

# Traumatic skull fractures in dogs and cats: A comparative analysis of neurological and computed tomographic features

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## Abstract

**Background:** Traumatic skull fractures (TSF) are relatively frequent in dogs and cats, but little information is available regarding their clinical and imaging features.

**Hypothesis/Objectives:** To describe the neurological and computed tomographic (CT) features of a large cohort of dogs and cats with TSF.

**Animals:** Ninety-one dogs and 95 cats with TSF identified on CT.

**Methods:** Multicenter retrospective comparative study. Signalment, cause of trauma, fracture locations and characteristics, presence of neurological deficits, and 1-week survival were recorded. Fractures were classified according to the extent of fragmentation and displacement.

**Results:** The cranial vault was affected more frequently in dogs ( $P = .003$ ), whereas the face and base of the cranium more often was affected in cats ( $P < .001$ ). Cats presented with multiple fractures more frequently ( $P < .001$ ). All animals with TSF in the cranial vault were more likely to develop neurological signs ( $P = .02$ ), especially when depressed fractures were present (95% confidence interval [CI], 1.7-8.2;  $P = .001$ ). Animals with TSF located only in the facial region were less likely to have neurological signs (odds ratio with Mantel-Haenszel's method [OR<sub>MH</sub>], 0.2; 95% CI, 0.1-0.6;  $P = .004$ ). Most affected animals (84.9%) survived the first week post-trauma. Death was more likely with fractures of the cranial vault ( $P = .003$ ), especially when fragmented ( $P = .007$ ) and displaced ( $P = .004$ ).

**Abbreviations:** CI, confidence interval; CT, computed tomography; IQR, interquartile range; MRI, magnetic resonance imaging; OR, odds ratios; PLR, pupillary light reflex; RTA, road traffic accident; TBI, traumatic brain injury; TSF, traumatic skull fracture.

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[Correction added on August 3, 2020 after first online publication: Michal Czopowicz's ORCID id updated.]

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**Conclusions and Clinical Importance:** Traumatic skull fracture distribution and patterns are different between dogs and cats. Cranial vault fractures were associated with neurological deficits and worse survival. The presence of TSF alone should not be considered a negative prognostic factor because most affected animals survived the first week.

**KEYWORDS**

canine, computed tomography, feline, skull fractures

## 1 | INTRODUCTION

Head trauma and secondary traumatic brain injury (TBI) are important causes of death in humans, dogs, and cats.<sup>1-3</sup> However, the mortality rate in dogs and cats remains unknown. Traumatic brain injury occurs as a consequence of damage to the brain caused by an external force. This injury may originate from direct disruption of the brain architecture (eg, depressed skull fractures, foreign body penetration) or from exposure of the brain to high velocities or forces or both because of the traumatic event.<sup>4,5</sup> These effects may cause transient or permanent damage to the brain parenchyma as a consequence of direct contusion, or as a result of a coup-contrecoup phenomenon, in which the first lesion occurs at the site of the impact and the second on the opposite side.<sup>6</sup> Injuries also may lead to metabolic and physiologic changes responsible for secondary brain damage.<sup>3-5</sup>

Traumatic skull fractures (TSF) influence the pathophysiology of TBI.<sup>7</sup> In a previous study, 36.8% of dogs had evidence of TSF on radiographs after head trauma.<sup>2</sup> However, radiological evidence of TSF did not appear to be a prognostic factor. In another study, 46.0% of dogs undergoing magnetic resonance imaging (MRI) of the head after TBI had skull fractures.<sup>8</sup> Fifty-two percent of dogs with fractures developed seizures.<sup>8</sup> More than the presence of a fracture alone, the distinction between different fracture locations and characteristics may influence the role fractures play in the pathophysiology of TBI. Cranial fractures may lead to direct compression of brain parenchyma, subsequent inflammation and infection, intracranial hematoma and hemorrhage, among other effects,<sup>9</sup> all of which may contribute to increased intracranial pressure. Recognition of these complications post-fracture is critical to limit patient morbidity and mortality. Although better described in human medicine,<sup>10</sup> the association between these complications and the presence, location, and type of skull fractures in dogs and cats has not been investigated.

To establish a standardized method for description of skull fractures in humans, a classification system for fractures of the craniomaxillofacial skeleton on computed tomography (CT) was published previously.<sup>11</sup> Classification systems are crucial in science because they create an effective communication tool for use among scientists, allow systematic differentiation and identification of disparate pathologies, and ultimately help provide optimal treatment for the patient. Although the availability of advanced imaging has increased in veterinary medicine and skull fractures and secondary

complications have become more easily identifiable, a standardized classification system is still lacking.

Our aims were: (1) to describe the type and anatomical location of TSF identified by CT in dogs and cats; (2) to identify any association with signalment, neurological signs, other imaging features, and 1-week outcome; and (3) to establish a TSF CT classification scheme for dogs and cats so as to standardize the nomenclature and evaluation of skull fracture patients in veterinary medicine.

