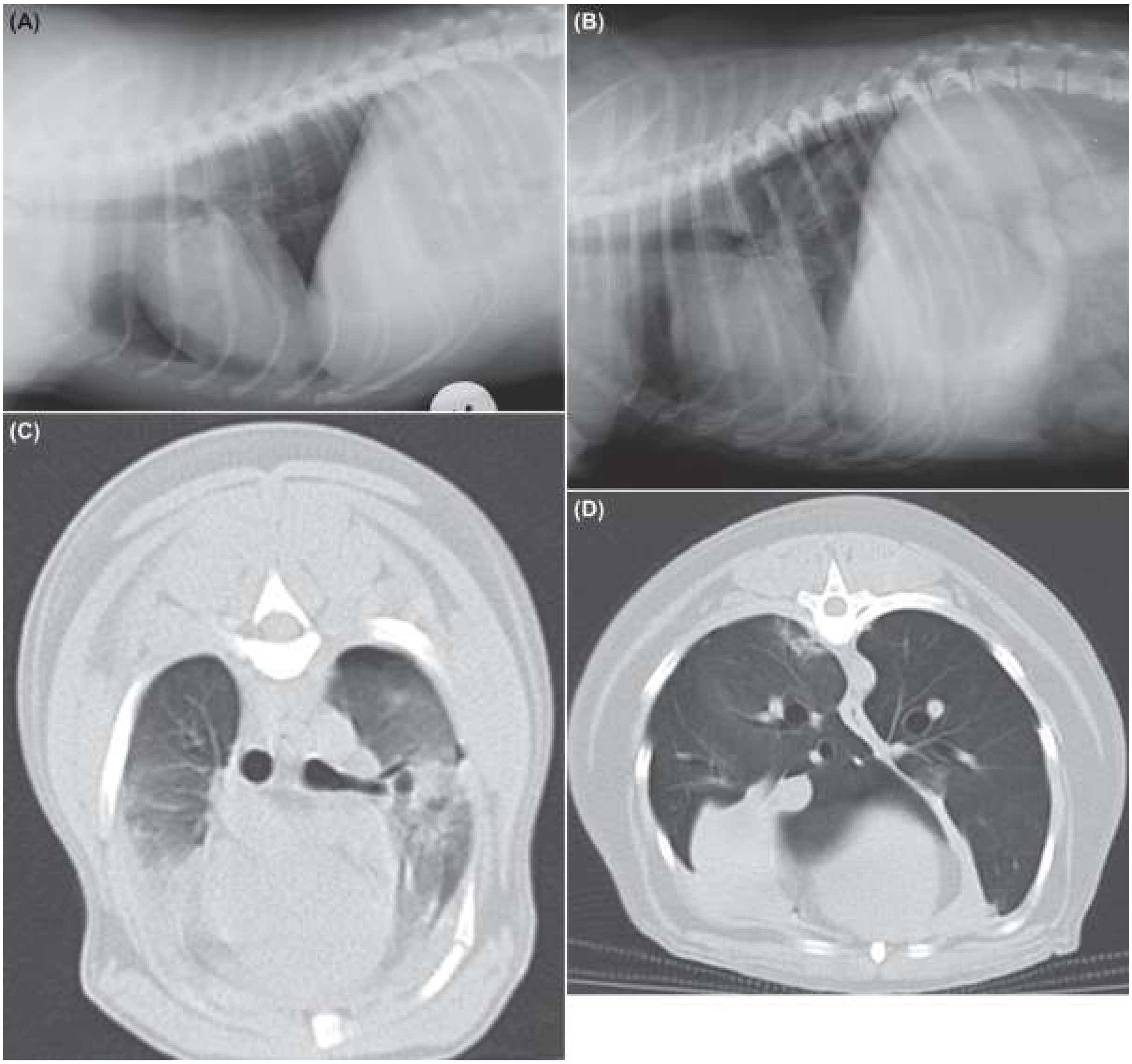

FIGURE 6. Right lateral recumbency radiographs with corresponding transverse CT images both obtained in sternal recumbency of a 2-year-old intact male Toy French Poodle (A and C) and an 8-year-old spayed female small crossbreed (B and D) that presented with trauma where pleural effusion was undetectable on radiographs but evident on CT. Mild, presumed lung contusions are noted on image (C). Right is to the left on the CT images. Window width 1200; window level −600

Nine patients (15%) had rib fractures detected on CT whilst only four patients (7%) were identified on consensus radiographs. Figure 8 illustrates an example of a false-negative radiographic study with rib fractures detected on CT. The sensitivity of radiography for detecting rib fractures was fair overall (Table 1).

