



RETROSPECTIVE STUDY OPEN ACCESS

Retrospective Evaluation of the Association of Pulmonary Contusion Volume as Assessed by Computed Tomography With Mortality and Provision of Mechanical Ventilation in Traumatized Dogs (2019–2023): 27 Cases

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ABSTRACT

Objectives: To evaluate the association between the percentage of pulmonary contusion volume (PPCV) found on computed tomography (CT) and survival to discharge or implementation of mechanical ventilation (MV) in a cohort of dogs with thoracic trauma.

Design: Retrospective multicenter study (March 2019 to April 2023).

Setting: Two veterinary teaching hospitals and one diagnostic imaging telemedicine service.

Animals: Twenty-seven client-owned dogs with thoracic trauma and CT findings compatible with pulmonary contusions.

Interventions: None.

Measurements and Main Results: Medical records were retrospectively searched for dogs with thoracic trauma and CT findings compatible with pulmonary contusions. Demographic parameters, PPCV, presence of pneumothorax or pleural effusion, number of fractured ribs, provision of MV, and outcome were recorded. CT studies were reviewed, and PPCV was calculated using commercial software following a standardized protocol. Nonsurvivors had a higher PPCV (median, 49.6% [range, 4.2–81.3]) than survivors (median, 6.5% [range, 0.1–52.9]; $p = 0.005$). Dogs that received MV also had a higher PPCV (median, 41.4% [range, 4.2–81.3]) compared with dogs that did not (median, 7.5% [range, 0.1–66.7]; $p = 0.015$).

Conclusions: In this population of dogs with thoracic trauma, nonsurvivors and dogs that received MV had a higher PPCV, as evidenced by CT.

Abbreviations: ARDS, acute respiratory distress syndrome; CT, computed tomography; DICOM, Digital Imaging and Communications in Medicine; HU, Hounsfield units; MV, mechanical ventilation; PPCV, percentage of pulmonary contusion volume; WL, window level; WW, window width.

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1 | Introduction

Pulmonary contusions are the most common lesions in dogs after blunt thoracic trauma, with an incidence of 23%–38% [1, 2]. Case fatality rates of approximately 20% have been reported; however, the fatality rate in mechanically ventilated patients can be as high as 70% [3, 4]. Pulmonary contusions are characterized by interstitial and alveolar hemorrhage, edema, increased capillary permeability leading to extravasation of protein-rich fluid, bronchospasm, increased mucus production, areas of right-to-left shunt, ventilation–perfusion mismatch, and decreased surfactant production that results in reduced pulmonary compliance in the affected areas [5]. Other injuries, such as pneumothorax, pleural effusion, and rib fractures, among others, are often associated with pulmonary contusions and may lead to secondary complications including acute respiratory distress syndrome (ARDS) and pneumonia [6–8]. Pathophysiological derangements associated with pulmonary contusions may progress during the first 48 h, with clinical signs ranging from subclinical cases to severe hypoxemia and respiratory distress, the latter of which may require intensive care, including advanced therapies such as mechanical ventilation (MV) and an associated increase in length of hospitalization and cost. After 48 h, healing of the affected areas begins; in noncomplicated cases, total resolution of a pulmonary contusion occurs 3–7 days later [5].

Diagnostic tools to evaluate the extent of pulmonary contusions include thoracic ultrasound, radiography, and computed tomography (CT). Although thoracic ultrasound is gaining prominence as an initial screening tool, its ability to assess pulmonary lesions is limited to those present in the lung's periphery [9]. Radiographic changes associated with pulmonary contusions typically present as localized or generalized areas of patchy or diffuse interstitial or alveolar lung infiltrates, but such changes may lag behind clinical signs by 12–24 h [5]. A recent veterinary publication supports CT as a more sensitive technique for detecting lesions after blunt thoracic trauma [10], and CT is considered the gold standard for diagnosing and assessing the extent of pulmonary contusions in people [11].