## 2 | MATERIALS AND METHODS

Dogs and cats were retrospectively recruited from 3 referral centers. Patients were included in the study if they had: (1) CT of the head, (2) any fracture involving the skull (animals with mandibular fractures only were not included), (3) fractures of traumatic origin (pathological fractures were excluded), and (4) a history of external trauma. Patients were excluded if no information was available regarding the neurological examination findings or status after the trauma. Signalment, history, physical and neurological examination findings, and first-week outcome were recorded for all the cases when available. All CT scan images were reviewed by a neurology resident and a board-certified neurologist. The images were evaluated using an open-source Picture Archiving and Communication System Workstation for Digital Imaging and Communication in Medicine viewer (Osirix Imaging Software, v 3.9.2, Pixmeo, Geneva, Switzerland) using bone and soft tissue windows, and the final classification and location of the fractures and associated imaging features were agreed upon.

### 2.1 | Fracture classification system<sup>12-15</sup>

The skull was topographically subdivided into 3 regions: (1) cranial vault, (2) base of the cranium, and (3) face. The bones that form the different areas are listed in Table 1. For simplification, the zygomatic arch was considered as a single entity although anatomically it is formed by the zygomatic process of the temporal bone and the temporal process of the zygomatic bone.<sup>16</sup>

Fractures were classified according to the extent of fragmentation and displacement using a bone tissue window as follows: (1) non-fragmented when a single fracture line was present (not taking into

account incomplete fractures or fissures) or (2) fragmented when multiple fracture lines were present, including comminuted fractures. Regarding displacement, fractures were classified as: (1) non-displaced or (2) displaced but not depressed when the bone fragment was displaced away from the brain for the cranial vault and the base of the cranium and nasal cavity and nasopharynx for the face, and (3) depressed when the bone fragment was displaced inwards toward the meninges and brain for the cranial vault and the base of the cranium and nasal cavity or nasopharynx for the face). Figures 1–3 show an example of each type.

**TABLE 1** The skull was subdivided into these 3 regions (face, cranial vault, and base of the cranium). In the second column, there are the names of each bone included in each region. For simplification, the zygomatic arch was considered as a single entity, and the presphenoid and basisphenoid bones named together as the sphenoid bone

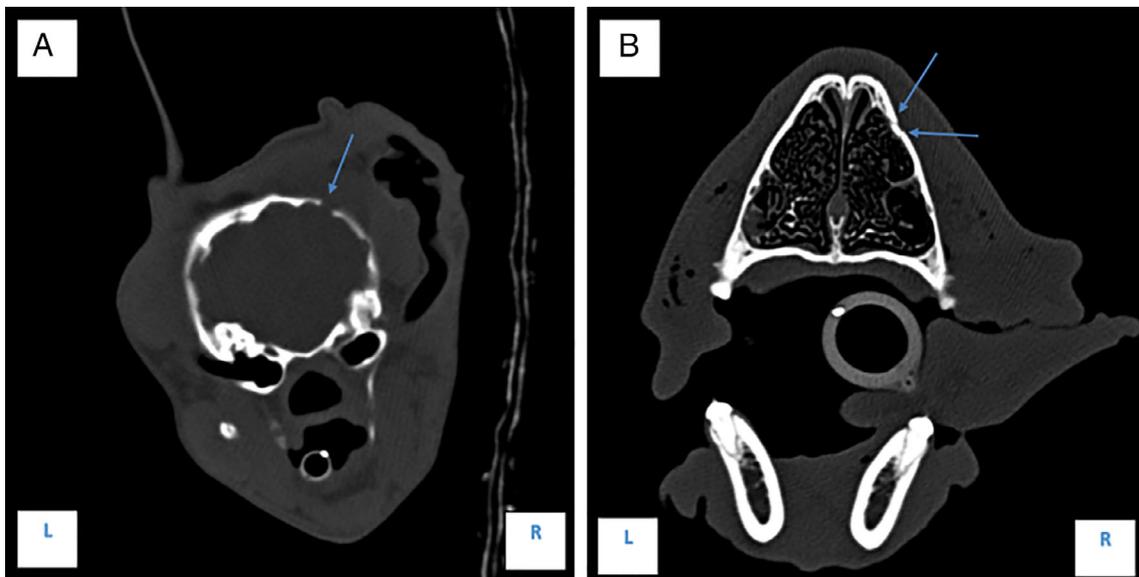
Region	Bones
Face	<ul style="list-style-type: none"> <li>• Incisive</li> <li>• Nasal</li> <li>• Maxillary</li> <li>• Lacrimal</li> <li>• Zygomatic arch</li> <li>• Palatine</li> <li>• Vomer</li> </ul>
Cranial vault	<ul style="list-style-type: none"> <li>• Frontal</li> <li>• Parietal</li> <li>• Temporal</li> <li>• Occipital</li> <li>• Ethmoidal</li> </ul>
Base of the cranium	<ul style="list-style-type: none"> <li>• Pterygoid</li> <li>• Sphenoid</li> <li>• Basisoccipital</li> </ul>