The interobserver agreement for rib fracture detection was fair. (Table 1).

4. DISCUSSION

Findings from this study supported our hypothesis that three-view and horizontal beam radiographs would be less sensitive relative to CT for detecting blunt trauma-related thoracic lesions commonly caused by motor vehicle accidents in dogs. Computed tomography detected more cases of presumed pulmonary contusions than radiology. This is consistent with findings in human studies where CT has proven to be more sensitive at detecting lung contusions due to its excellent contrast resolution.[8, 19, 20] The importance of lung contusions detected by CT but missed on radiology has been debated in human literature that found that contusions detected only on CT are usually not severe enough to change patient management and outcome.[4, 6, 19, 20] One particular human study showed that lung contusions detected on radiographs had higher mortality and morbidity rates compared to lung contusions detected on CT only.[21] It is therefore speculated by the authors that the lung contusions in dogs detected on CT only would, as seen in humans, not affect patient outcome.

Observers often overestimated severities of presumed lung contusions on radiographs and interobserver agreement was poor as evidenced by the high coefficients of variation. Each severity grade differing by one point increased the severity score by 11% overall, which contributed to lower interobserver agreement. The grading score was adapted from a human and two veterinary studies that were performed by single observers and thus the repeatability of those scoring systems were not validated.[1, 13, 14] It was suspected that a contributing factor to high interobserver variability might have been due to disagreement as to what constituted moderate and severe scores, despite the evaluators attempt to obtain consensus prior to the study. Differences might have occurred due to variable experience levels. S.C.D. likely utilized a very specific theoretical criterion to score lung severities in fear of missing or underscoring presumed contusions, whereas R.M.K. based severity scoring on 30 years of experience. These findings are supported by another study that reported that inexperienced observers tend to over-interpret lesions as a result of lack of anatomic knowledge, fear of missing lesions, and their belief that a radiograph is abnormal.[22] C.L.R. demonstrated a combination of experience and theoretical knowledge, which most likely improved this individual's accuracy.

The poor Se of three-view thoracic radiology for detecting pneumothorax is consistent with human studies that reported CT being able to detect more than twice the number of pneumothoraxes compared to radiology.[19, 23] The cases missed in our study were most likely due to small amounts of air being trapped between lung lobes and the mediastinum instead of accumulating at the highest point in the thorax. This also might have caused the greater degree of interobserver variability and lower sensitivities. The clinical significance of small volume pneumothoraxes cannot be overemphasized since undiagnosed asymptomatic small volume pneumothorax cases in humans can increase in volume during mechanical ventilation or develop into tension pneumothorax during general anesthesia.[24]

Although dogs are able to tolerate thoracic expansion by 2.5-3.5 times the residual volume, it is unknown whether the presence of an undetected pneumothorax is life-threatening in dogs undergoing general anesthesia or mechanical ventilation.[23] It is thus prudent to monitor ventilation closely for complications where pneumothoraxes are equivocal or absent on thoracic radiographs.

As expected, horizontal beam radiography had greater Se for detecting pneumothorax compared to three-view radiography. These results are consistent with a previous study that reported a significant difference for detecting pneumothorax on horizontal beam compared to standard radiographic views.[25] Our study detected a higher proportion of pneumothorax cases (10/16) compared to the aforementioned study (12/26). These differences might be due to our inclusion criteria for blunt trauma patients that comprised of patients either presenting with respiratory distress or patients with fractures that might not have had signs of respiratory distress. The aforementioned study included patients with known thoracic trauma or where there was a clinical suspicion of pneumothorax. The results obtained thus re-emphasize the value of horizontal beam radiography for detecting pneumothorax in trauma patients with or without signs of dyspnea and should be included as an additional view when CT is not available. This is particularly indicated in patients that may undergo general anesthesia.

