Sensitivity and specificity of thoracic radiography relative to computed tomography in dogs affected by blunt trauma caused by a motor vehicle accident

By

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Abbreviations

CT	- Computed tomography
COV	- Coefficient of variation
DV	- Dorsoventral
HB	- Horizontal beam
LLR	- Left lateral recumbency
MVA	- Motor vehicle accident
OVAH	- Onderstepoort Veterinary Academic Hospital
RAD 4	- Radiologist with 4 years' experience
RAD 30	- Radiologist with 30 years' experience
RES 1	- First year diagnostic imaging resident
RLR	- Right lateral recumbency
T11	- Eleventh thoracic vertebra
VD	- Ventrodorsal

Summary

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Thoracic injuries caused by blunt trauma are commonly encountered emergencies in veterinary medicine. However, no literature exists comparing radiography to computed tomography (CT) in blunt thoracic trauma caused by motor vehicle accidents in canine patients. The aim of this prospective case series was to estimate the sensitivity (Se) and specificity (Sp) of thoracic radiography relative to CT for detecting lung contusions, pneumothorax, pleural effusion and rib fractures. The study further aimed to establish a severity scoring system for radiography and CT and to compare the findings between the two modalities. The hypothesis was that radiography would be less sensitive than CT at detecting these injuries and that radiography would underestimate the severity of lung contusions compared to CT. Fifty-nine patients met the inclusion criteria. Radiography underestimated the presence of lung contusions (Se = 69%, 95% Confidence interval (CI)) and overestimated the severity of the contusions relative to CT. There was also 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 detection of pneumothorax (Se = 19% and 63% respectively) and pleural effusions (Se = 43% and 71% respectively). Similarly, the sensitivity (56%) of three-view thoracic radiographs for the detection of rib fractures was poor relative to CT. To conclude, three-view thoracic radiography had low sensitivity for pathology related to blunt thoracic trauma caused by motor vehicle accidents and CT could be considered as an additional diagnostic imaging modality in these patients.

KEYWORDS

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

Chapter 1: Introduction

1.1 Background

Thoracic injuries caused by blunt trauma secondary to motor vehicle accidents (MVA) are commonly encountered emergencies in companion veterinary medicine.[1] In humans presenting with blunt trauma, the use of computed tomography (CT) as a first-line diagnostic tool 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 radiography.[4,5] A comparative study of human trauma cases reported that CT was able to identify up to 66% more thoracic injuries than radiography 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 radiography.[4-6] Over the last 10-15 years, the use of CT examinations in patients with thoracic pathology has become more common in veterinary medicine.[7-9] However, no literature exists comparing conventional radiography to CT in dogs with blunt thoracic trauma secondary to 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.

1.2 Problem statements

- No veterinary literature exists comparing radiography to CT in blunt thoracic trauma patients secondary to MVA's.

- The sensitivity and specificity of thoracic radiographs compared to the gold standard imaging technique of CT to detect changes related to blunt thoracic trauma is unknown in small animals.
- Computed tomography is a common modality in bigger practices and its value in veterinary blunt thoracic trauma secondary to MVA's is unknown.

1.3 Hypotheses

Null hypothesis 1: There is no difference between standard and HB thoracic radiography and gold standard thoracic CT in detecting blunt thoracic trauma induced pathology secondary to a motor vehicle accident.
Null hypothesis 2: There is no difference between the severity scoring established with standard thoracic radiography and CT for lung contusions.

Alternative hypothesis 1: Standard and HB-beam thoracic radiography have poorer sensitivities and specificities for detecting blunt thoracic trauma induced pathology relative to gold standard thoracic CT.
Alternative hypothesis 2: Standard radiography underestimates the severity of lung contusions relative to CT.

1.4 Objectives

- To compare the sensitivity and specificity of thoracic radiography relative to the gold standard technique of thoracic CT for detecting changes associated with blunt trauma caused by motor MVA for the following changes:
    - Lung contusions
    - Pneumothorax
    - Pleural effusion
    - Rib fractures

    - Thoracic wall pathology
    - Pneumomediastinum
    - Diaphragmatic rupture

- Establish a scoring system for lung contusion severity for radiography.

1.5 Benefits

- Establishing the accuracy of thoracic radiographs in blunt thoracic trauma compared to thoracic CT.
- Promoting the use of thoracic CT in trauma patients that will benefit patient outcome.
- The research conducted will serve as partial fulfilment of the principal investigator's MMedVet (Diagnostic Imaging) degree.

Chapter 2: Literature Review

2.1 Overview

Thoracic injuries caused by blunt trauma are commonly encountered emergencies in small animal veterinary medicine.[1] Early diagnostic intervention in the thoracic blunt trauma patient is critical in the successful management of veterinary patients, since this often leads to serious injury, which may result in death if left untreated.[1,10] Motor vehicle accidents are typical and often serious veterinary emergencies, with canine patients frequently presenting with multiple concomitant injuries.[11-13] In small animals presenting with limb fractures following MVA, coexisting thoracic trauma is reported to be present in 16% to 57% of cases.[11,14,15] Even though musculoskeletal trauma to the cranial half of the body is often associated with blunt thoracic trauma, up to 51% of veterinary patients with musculoskeletal injuries to the caudal half of the body, have concurrent thoracic trauma.[11] Identification of concurrent thoracic trauma with musculoskeletal injuries following a MVA is a serious concern, since many life-threatening thoracic injuries are underdiagnosed, especially in patients with obvious injury to the caudal half of their bodies.[11,14] Other factors that contribute to the under-diagnosis of blunt thoracic trauma include poor sensitivity of thoracic auscultation in detecting abnormalities, the anatomy of the canine thorax and the ability of veterinary patients to compensate despite the presence of serious thoracic injuries.[14]

The anatomy of the canine thorax is the reason why thoracic injuries in canines are common sequela to blunt trauma.[16] The canine ribcage is highly flexible and thus allows the impact of blunt trauma to be transferred to the internal thoracic structures with ease.[16] Injury to thoracic structures can occur in several ways, such as deceleration injuries that can result in lung contusions, abdominal compression injuries that can lead to diaphragmatic rupture or changes in intrathoracic pressures that can give rise to rupture of alveoli or their associated capillaries.[16,17] Several factors contribute to the severity and outcome of blunt trauma delivered to the thorax. These include the amount and duration of the force delivered as well as the region of the thorax and surface area that received the force.[18]

Blunt thoracic trauma can have several outcomes including, but not limited to, lung contusions, pneumothorax, haemothorax, rib-, sternal- or vertebral fractures, injuries pertaining to the mediastinum and mediastinal structures, thoracic wall injuries or abdominal pathology.[10,12,13] Reports vary on which of these clinical outcomes are the most common manifestation of blunt trauma, with some authors reporting pneumothorax as the most common, whilst others report lung contusion as more frequent.[10,12,13]

In human medicine, the initial period between initiation of diagnostic tests until the implementation of the appropriate therapy is known as the "golden hour".[19] If the correct diagnostic tests are initiated during the "golden hour", survival chances for patients can be improved.[19] Diagnostic radiography is a routine tool used in both human and veterinary medicine during the initial assessment of thoracic blunt trauma in order to identify suspected intrathoracic pathology.[1,20] Human studies have shown that thoracic radiography is useful in identifying life-threatening medical conditions, such as extensive pneumothorax, haemothorax, and pulmonary contusions.[21] In veterinary medicine, diagnostic radiography is often used as the first diagnostic tool to evaluate thoracic trauma.[22]

2.2 Thoracic radiography

In order to completely evaluate the canine thorax radiographically, at least two orthogonal views of the thorax are required.[23] The inclusion of three vertical beam views (dorsoventral (DV), right lateral recumbency (RLR) and left lateral recumbency (LLR)) together with the addition of a horizontal beam-view (HB-view) of the thorax, have proven to be useful in identifying thoracic pathology.[24] The inclusion of HB-views have shown to improve the detection of subtle pleural cavity air or fluid accumulation.[24] Horizontal beam-views take advantage of the properties of gas, which rises and fluid which accumulates in gravity-dependent locations.[24] The pleural space containing air will become more apparent on the HB-view due to greater lung lobe retraction and better visibility of the lung-pleural space interface to the x-ray beam.[24] Similarly, fluid accumulation on the dependent side of the patient will be detected.[24] Horizontal beam-radiography has the additional advantage of enabling the observer to differentiate free, trapped and encapsulated fluid from lung, mediastinal or pleural pathology.[24] Results of studies have shown that a patient positioned in RLR for the ventrodorsal (VD) HB-view is superior when quantifying the severity of bilateral pneumothorax compared to standard three-view thoracic and LLR VD HB-views.[24,25]

2.3 Respiratory system

Tracheal injuries have been described as a consequence of MVA's.[26] Cervical tracheal trauma is well described in the literature, but although MVA have been mentioned as a potential cause for this injury, bite wounds appear to be the most common cause of cervical tracheal injuries in dogs.[27-29] Thoracic tracheal avulsions secondary to MVA has been described in cats whilst no reports exist of MVA induced traumatic thoracic tracheal avulsions in dogs.[22,26,30] The most common location of a tracheal avulsion is the mid-thoracic portion of the trachea, which represents the transition between the immobile cranial part and the more mobile caudal part of the trachea.[22,31] Radiological signs associated with tracheal avulsion include pneumomediastinum, changes in the position and diameter of the trachea and dynamic gas opacities associated with the trachea.[22,31]

Lung lobe laceration may occur secondary to fractured ribs in blunt trauma patients.[22] These lacerations generally give rise to focal areas where blood and air accumulate, resulting in cavitary lesions.[22] Radiologically, these lesions are normally visible at the periphery of the lung and may vary in appearance from a poorly marginated soft tissue structure, to a well-marginated, gas opaque structure which can be described as a traumatic bulla.[22]

Lung contusions are a very common consequence of blunt thoracic trauma and constitute up to 55% of thoracic injuries in humans.[32] Lung contusions contribute significantly to the morbidity and mortality of both human and veterinary patients.[16] The lungs are particularly prone to injury and can become severely injured in blunt trauma.[18] Even though the lungs are highly elastic, the air-filled alveoli with their thin walls and delicate blood vessels, make these structures susceptible to rupture.[18] The damage that occurs to the lung parenchyma is as a result of a combination of compression and decompression injuries to the lung tissue.[16,22] This leads to structural alveolar and interstitial damage, resulting in haemorrhage and oedema.[1] Oedema worsens since there is a degree of damage inflicted on the pulmonary vascular endothelium, which leads to increased vascular permeability.[16] The consequence of these changes include diminished pulmonary compliance, which ultimately leads to an increased respiratory shunt fraction, giving rise to hypoxaemia.[1,16] In dogs, lung contusions are considered the most common cause of selective lung lobe collapse.[33] Lung lobe collapse will be exacerbated in the presence of a concomitant pneumothorax, since free air will tend to collect around the collapsed lung lobe instead of accumulating along the sternum as in the case of pneumothorax without lung lobe collapse.[33] The biggest challenge with diagnosing lung contusions is that the changes associated with lung contusions may only become radiologically apparent four to even 24 hours after injury as was demonstrated in one experimental trauma study in monkeys.[34] It is thus assumed than in these instances, where lung contusions are suspected, follow-up radiographs may be of great value to monitor progression and resolution of lung contusions. Typical radiological findings indicative of lung contusions include interstitial to patchy alveolar lung patterns.[16,35] These lesions may be focal, involving a single lobe or diffuse, extending to involve multiple lobes.[16,35] In humans, lung contusions develop as a result of blood leakage into the alveoli and interstitium.[36] Damage to blood vessels occur due to shearing of lung tissue across ribs and other bony structures and therefore contusions are often adjacent to rib fracures.[36] In the authors’ experience, the same pattern of distribution can be observed in dogs. Lung contusions will radiologically improve within 24 to 48 hours and completely resolve within three to 10 days, depending on the severity and extent.[14] It can be assumed that radiological signs of lung contusions will resolve as the clinical picture of the patient improves.

2.4 Pleural space pathology

Pleural space pathology in veterinary trauma patients usually include pneumothorax and haemothorax, both of which are life-threatening conditions, since lung expansion becomes limited with progression of these conditions.[20] Normally the pleural space is described as a “potential space” that exists between the closely apposed visceral pleura that covers the lung parenchyma and the parietal pleura, which covers the mediastinum, diaphragm, and thoracic wall.[37,38] The pleural space contains a small amount of fluid (approximately 0.3 ml/kg in canines), which allows for a smooth interaction between the lung and thoracic wall.[37,38] The amount of fluid present in the pleural space is governed by Starling’s forces which dictate the amount of fluid that will be removed by the lymphatic drainage system.[38] In normal canines, the pleural space is maintained at sub-atmospheric pressures by forces that oppose elastic recoil of the lung and forces that overcome resistance to air flow. [25,37,38] This negative pressure is essential in preventing lung collapse.[25] The mediastinum forms the division between the left and right pleural cavities.[38] Communication between the left and right pleural cavities in canines has been a subject of much dispute.[25,38] Anatomists have described the canine mediastinum to be a complete structure that divides the thorax into left and right pleural cavities.[38] However, clinical findings have proven that unilateral pleural space pathology most often progresses to become bilateral.[25,38] Several theories have been proposed to explain how bilateral pleural pathology develops. Some authors believe that the mediastinum may be fenestrated in canines.[25,38,39] Another theory is that the mediastinum in dogs is complete but very thin and thus prone to rupture when pleural space pathology is significant.[25,40]

Pneumothorax has been described by several authors as the most common sequel to blunt thoracic trauma.[10,12] Traumatic pneumothorax is most often bilateral, although some asymmetry may exist between the left and right thoracic cavities.[22] Pneumothorax develops when air escapes into the pleural space.[41] Several mechanisms such as forceful compression of the thorax against a closed glottis, resulting in bronchial tree or lung parenchymal rupture or shearing forces inflicted on the lung parenchyma have been proposed.[10,16] Thoracic radiography is commonly used in veterinary medicine for detecting pneumothorax as well as for the evaluation of concomitant thoracic pathology.[42] Expiratory radiographs have proven to be better at detecting small volumes of air in the pleural space, since the contrast between the free pleural air and the non-aerated lungs becomes more apparent.[25] Several radiological findings are typically associated with pneumothorax, but are dependent on the amount of air accumulation in the pleural space.[37,41] Differentiating between normal pulmonary air and free air in the pleural space is important for the detection of pneumothorax and can be achieved by identifying the absence of a vascular pattern in the area of interest, which would indicate free pleural air.[37,41] Pneumothorax prevents full expansion of the lung parenchyma with resultant pulmonary atelectasis evident radiographically as an increased soft tissue opacity of the lung lobes and increased visibility of the lung lobe edges.[41] One of the typically described radiological findings of pneumothorax on a lateral radiograph is the displacement of the cardiac apex away from the sternum.[25,41] The cause of this radiological sign is due to displacement of the cardiac apex towards the dependent side in lateral recumbency, because of lung lobe retraction, which subsequently leads to the shifting of pleural air to the uppermost hemithorax.[25,41] However, a diagnosis of pneumothorax cannot solely be made on the displacement of the cardiac apex away from the sternum.[25,41] Conditions like microcardia, pulmonary overinflation, mediastinal shifts and fat accumulation in or around the pericardium may mimic pneumothorax.[25,41] The lack of sternal contact of the cardiac silhouette may also be a normal finding in deep-chested dogs.[25] To the authors' knowledge, there is currently no reference that grades or scores the extent of canine pneumothorax on radiographs.