## 2.2 | Other associated imaging features

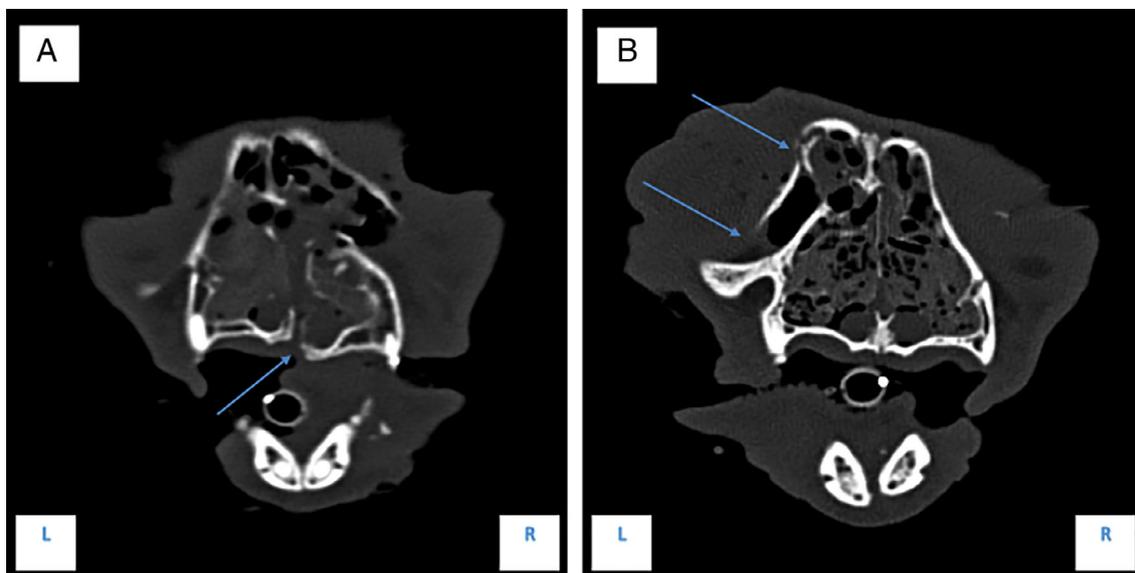
Other associated imaging features also were recorded using the bone and soft tissue windows. These included presence of pneumocephalus, fluid in the frontal sinuses, orbit involvement, brain edema, intra-axial hemorrhage, extra-axial hemorrhage, midline shift, and fracture following the suture lines. The presence of vertebral fractures or luxations or both in the cervical vertebral column also was recorded. In all cases, a variable number of cervical vertebrae were included in the CT scan, and for specific cases that presented with clinical signs compatible with a cervical spinal cord lesion, the entire anatomical region was included.

## 2.3 | Statistical analysis

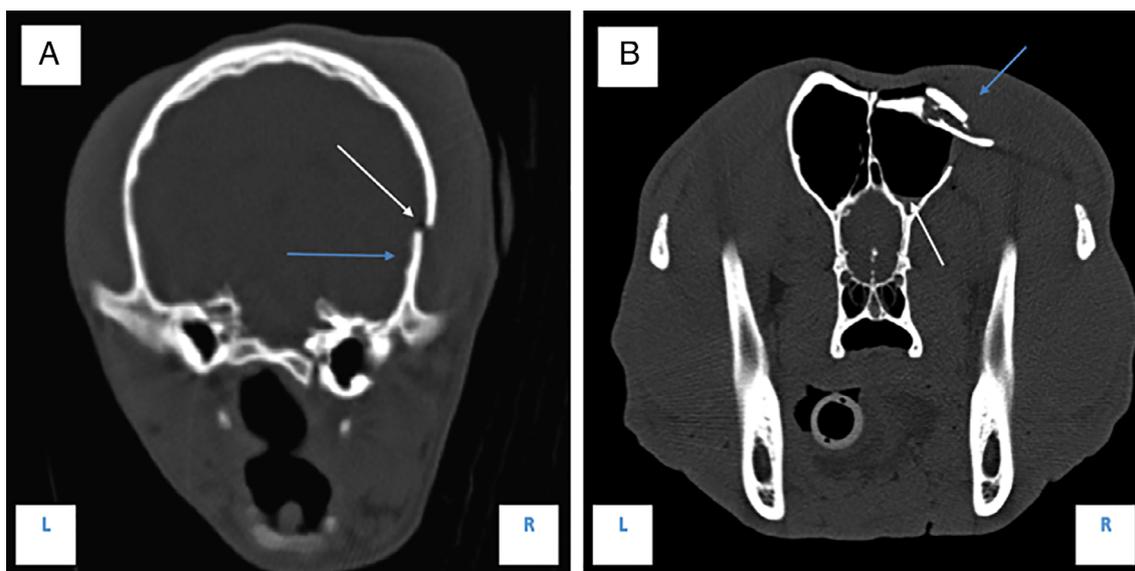
Categorical variables were presented as count and percentage in a group and compared between groups using the Pearson's chi-square test. The relationship between various aspects of skull bone fractures and the occurrence of neurological signs was investigated using the Cochran-Mantel-Haenszel test controlling for species as a potential confounder. Crude odds ratios (ORs) were calculated separately for dogs and cats using partial  $2 \times 2$  contingency tables and the homogeneity of OR was verified using a Breslow-Day test with Tarone's modification.<sup>17</sup> If proved insignificant, common OR ( $OR_{MH}$ ) were calculated using a Mantel-Haenszel procedure. Confidence intervals for 95% level of confidence (95% CI) were calculated using the Wilson score method. Given that numerical variables were non-normally distributed (mostly right-hand skewed), they were presented using median, interquartile range (IQR), and range. They were compared between unpaired groups