No publications could be found where the Se of horizontal beam radiography was compared to CT for detecting pneumothorax. The results from this study is thus of particular interest, since the findings indicated that even though detection improved using horizontal beam radiography, the Se of this technique was still lower than CT.

The low interobserver agreement for horizontal beam radiography most likely reflected a degree of uncertainty that arises in cases with subtle pneumothorax. Gas can be trapped and might not rise to the uppermost hemithorax where the radiologist tends to look on the horizontal beam radiographs. Another factor to consider is that this view is not often utilized and thus variation in sensitivities could reflect lack of familiarity with interpreting this view.

Pleural effusion results were similar to pneumothorax findings. The three-view thoracic radiography views were only able to detect half of the CT diagnosed cases. Human studies have reported similar findings where CT identified more than twice as many pleural effusions and also suggested a greater degree of severity.[19] The pleural effusions identified on radiographs were not overt cases and represented subtle changes or trapped fluid. These findings, similar to pneumothorax, most likely caused low sensitivities and high interobserver variability. It is suspected that if the ventrodorsal view was employed, the Se of detecting pleural effusions would have improved since fluid accumulation in the costophrenic angle and widening of the interlobar fissures of the right middle lung lobe are the first abnormalities detected for pleural effusions.[26]

The improved Se and interobserver agreement for detecting pleural effusion on horizontal beam radiographs differed from a previous study that reported no significant differences between horizontal beam views compared to standard vertical beam views for the detection of pleural effusion.[25] However, it must be noted that the sample size in our study was small resulting in substantial imprecision in our reported estimates.

The clinical significance of pleural effusions detected only on CT is questionable since there is a continuous high turnover of pleural fluid, which would allow a patient with a small amount of pleural fluid to compensate without becoming clinically compromised.[27] In fact, a historical clinical study reported that lymphatic absorption occurred at 0.57 mL/kg/h when heparinized plasma was injected into the pleural cavity.[28] Although absorption of fluids from the pleural space is a complex interaction between lymphatic drainage and Starling's forces, it was believed that as long as the absorptive capacity of the body is not overwhelmed, small amounts of pleural effusion will remain clinically insignificant.[29]

Only one-half of rib fractures were detected on radiographs relative to CT as the reference standard. Rib fractures are easily missed because of the low contrast imaging technique used for thoracic radiography.[30] The inability to detect rib fractures is concerning since this injury compromises breathing secondary to pain and carries a poorer prognosis. [30] Identification of rib fractures guides the clinician to look for additional lesions since caudal rib fractures could be associated with cranial abdominal trauma, while more cranial rib fractures might be indicative of cranial mediastinal vascular and cardiac trauma.[31] Rib fractures can also be an indicator of adjacent lung injury, which is important to assess. [30] Since rib fractures are described as painful and may alert the clinician to certain concomitant injuries, identifying these fractures could improve patient management.

Although CT identified more rib fractures, the results were challenging to obtain. The radiologist who evaluated CT images in this study noted that motion blur complicated interpretation of rib fractures. This was less of a problem on transverse images, but transverse images posed an additional challenge since the entire rib cannot be visualized on a single slice as the ribs are angled caudally. These challenges could possibly be overcome by employing maximum intensity projections, multiplanar reconstructions, and volume rendered images, especially if the patient lies on the side of the fracture to limit motion artifact causing pseudo rib fractures. In this study, volume rendered images viewed from caudally were considered to be particularly helpful for identifying fractures of the first two ribs.

The study had several limitations. The high coefficient of variation between observers when presumed lung contusions were scored indicated that this method of scoring had poor repeatability. It was beyond the scope of this study to evaluate the potential risks of small volume pneumothorax detected only on CT. Another important limitation of this study was the small sample size for certain abnormalities. Less common trauma-associated injuries such as injuries to the upper airway, mediastinal effusion, pneumomediastinum, and heart abnormalities were absent from the study population. Only a single observer (R.M.K.) evaluated CT images for abnormalities, which might have influenced the reported findings.