The presence of pleural effusion needs to be assessed in patients presenting with blunt trauma. The type of fluid present can have a characteristic radiological appearance, which may help differentiate the type of effusion. Pleural effusions can be classified as exudates, modified transudates or transudates, based on their cellular and protein content.[38] Haemothorax is the most likely pleural fluid accumulation in blunt thoracic trauma and may occur due to either laceration or rupture of the lungs, small blood vessels or even one of the great vessels.[43] The radiological appearance of haemothorax may differ from other pleural effusions since haemorrhaging may be more focal whilst transudates will tend to be more diffuse and bilateral.[22] Despite these differences, the radiological appearance of haemothorax has similar characteristics to many other pleural fluid types. These findings include border effacement of the cardiac and diaphragmatic silhouettes, widened interlobar fissures due to fluid accumulation from the periphery, extending more centrally and lung lobe retraction.[43] Fluid accumulation along the ventral aspect of the thorax on a lateral radiograph, creating a soft tissue opacity appearance in the ventral aspect of thoracic radiographs, may be the only evidence of haemothorax in the early stages or when only mild haemorrhaging is present.[44] This location of pleural fluid accumulation occurs because the ventral edges of the lung are more susceptible to retraction.[44] In severe cases, lung lobe retraction towards the hilus will be evident, with the cranial lung lobes and the right middle lung lobe being most severely affected.[44] These lobes are more involved, since they appear to be less resistant to compression by pleural fluid due to their relatively large surface to volume ratio compared to the other lobes.[44]

The assessment of the severity of pleural effusions has been described in detail and can be divided into a small, moderate or large amounts of pleural fluid.[43] On lateral views, a small amount can be defined as the presence of a soft tissue opacity dorsal to the sternum, with mild lung lobe retraction.[43] A moderate amount of pleural fluid has been described as the presence of a soft-tissue opacity, causing border effacement of two-thirds of the cardiac and diaphragmatic silhouettes as well as prominent interlobar fissures and moderate lung lobe retraction.[43] A large amount of pleural fluid can be recognised when there is severe retraction of the lung lobes and the trachea and pulmonary hilus are dorsally displaced.[43] On the DV-view, a small amount of fluid is recognised when the cardiac and diaphragmatic silhouette are partially effaced and fissures adjacent to the accessory lung lobe may be visible.[43] A moderate amount of pleural effusion is defined as apparent cranial mediastinal widening, together with complete effacement of the cardiac and diaphragmatic silhouettes, interlobar fissures at the periphery and moderate retraction of the lung lobes.[43] A large amount of fluid can be recognised as retraction of the lung lobes with marked interlobar fissures.[43] Pleural effusions have a different appearance on ventrodorsal (VD)-views compared to DV-views. Pleural fluid tends to accumulate in the paraspinal "gutters" in dorsal recumbency and therefore smaller amounts of fluid will be superimposed over the overlying heart, mediastinum, sternum and spine.[43,45] The cardiac silhouette is therefore usually visible on VD-views.[43,45] The VD-view may be useful to determine if the pleural fluid is mobile or trapped and may also assist in differentiating pleural pathology from other thoracic pathology.[45]

2.5 Rib fractures

Rib fractures are a common finding in blunt thoracic trauma patients.[13,18] Normally ribs, like other bones, can tolerate a tremendous amount of force, since bone is relatively elastic.[18] With blunt force trauma, ribs will most likely fracture at the point of maximal tension, due to the blunt force energy dispersing from that point.[18] Traumatic rib fractures often tend to be unilateral and fracture in groups.[46] These groupings consist of ribs one to three, ribs four to seven, eight to ten and lastly ribs 11 to 13.[46] The cranial ribs have a higher likelihood of fracturing since they are stiffer with less costal cartilages and thus lack the elasticity of the more caudally located ribs.[46] Fractures of the ribs located more cranially have also been associated with a higher mortality rate of up to 36%.[17] This is most likely due to lacerations of major cranial thoracic blood vessels, comorbidities such as cranial trauma, or brachial plexus and subclavian artery injuries.[17] Comminuted rib fractures are at risk of causing serious injuries such as blood vessel and lung parenchymal lacerations.[18] Rib fractures can sometimes be overlooked on radiographs but this can be overcome by carefully assessing any disruptions of the rib cortices.[47] Another technique that can be used, is to change the orientation of the radiograph which may aid the observer in identifying rib fractures.[48] It must be noted that the observer must not confuse incomplete mineralisation of the costal cartilages with fractures.[22]

2.6 Diaphragmatic rupture

Diaphragmatic rupture represents up to six percent of all clinical manifestations of blunt thoracic trauma and is as a result of a compression injury to the abdomen.[13,47] The diagnosis of a diaphragmatic rupture is simple, provided that there is abdominal viscera evident within the thoracic cavity.[22] Other radiological signs include cranial displacement of the abdominal organs, mediastinal shift away from eventrated abdominal organs and a tucked-up abdomen.[47] The diagnosis of diaphragmatic rupture becomes challenging when fluid in the pleural cavity effaces all intrathoracic structures.[22,47] In these instances, contrast radiography may assist the diagnosis and procedures such as a positive contrast celiogram or a positive contrast gastrointestinal follow-through, may be utilised to aid the diagnosis.[47] Ultrasound can also be employed to evaluate potential diaphragmatic ruptures, especially in cases where the presence of a rupture is uncertain.[47] The typical ultrasonographic signs to look for include the presence of abdominal organs in the pleural cavity and the loss of the normal diaphragm-lung interface.[47] Finally, fluoroscopic examination for paradoxical movement of the diaphragm has also been suggested to determine the presence of a diaphragmatic rupture.[49]

2.7 Mediastinal injuries

Injury to the mediastinum and mediastinal structures have been described in veterinary literature as a consequence of thoracic blunt trauma.[18,50] The mediastinum represents the space that divides the thorax into its left side and right side.[37] The mediastinum is bordered by the mediastinal pleurae and contains the heart and its major vessels, trachea, oesophagus and thymus.[37] The mediastinum forms a continuum cranially with the cervical fascial planes and caudally with the retroperitoneal space.[37]

Pneumomediastinum as a result of blunt trauma can arise when there is a rupture of the trachea, terminal bronchioles or alveoli.[50,51] Pneumomediastinum secondary to tracheobronchial rupture occurs due to direct air leakage into the mediastinum.[52] Pneumomediastinum arising from alveolar rupture occurs because of air dissecting along the bronchovascular sheaths as well as through extension of pulmonary interstitial emphysema to the mediastinum.[52] This phenomenon is known as the Macklin effect.[52] Pneumomediastinum is in most instances clinically insignificant, but may become problematic when continuous air accumulation acts as a space-occupying lesion or when mediastinal air escapes into the pleural cavity.[27,30] The radiological findings of pneumomediastinum include the ability to visualise the luminal and serosal surfaces of the trachea, as well as the major blood vessels of the thorax and oesophagus.[51] Because the mediastinum freely communicates with the retroperitoneal space and fascial planes of the neck, pneumoretroperitoneum, as well as cervical subcutaneous emphysema can develop, respectively.[22]

Traumatic mediastinal haemorrhage most often occurs due to bleeding of a mediastinal blood vessel or as an extension from cervical traumatic haemorrhage.[51] Mediastinal haemorrhage can also occur when an animal runs into an object such as a car, leading to a deceleration injury where the intrathoracic structures move relative to the musculoskeletal structures, resulting in blood vessel damage.[22] Mediastinal haemorrhage, similar to other mediastinal effusions, is radiologically characterised by the widening of the cranial and caudoventral parts of the mediastinum, reverse fissure lines, which represents a soft tissue opacity arising from the mediastinum that tapers away from the mediastinum as the fluid dissects between the lobes, and either dorsal or ventral displacement of the trachea.[22,51]

2.8 Thoracic wall pathology

Blunt thoracic trauma can lead to serious thoracic wall injury, which must be evaluated for the presence of subcutaneous emphysema, fractures and luxation of the thoracic osseous structures, eventration of internal tissues or organs as well as thoracic wall swelling.[10,22,51] A major cause of thoracic wall instability is the presence of a flail chest.[22] A flail chest develops as a result of at least two adjacent segmental rib fractures or at least five single rib fractures, leading to paradoxical thoracic wall movement during respiration.[51] Consequently, the patient will experience respiratory distress as result of diminished tidal volume.[22]

2.9 Cardiac injuries

Injury to the heart and associated structures, is a relatively rare consequence of thoracic blunt trauma, since the heart is well-protected by the rib cage, lungs and its location in the mediastinum.[18] Blunt trauma may occasionally lead to cardiac contusions or lacerations of the coronary arteries.[18] Pneumopericardium may develop as a consequence of alveolar rupture and pneumomediastinum secondary to thoracic trauma.[53] Free gas may dissect from the pericardial reflection of the pulmonary vessels into the pericardium.[53] This life-threatening condition can be recognised radiologically as a gas opacity around the heart delineating the epicardium, pericardium, auricles and the major blood vessels entering and exiting the heart.[53]

2.10 The use of CT in human blunt trauma patients

While in veterinary medicine radiography is the first-line diagnostic tool for blunt thoracic trauma, in human medicine some authors believe that in trauma patients or patients that are intubated on presentation, CT should be performed first to decrease the risk of complications and improve patient outcome.[2-4] Several studies have identified limitations of radiography in human trauma patients. [54,55] These limitations include the inability to detect mild or early thoracic pathology, the inability of radiological abnormalities to infer a specific diagnosis or cause and the high amount of radiological variability associated with patient positioning.[21,55] The biggest concern when using radiography in thoracic trauma patients, is the lack of sensitivity of this modality.[21] A comparative study looking at the difference between conventional radiography and CT, has shown that CT is able to identify up to 66% more thoracic injuries than radiography, leading to up to 20% change in the treatment plans of these patients due to these additional findings seen on CT.[5] Despite these promising results, other authors have reported that CT in thoracic blunt trauma cases should complement radiography and is only of value in human patients with obvious respiratory abnormalities or if these patients show significant changes on radiography.[4,6,54] Even though these differences exist in the literature, the clear advantages of multi-detector whole-body CT's cannot be denied. The most obvious advantage of CT in human trauma patients, other than elimination of superimposition, is the ability of CT to acquire high-quality images in a short period of time, which improves diagnostic accuracy and ultimately patient management.[19,56,57] The standard time taken to perform an initial investigation of a trauma patient, which includes an ultrasound and radiographs of the thorax, spine and pelvis, amounts to 15 minutes.[19] On the other hand, acquisition of a whole body CT in a trauma room only takes two to four minutes, which can decrease mortality rate by up to 4%, since more time can be assigned to therapy instead of diagnostic procedures.[19] The CT examination of thoracic blunt trauma in humans has undoubtedly proven to detect significantly more thoracic conditions such as pneumothorax, haemothorax, lung contusions, injuries to the mediastinum and associated structures as well as rib and sternal fractures when compared to thoracic radiography.[4,58] For many trauma centres, CT examination has become the foundation of accurate diagnosis and management in polytrauma patients with life-threatening conditions.[19,57,58]

2.11 Conclusion

The utility of CT-examination in patients with thoracic pathology has gained in popularity in veterinary medicine in recent years.[7,8] Computed tomography has proven to be superior to radiography since superimposition is eliminated in CT and because it has superior contrast resolution compared to radiographs due to its elimination of out-of-slice structures in cross-sectional imaging.[7,8,59] There are several authors that have evaluated and mentioned the value of thoracic CT in veterinary patients. One such publication showed that CT is significantly more sensitive at detecting pulmonary metastases compared to radiography, which failed to detect approximately 90% of metastases picked up on CT.[9] Another article that compared radiography to CT in assessing non-cardiac thoracic disease did not mention trauma, where another author briefly mentions the potential value of CT in trauma patients with pneumothorax.[7,8] Only one recent article on radiography of thoracic trauma in the dog and cat has some CT examples of traumatically induced cavitary lesions, pneumomediastinum and pulmonary contusion and advocated the greater sensitivity of CT to detect pulmonary pathology.[22]

It is clear from human literature that the use of CT in blunt thoracic trauma is superior to conventional radiography, which lacks sensitivity due to the limitations of this modality. However, no veterinary literature exists comparing CT to conventional radiography in blunt thoracic trauma and thus should be addressed.

Chapter 3: Materials and Methods

3.1 Experimental design

The study was approved by the institutional research and animal use and care committees and owner consent was obtained to enrol dogs into the study. The study was conducted as a prospective case series. Dogs that presented to the Onderstepoort Veterinary Academic Hospital (OVAH) with blunt thoracic trauma due to MVA's between April 2011 to January 2015 were included if they met the inclusion criteria.