**FIGURE 1** CT transverse images of the head of 2 dogs. A, Level of the tympanic bullae. A single fracture line can be seen affecting the parietal bone on the right (blue arrow). B, Level of the nasal cavity. Two small fracture lines affecting the maxillary bone on the right are visible (blue arrows), without significant displacement of the fragment. These fractures were classified as non-fragmented non-displaced and fragmented non-displaced, respectively



**FIGURE 2** CT transverse images of the head of 2 cats. A single fracture line with displacement of the right palatine bone can be seen in A (blue arrow). In B, a displaced fragment of the left maxillary bone is detected. This bony fragment presents two fracture lines (blue arrows). A was classified as non-fragmented displaced and B as fragmented displaced



**FIGURE 3** CT transverse images of the head of 2 dogs. Notice the mildly depressed fracture present in A (blue arrow), with a small hypoattenuating region compatible with pneumocephalus (white arrow). This fracture is affecting the right temporal bone and was classified as non-fragmented depressed. In B, there are multiple fracture lines affecting the right frontal bone (blue arrow). These fragments are displaced inwards, causing narrowing of the right frontal sinus. There is also a small amount of soft tissue attenuating material in the ventral aspect of the left frontal sinus (white arrow). The fracture was classified as fragmented depressed

using the Mann-Whitney *U* test and between paired groups using the Wilcoxon signed rank test with Bonferroni correction of *P*-value if >2 groups were compared. All statistical tests were 2-tailed. Significance level ( $\alpha$ ) was set at .05. Statistical analysis was performed in TIBCO Statistica 13.3.0 (TIBCO Software Inc, Palo Alto, California) and IBM SPSS Statistics 24 (IBM Corporation, Armonk, New York). Graphs were prepared using Microsoft Excel 2018.

### 3 | RESULTS

#### 3.1 | Study population

In total, 186 animals, 91 dogs (48.9%) and 95 cats (51.1%), satisfied eligibility criteria and were enrolled in the study. Detailed characteristics are presented in Table 2. There were slightly more males of both species (60%), but the proportion of sexes was similar in

dogs and cats ( $P = .1$ ). Most cats (93%) were neutered compared to 44% of dogs, but the proportions of neutered individuals were similar between males and females in both dogs ( $P = .3$ ) and cats ( $P = .6$ ). Animals enrolled in the study were young, with an overall median age of 3.5 years (IQR, 1-6 years) and dogs were significantly younger than cats ( $P = .001$ ). Most dogs were purebred (90%) and no particular breed predominated, although Chihuahua and Yorkshire Terrier were the 2 most commonly affected purebred breeds. Most of cats were domestic cats (81%), usually short-haired.

The most common cause of trauma was road traffic accident (RTA), which was much more common in cats (61%) than in dogs (26%). The next was dog attack (21% in dogs and 7% in cats). Twenty other causes were described in dogs and 3 in cats, but in approximately 17% of dogs and 25% of cats the inciting cause of trauma was unknown.

### 3.2 | Characteristics of skull fractures in dogs and cats

One-hundred twenty-eight animals (69%) had face fractures, 128 (69%) had cranial vault fractures, and 88 (47%) had fractures of the base of the cranium. The distribution of fractures of these 3 regions was significantly different between dogs and cats in that cranial vault fractures were significantly more frequent in dogs ( $P = .003$ ), whereas face and base of cranium fractures were significantly more frequent in cats ( $P < .001$  for both; Table 3). The total number of fractures per animal ranged from 1 to 17 with the median of 4 (IQR, 2-8) and was significantly higher in cats ( $P < .001$ ). In dogs, the numbers of fractures of the face and cranial vault region per individual both were significantly higher than the number of fractures of the base of the cranium region ( $P < .001$  for both). In cats, the number of fractures of the face region per individual was significantly higher than the numbers of

**TABLE 2** General characteristics of the study population of 186 animals with TSF

Characteristics	n (%)		Dog versus cat
	Dogs (n = 91)	Cats (n = 95)	P value
Sex			.1
Males	49 (53.8)	62 (65.3)	
Females	42 (46.2)	33 (34.7)	
Neutering status			<.001
Intact	51 (56.0)	7 (7.4)	
Neutered	40 (44.0)	88 (92.6)	
Sex and neuter status combined			
Intact male	30 (33.0)	4 (4.2)	
Neutered male	19 (20.8)	58 (61.0)	
Intact female	21 (23.1)	3 (3.2)	
Neutered female	21 (23.1)	30 (31.6)	
Breed			
	Cross Breed (n = 9, 9.9%)	Domestic short-haired (n = 70), domestic long-haired or medium-haired (n = 7)	
	Pedigree (n = 82, 90.1%): Chihuahua (n = 9), Yorkshire Terrier (n = 8), Labrador Retriever (n = 6), Cocker Spaniel (n = 5), German Shepherd Dog (n = 5), and 34 others represented by 3 or fewer individuals	Pedigree cats: Norwegian Forest (n = 3) Bengal (n = 2), Maine Coon (n = 2), British Short Haired (n = 2), Siamese (n = 2), and 7 others represented by one individual	
Age on presentation (years, if not stated otherwise) <sup>a</sup>	2, 0.5-6 (1 month - 18)	4, 2-6 (1 month - 16)	.001
Cause of fracture			
RTA	24 (26.4)	58 (61.1)	
Attacked by a dog	19 (20.9)	7 (7.4)	
Others	32 (35.1)	5 (5.3)	
Unknown	16 (17.6)	25 (26.3)	

Abbreviations: RTA, road traffic accident; TSF, traumatic skull fracture.