The lack of general anesthesia for diagnostic imaging in these traumatized, and often physiologically compromised patients was deliberate and a few studies had to be repeated due to excessive motion blur. This, together with loss of quality when transverse CT images were reconstructed into dorsal and sagittal planes, further contributed to image quality degradation of the CT images, while the lack of good inspiratory views also influenced image quality and may have compromised the accuracy of our results. However, as radiologists we have to make our diagnoses without causing more harm to the patient, and we believe the imaging findings remained clinically relevant.

In conclusion, this study provides evidence that supports the use of CT for veterinary trauma patients. Radiology was less sensitive relative to CT for the detection of presumed lung contusions, pneumothorax, pleural effusion, and rib fractures in this sample. Computed tomography could thus be considered as an additional diagnostic imaging modality in patients presenting with blunt trauma, while radiology is still an excellent screening tool to identify more severe thoracic abnormalities in these patients. The decision to use CT in veterinary trauma patients will thus remain at the discretion of the clinician assessing the patient and considering the financial implications to the owner. This decision-making process to employ CT in a veterinary patient could possibly be based on whether the patient presents with obvious respiratory distress or thoracic wall tenderness. Finally, the study also highlighted the value of horizontal beam radiography in trauma patients with equivocal or no evidence of pneumothorax. It is thus the authors' opinion that private practitioners with no access to CT, or where academic hospital services may only have CT service available the next day, should employ two orthogonal views of the thorax with the addition of a horizontal beam view in right lateral recumbency. Future studies with larger populations of blunt thoracic trauma patients should be implemented to objectively evaluate the Se and Sp of thoracic radiography for detection of thoracic lesions that were absent or present in small numbers in our sample. Future studies should also consider including a wider scoring range for presumed pulmonary contusions to help reduce interobserver variability and evaluate patient outcomes where pulmonary contusions were only detectable on CT. It would also be helpful to determine the risks and complications of mechanical ventilation in dogs with small volume pneumothorax detectable only on CT.

REFERENCES

1. Sigrist NE, Doherr MG, Spreng DE. Clinical findings and diagnostic value of post-traumatic thoracic radiographs in dogs and cats with blunt trauma. *J Vet Emerg Crit Care*. 2004;14:259-268.
2. Trupka A, Waydhas C, Hallfeldt K, Nast-Kolb D, Pfeifer K, Schweiberer L. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. *J Trauma Acute Care Surg*. 1997;43:405-412.

3. Okamoto K, Norio H, Kaneko N, Sakamoto T, Kaji T, Okada Y. Use of early-phase dynamic spiral computed tomography for the primary screening of multiple trauma. *Am J Emerg Med*. 2002;20:528-534.
4. Traub M, Stevenson M, McEvoy S, et al. The use of chest computed tomography versus chest X-ray in patients with major blunt trauma. *Injury*. 2007;38:43-47.
5. Omert L, Yeaney WW, Protetch J. Efficacy of thoracic computerized tomography in blunt chest trauma. *Am Surg*. 2001;67:660.
6. Kea B, Gamarallage R, Vairamuthu H, et al. What is the clinical significance of chest CT when the chest x-ray result is normal in patients with blunt trauma? *Am J Emerg Med*. 2013;31:1268-1273.
7. Johnson EG, Wisner ER. Advances in respiratory imaging. *Vet Clin North Am Small Anim Pract*. 2007;37:879-900.
8. Prather AB, Berry CR, Thrall DE. Use of radiography in combination with computed tomography for the assessment of noncardiac thoracic disease in the dog and cat. *Vet Radiol Ultrasound*. 2005;46:114-121.
9. Nemanic S, London CA, Wisner ER. Comparison of thoracic radiographs and single breath-hold helical CT for detection of pulmonary nodules in dogs with metastatic neoplasia. *J Vet Intern Med*. 2006;20:508-515.
10. Schwarz T, Johnson V. Lungs and bronchi. In: Schwarz T, Saunders J, (eds.): *Veterinary Computed Tomography*. West Sussex: John Wiley & Sons Ltd. 2011;261-276.