3.1.1 Inclusion criteria:

- Any dog involved in a MVA not more than 48 hours prior to presentation with the following criteria:
  - Persistent polypnoea, tachypnoea or dyspnoea despite initial stabilisation.
  - Traumatic fractures of the ribs, cranium, vertebra cranial to T11 and/or thoracic and/or pelvic limbs (including pelvis).
- Patients that had undergone thoracic radiographs and thoracic CT within 24 hours of admittance to the OVAH but not within four hours of the traumatic incident. Four hours were chosen as the minimum time required to have elapsed from the time of the MVA, since radiographic evidence of lung contusions may require four to twenty four hours to become apparent.[34]

3.2 Experimental procedure

3.2.1 CT-procedure:

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. The CT-procedure was performed within an hour of the thoracic radiographs and usually performed after obtaining radiographs, depending on the clinic work flow of the day. A non-breath held thoracic CT, mostly performed in sternal recumbency, depending on the injury of the patient, was obtained from caudal to cranial starting from the third lumbar vertebra up to the fourth cervical vertebra. 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 anaesthesia but many patients were administered pain medication and/or sedation to prevent 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 analysed 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 was analysed for another study by a European board-certified radiologist (Rad 30).[60] This data served as the gold standard benchmark to which the radiological findings were compared.

For analysis of lung contusions, lung lobes were assigned from L1 to L7 (where L1 represented the *pars cranialis* of the left cranial lung lobe; L2 was the *pars caudalis* of the left cranial lung lobe; L3 represented the left caudal lung lobe; L4 was the right cranial lung lobe; L5 represented the right middle lung lobe; L6 was the right caudal lung lobe and L7 represented the accessory lung lobe). Pulmonic changes believed to be due to haemorrhage or contusions, or secondary to atelectasis, were given a subjective CT pulmonary contusion severity score for each lobe based on its attenuation (absent/normal (0), mild (1) interstitial/ground glass pattern (2) or alveolar pattern/consolidation (3)). A composite lung 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[61]) 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 (e.g. lung collapse secondary to pneumothorax) percentage. This was multiplied by the lung contusion 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 and finally expressed as the total lung lobe contusion volume score.[62] The totals of the seven lobes were added together to give a composite lung trauma index that represented a semi objective estimation of the total degree of lung lobe contusion or collapse (Appendix A). Soft tissue thoracic wall and mediastinal abnormalities were not included in the thoracic indices.

Computed tomography data was further extracted from the aforementioned study and the presence (1) or absence (0) of the following conditions were used to compare to the radiographic data obtained:

- Pneumothorax
- Pleural effusion
- Rib fractures
- Diaphragmatic ruptures
- Pneumomediastinum
- Thoracic wall changes

3.2.2 Radiographs:

Digital radiographs were made (Apelum Baccara 90/20, Italy) using a Fuji CR console system (Fujifilm Medical Systems, Stamford, USA). Radiographs were usually obtained prior to CT, but were dependent on the clinic work load. However, regardless of the order of procedure, radiographs and CT were performed within an hour of each other. Standard three-view DV, RLR, and LLR thoracic radiographs, as well as a VD thoracic HB-view in RLR or LLR (where patient injury prevented VD RLR HB-view) were obtained for each patient, using standard positioning aids. Images were usually obtained in a set order of RLR, DV, LLR and lastly, the HB-view in RLR. Time taken to perform these views were between five to 10 minutes. The vertical beam DV-view was chosen over the VD-view since the patients selected for this study suffered from some degree of respiratory compromise and positioning these patients in dorsal recumbency may have exacerbated respiratory distress. A patient in sternal recumbency can fully expand the rib cage, allow abduction of the thoracic limbs and improve breathing through natural extension of the patient's neck.[63] Imaging settings were based on a long-scale thoracic radiography technique chart constructed by the hospital's diagnostic imaging department.

3.2.3 Image analysis:

The thoracic radiographs were evaluated and data recorded in tables (Appendix B) by three observers consisting of a first-year diagnostic imaging resident (RES 1), a recently qualified European Diplomat in Diagnostic Imaging with four years' experience (RAD 4) and a European Diplomat in Diagnostic Imaging with 30 years' experience (RAD 30). 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 the cases. All images were considered to be of acceptable quality for analysis and none of the minor technical problems identified interfered with the assessments. The presence of peritoneal effusion and abdominal abnormalities were recorded but not enough cases were obtained and thus excluded from the results. Each observer performed the image analysis independently in order to assess interobserver variability. Thereafter, a majority ruling for a particular abnormality was obtained, which was used to compare to the CT-findings. The standard thoracic views were first evaluated, whilst the HB radiographs were assessed independently at a separate occasion. All the evaluations for thoracic pathology were performed on the standard views except where stated for HB-radiography.

3.2.3.a <u>Respiratory system</u>

Lung contusions

- Lung lobes were assigned from L1 to L7 in the same order as for CT
- Each lung lobe's boundary was estimated as described in a standard thoracic imaging textbook with the lateral views used to evaluate the upper lungs.[35]
- A total radiographic lung lobe contusion score and total lung lobe contusion volume score, adapted from a previous human study and two other veterinary thoracic trauma studies, were 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, respectively as described below.[1,16,32,62]
- Before commencing the study, prior consensus between the observers were practiced on thoracic trauma cases not related to the study to ensure uniform scoring.
- The presence of lung contusions was evaluated by looking at each individual lung lobe and allocating radiography severity- and extent scores (See Appendix B).

- A radiography lung contusion severity score out of a total score of three (3), for each lung lobe was assigned based on the predominant lung pattern present as follows:
    - Mild (1/3): interstitial lung pattern
    - Moderate (2/3): interstitial to early alveolar lung pattern
    - Severe (3/3): alveolar lung pattern
- A radiography lung contusion extent score out of a total score of three (3) for each lung lobe was assigned based on the extent of the lung pattern as follows:
    - Less than one third (1/3), up to two thirds (2/3) or more than two thirds of the lung lobe (3/3)
- A total lung lobe contusion score out of nine (maximum possible score) was given to each lung lobe by multiplying the given grade score (out of a total score of three) of a lung lobe by its extent score (out of a total score of three). These answers were converted into percentages (actual total lung lobe contusion score/maximum total lung lobe contusion score possible (9) multiplied by 100).
- The contribution of the lobe contusion to overall lung volume was calculated to quantify the total lung lobe contusion volume score.[62] This was performed because each lung lobe's has a specific lung volume and therefore its contribution to the overall aeration of the lung lobes will differ. The total lung lobe contusion score for each lung lobe expressed as a percentage was multiplied by the percentage volume expressed as a fraction of that particular lung lobe's contribution to the total lung volume. The calculation of the total lung lobe contusion volume score is set out in Appendix C.
- A composite lung index was finally calculated by adding all the lung lobes' total lung lobe contusion volume scores together to get a final index.
- Finally, the mean total lung lobe contusion volume score was calculated by obtaining an average calculated from the addition of the individual observers' total lung lobe contusion volume scores divided by three. These values were then used to compare to the total lung lobe contusion volume scores of the CT-data.

- Further elaboration on specific definitions used in lung contusions subsection of the materials and methods is available in Appendix D.

3.2.3.b <u>The pleural space</u>

The presence of pleural space abnormalities such as pneumothorax and pleural effusion were evaluated on both the three-view and horizontal beam radiographs. The findings were recorded in the data sheet as either present (1) or absent (0) as follows:

Standard thoracic views to evaluate the presence of pneumothorax and pleural effusion:

- Pneumothorax: Present (1)/ Absent (0)
  - The presence of pneumothorax was determined based on the presence of free gas in the pleural space resulting in absence of pulmonary vessel marking, lung lobe retraction and atelectasis as well as decreased cardiac sternal contact.[43]
- Pleural effusion: Present (1)/ Absent (0)
  - The presence of pleural effusion was determined based on the presence of a soft tissue opacity in the pleural space, resulting in fissure lines, border effacement of the cardiac silhouette and diaphragm and lung lobe retraction.[43]

Horizontal beam view to evaluate pneumothorax:

- Pneumothorax: Present (1)/ Absent (0).
  - The presence of pleural gas was evaluated on the non-dependent side of the thorax as previously described in another study.[24]

Further evaluation on the horizontal beam radiographs were performed to determine if a repeatable gas width to tenth thoracic vertebra (T10) ratio could be established that would accurately reflect the severity of the pneumothorax. This was performed as follows:

- The widest dimension of the pleural gas was identified and measured in mm on the horizontal beam view.
- Gas width: tenth thoracic vertebra (T10) ratio
    - A ratio was determined between the maximum width of gas to the length of T10, which was measured from the midpoint of the cranial endplate to the midpoint of the caudal endplate of T10 on the right lateral recumbent view (see Appendix E). The tenth thoracic vertebra was selected because it morphologically represent the thoracic vertebrae and its location was easily identifiable, if the thirteenth thoracic vertebra and paired ribs were included in the lateral thoracic radiographic views.
    - The ratio was then compared to the CT pneumothorax severity score to determine if a correlation existed

Horizontal beam view to evaluate pleural effusion:

- Pleural effusion: Present (1)/ Absent (0)
    - The presence of pleural fluid was evaluated on the dependent side of the thorax as previously described in another study.[24]
    - Further evaluation on the horizontal beam radiographs were performed to determine if a repeatable pleural fluid width to tenth thoracic vertebra (T10) ratio could be established that would accurately reflect the severity of the pleural effusion. This was performed in a similar way as described for pneumothorax. The widest dimension of the pleural fluid was identified and measured in mm
    - Fluid width: T10 ratio
        - The ratio was worked out in an identical manner by taking the maximum width of effusion and determining a ratio based on the T10-length.
    - The ratio was then compared to the CT pleural effusion severity score to determine if a correlation existed

3.2.3.c <u>Ribs</u>

The presence of rib fractures was evaluated by scrutinizing each rib for a disruption of the cortices. Luxations were evaluated by identifying a disruption of the articulation between a rib's articular facet and its corresponding vertebrae and resultant displacement. The findings were recorded as follows:

- Ribs fracture or luxation: Present (1)/ Absent (0)
    - Location (rib number and side)
    - Number of fractures per rib

3.2.3.d <u>Miscellaneous</u>

All radiographs were also evaluated for the presence of less common trauma-related abnormalities and included:

- Diaphragmatic rupture: Present (1)/ Absent (0)
    - This was determined by identifying any disruption of the normal diaphragmatic contour, displacement of abdominal organs into the thoracic cavity, mediastinal shift away from eventrated organs and empty, tucked-up abdomen.[47]
- Pneumomediastinum: Present (1)/ Absent (0)
    - The presence of pneumomediastinum was identified by the presence of gas in the mediastinum, which results in visualisation of mediastinal structures not normally visible on thoracic radiographs.[51]
- Thoracic wall covering the ribs
    - Presence of gas: Present (1)/ Absent (0)
- Presence of thoracic wall soft tissue swelling (including oedema and haemorrhage: Present (1)/ Absent (0)

3.4 Data analysis

A qualified statistician performed statistical analysis. Quantitative data were described using scatter and box plots created within the ggplot2 package of R.[64,65] 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 reported formulas entered into a commercial spreadsheet program (Excel, Microsoft Office Professional 2010, Redmond, WA, USA).[66] Repeatability for quantitative data measured by the three radiologists was estimated by calculating the coefficient of variation (COV). The correlation between data collected via evaluation of standard radiographic views and CT was estimated using Spearman's rho using commercial software (IBM SPSS Statistics Version 24, International Business Machines Corp., Armonk, New York, USA). Sensitivity of radiographic detection of common thoracic lesions was estimated as the proportion of CT diagnosed lesions detected using the consensus radiographic diagnosis. Specificity was estimated as the proportion of cases without the lesion detected by CT determined to be free of the 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.[67] Statistical significance was evaluated at the 5% level.

Chapter 4: Results

4.1 Study population

Sixty-one dogs were enrolled in the study. Of these, 59 dogs met the inclusion criteria and had all the data available for this study. There were 12 Jack Russel Terriers, ten 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, 7 neutered males and 10 neutered females.

Since all the patients were trauma cases, several radiographs and CT-images that were obtained were not optimal because of the nature of the presenting complaint. Despite these difficulties, images were evaluated for quality and all images collected were still deemed diagnostic.

The time from accident to presentation was a mean of 3.4 hours (median 1 and range 0.25 - 24 hours). Sixteen dogs were euthanized after the imaging procedures due to cost constraints or poor prognosis, four dogs died despite treatment and 39 dogs recovered and were discharged.

4.2 Lung contusions

Lung contusions were detected on CT in 35 dogs, whilst only 28 cases of lung contusions were identified on consensus radiographs across all observers (RES 1 - 28; RAD 4 - 29; RAD 30 - 26). Figure 1 illustrates an example of a false-negative radiographic study with contusions evident on CT imaging.