Published evidence in people shows that the severity of pathophysiological abnormalities and the development of complications, such as ARDS or pneumonia, are directly related to the extent of the pulmonary contusion [12, 13]. Pulmonary contusions affecting more than 20% of lung volume have consistently been associated with a higher incidence of ARDS, pneumonia, and provision of MV [13, 14]. However, published studies in dogs and cats show discrepancies between the extent of pulmonary contusion using thoracic radiographs and the development of complications. One study found an association between changes on thoracic radiographs and the need for oxygen supplementation and longer hospitalization, while another study reported no correlation between the Acute Trauma Triage score and a radiographic scoring system for evaluating thoracic lesion severity [1, 3]. The aim of the current study was to evaluate for an association between the percentage of pulmonary contusion volume (PPCV) observed on CT and survival to discharge or implementation of MV in a population of dogs with thoracic trauma. The hypothesis was that as PPCV increases, both mortality and requirement of MV would also increase.

2 | Materials and Methods

Medical records of client-owned dogs admitted to the emergency department of two veterinary university teaching hospitals and one private veterinary diagnostic imaging telemedicine service were retrospectively searched between March 2019 and April 2023 using the terms “thoracic trauma,” “polytrauma,” “high rise fall,” “pulmonary contusions,” and “computed tomography.” Dogs were included if they had a history of thoracic trauma and CT findings compatible with pulmonary contusions. Dogs were excluded if CT studies were deemed of insufficient diagnostic quality or if data regarding treatment with MV or survival were missing. Data collected from the medical records included age, sex, reproductive status, breed, type of trauma (classified as motor vehicle trauma, high-rise fall, fall from owner's arms, thoracic bite trauma, and unknown), presence of pneumothorax or pleural effusion, number of fractured ribs, implementation of MV, and survival to hospital discharge.

With dogs positioned in sternal recumbency, thoracic CT studies were acquired under general anesthesia or sedation using various third-generation CT units¹ in helical scan mode. Similar protocols were followed across the different centers, including high kV (120–130), appropriate mAs, and a patient size-adjusted field of view. Images were reconstructed with slice thicknesses ranging from 1.25 to 2.5 mm using both soft-tissue and lung algorithms. When contrast was used, an IV injection of iodinated contrast medium² was administered through the cephalic or saphenous vein at a dose of 2 mL/kg. In some cases, a power injector³ was used at 4 mL/s, while in other cases, the contrast was administered manually.

The CT studies were reviewed using a Digital Imaging and Communications in Medicine (DICOM) viewer⁴. The images were displayed in the transverse plane using settings for both soft tissue (window width [WW] = 350 Hounsfield units [HU] and window level [WL] = 40 HU) and lung (WW = 1500 HU and WL = −500 HU). During the analysis, radiologists were aware that all dogs had a history of trauma, but they were blinded to the final report and other clinical information, including outcome. The protocol for performing measurements and computer-generated segmentations of pulmonary contusions, atelectasis, and aerated lung was established through consensus among three radiologists (two board-certified radiologists and one PhD holder), with reference to previously published studies in both veterinary and human medicine [15–17]. All radiologists, including diagnostic imaging residents, underwent a training session in which discrepancies between measurements and other sources of error were addressed. Measurements were performed by two diagnostic imaging residents and one board-certified radiologist, with studies from each institution being assessed individually by that institution's radiologist.