11. Yilmaz C, Ravikumar P, Dane DM, Bellotto DJ, Johnson RL, Hsia CC. Noninvasive quantification of heterogeneous lung growth following extensive lung resection by high-resolution computed tomography. *J Appl Physiol*. 2009;107:1569-1578.

12. Kirberger RM, Leisewitz AL, Rautenbach Y, et al. Association between computed tomographic thoracic injury scores and blood gas and acid–base balance in dogs with blunt thoracic trauma. *J Vet Emerg Crit Care*. 2019; 29: 373- 384.

13. Tyburski JG, Collinge JD, Wilson RF, Eachempati SR. Pulmonary contusions: quantifying the lesions on chest X-ray films and the factors affecting prognosis. *J Trauma Acute Care Surg*. 1999;46:833-838.

14. Powell LL, Rozanski EA, Tidwell AS, Rush JE. A retrospective analysis of pulmonary contusion secondary to motor vehicular accidents in 143 dogs: 1994-1997. *J Vet Emerg Crit Care*. 1999;9:127-136.

15. Wickham H. Build a plot layer by layer. In (eds.): Wickham H. *ggplot2: Elegant Graphics for Data Analysis*. New York: Springer-Verlag, 2009;41-64.

16. Magis D, Barrada JR. Computerized adaptive testing with R: Recent updates of the package catR. *J Stat Softw*. 2017;76:1-19.

17. Fleiss JL, Levin B, Paik MC. The comparison of proportions from several independent samples. In (eds.): Fleiss JL, Levin B, Paik MC. *Statistical Methods*

for Rates and Proportions, Third Edition. West Sussex: John Wiley & Sons Ltd. 2003;187-233.

18. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;159-174.
19. Guerrero-López F, Vázquez-Mata G, Alcázar-Romero PP, Fernández-Mondéjar E, Aguayo-Hoyos E, Linde-Valverde CM. Evaluation of the utility of computed tomography in the initial assessment of the critical care patient with chest trauma. *Crit Care Med*. 2000;28:1370-1375.
20. Požgain Z, Kristek D, Lovrić I, Kondža G, Jelavić M, Kocur J, et al. Pulmonary contusions after blunt chest trauma: clinical significance and evaluation of patient management. *Eur J Trauma Emerg Surg*. 2017;1-5.
21. Cobanoglu U, Melek M, Edirne Y. Chest radiography diagnosis of pulmonary contusion is associated with increased morbidity and mortality. *Indian J Thorac Cardiovasc Surg*. 2010;26:24-29.
22. Lamb CR, Parry AT, Baines EA, Chang Y. Does changing the orientation of a thoracic radiograph aid diagnosis of rib fractures? *Vet Radiol Ultrasound*. 2011;52:75-78.
23. Pawloski DR, Broaddus KD. Pneumothorax: a review. *J Am Anim Hosp Assoc*. 2010;46:385-397.
24. Bacon A, Paix A, Williamson J, Webb R, Chapman M. Crisis management during anaesthesia: pneumothorax. *BMJ Qual Saf*. 2005;14:e18-e18.

25. Lynch KC, Oliveira CR, Matheson JS, Mitchell MA, O'Brien RT. Detection of pneumothorax and pleural effusion with horizontal beam radiography. *Vet Radiol Ultrasound*. 2012;53:38-43.

26. Lord P, Suter P, Chan K, Appleford M, Root C. Pleural, extrapleural and pulmonary lesions in small animals: A radiographic approach to differential diagnosis. *Vet Radiol*. 1972;13:4-17.

27. Frame M, King A. The pleural space. In: Schwarz T, Johnson V (eds): *BSAVA Manual of Canine and Feline Thoracic Imaging*. Quedgley: British Small Animal Veterinary Association, 2008;322-329.

28. Stewart PB, Burgen ASV. The turnover of fluid in the dog's pleural cavity. *J Lab Clin Med*. 1958;52:212-230.

29. Stillion JR, Letendre JA. A clinical review of the pathophysiology, diagnosis, and treatment of pyothorax in dogs and cats. *J Vet Emerg Crit Care*. 2015;25:113-129.