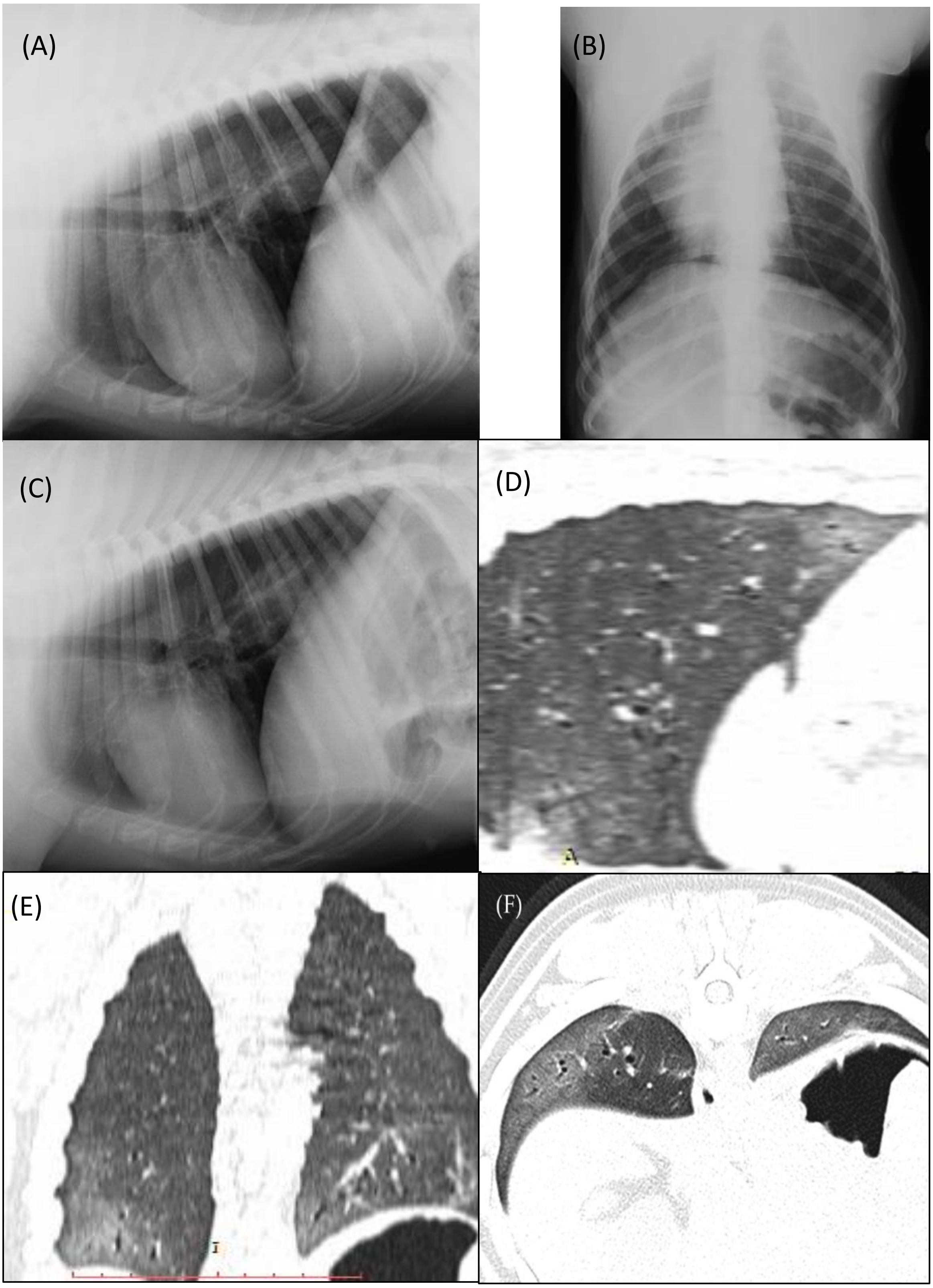


FIGURE 1 Left lateral recumbency (A), dorsoventral (B) and right lateral recumbency (C) radiographs and corresponding sagittal (D), dorsal (E) and transverse plane (F) computed tomographic (CT)-images obtained in sternal recumbency of a three-year-old spayed female Labrador Retriever that presented with blunt trauma. Lung contusions were undetectable on radiographs but clearly evident on CT. The CT lung contusion score was low (2.88%) with ground glass opacities in the caudodorsal lung fields. Right is to the left on the CT images. WW 1500; WL -400

Overall, the results from this study showed a good correlation between consensus radiological findings and CT for determining the mean total lung lobe contusion volume scores (Fig. 2). Good correlation between radiography (mean of three observers) and CT for individual lung lobes were seen for only three lobes (L1, L2, and L4) as expressed by the Spearman's Rho correlation coefficient (Table 1). Results showed that the mean total lung lobe contusion scores were overall higher for radiography than CT, with five of the seven lung lobes eliciting higher mean total lung lobe contusion scores on radiography compared to CT (Table 2). Figure 3 demonstrates two cases where radiography overestimated the mean total lung lobe contusion score compared to CT.

The COV was poor for radiography total lung lobe contusion volume scores with high inter-observer variability across all lung lobes (Table 1). Lung lobes L3 and L7 demonstrated the worst COV, with both lung lobes' medians representing the largest values (Fig. 4). Lung lobes four, five, and six demonstrated similar COV. Lung lobe 1 showed several cases with perfect correlation, whilst the majority of the data demonstrated poor COV. RES 1 tended to over interpret the presence of lung contusions when compared to RAD 4 and RAD 30.

Overall, the detection of the presence of lung contusions on radiographs (consensus of three observers) showed a fair to moderate sensitivity (0.69) and a moderate specificity (0.83) (Table 3). RES 1 showed the highest sensitivity for detecting lung contusions, followed by RAD 4 and lastly by RAD 30 (Table 4). All three observers elicited the same fair specificity for detecting lung contusions (Table 4).

The inter-observer agreement was considered substantial for detecting the presence of lung contusions (Table 3).

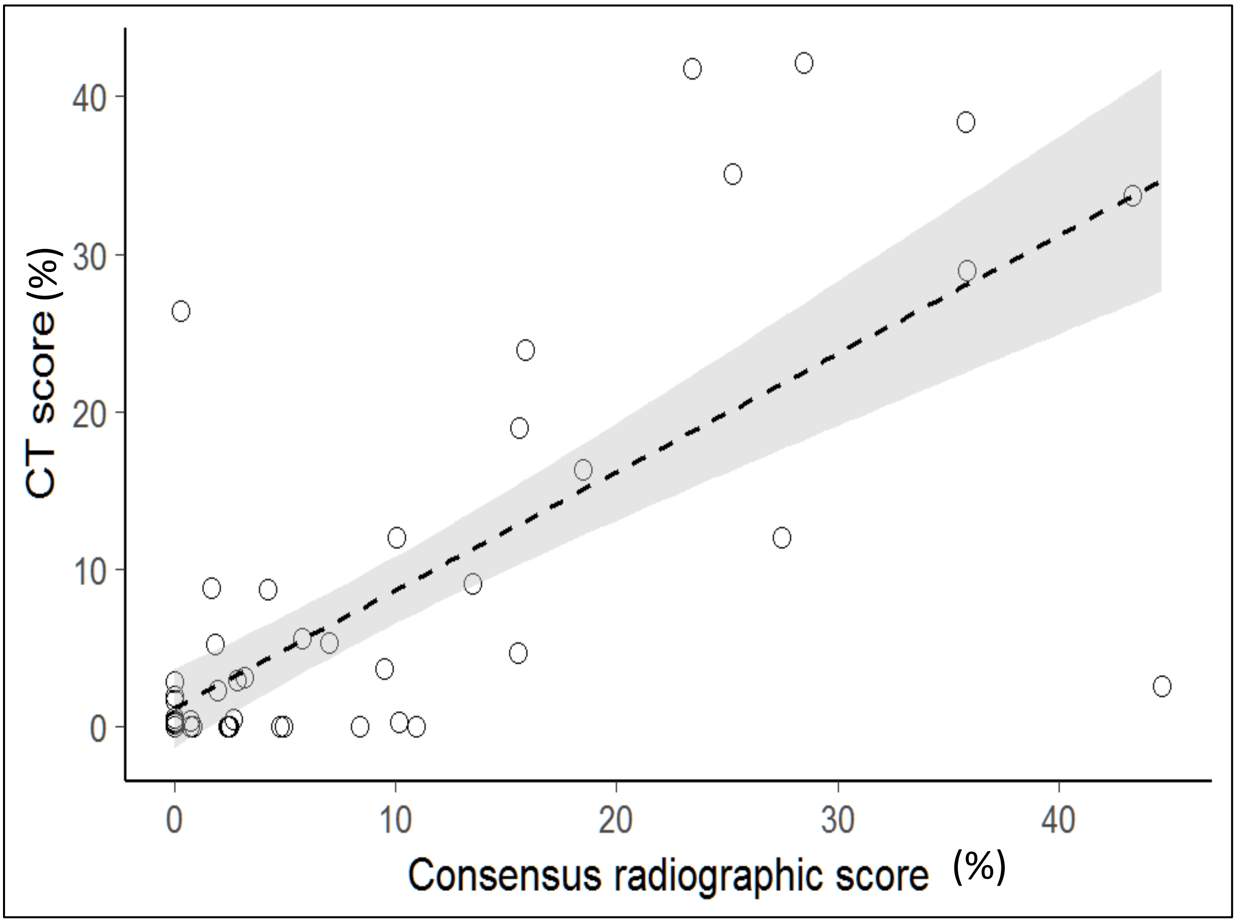
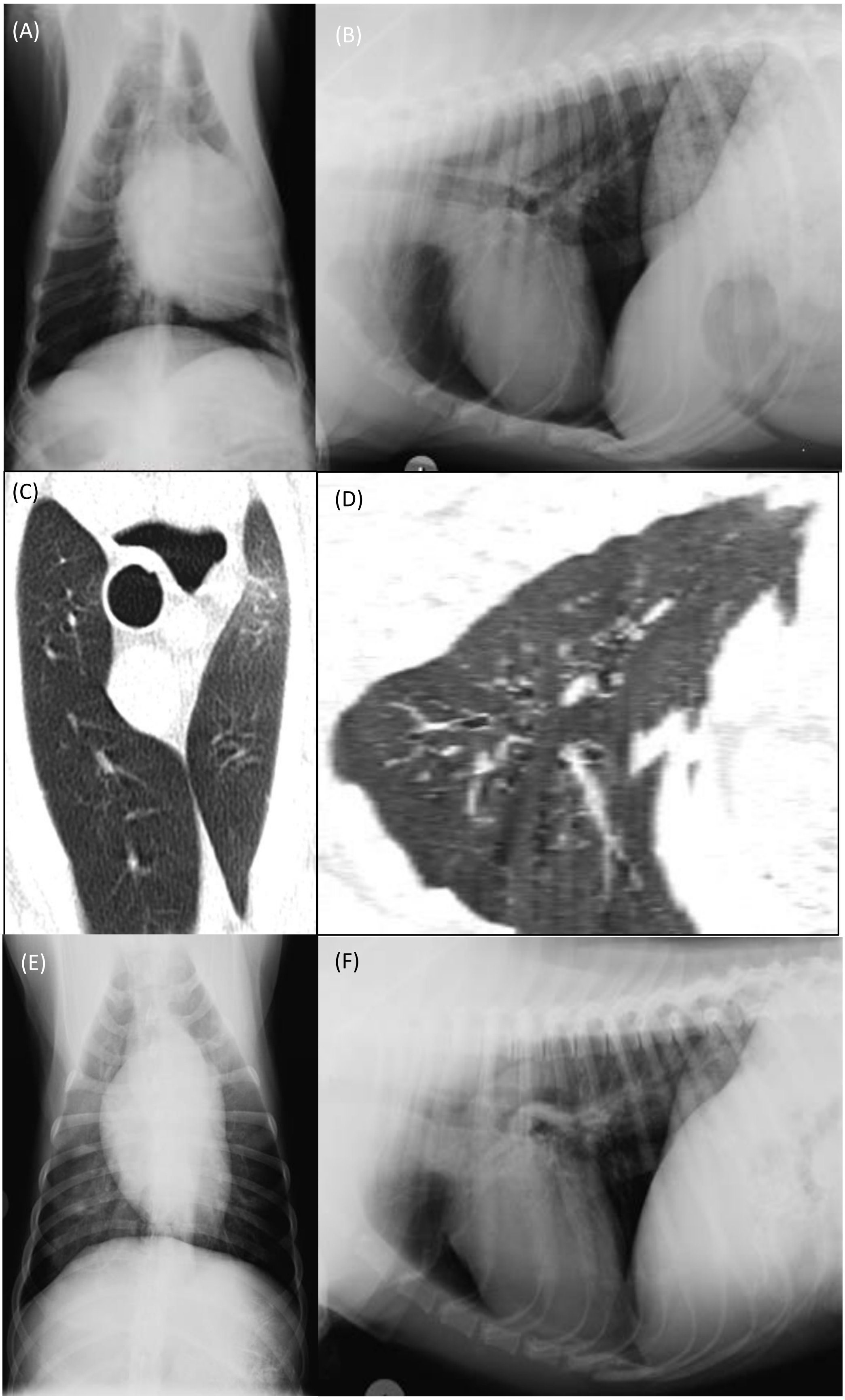


FIGURE 2 Consensus radiographic total lung lobe contusion volume scores was positively correlated with the analogous scores calculated from computed tomography (CT; ϱ=0.681, P<0.001)

Overall, radiography underestimated the presence of lung contusions for six of the seven individual lung lobes (Table 2). With the exception of L1, the severity of the total lung lobe contusion score, when present, were overestimated on radiographs. The overestimation of radiography total lung lobe contusion score were particularly noteworthy for L3 and L7, which differed from the CT-scores by 11.48% and 12.53%, respectively.


(A)
(B)
(C)
(D)
(E)
(F)

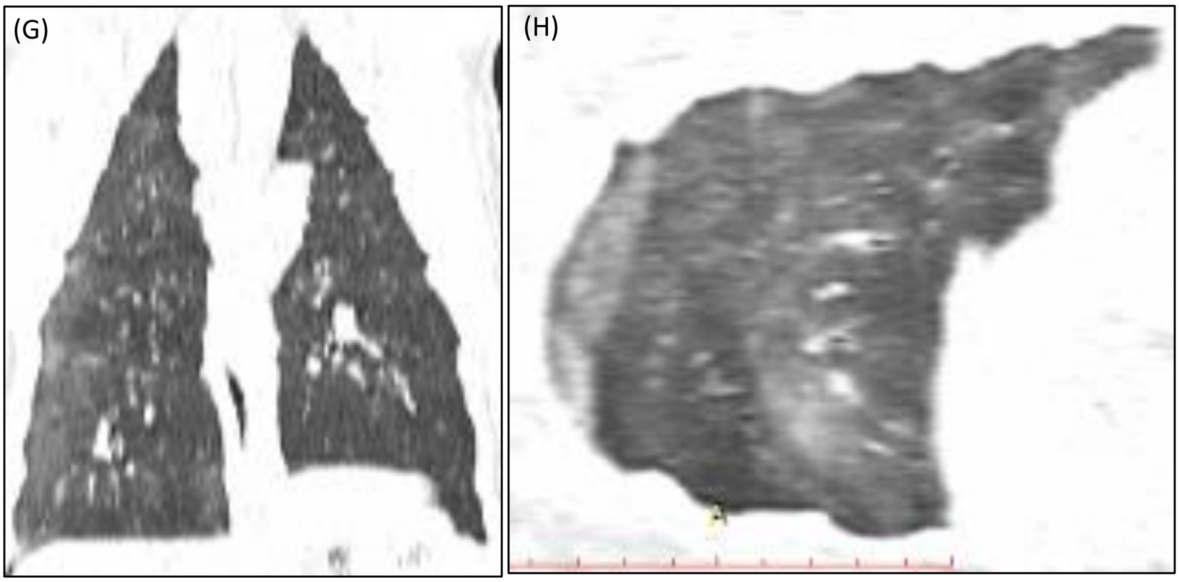


FIGURE 3 Ventrodorsal (A) Dorsoventral (E) and left lateral recumbency (B, F) radiographs with corresponding transverse (C), sagittal (D, H) and dorsal (G) CT-images both obtained in sternal recumbency of a nine-year-old intact male Weimaraner (A – D) with a radiographic composite lung index of 4.93% and a CT composite lung index of 0% and a one-year-old intact male Labrador Retriever (E - H) with a radiographic composite lung index of 15.52% and a CT composite lung index of 4.63%. Both cases represent patients where the severity of lung contusion was overestimated radiographically compared to CT. Right is to the left on the CT images. WW 1500; WL -400