The volumes of pulmonary contusions, atelectatic lung, aerated lung, and total lung volume were measured using the DICOM viewer. The volumes of atelectatic lung and pulmonary contusion were measured by manually drawing a region of interest in each transverse image using the DICOM viewer's “open polygon” tool. A lung region was considered atelectatic when the HU values were consistent with nonaerated lung (−100 to +100 HU) and

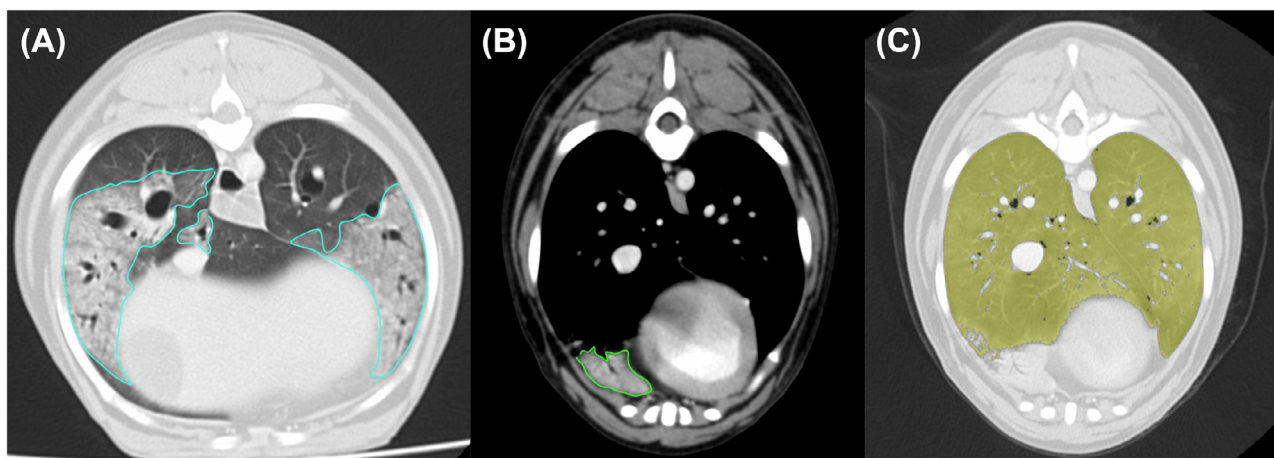


FIGURE 1 | Representative computed tomography images obtained in the transverse plane for measurements of (A) pulmonary contusion, (B) atelectatic lung, and (C) aerated lung in 27 dogs with thoracic trauma. In each image, the right is to the left of the image. (A) Pulmonary contusion measurements were performed by manually drawing a region of interest in each transverse image using the software tool “open polygon” in lung window (outlined in blue). (B) Atelectatic lung measurements were done with the same method as for pulmonary contusion in soft-tissue window (outlined in green). (C) Aerated lung measurements were calculated with the “2D/3D segmentation tool” using a threshold of lung attenuation between -1000 and -250 Hounsfield units in lung window. The volume of aerated lung was automatically calculated with the software (yellow area).

reduced lung volume was present. A region was considered to have a pulmonary contusion when the HU values were consistent with poorly aerated lung (-500 to -101 HU) but retained normal lung volume [10, 18]. The measurements for atelectasis were performed in the soft-tissue window, while pulmonary contusions were measured in the lung window. When all the regions of interest were traced, the total volume of pulmonary atelectasis or pulmonary contusion was automatically calculated by the software. The software also automatically calculated the volume of aerated lung, which included the trachea and bronchi. To calculate the total volume of aerated lung, the “2D/3D segmentation tool” was used with a threshold between -1000 and -250 HU. Total lung volume was obtained by summing the previously calculated volumes: atelectasis, pulmonary contusion, and aerated lung. To calculate the PPCV, the ratio of pulmonary contusion volume to total lung volume was computed (Figure 1). Additional findings, such as the presence or absence of pneumothorax, pleural effusion, and the number of fractured ribs, were also recorded.

2.1 | Statistical Analysis

Qualitative variables were reported as counts and percentages. A Shapiro–Wilk test was used to evaluate the distribution of continuous variables. Quantitative variables were reported as mean $\pm$ SD if they followed a normal distribution or median and range if they did not. A comparison of categorical variables between survivors and nonsurvivors was performed with Pearson χ^2 test or Fisher exact test if any cell had a count <5 . Student's *t*-test or the Mann–Whitney *U*-test was used to compare quantitative variables between survivors and nonsurvivors as appropriate. A commercially available statistics program⁵ was used for the statistical analysis.