30. Llabres-Diaz F, Petite A, Saunders JH, Schwarz T. The thoracic boundaries. In: Schwarz T, Johnson V (eds): *BSAVA Manual of Canine and Feline Thoracic Imaging*. Quedgley: British Small Animal Veterinary Association, 2008;344,354-355,367-368.

31. Wouk F. Thoracic trauma in dogs and cats. Paper presented at: *34th World Small Animal Veterinary Association Congress 2009*; July 21-24, 2009; Sao Paulo, Brazil.

APPENDIX

Example of CT calculation to determine lung lobe contusion and contribution to overall lung involvement of left cranial lobe *pars cranialis*. Row 2 shows formulae used and rows 3 & 4 are examples of differing values of lung involvement. Total lung involvement was determined by adding each lung lobe's contribution together.

Row/Column	**A**	**B**	**C**	**D**	**E**	**F**
1	**Severity**	**HU lobe**	**% aeration**	**% contusion**	**Tot lobe involved**	**Tot lung involved**
2	e.g. 1	e.g. -630	=(B2/-713)*100	=100-C2	=(A2*D2/3)	=E13*0.12†
3	1	-630	88.36%	11.64%	3.88%	0.47%
4	3	-300	42.08%	57.92%	57.92%	6.95%

†Contribution of each lung lobes volume to total lung lobe volume according to Yilmaz *et al.*[7] Left cranial lobe *pars cranialis* 12%; *pars caudalis* 7%; left caudal lobe 22%; right cranial lobe 19%: right middle lobe 11%: right caudal lobe 21% and accessory lobe 8%

References

1. Sigrist NE, Doherr MG, Spreng DE. Clinical findings and diagnostic value of post-traumatic thoracic radiographs in dogs and cats with blunt trauma. *J Vet Emerg Crit Care*. 2004;14:259-268.
2. Trupka A, Waydhas C, Hallfeldt K, Nast-Kolb D, Pfeifer K, Schweiberer L. Value of thoracic computed tomography in the first assessment of severely injured patients with blunt chest trauma: results of a prospective study. *J Trauma Acute Care Surg*. 1997;43:405-412.
3. Okamoto K, Norio H, Kaneko N, Sakamoto T, Kaji T, Okada Y. Use of early-phase dynamic spiral computed tomography for the primary screening of multiple trauma. *The American journal of emergency medicine*. 2002;20:528-534.
4. Traub M, Stevenson M, McEvoy S, Briggs G, Lo SK, Leibman S, et al. The use of chest computed tomography versus chest X-ray in patients with major blunt trauma. *Injury*. 2007;38:43-47.
5. Omert L, Yeaney WW, Protetch J. Efficacy of thoracic computerized tomography in blunt chest trauma. *Am Surg*. 2001;67:660-664.
6. Kea B, Gamarallage R, Vairamuthu H, Fortman J, Lunney K, Hendey GW, et al. What is the clinical significance of chest CT when the chest x-ray result is normal in patients with blunt trauma? *Am J Emerg Med*. 2013;31:1268-1273.
7. Johnson EG, Wisner ER. Advances in respiratory imaging. *Vet Clin North Am Small Anim Pract*. 2007;37:879-900.
8. Prather AB, Berry CR, Thrall DE. Use of radiography in combination with computed tomography for the assessment of noncardiac thoracic disease in the dog and cat. *Vet Radiol Ultrasound*. 2005;46:114-121.
9. Nemanic S, London CA, Wisner ER. Comparison of thoracic radiographs and single breath-hold helical CT for detection of pulmonary nodules in dogs with metastatic neoplasia. *J Vet Intern Med*. 2006;20:508-515.
10. Schwarz T, Saunders J. *Veterinary computed tomography*: John Wiley & Sons, 2011.
11. Yilmaz C, Ravikumar P, Dane DM, Bellotto DJ, Johnson RL, Hsia CC. Noninvasive quantification of heterogeneous lung growth following extensive lung resection by high-resolution computed tomography. *J Appl Physiol*. 2009;107:1569-1578.
12. Tyburski JG, Collinge JD, Wilson RF, Eachempati SR. Pulmonary contusions: quantifying the lesions on chest X-ray films and the factors affecting prognosis. *J Trauma Acute Care Surg*. 1999;46:833-838.
13. Powell LL, Rozanski EA, Tidwell AS, Rush JE. A retrospective analysis of pulmonary contusion secondary to motor vehicular accidents in 143 dogs: 1994-1997. *J Vet Emerg Crit Care*. 1999;9:127-136.
14. Wickham H. ggplot2: Elegant graphics for data analysis Springer-Verlag. *New York*. 2009;
15. Magis D, Barrada JR. Computerized adaptive testing with R: Recent updates of the package catR. *J Stat Softw*. 2017;76:1-19.
16. Fleiss JL, Levin B, Paik MC. The comparison of proportions from several independent samples. *Statistical Methods for Rates and Proportions, Third Edition*. 2003;187-233.
17. Landis JR, Koch GG. The measurement of observer agreement for categorical data. *Biometrics*. 1977;159-174.
18. Guerrero-López F, Vázquez-Mata G, Alcázar-Romero PP, Fernández-Mondéjar E, Aguayo-Hoyos E, Linde-Valverde CM. Evaluation of the utility of computed tomography in the initial assessment of the critical care patient with chest trauma. *Crit Care Med*. 2000;28:1370-1375.
19. Požgain Z, Kristek D, Lovrić I, Kondža G, Jelavić M, Kocur J, et al. Pulmonary contusions after blunt chest trauma: clinical significance and evaluation of patient management. *Eur J Trauma Emerg Surg*. 2017;1-5.