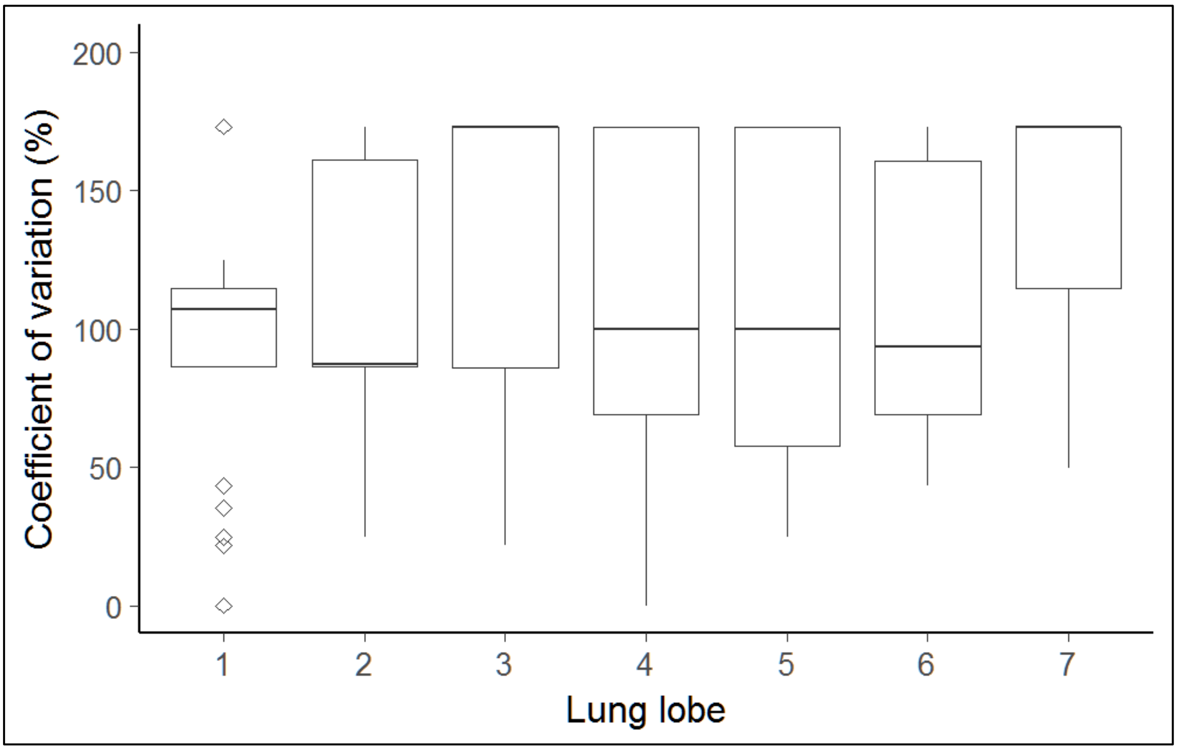


FIGURE 4 The effect of consensus total lung lobe contusion volume score on the repeatability of radiography derived total lung score as measured by the coefficient of variation

TABLE 1 Inter-observer repeatability of thoracic radiographic individual and mean total lung lobe contusion volume 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	**A (RES 1)**	**B (RAD 4)**	**C (RAD 30)**	**COV**	**radiologists**	**CT score**	**(P value)***
1	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)
2	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)
3	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)
4	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)
5	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)
6	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)
7	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 total lung lobe contusion volume radiography- and CT scores for all dogs

TABLE 2 The consensus prevalence and mean total lung lobe contusion scores determined for each affected lung lobe for radiography and single observer computed tomography (CT)

Radiographic findings for lung contusion				CT findings for lung contusion		
Lobe	**Frequency**	**Prevalence (%)**	**Mean severity score (%)**	**Frequency**	**Prevalence (%)**	**Mean severity score (%)**
1	19	32.20	27.08	17	28.81	27.57
2	13	22.03	27.91	16	27.11	28.52
3	9	15.25	49.38	12	20.34	37.9
4	15	25.42	29.38	17	28.81	27.1
5	9	15.25	39.91	12	20.34	24.7
6	9	15.25	32.75	15	25.42	19.72
7	4	6.78	40.73	13	22.03	28.2

TABLE 3 Inter-observer repeatability of consensus detection of common thoracic pathology using standard 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)
Pneumomediastinum	5	-0.02 (-0.18, 0.13)	0 (0, 0.45)	1.0 (0.95, 1.0)
Diaphragmatic rupture	6	1.0 (0.85, 1.0)	0.83 (0.41, 0.99)	1.0 (0.95, 1.0)
Thoracic wall gas	5	0.87 (0.72, 1.0)	0.80 (0.33, 0.99)	0.98 (0.91, 1.0)
Thoracic wall soft tissue swelling	5	0.56 (0.42, 0.71)	0.40 (0.07, 0.82)	0.94 (0.86, 0.99)

CI = confidence interval. LL = left lateral view. RL = right lateral view. VD = ventral-dorsal view

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

TABLE 4 Individual reader level sensitivity and specificity of standard radiographic views for the detection of common thoracic pathology calculated relative to computed tomography (CT) in 59 dogs diagnosed with blunt trauma from a single veterinary teaching hospital.

Lesion	Measure*	n	RES 1 (95% CI)	RAD 4 (95% CI)	RAD 30 (95% CI)
Lung contusion	Sensitivity	35	0.66 (0.49, 0.80)	0.69 (0.52, 0.82)	0.63 (0.46, 0.78)
	Specificity	24	0.79 (0.60, 0.92)	0.79 (0.60, 0.92)	0.79 (0.60, 0.92)
Pneumothorax	Sensitivity	16	0.25 (0.08, 0.50)	0.06 (0.00, 0.27)	0.19 (0.05, 0.43)
	Specificity	43	1.0 (0.93, 1.0)	1.0 (0.93, 1.0)	0.95 (0.85, 0.99)
Pleural effusion	Sensitivity	7	0.43 (0.12, 0.78)	0.57 (0.22, 0.88)	0.14 (0.01, 0.53)
	Specificity	52	0.96 (0.88, 0.99)	0.85 (0.73, 0.93)	0.96 (0.88, 0.99)
Rib fractures (left)	Sensitivity	5	0.80 (0.33, 0.99)	0.60 (0.18, 0.93)	0.40 (0.07, 0.82)
	Specificity	54	0.89 (0.78, 0.95)	0.94 (0.86, 0.99)	0.93 (0.83, 0.98)
Rib fractures (right)	Sensitivity	7	0.43 (0.12, 0.78)	0.57 (0.22, 0.88)	0.14 (0.01, 0.53)
	Specificity	52	0.88 (0.78, 0.95)	0.96 (0.88, 0.99)	0.98 (0.91, 1.0)
Rib fractures (any)	Sensitivity	9	0.78 (0.44, 0.96)	0.78 (0.44, 0.96)	0.44 (0.16, 0.76)
	Specificity	50	0.78 (0.65, 0.88)	0.94 (0.85, 0.98)	0.92 (0.82, 0.97)
Pneumo-mediastinum	Sensitivity	5	0.20 (0.01, 0.67)	0.20 (0.01, 0.67)	0.00 (0.00, 0.45)
	Specificity	54	1.0 (0.94, 1.0)	0.98 (0.91, 1.0)	1.0 (0.95, 1.0)
Diaphragmatic rupture	Sensitivity	6	0.83 (0.41, 0.99)	0.83 (0.41, 0.99)	0.83 (0.41, 0.99)
	Specificity	53	1.0 (0.95, 1.0)	1.0 (0.95, 1.0)	1.0 (0.95, 1.0)
Thoracic wall gas	Sensitivity	5	0.80 (0.33, 0.99)	0.80 (0.33, 0.99)	0.80 (0.33, 0.99)
	Specificity	54	0.98 (0.91, 1.0)	0.98 (0.91, 1.0)	0.94 (0.86, 0.99)
Thoracic wall soft tissue swelling	Sensitivity	5	0.40 (0.07, 0.82)	0.60 (0.18, 0.93)	0.40 (0.07, 0.82)
	Specificity	54	0.98 (0.91, 1.0)	0.93 (0.83, 0.98)	0.94 (0.86, 0.99)

CI = confidence interval. LL = left lateral view. RL = right lateral view. VD = ventral-dorsal view. * Estimated for the diagnosis relative to CT as the gold standard

4.3 Pneumothorax

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 5 illustrates examples of false-negative radiographic studies with pneumothorax evident on CT. The inter-observer agreement was moderate (Table 3).

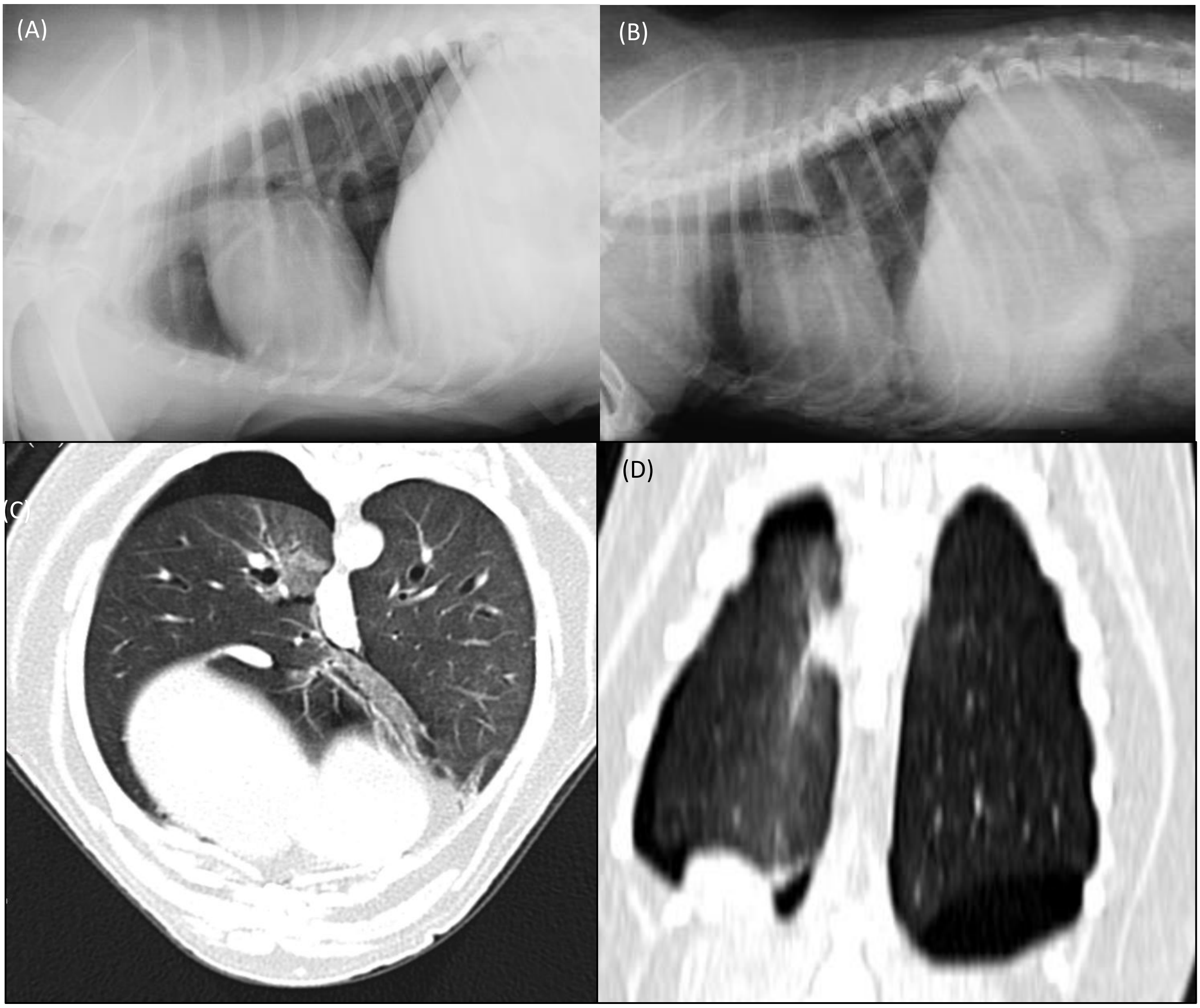


FIGURE 5 Left lateral recumbency and right lateral recumbency radiographs with corresponding transverse and dorsal CT-images, respectively of an eight-year-old spayed female Pug (A & C) and an eight-year-old spayed female small crossbreed (B & D) obtained in left lateral and sternal recumbencies, respectively that presented with trauma where pneumothorax was undetectable on radiographs but evident on CT. Right is to the left on the CT images. WW 1500; WL -400

Pneumothorax was detected in 10 (17%) patients on consensus HB-radiography (RES 1- 10; RAD 4 - 14; RAD 30 - 6). Figure 6 illustrates examples of false-negative HB-radiographs with pneumothorax evident on CT.