<sup>a</sup>Median, IQR, range.

**TABLE 3** Distribution of fractures in the 3 anatomical regions

Region	n (%)		P value
	Dogs (n = 91)	Cats (n = 95)	
Face	45 (49.5)	83 (87.4)*	<.001
Cranial vault	72 (79.1)*	56 (59.0)	.003
Base of the cranium	18 (19.8)	70 (73.7)*	<.001

\*denotes *P* value.

fractures of the cranial vault and base of the cranium region ( $P < .001$  for both; Table 4).

The number of skull regions affected differed significantly between dogs and cats ( $P < .001$ ) in that only 7 dogs (8%) and 38 cats (40%) had fractures of all 3 regions. Most of the dogs ( $n = 54$ , 59%) and a minority of cats ( $n = 19$ , 20%) had fractures of only 1 region. Fractures of 2 regions were observed in 30 (33%) dogs and 38 (40%) cats (Figure 4).

In total, 993 skull fractures were found (293 in dogs and 700 in cats). In dogs, similar numbers were found in the face ( $n = 135$ , 46%) and cranial vault region ( $n = 137$ , 47%), whereas many fewer were found in the base of the cranium region ( $n = 21$ , 7%). In cats, most of the fractures were located in the face region ( $n = 488$ , 70%), a similar number were found in the cranial vault ( $n = 98$ , 14%) and the fewest were found in the base of the cranium region ( $n = 114$ , 16%; Supplementary Table 1).

For the face region, fractures of the maxillary bone were most common (>25% of all fractures of face region) and fractures of the vomer were least common (<10%) in both species. Considerable discrepancy between dogs and cats was observed in the nasal bone (more often affected in dogs) and in the lacrimal bone (more often affected in cats; Figure 5A).

For the cranial vault region, fractures of the frontal bone were most common in both species (approximately 33% of all fractures of the cranial vault region). Considerable discrepancy between dogs and cats was observed in the ethmoidal bone (more often affected in dogs) and in the parietal and occipital bone (both more often affected in cats; Figure 5B).

For the base of the cranium region, fractures of the pterygoid bone were more common than those of the sphenoid bone in both species (Figure 5C).

Approximately 50% of skull fractures were fragmented both in dogs ( $n = 148$ , 51%) and in cats ( $n = 392$ , 56%). Most non-fragmented fractures were non-displaced (60% in dogs, 80% in cats), whereas most fragmented fractures were displaced (83% in dogs, 79% in cats; Table 5).

Fractures following the suture lines were observed in 27 dogs (30%) and 35 cats (37%).

### 3.3 | Relationship between skull fractures and neurological signs

Of 186 animals with TSF, 104 had neurological signs (55.9%; 95% CI, 48.7%-62.9%): 57 of 91 dogs (62.6%; 95% CI, 52.4%-71.9%) and 47

**TABLE 4** Number of fractures per an animal in particular skull regions

	Median, IQR (range) of fractures	Median, IQR (range) of fractures
Skull region	Dogs (n = 91)	Cats (n = 95)
Face	2, 1-4 (1-9)	5, 3-8 (1-15)
Cranial vault	1, 1-3 (1-6)	1, 1-2 (1-6)
Base of cranium	1, 1-1 (1-3)	2, 1-2 (1-3)
Overall	3, 1-4 (1-13)	7, 4-10 (1-17)
Face versus cranial vault	$P = 1.0$	$P < .001$
Face versus base of cranium	$P < .001$	$P < .001$
Cranial vault versus base of cranium	$P < .001$	$P = .2$

of 95 cats (49.5%; 95% CI, 39.6%-59.4%) and these percentages did not differ significantly ( $P = .07$ ).