3 | Results

Twenty-nine dogs were identified during the initial search, but two dogs were excluded due to inappropriate CT studies. Twenty cases were recruited from the two veterinary teaching hospitals (15 from Institution 1, and 5 from Institution 2), and seven were from the diagnostic imaging telemedicine service. Of the 27 dogs included in the final analysis, 14 (51.9%) were male (eight neutered and six intact) and 13 (48.1%) were female (six neutered and seven intact). The mean age was 5.2 ± 4.1 years. A total of 17 pure breeds were represented, including Border Collie ($n = 3$), Doberman Pinscher ($n = 3$), Yorkshire Terrier ($n = 3$), Maltese ($n = 2$), Poodle ($n = 2$), one dog each of 12 pure breeds, and two mixed breed dogs. The most common type of trauma was motor vehicle trauma ($n = 12$ [44.4%]), followed by thoracic bite trauma ($n = 6$ [22.2%]), high-rise fall ($n = 5$ [18.5%]), unknown origin ($n = 3$ [11.1%]), and fall from the owner's arms ($n = 1$ [3.7%]).

The median time between trauma and CT was 17 h (range, 2–144 h). CT was performed within the first 12 h in 10 (37%) dogs, between 13 and 24 h in nine (33%) dogs, between 25 and 48 h in three (11%) dogs, and after 48 h in four (14.8%) dogs. The time interval was unknown in one case. Six (22%) dogs had no thoracic lesions apart from pulmonary contusions; three (11%) dogs had pneumothorax with pleural effusion and rib fractures; and 19 (70%) dogs had either pneumothorax ($n = 18$ [66.7%]), pleural effusion ($n = 8$ [26.6%]), rib fractures ($n = 10$ [37%]), or a combination of two of the three conditions ($n = 8$ [29.6%]). Six (22%) dogs had one or two fractured ribs, and four (14.8%) dogs had between three and eight fractured ribs. Information concerning the origin of pleural effusion was not available in any dog. A total of seven (25.9%) dogs did not survive, and six (22.2%) dogs received MV due to persistent hypoxemia despite noninvasive oxygen support. Of the six dogs that were

TABLE 1 | Comparison of demographic variables, type of trauma, computed tomography findings, and provision of mechanical ventilation between 20 surviving and 7 nonsurviving dogs with thoracic trauma.

Parameter		Survivors (<i>n</i> = 20) Mean $\pm$ SD/median (range)/number	Nonsurvivors (<i>n</i> = 7) Mean $\pm$ SD/median (range)/number	<i>p</i> -value
Age (years)		4.5 $\pm$ 3.5	7.3 $\pm$ 5.5	0.134
Sex (<i>n</i>)	Male	8	6	0.077
	Female	12	1	
Reproductive status (<i>n</i>)	Entire	9	5	0.385
	Neutered	11	2	
Type of trauma (<i>n</i>)	Motor-vehicle trauma	9	3	0.5
	Bite wounds	3	3	
	High-rise fall	4	1	
	Fall from owner's arms	1	0	
	Unknown	3	0	
PPCV (%)		6.5 (0.1–52.9)	49.6 (4.2–81.3)	0.005
Fractured ribs (<i>n</i>)		0 (0–8)	1 (0–8)	1
Pneumothorax (<i>n</i>)		13	5	0.756
Pleural effusion (<i>n</i>)		4	4	0.145
Mechanical ventilation (<i>n</i>)		2	4	0.024

Note: Statistically significant values appear in **bold** text.