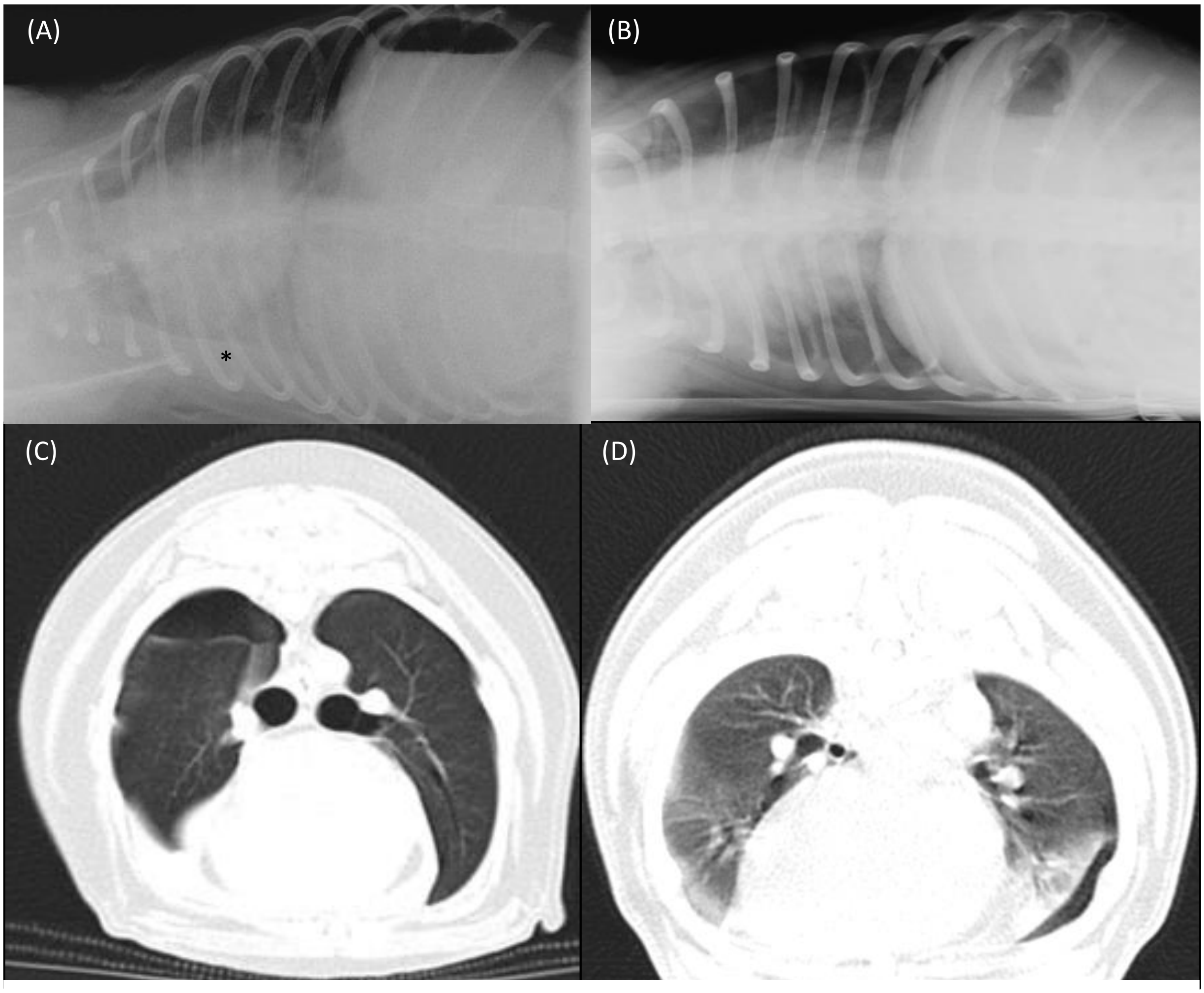


FIGURE 6 Horizontal beam radiographs in right lateral recumbency with corresponding transverse CT-images of an eight-year-old spayed female small crossbreed (A & C) and an eight-month-old intact male Jack Russel Terrier (B & D) both obtained in sternal recumbency that presented with trauma where pneumothorax was undetectable on horizontal beam radiographs (and three-view 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 lung contusions are noted on image D. Right is to the left on the CT images. WW 1500; WL -400

The overall sensitivity of detecting pneumothorax on HB radiography was fair to moderate (Se = 0.63; Sp = 0.95) (Table 5). The sensitivity of detecting the presence of pneumothorax on HB for each individual observer varied from moderate to poor with RAD 4 showing the highest sensitivity, followed by RES 1 and lastly by RAD 30 (Table 5). The specificity of radiographs for pneumothorax was good to excellent for the three observers, with RAD 30 showing the highest specificity, followed by RES 1 and lastly by RAD 4 (Table 5). The interobserver agreement for detecting pneumothorax on HB was fair (κ = 0.39).

TABLE 5 Sensitivity and specificity of the right lateral horizontal beam radiographic views for detection of pneumothorax and pleural effusion calculated relative to computed tomography (CT) in 56 dogs diagnosed with blunt trauma from a single veterinary teaching hospital.

Lesion	Reader	n	Kappa (95% CI)	Sensitivity* (95% CI)	Specificity* (95% CI)
Pneumothorax	RES 1	16	NA	0.69 (0.44, 0.88)	0.88 (0.74, 0.95)
	RAD 4	16	NA	0.81 (0.57, 0.95)	0.80 (0.66, 0.90)
	RAD 30	16	NA	0.38 (0.17, 0.62)	0.98 (0.88, 1.0)
	Consensus	16	0.39 (0.24, 0.54)	0.63 (0.38, 0.83)	0.95 (0.84, 0.99)
Pleural effusion	RES 1	7	NA	0.71 (0.33, 0.95)	0.88 (0.76, 0.95)
	RAD 4	7	NA	0.86 (0.47, 0.99)	0.82 (0.69, 0.91)
	RAD 30	7	NA	0.71 (0.33, 0.95)	0.94 (0.84, 0.98)
	Consensus	7	0.56 (0.41, 0.71)	0.71 (0.33, 0.95)	0.90 (0.79, 0.96)

n = number of affected dogs. CI = confidence interval. NA = not applicable.
* Estimated for the diagnosis relative to CT as the gold standard.

4.4 Pleural effusion

Seven patients (12%) had pleural effusion evident on CT but only three (5%) were identified on consensus radiographs (RES 1 - 3; RAD 4 - 4; RAD 30 - 1). Figure 7 illustrates examples of false-negative radiographs with pleural effusion visible on CT. The inter-observer agreement for detecting pleural effusion on standard thoracic radiographic views was fair (Table 3). The observers elicited sensitivities for detecting pleural effusion on standard radiographs ranging from poor to fair with RAD 4 showing the highest sensitivity, followed by the RES 1 and lastly by the RAD 30 (Table 3). All observers demonstrated a high specificities (Table 4).

Pleural effusion was detected in five of the seven patients on HB-radiography (RES 1- 5; RAD 4 - 6; RAD 30 - 5). The overall sensitivity of detecting pleural effusion on horizontal beam radiography in RLR was fair to moderate, whilst the overall specificity was moderate to good (Table 5). The sensitivity of detecting the presence of pleural effusion on HB for each individual observer was fair for all the observers with the RAD 4 showing the highest sensitivity, followed by the RES 1 and RAD 30 having identical sensitivities (Table 5). The specificity was fair to good for the three observers, with RAD 30 showing the highest specificity, followed RES 1 and lastly by RAD 4 (Table 5). The interobserver agreement for detecting pleural effusion on HB was moderate (Table 5).

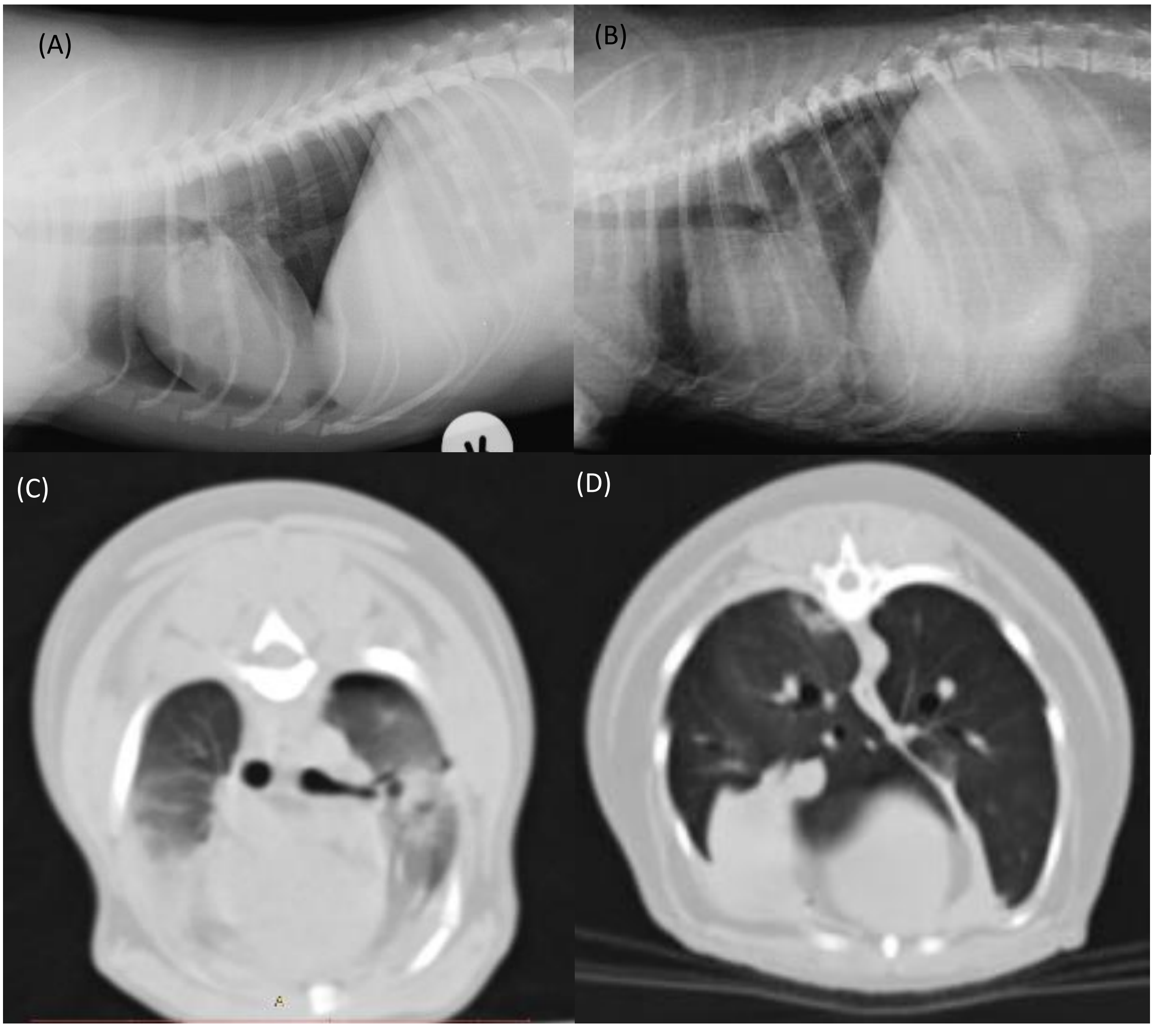


FIGURE 7 Right lateral recumbency radiographs with corresponding transverse CT-images both obtained in sternal recumbency of a two-year-old intact male toy French Poodle (A & C) and an eight-year-old spayed female small crossbreed (B & D) that presented with trauma where pleural effusion was undetectable on radiographs but evident on CT. Mild lung contusions are noted on image C. Right is to the left on the CT images. WW 1200; WL -600

4.5 Rib fractures

Nine patients (15%) presented with rib fractures as detected on CT whilst only four patients with rib fractures were identified on consensus radiographs (RES 1- 6; RAD 4 - 5; RAD 30 - 4). Figure 8 demonstrates a case where rib fractures were missed on radiographs but present on CT.

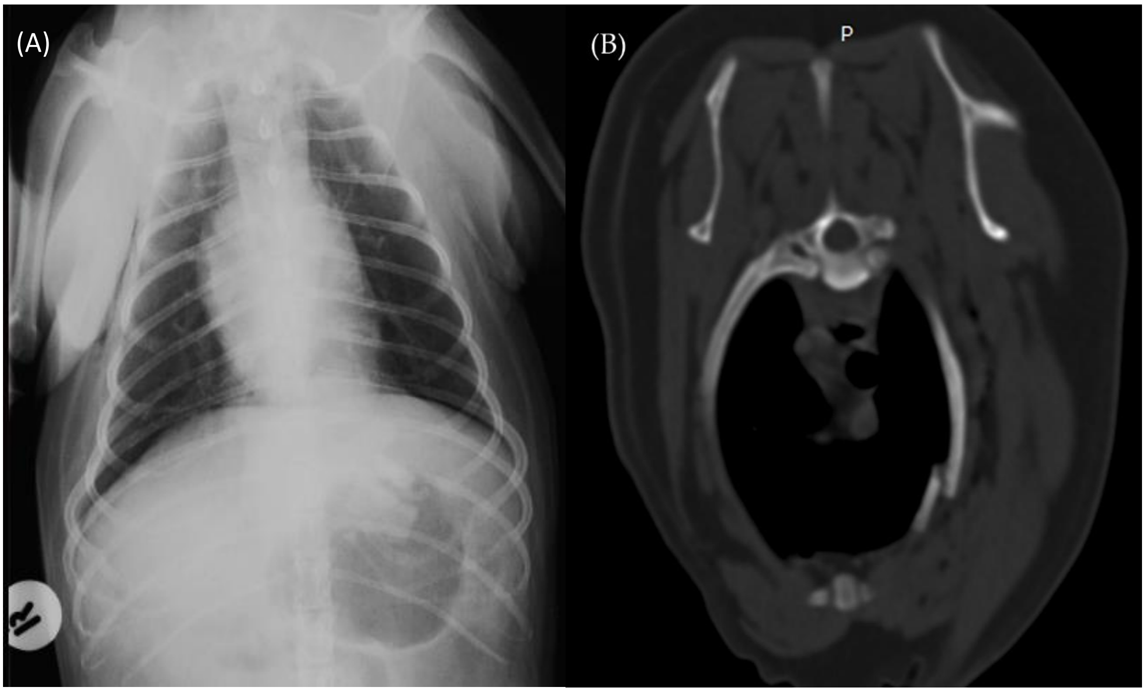


FIGURE 8 Dorsoventral radiograph with corresponding transverse CT-images obtained in left lateral recumbency of a six-month-old medium sized spayed female crossbreed that presented with trauma where the rib fracture of the first rib on the left-side was undetectable on radiographs but evident on CT. Right is to the left on the CT image. WW 1500; WL 450

The inter-observer agreement for rib fractures in general was fair, with slight agreement on right-sided rib fractures and fair agreement on left-sided rib fractures (Table 3). The sensitivity of rib fractures in general was fair with a fair to moderate sensitivity for left-sided rib fractures and a poor sensitivity for right-sided fractures (Table 3). Individual sensitivity of rib fractures was moderate to poor with RAD 4 and RES 1 showing identical sensitivities, whilst RAD 30 demonstrated the lowest sensitivity (Table 4). Individual sensitivity for left-sided rib fractures varied from poor to moderate with RES 1 having the highest sensitivity, followed by RAD 4 and lastly RAD 30 (Table 4).