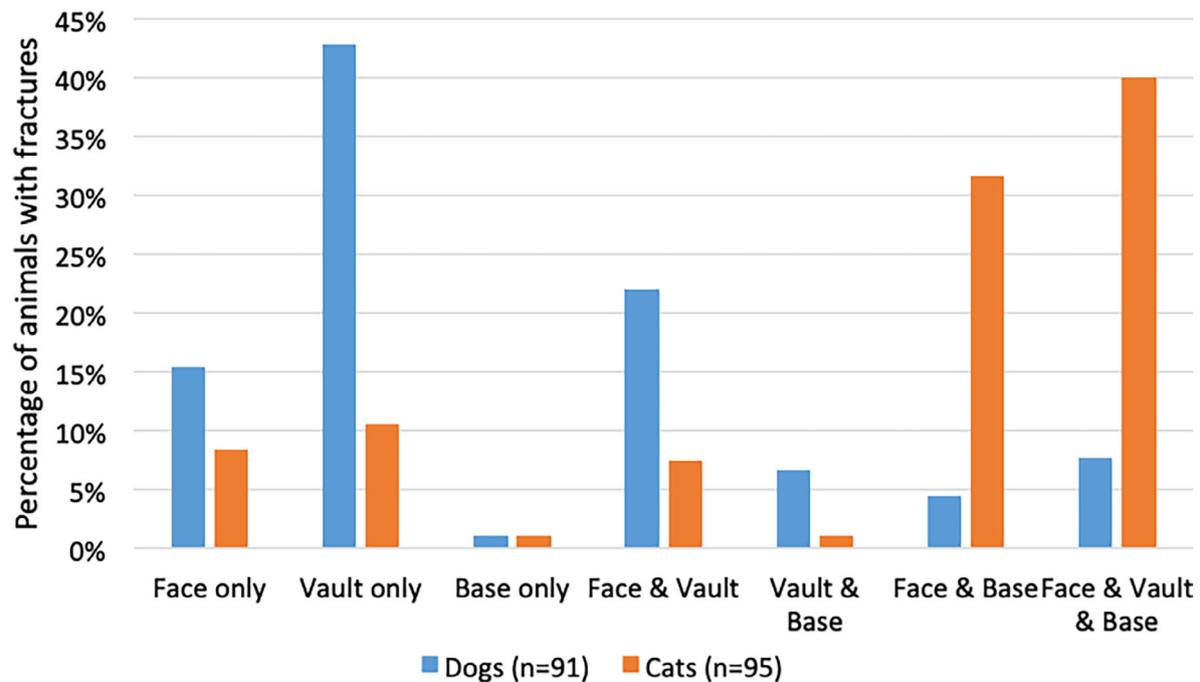
Number of regions affected was not a significant risk factor for the occurrence of neurological signs, either in dogs ( $P = .8$ ) or cats ( $P = .3$ ). Neither was there any link between the number of fractures and the occurrence of neurological signs, regardless of the region ( $P = .1$  for the face region, and cranial vault region, and  $P = .45$  for the base of the cranium region).

On the other hand, distribution of fractures across skull regions was significantly linked to the presence of neurological signs both in dogs ( $P = .2$ ) and in cats ( $P = .02$ ; Figure 6). Generally, neurological signs were more common in animals in which the cranial vault region was fractured (66.4%) compared to those in which the cranial vault region was unaffected (32.8%), and a fracture of the cranial vault region was a strong risk factor for the occurrence of neurological signs both in dogs and in cats with  $OR_{MH}$  of 3.8 (95% CI, 1.9 to 7.5;  $P < .001$ ). Neurological signs were more likely to occur in both dogs and cats with depressed fractures of the cranial vault region compared to non-displaced or displaced but not depressed fractures and this feature was another risk factor for neurological signs with  $OR_{MH}$  of 3.8 (95% CI, 1.7-8.2;  $P = .001$ ). Animals with skull fractures located only in the face region were significantly less likely to have neurological signs ( $OR_{MH}$ , 0.2; 95% CI, 0.1 to 0.6;  $P = .004$ ; Table 6).

Neuroanatomical localization was similar for dogs and cats with the brainstem affected slightly more often than the forebrain. Neurolocalization in the spinal cord was observed only in dogs (Supplementary Table 2). No link was found between anatomical region of the fracture and neurolocalization either in dogs ( $P = .9$ ) or in cats ( $P = 1.0$ ). Acute (<24 hours) seizures were reported in only 1 dog and 2 cats.

### 3.4 | Relationship between skull fractures and other associated imaging features

The most common associated imaging features were fluid in the frontal sinus (41%), brain edema (21%), intra-axial hemorrhage (15%), and



**FIGURE 4** Bar graph showing the percentage of animals with fractures in each anatomical region. Vault, cranial vault; Base, base of cranium

orbit involvement (10%). Pneumocephalus, cervical involvement, midline shift, and extra-axial hemorrhage were uncommon (observed in  $\leq 5\%$  of animals). Brain edema, intra-axial hemorrhage, midline shift, and cervical involvement were significantly more common in dogs than in cats (Supplementary Table 3). A fracture of the cranial vault region was present in most animals with associated intracranial changes such as pneumocephalus (10/10), brain edema (38/39), intra-axial hemorrhage (28/28), extra-axial hemorrhage (3/3), and midline shift (7/8). Interestingly, a fracture of the base of the cranium region was present in almost 50% of animals with associated intracranial changes. Animals in which the face was the only region affected did not have secondary intracranial changes (Supplementary Table 4).

Fluid was present in the frontal sinus in animals with fractures of the cranial vault region ( $n = 63$ ) and in those with fractures of the face region ( $n = 13$ ).

### 3.5 | One-week outcome

Of 185 animals with outcome data available, 157 survived 1 week (84.9%), which resulted in an overall 1-week case fatality rate of 15.1% (95% CI, 10.7%-21.0%). One-week case fatality rate was similar for dogs (16.5%; 95% CI, 10.3%-25.4%) and cats (13.8%; 95% CI, 8.3%-22.2%;  $P = .6$ ). Of 28 animals with negative outcome, 4 died spontaneously (2.1%; 1 dog and 3 cats) and 24 were euthanized (13.0%; 14 dogs and 10 cats), and thus euthanasia accounted for most immediate deaths (86%).