Abbreviation: PPCV, percentage of pulmonary contusion volume.

mechanically ventilated, four did not survive. One (16%) dog was euthanized due to worsening of respiratory function, likely secondary to ventilator-associated pneumonia after 12 days of MV. The other three (50%) dogs died, one associated with worsening respiratory function and multiple organ dysfunction syndrome, another with signs of increased intracranial pressure followed by cardiopulmonary arrest, and the final dog of unknown cause. Of the three dogs that died without being mechanically ventilated, one died due to respiratory failure and neurologic worsening. This dog was suspected to have sustained a traumatic brain injury because jaw fractures were identified on CT, with no evidence of other cranial fractures or intracranial damage. The specific neurologic signs exhibited by this dog before death were not documented. The other two dogs were euthanized due to severe concurrent neurologic signs associated with spinal fractures. Respiratory impairment could neither be confirmed nor be excluded as a contributing factor in the decision to proceed with euthanasia in these two cases, particularly given that both patients presented with concurrent pleural effusion, rib fractures, and extensive pulmonary contusions of 19% and 33%, respectively.

Table 1 shows the demographic variables, type of trauma, CT findings, and provision of MV between survivors and nonsurvivors. Nonsurvivors had a higher PPCV (median, 49.6% [range, 4.2–81.3]) than survivors (median, 6.5% [range, 0.1–52.9]; $p = 0.005$) (Figure 2). Dogs that were mechanically ventilated also had a higher PPCV (median, 41.4% [range, 4.2–81.3]) compared with dogs that did not receive MV (median, 7.5% [range, 0.1–66.7]; $p = 0.015$) (Figure 3).

4 | Discussion

The results of the current study support the primary hypotheses that, in dogs with thoracic trauma, more extensive pulmonary contusions assessed via CT are associated with higher case fatality rates and an increased likelihood of undergoing MV. The overall case fatality rate in this cohort of dogs was 25.9% and was higher in dogs that were mechanically ventilated (66.6%) than in those that were not.

The main findings of the current study are consistent with previous studies in human medicine. In one study of 23 patients with blunt thoracic trauma, the degree of hypoxemia was positively correlated with the volume of contused lung on initial CT scan [14]. Another important finding from this study, which has been corroborated by subsequent research, was that a PPCV $\geq 20\%$ or 24% was significantly associated with the development of ARDS, pneumonia, and higher case fatality rates. This suggests that volumetric analysis of thoracic CT scans can help identify patients at high risk of respiratory decompensation [6, 12–14, 19–21]. However, two dogs in the current study survived to hospital discharge despite having extensive pulmonary contusions, emphasizing the importance of the patient's overall clinical assessment.

The prevalence of pneumothorax (66.7% vs. 24%–47%), pleural effusion (29.6% vs. 18%), and rib fractures (37% vs. 14%) in the current study was higher than reported in previous publications [22, 23]. In those studies, pulmonary contusions were diagnosed using thoracic radiographs, whereas this study used CT. The patients in the current study may represent a more severely ill