The overall specificity for rib fractures were excellent, regardless of which side the fracture occurred (Table 3). The individual specificities for rib fractures were moderate to good, with RAD 4 having the highest specificity, followed by RAD 30 and lastly by RES 1 (Table 4).

4.6 Other thoracic pathology associated with blunt trauma

There were several abnormalities that were defined in the materials and methods, but yielded small sample sizes for these conditions, which prevented accurate measurement of the sensitivities for these cases (thoracic wall gas; thoracic wall soft tissue swelling; pneumomediastinum and diaphragmatic rupture). The absence of these abnormalities however had large enough populations sizes and showed good to excellent specificities on radiographs, with diaphragmatic rupture and pneumomediastinum eliciting 100% specificity, whilst the absence of thoracic wall gas was ranked the third highest, followed by thoracic wall soft tissue swelling with the lowest specificity (Table 3). All but one case of diaphragmatic rupture were detected on radiographs. Figure 9 demonstrates the only case of diaphragmatic rupture that was only detectable on CT.

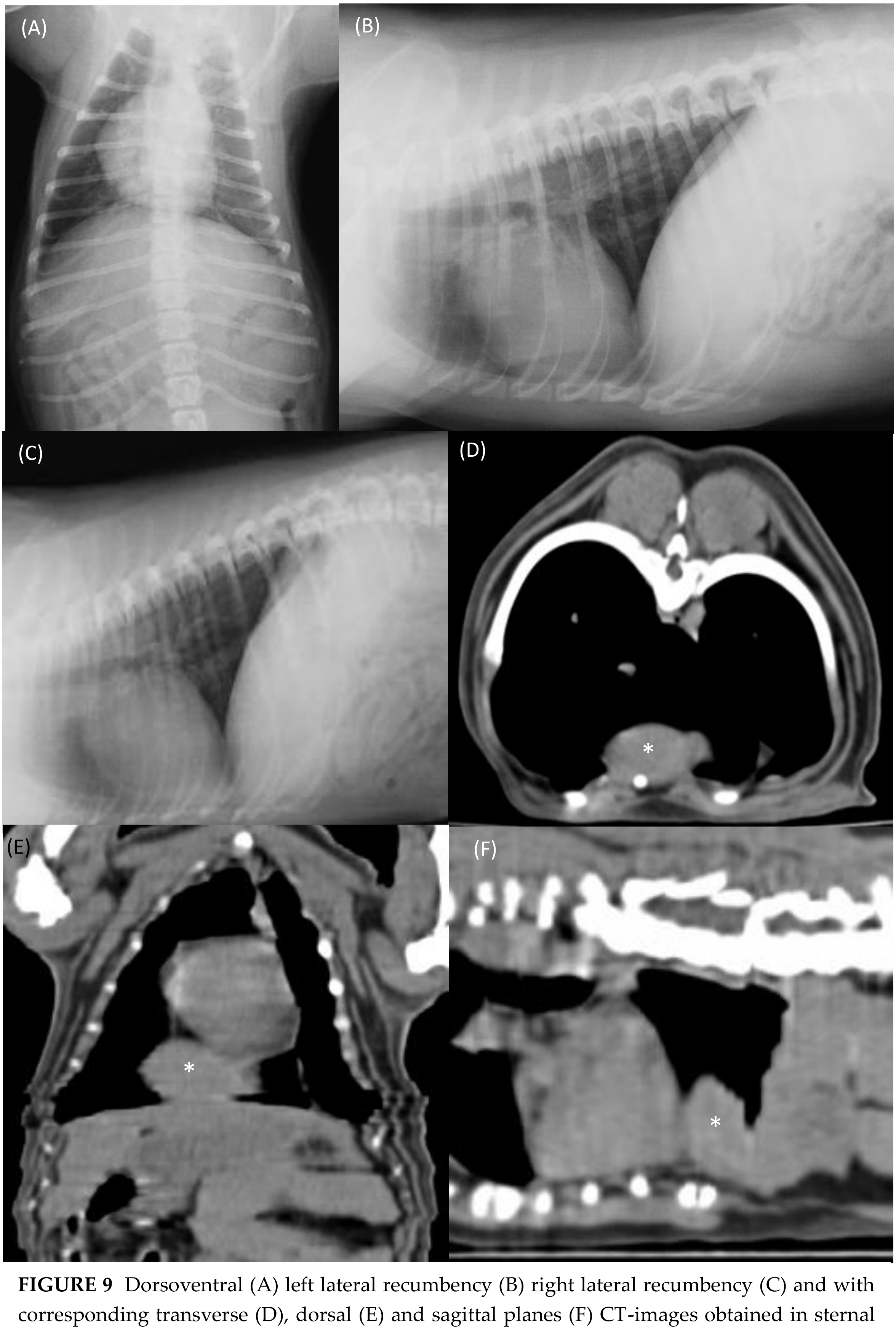


FIGURE 9 Dorsoventral (A) left lateral recumbency (B) right lateral recumbency (C) and with corresponding transverse (D), dorsal (E) and sagittal planes (F) CT-images obtained in sternal recumbency of a seven-month-old intact female Pekingese that presented with blunt trauma of which a diaphragmatic rupture was undetectable on radiographs but clearly evident on CT (*). Right is to the left on the CT images. WW 350; WL 40

Chapter 5: Discussion

This study provides the sensitivity of radiography for detecting common blunt trauma-related thoracic pathologies secondary to MVA relative to CT and confirmed our hypothesis that three-view and HB radiographs are less sensitive relative to CT at detecting these common thoracic pathologies.

5.1 Lung contusions

Results from this study indicated that pulmonary contusions were the most common thoracic abnormality in the study population with 59% of dogs affected. These findings are consistent with some veterinary radiographic trauma studies whilst other studies described pulmonary contusion as the second most common abnormality in blunt trauma patients, after pneumothorax.[10,12,13] Further evaluation of the results indicated that CT could detect more cases of pulmonary contusions than radiography. This is consistent with findings in human studies where CT has proven to be more sensitive at detecting lung contusions due to its good spatial resolution and tomographic nature.[68,69] Another advantage CT has over radiography is its ability to detect lung contusions almost immediately after a traumatic event, whereas it may take between four to 24 hours before radiological changes of lung contusions are detectable.[34,68,69] The importance of lung contusions detected by CT but missed on radiography has been debated in human literature, where contusions detected only on CT were usually found not to be severe enough to change patient management and outcome.[4,6,68,69] One particular study done in humans showed that lung contusions detected on radiographs were associated with higher mortality and morbidity rates compared to lung contusions detected on CT only.[70,64] It is therefore speculated by the authors that in dogs, the lung contusions detected on CT only would not affect patient outcome, similar to people. The results from our study support this interpretation, as lung contusions missed on radiographs all had low severity scores on CT. Findings thus suggested that even though some cases of lung contusions were missed on radiographs, the significance of these abnormalities detected on CT is negligible. Correlation between clinical findings and CT severity scores was however beyond the scope of this study and should be considered in future studies.

Observers often overestimated severity of lung contusions on radiographs and interobserver agreement was poor as evidenced by the high COVs. Radiographic severity grade increase by one point increased the CT severity score by 11%, which contributed to lower interobserver agreement. The radiographic 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.[1,16,32] In this study, it is suspected that disagreement as to what constitutes a moderate and severe score contributed to high interobserver variability, despite the evaluators' attempt to obtain consensus prior to the study. Differences might have occurred due to variable experience levels. RES 1 likely utilised a very specific theoretical criterion to score lung severity in fear of missing or underscoring contusions, whereas RAD 30 based severity scoring on 30 years of experience. These findings are supported by another study that reported that inexperienced observers tend to over-interpret pathology as a result of lack of anatomical knowledge, fear of missing pathology and their belief that a radiograph is abnormal.[48] RAD 4 demonstrated a combination of experience and theoretical knowledge, which most likely improved this individual's accuracy. Future studies should consider including a wider scoring range in effort to reduce interobserver variability and can aim to evaluate patient outcomes where contusions were only detectable on CT.

Radiographic severity scoring was most overestimated in lung lobes L3 and L7. Increased interobserver variability of the accessory lung lobe (L7) was expected based on this lung lobe's location, especially on the DV-view where the caudal aspect of this lobe overlies the central aspect of the diaphragm and the cranial aspect abuts the cardiac silhouette. Additionally, due to superimposition on the DV- and lateral views, the interpretation of accessory lung lobe pathology becomes challenging, which most likely led to the low interobserver agreement. It is suspected that if VD-views were employed, the accessory lung lobe would have been better visualised due to an increased cardiac diaphragmatic separation.[63,65] The left caudal lung lobe (L3) showed both a high interobserver variability and pathology in this lobe was also often over interpreted radiographically. The left caudal lung lobe partially superimposes over the diaphragmatic silhouette, which may have hampered interpretation of pathology of this particular lung lobe. That being said, the same result would have been expected for the right caudal lung lobe that also partially superimposes over the diaphragm with the additional superimposition of the caudal vena cava. It is therefore difficult to determine why the left caudal lung lobe had generated a high degree of disagreement on radiographs and why the presence of contusions was often misdiagnosed when compared to the right caudal lung lobe. The right-sided lung lobes (L4 to L6) demonstrated similar COV but did not necessarily demonstrate less interobserver disagreement compared to the left-sided lung lobes (L1 to L3). The cranial part of the left cranial lung lobe (L1) demonstrated in certain cases high interobserver agreement, whilst for most of the data showed a high degree of interobserver variability. Lung contusions were often assigned to this lobe that were disproven with CT. It is expected that the left and right cranial lung lobes are more challenging to interpret due to superimposition of soft tissue structures associated with the thoracic limbs. However, the right cranial lung lobe is subject to the same soft tissue superimposition of the thoracic limbs as the left cranial lung lobe, but the same observations were not made for the right cranial lobe. These findings were thus difficult to interpret but other factors such as patient positioning, body condition and dog breed may all have contributed to making certain cases more challenging to evaluate objectively. In these instances, CT is considered a superior modality since superimposition is eliminated.[19]

A good correlation between the overall radiological severity scores and CT-scores for lung contusions demonstrated that the subjective estimation of severity on radiographs correlated with CT and thus private practitioners that only have radiography at their disposal can assess lung involvement fairly accurately on radiographs. Despite these correlations, CT does offer the advantage of more accurate assessment of extent of lung involvement and to predict whether mechanical ventilation may be required when combined with the clinical picture of the patient.[69] Acceptable correlation between radiography and CT for individual lung lobes was only observed for the left and right cranial lung lobes. This finding was unexpected, since the cranial lung lobes would be over interpreted for the presence of pathology due to overlying anatomical structures such as the scapulae and dorsal thoracic soft tissues, with resultant decreased correlation. This was observed for the cranial part of the left cranial lung lobe that was often thought to have contusions on radiographs that was not reflected in the CT-findings. The other lobes however, did not show this trend. It could be speculated that if the thoracic limbs were pulled caudally, superimposition of the scapulae would have been avoided, which could have resulted in more correct interpretation of this region since the thorax is the narrowest cranially.

A limitation of this study is that the six dogs that were diagnosed with diaphragmatic ruptures were attributed radiographic lung scores and were included in the final lung score data. While lung radiographic scores were high, these scores did not necessarily represent lung contusions, since it was impossible to distinguish between lung contusions and compressive pulmonary atelectasis.

5.2 Pneumothorax

The poor sensitivity of three-view thoracic radiography for detecting pneumothorax is consistent with human studies that reported CT being able to detect more than twice the number of pneumothoraxes compared to radiography.[37,68] 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 in humans can increase in volume during mechanical ventilation or develop into tension pneumothorax during general anaesthesia.[71] Although dogs are able to tolerate thoracic expansion by 2.5 to 3.5 times the residual volume, it is unknown whether the presence of an undetected pneumothorax is life-threatening in dogs undergoing general anaesthesia or mechanical ventilation.[37] It is thus prudent to monitor ventilation closely for complications where pneumothoraxes are equivocal or absent on thoracic radiographs. Future studies could endeavour to determine the risk and complications of mechanical ventilation in dogs with small volume pneumothorax detectable only on CT.

As expected, HB radiography had greater sensitivity 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 HB compared to standard radiographic views.[24] 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 after MVA 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 HB-radiography for detecting pneumothorax in all trauma patients with or without signs of dyspnoea and should be included as an additional view when CT is not available.

The sensitivity of HB-radiography for detecting pneumothorax has never been compared to CT in small animals and the results from this study indicated that even though detection improved using HB-radiography, the sensitivity of this technique was still lower than CT.

The low interobserver agreement for HB-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 HB radiographs. Another factor to consider is that this view is not often utilised and thus variation in sensitivities could reflect lack of familiarity with interpreting this view.

It was attempted to devise a severity grading score for pneumothorax on HB-views, but results from these attempts demonstrated no correlation with the CT severity scores for pneumothoraxes and thus were omitted from the study.

5.3 Pleural effusion

Pleural effusion results were similar to pneumothorax findings. Three-view thoracic radiography was only able to detect half of the CT diagnosed cases. Studies done in humans have reported similar findings where CT identified more than twice as many pleural effusions and also suggested a greater degree of severity.[68] 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 VD-view had been employed, the sensitivity for detection of 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 radiographic signs detected in pleural effusions and for anatomic reasons these are not detected in the DV-view.[44]

The improved sensitivity and interobserver agreement for detecting pleural effusion on HB-radiographs differed from a previous study that reported no significant differences between HB-views compared to standard vertical beam views for the detection of pleural effusion.[24] However, it must be noted that the sample size in our study was small resulting in substantial imprecision in our reported estimates.

It was also attempted to devise a severity grading score for pleural effusion on HB-views, but findings from these attempts were similar to the pneumothorax results and were thus omitted from the study.

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.[43] In fact, a historical clinical study reported that lymphatic absorption occurred at 0.57 ml/kg/hour when heparinized plasma was injected into the pleural cavity.[72] 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.[73]

5.4 Rib fractures

Only one-half of rib fractures were detected on radiographs relative to CT as the reference standard. It has been suggested that rib fractures are easily missed as a result of the low contrast imaging technique used for thoracic radiography, which results in the unapparent appearance of ribs.[47] This radiographic technique most likely contributed to the lower than expected sensitivities and interobserver agreement despite the ability to window an image in computed radiography. The inability to detect rib fractures is concerning since this injury compromises breathing secondary to pain and carries a poorer prognosis.[47] Identification of rib fractures guides the clinician to look for additional pathology since caudal rib fractures could be associated with cranial abdominal trauma, whilst more cranial rib fractures might be indicative of cranial mediastinal vascular and cardiac trauma.[17] Rib fractures can also be an indicator of adjacent lung injury, which is important to assess.[47] 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. Motion blur can complicate interpretation of CT studies. This is less of a problem on transverse images compared to reconstructions, but transverse images pose an additional challenge since the entire rib cannot be visualized on a single slice as the ribs are angled caudally. These challenges can 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 artefact causing pseudo rib fractures. Volume rendered images viewed from caudally are particularly helpful to identify fractures of the first two ribs in the authors' opinion.