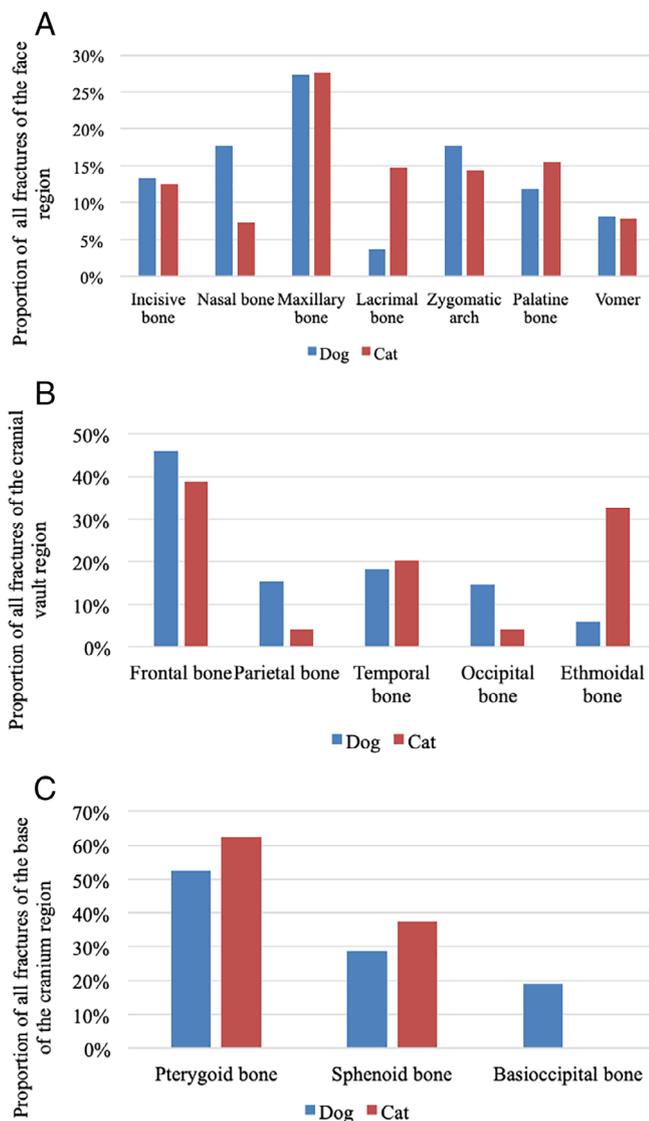
One-week death was more likely to occur in animals with fractures of the cranial vault region ( $P = .003$ ), whereas no animal with fractures of only the face region died ( $P = .03$ ). Animals with

fragmented fractures ( $P = .007$ ) and those with displaced but not depressed fractures of the cranial vault region ( $P = .004$ ) were more likely to die within the first week.

The occurrence of neurological signs was significantly associated with the immediate death ( $P = .008$ ) and animals with neurological signs were significantly more likely to be euthanized compared to animals without neurological signs (18.5 versus 6.1%.  $P = .01$ ).

## 4 | DISCUSSION

We evaluated the characteristics of TSF in dogs and cats, the relationship between those fractures and neurological signs, and other variables that may affect outcome, such as presence of brain edema or hemorrhage. Our results indicate that the TSF pattern in dogs and cats is significantly different, with the cranial vault more commonly involved in dogs and the face and base of the cranium more commonly involved in cats. In addition, the number of fractures per animal was found to be higher in cats than in dogs. Several reasons can be hypothesized to explain these findings, including anatomical variations between dogs and cats (eg, dogs in general are larger than cats). Therefore, for the same type of traumatic event, cats are expected to suffer more damage than dogs, because dogs generally have thicker bones and muscles that likely provide additional protection during trauma. Although the anatomic region in which the trauma occurs plays a role, some of the fractures could have been caused by the way the animals strike the pavement. Cats more often may land on all 4 limbs, making fractures of the base of the cranium more likely. Interestingly, for cats, a recent study reported findings similar to ours with the face region more often affected and multiple fractures present per cat.<sup>18</sup>



**FIGURE 5** Bar graphs showing the specific bone location of fractures of the face (A), cranial vault (B), and the base of the cranium (C)

Chihuahuas and Yorkshire Terriers represented almost 20% of the dogs in our study. These breeds have very similar or even lower body weight than cats, which may predispose them to more damage than larger dog breeds, as discussed for cats. Furthermore, the predisposition of the Chihuahua and Yorkshire Terrier to delayed fontanelle closure, usually as a consequence of congenital hydrocephalus,<sup>19</sup> creates a weaker point in the skull, which likely increases the risk of fractures in this area, sometimes following bony sutures. Also, both breeds tend to show more signs of aggression compared to other breeds, which also could explain why they more often are involved in traumatic events.<sup>20</sup>