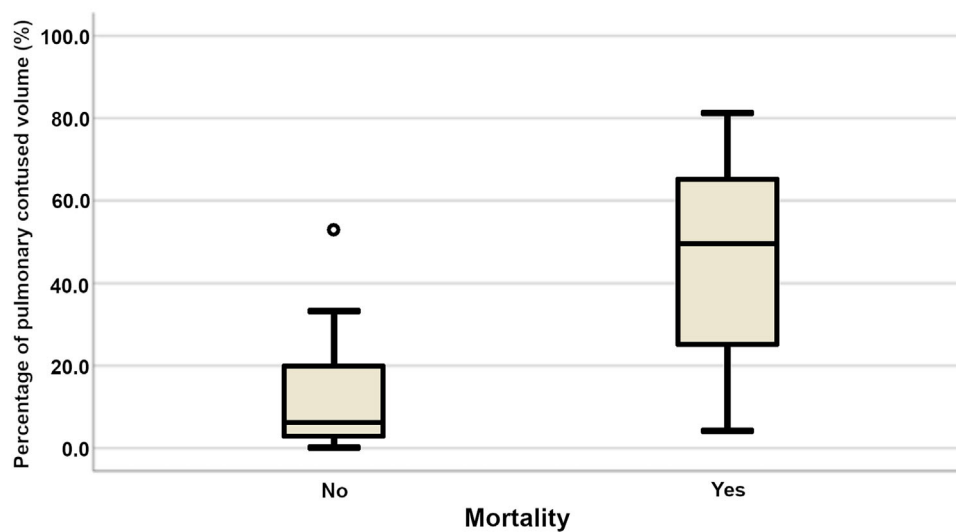


FIGURE 2 | Box-and-whisker plots of 27 dogs with thoracic trauma comparing the percentage of pulmonary contusion volume (PPCV) between survivors and nonsurvivors. Boxes represent the interquartile range (25th to 75th percentile). The horizontal bar in each box represents the median value. The median PPCV was higher in dogs that died (median, 49.6% [range, 4.2–81.3]) than in dogs that survived (median, 6.5% [range, 0.1–52.9]; $p = 0.005$).

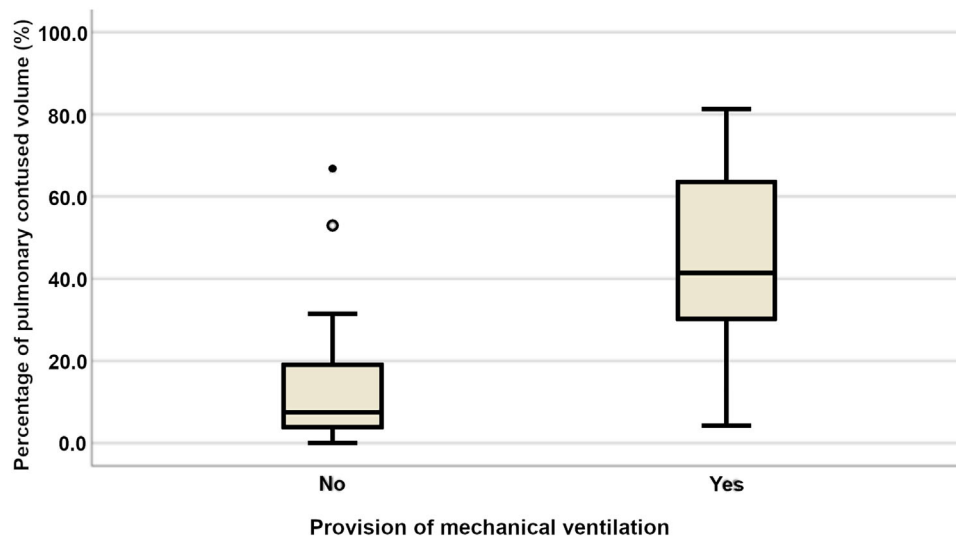


FIGURE 3 | Box-and-whisker plots of 27 dogs with thoracic trauma comparing the percentage of pulmonary contusion volume (PPCV) between dogs that were mechanically ventilated dogs and those that were not. Boxes represent the interquartile range (25th to 75th percentile). The horizontal bar in each box represents the median value. The median PPCV was higher in dogs that were mechanically ventilated (median, 41.4% [range, 4.2–81.3]) compared with those that were not (median, 7.5% [range, 0.1–66.7]; $p = 0.015$).

population, considering clinicians may be more likely to choose CT (either instead of or in addition to radiographs) in more severely traumatized dogs. This could also explain why the case fatality rate in the current study was higher than previously reported (26% vs. 18%) [3]. However, it is important to consider the small sample size of our study, and therefore, these results should be interpreted with caution.

In a retrospective study by Powell et al. that included 143 dogs presenting with pulmonary contusions after blunt thoracic trauma, 82% survived to discharge, and only 10 (7%) dogs died from respiratory failure secondary to severe pulmonary contusions. The authors explained that some patients were referred after having been stabilized in a primary care center, with more

severely affected dogs potentially having died before reaching a veterinary referral hospital [3]. The case fatality rate in the current study was high in mechanically ventilated dogs (67%) but is in line with a previous publication (70%) [4]. Higher mortality in dogs that received MV could potentially be explained by the severity of their pulmonary contusions. Complications such as ARDS and pneumonia are more likely in people with greater pulmonary contusions, and dogs with more severe pulmonary contusions may also be more likely to require ventilation, as evidenced by the significantly higher PPCV in the MV cohort found in this study [14].