20. Cobanoglu U, Melek M, Edirne Y. Chest radiography diagnosis of pulmonary contusion is associated with increased morbidity and mortality. *Indian journal of thoracic and cardiovascular surgery*. 2010;26:24-29.
21. Bakowitz M, Bruns B, McCunn M. Acute lung injury and the acute respiratory distress syndrome in the injured patient. *Scand J Trauma Resusc Emerg Med*. 2012;20:54.
22. Ganie FA, Lone H, Lone GN, Wani ML, Singh S, Dar AM. Lung contusion: a clinico-pathological entity with unpredictable clinical course. *Bulletin Emerg Trauma*. 2013;1:7.
23. Lamb CR, Parry AT, Baines EA, Chang Y. Does changing the orientation of a thoracic radiograph aid diagnosis of rib fractures? *Vet Radiol Ultrasound*. 2011;52:75-78.
24. Pawloski DR, Broaddus KD. Pneumothorax: a review. *J Am Anim Hosp Assoc*. 2010;46:385-397.
25. Bacon A, Paix A, Williamson J, Webb R, Chapman M. Crisis management during anaesthesia: pneumothorax. *BMJ Quality & Safety*. 2005;14:e18-e18.
26. Lynch KC, Oliveira CR, Matheson JS, Mitchell MA, O'Brien RT. Detection of pneumothorax and pleural effusion with horizontal beam radiography. *Vet Radiol Ultrasound*. 2012;53:38-43.
27. Lord P, Suter P, Chan K, Appleford M, Root C. Pleural, extrapleural and pulmonary lesions in small animals: A radiographic approach to differential diagnosis. *Vet Radiol*. 1972;13:4-17.
28. Frame M, King A. The pleural space. In: Schwarz T, Johnson V (eds): *BSAVA manual of canine and feline thoracic imaging*. Quedgley: British Small Animal Veterinary Association, 2008;322-329.
29. Stewart PB, Burgen ASV. The turnover of fluid in the dog's pleural cavity. *J Lab Clin Med*. 1958;52:212-230.
30. Stillion JR, Letendre JA. A clinical review of the pathophysiology, diagnosis, and treatment of pyothorax in dogs and cats. *J Vet Emerg Crit Care*. 2015;25:113-129.
31. Llabres-Diaz F, Petite A, Saunders JH, Schwarz T. The thoracic boundaries. In: Schwarz T, Johnson V (eds): *BSAVA manual of canine and feline thoracic imaging*. Quedgley: British Small Animal Veterinary Association, 2008;344,354-355,367-368.
32. Wouk F. Thoracic trauma in dogs and cats. *34th World Small Animal Veterinary Association Congress, Sao Paulo, Brazil, 21-24 July 2009*. 2009;unagnated.