Unexpectedly, radiographs showed poor sensitivity for right- sided rib fractures as opposed to left-sided rib fractures. This confounding result is difficult to explain since thoracic boundaries are symmetrical. The right hemithorax is also more radiolucent compared to the left hemithorax, which contains the most of the cardiac silhouette. It is however difficult to interpret these results objectively, because the sample size was small. It may be considered to implement future studies with larger cohorts to evaluate all factors involved in rib fracture detection.

5.5 Other thoracic pathology associated with blunt trauma

Many of the less common pathologies associated with blunt trauma yielded small sample populations. Due to lack of cases representing these pathologies, objective analysis for sensitivity and interobserver agreement could not be obtained. Despite the small sample sizes, the general trend of the results indicated that CT was superior in its ability to elucidate thoracic pathology. These findings are supported by results from human studies that found CT to be more sensitive for detecting thoracic trauma injuries that are missed on radiographs.[4,6,57,69] What can however be confidently concluded from this study, is that the high specificities obtained for all these less common conditions reflected that the observers seldom misinterpreted the radiological abnormalities indicative of these pathologies as other conditions.

The results obtained for diaphragmatic ruptures were interesting. Observers detected all but one case and there was perfect interobserver agreement of all cases confirmed to have diaphragmatic ruptures. The missed case was easily identifiable on CT (Fig 12) and is suspected that a dynamic component may have altered the appearance of rupture between the time of the radiographs and the CT. Albeit the small sample size, our results indicate that radiography remains a reliable method for detecting diaphragmatic ruptures despite observer experience and degree of difficulty when the typical abnormalities associated with ruptures are absent.

5.6 Differences between observers

The general trends followed by different observers based on experience is worth mentioning. The overall trend noted was that RAD 4 consistently elicited the highest sensitivity, whilst RAD 30 consistently demonstrated the highest specificity. RES 1 consistently showed an intermediate sensitivity and specificity. These findings correlate with other studies that have shown that experienced radiologists have a much higher diagnostic accuracy due to higher specificities but not as a result of increased sensitivities.[48,74] These findings suggest that experienced radiologist are more apt at determining when a study is normal.[74] This is believed to be as a result of their ability to draw from years of clinical experience. It has also been found by others that newly qualified radiologists have higher sensitivities but lower specificities.[48,75] These findings may possibly be ascribed to the fact that these individuals have received recent training.[75] It is therefore speculated that a newly qualified radiologists make conclusions about a study by drawing from their recent training and the experience they gained during their residency.

5.7 Study limitations

The primary study limitation for this project was small population size for certain abnormalities, which subsequently could not be objectively scrutinized. Future studies with larger populations of patients with less frequent abnormalities associated with blunt thoracic trauma should be pursued to objectively evaluate the sensitivity of radiography for detecting these abnormalities.

Several other less common injuries such as injuries to the upper airway, mediastinal effusion and heart abnormalities were absent from the study population. Future studies should therefore be conducted with bigger sample sizes to evaluate the sensitivity of thoracic radiography for these abnormalities.

Another study limitation is that prolonged patient recumbency prior to imaging was not observed. This may have caused increased atelectasis in some recumbent patients observed on radiographs, which could have resolved by the time the CT-procedure was performed. This would have precipitated overestimation of lung contusions on radiographs compared to CT. Future studies as well as all clinical cases undergoing thoracic radiographs should endeavour to ensure patients remain in sternal recumbency prior to imaging procedures.

Finally, only a single observer (RAD 30) evaluated the CT-images for abnormalities, which may have influenced the outcome of some of the cases.

Chapter 6: Conclusion

In conclusion, this study provides evidence of the value of CT for veterinary trauma patients. Radiography was less sensitive relative to CT for the detection of lung contusions, pneumothorax, pleural effusion and rib fractures. Computed tomography could thus be considered as an additional diagnostic imaging modality in patients presenting with blunt trauma, whilst radiography, is still an excellent screening tool to identify more severe thoracic abnormalities in these patients. Finally, the study also highlighted the value of HB-radiography in trauma patients with equivocal or no evidence of pneumothorax.

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Appendix A: Sample of Computed Tomography Lung Index

Case number	L1* severity	L1 HU# lobe	% aeration	% contusion	Total lobe involved	Total lung involved
64	0	-713	100	0	0	0
65	0	-713	100	0	0	0
66	3	-3	0,42075736	99,5792426	99,57924264	11.9450912
67	2	-269	37,7279102	62,2720898	41,51472651	4.981767181
68	1	-604	84,7124825	15,2875175	5,095839177	0.611500701

* Lobe 1 (Left *pars cranialis);* # Hounsfield unit

Appendix B: Sample of Thoracic Radiograph Findings Tables used for Recording Data

	% Lung involvement: L1*													
Case number	**Res 1**				**Rad 4**				**Rad 30**				**Average of total volumes affected**	**Computed tomography**
	Severity	**Extent**	**Severity x Extent/9 x 100**	**Total volume affected**	**Severity**	**Extent**	**Severity x Extent/9 x 100**	**Total volume affected**	**Severity**	**Extent**	**Severity x Extent/9 x 100**	**Total volume affected**		
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0
65	2	3	66.667	8	1	3	33.333	4	0	0	0	0	4	11.95
66	2	3	66.667	8	1	3	33.333	4	1	3	33.333	4	5.33	4.98

* Lobe 1 (Left *pars cranialis)*

Case number	**Pneumothorax**												
	Res 1			**Rad 4**			**Rad 30**			**Majority**			**Computed tomography**
	Std*	**HB****		**Std**	**HB**		**Std**	**HB**		**Std**	**HB**		
		RLR#	**LLR##**		**RLR**	**LLR**		**RLR**	**LLR**		**RLR**	**LLR**	
64	0	1	0	0	1	0	0	0	0	0	1	0	0
65	0	0	0	0	1	0	0	0	0	0	0	0	1
66	0	1	1	0	0	1	0	0	0	0	0	1	1

* Standard; ** Horizontal beam; # Right lateral recumbency; ## Left lateral recumbency

Case number	Pleural effusion											
	Res 1			Rad 4			Rad 30			Majority			Computed tomography
	Std*	HB**		Std	HB		Std	HB		Std	HB		
		RLR#	LLR##		RLR	LLR		RLR	LLR		RLR	LLR	
64	0	0	0	0	0	0	0	0	0	0	0	0	0
65	0	1	0	0	0	1	0	1	0	0	1	0	1
66	1	0	0	1	1	0	0	0	1	0	0	0	1

* Standard; ** Horizontal beam; # Right lateral recumbency; ## Left lateral recumbency

Case number	Rib fractures									
	Res 1		Rad 4		Rad 30		Majority		Computed tomography	
	Le*	Rt**	Le	Rt	Le	Rt	Le	Rt	Le	Rt
64	0	0	0	0	0	0	0	0	0	0
65	1	0	1	0	1	0	1	0	1	1
66	0	0	0	0	0	0	0	0	0	0

* Left; ** Right

Appendix C: Percentage Contribution of Each Lung Lobe to the Total Lung Volume in Dogs

Lung lobe	**Volume percentage contribution**
Pars cranialis of the Le cranial (L1)	12%
Pars caudalis of the Le cranial (L2)	7%
Le caudal (L3)	22%
Rt Cranial (L4)	19%
Rt Middle (L5)	11%
Rt Caudal (L6)	21%
Accessory Lung lobe (L7)	8%

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.

Total lung lobe contusion volume score = total lung lobe contusion score of a particular lung lobe (expressed in a percentage) x lung lobe volume (expressed as a fraction)

Appendix D: Lung Contusion Calculation Definitions

Lung contusion severity score: A score assigned out of a total of three (3) for the predominant lung pattern present involving a particular lung lobe

Lung contusion extent score: A score assigned out of a total of three (3) for the extent of lung lobe involvement

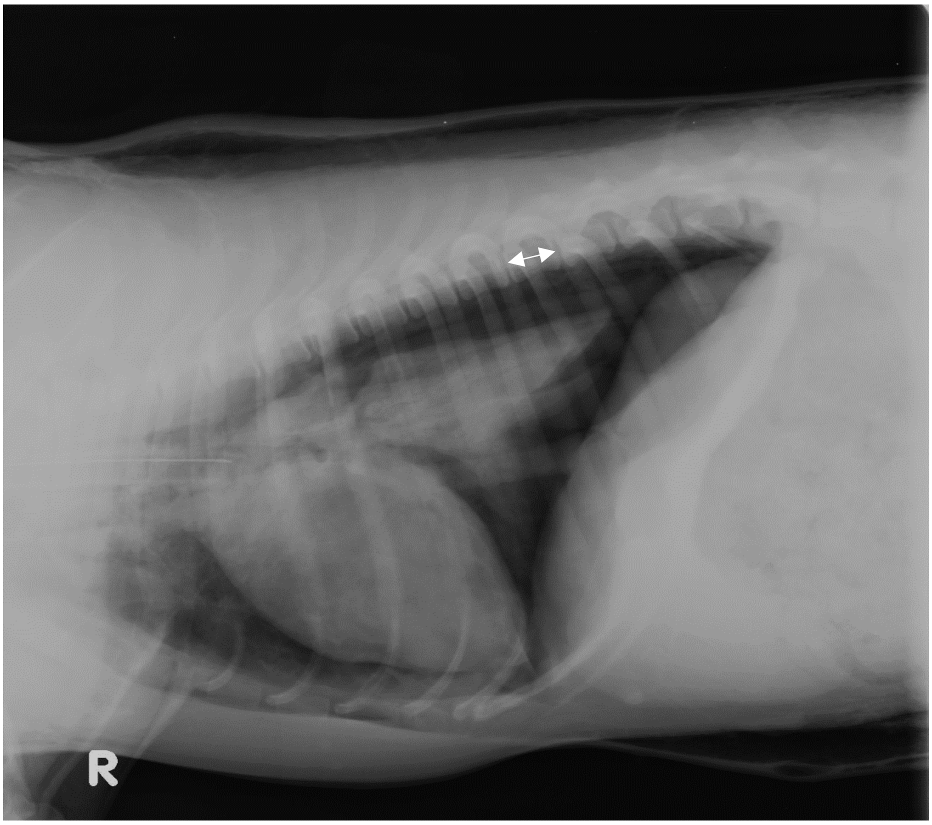
Total lung lobe contusion score: A score derived out of a total of nine (9) which is obtained by multiplying the lung contusion severity score by the lung contusion extent score

Total lung lobe contusion volume score: A score that represents the percentage of contused lung volume according to a specific lung lobe's contribution to the total lung volume in a dog. This is determined by multiplying the total lung contusion score of a lung lobe (expressed as a percentage) by the specific volume of the involved lung lobe (expressed as a fraction)

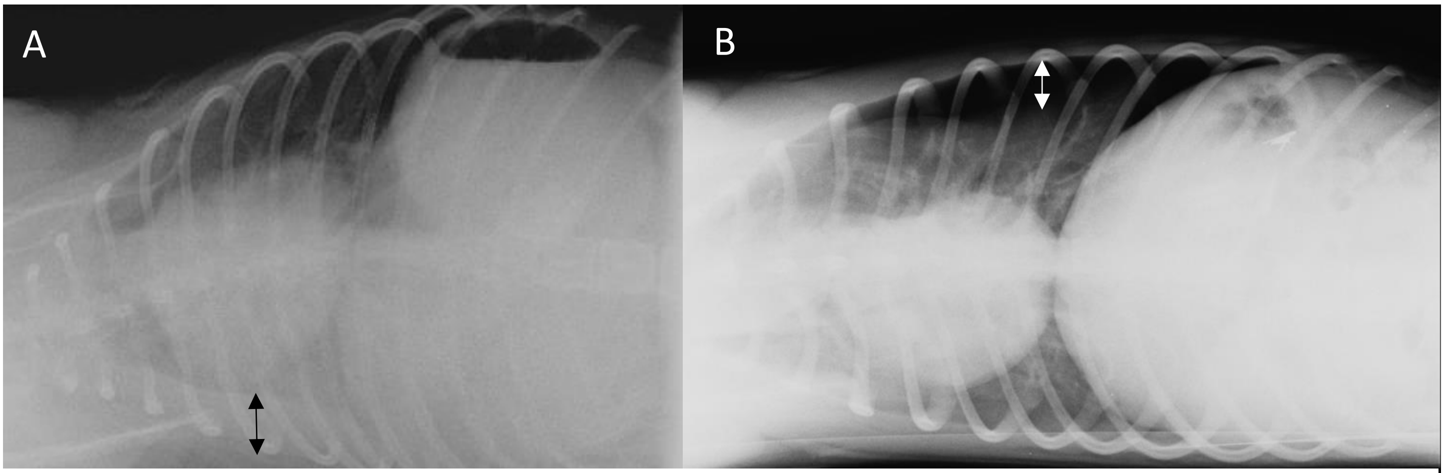
Mean total lung lobe contusion volume score: The averaged total lung lobe contusion volume score determined by adding all three observers' individual total lung lobe contusion volume score of each lobe and dividing it by three (since there were three observers)

Composite lung index: This index represent the addition of all the lung lobes' total lung contusion volume scores to obtain a final index that reflects a semi objective estimation of the total degree of lung lobe contusion or collapse

Appendix E: Examples of Vertebral Body to Gas and Fluid Width Determination



A right lateral recumbency view of an adult canine with pneumothorax. The measurement of the tenth thoracic vertebrae is illustrated (white arrow).



Ventrodorsal horizontal beam radiographs in right lateral recumbency of two adult canines with pleural effusion (A) and pneumothorax (B). The black arrow indicates the widest measurement of the pleural effusion from the lung lobe edge to the thoracic wall. The white arrow indicates the widest measurement of the pleural gas from the lung lobe edge to the thoracic wall