Regarding the cause of death, five of the fatalities were entirely or predominantly attributable to respiratory failure associated

with pulmonary contusion. The dog that died without MV was suspected to have sustained a traumatic brain injury because jaw fractures were identified on CT, with no evidence of other cranial fractures or intracranial damage. The specific neurologic signs exhibited by this dog before death were not documented, and neurologic worsening due to severe hypoxemia should be considered. In the two cases that did not receive MV but were euthanized, severe neurologic injuries were present alongside pulmonary contusions. The role of respiratory failure as a contributing factor in the decision to proceed with euthanasia could not be definitively confirmed or excluded in these cases, given that both patients had concurrent pleural effusion, rib fractures, and extensive pulmonary contusions measuring 19% and 33%, respectively. Consequently, the true impact of the presence and extent of pulmonary contusions on these patients' mortality remains uncertain, especially when considering the confounding effects associated with euthanasia.

Our study has several limitations, mostly related to its retrospective nature and the small sample size. It would have been valuable to include illness severity scores, such as the Acute Trauma Triage score or VetCOT score; however, this was not possible because of insufficient data. The decision to perform CT was not standardized or reported, and it is likely that clinicians considered its use in dogs more severely affected by trauma, which introduced a source of bias. Additionally, the variability between observers when CT is used to determine lung measurements should be considered. Further studies could address the interobserver repeatability of lung volumetry measurements on CT scans of healthy and traumatized dogs. Time from trauma to image acquisition is another source of bias in our study. Eight of 27 (29%) dogs underwent CT scans within the first 12 h. Because the inflammatory peak after a pulmonary contusion happens during the first few hours, it is likely that the full extent of contusions might not have been detected in cases where CT scans were performed shortly after the trauma [5]. Other confounding factors to consider when interpreting our findings include the heterogeneity of trauma types and treatment strategies among different centers, the presence of additional comorbidities, particularly severe neurologic injuries, as well as the limitations of mortality analysis due to euthanasia.

Moreover, in this cohort of dogs with thoracic trauma, a higher PPCV on CT was associated with higher case fatality rates and provision of MV, suggesting that CT may be a useful technique to augment outcome prediction in dogs after thoracic trauma. Further prospective studies, including the use of illness severity scores and evaluation of the relationship between PPCV and the development of respiratory complications in dogs, are warranted.

Author Contributions

Alicia Álvarez-Punzano: conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft. **Anna Palomares:** Data curation, investigation, methodology, writing – original draft. **Miriam Martínez:** conceptualization, data curation, investigation, methodology, resources, supervision, writing – review and editing. **Noemi Gómez-Martínez:** data curation, methodology, writing – review and editing. **Rosa Novellas:** methodology, resources, supervision, validation, writing – review and editing. **Yvonne Espada:** methodology, super-

vision, validation, writing – review and editing. **Luis Bosch-Lozano:** data curation, methodology, writing – review and editing. **Vicente Herrera-Bustillo:** conceptualization, formal analysis, investigation, methodology, resources, supervision, validation, writing – review and editing.

Conflicts of Interest

The authors declare no conflicts of interest.

ENDNotes

- ¹ Somatom Siemens Medical Solutions Europe; or General Electric Brivo CT 385.
- ² Omnipaque (Iohexol 300 mg/mL) GE Healthcare; or Xenetix (Iobitridol 300 mg/mL) Guerbet.
- ³ Medrad Stellant; or Nemoto A-60.
- ⁴ OsiriX, Pixmeo SARL, Switzerland.
- ⁵ IBM SPSS Statistics version 27.

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