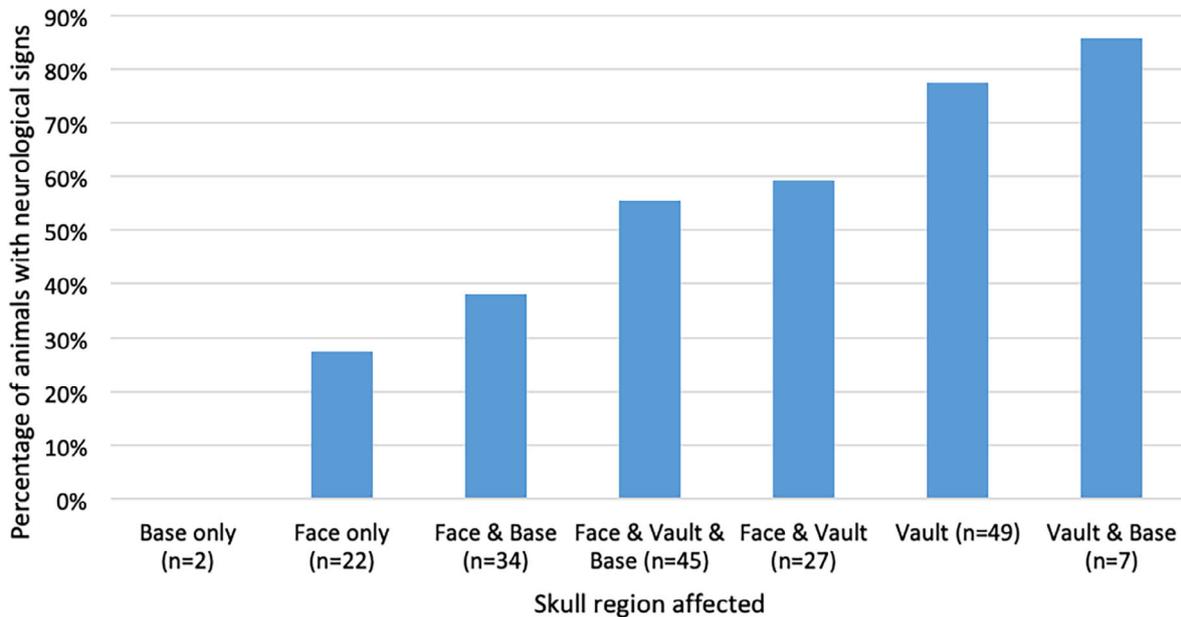
Road traffic accident was the most commonly reported cause of skull fractures in both dogs and cats. Several studies have analyzed the epidemiology, signalment, clinical signs, and outcome of RTA in dogs and cats. A previous study evaluated the prevalence of RTA in dogs throughout central and southeastern United Kingdom.<sup>21</sup> This study showed a total prevalence of 0.41%, compared to other

**TABLE 5** Type of fractures observed in dogs and cats with TSF

Type of fracture	n (%) of fractures	
	Dogs (n = 293)	Cats (n = 700)
Non-fragmented	145 (49.5% of 293)	308 (44.0% of 700)
Non-displaced	87 (60.0)	246 (79.9)
Displaced not depressed	33 (22.8)	40 (13.0)
Depressed	25 (17.2)	22 (7.1)
Fragmented	148 (50.5% of 293)	392 (56.0% of 700)
Non-displaced	26 (17.6)	122 (31.1)
Displaced not depressed	63 (42.6)	151 (38.5)
Depressed	59 (39.9)	119 (30.4)

common diseases such as epilepsy (0.62%) or chronic kidney disease (0.37%). Also, being <3 years of age resulted in higher odds of RTA compared to older dogs (>14 years). These findings resembled our findings. In dogs, use of a lead while being walked outside, presence of behavioral abnormalities or other medical comorbidities, appropriate training, and other factors have been hypothesized to play a role.<sup>18,21,22</sup> Nevertheless, it is probably a combination of all of these features that predisposes younger dogs to vehicular accidents. One limitation in evaluating the predisposition of our population is the geographic diversity. Animals living in rural regions may be more likely to be attacked by wild animals and horses. On the other hand, dogs and cats living in urban areas, especially those close to parks in which dogs are left off-lead or in rural areas close to roads, may be at increased risk of being hit by a car.<sup>18</sup>

Our results suggest that TSF of the cranial vault and depressed fractures in this region are strong risk factors for the occurrence of neurological signs and TBI in both species. In addition, other intracranial changes such as brain edema or intra-axial or extra-axial hemorrhage were almost exclusively found in patients with this region affected. Previous studies have reported several aspects of TBI both on MRI and CT.<sup>8,23</sup> The main aim of these studies was to develop prognostic scores for dogs after suffering head trauma with brain involvement. In both studies, significant associations were found between MRI and CT findings and prognosis in dogs with TBI. In our study, patients with TSF in the cranial vault had lower first-week survival compared to the other patients, especially when those fractures were fragmented or displaced. The cranial vault provides protection to the brain except for its ventral portion. Therefore, direct damage to these bones is more likely to involve the brain parenchyma. These findings are further supported by the decreased likelihood of developing neurological signs and intracranial changes when only the face is involved, because this region does not cover the brain. In the patients with only face fractures, the cause of TBI is likely high velocity or force associated with the traumatic event, as previously discussed. Patients with neurological signs were also more likely to be euthanized. Nevertheless, almost 85% of our patients survived for at least 1 week after trauma, suggesting a relatively good prognosis despite the presence of TSF.



**FIGURE 6** Bar graph showing the percentage of animals with neurological signs per anatomical region affected. Vault, cranial vault; Base, base of cranium

Seizures were reported in only a few cases. One dog and 2 cats had seizures after the initial traumatic event (24 hours). These results are in contrast to previous studies,<sup>8</sup> in which 52% of dogs with TSF had seizures. In this previous study, the investigators subdivided the patients by time of seizure development into immediately (<24 hours), early (within a week), and late-onset (>1 week) seizures. In our study, animals were evaluated for seizures at the initial presentation. Therefore, it is unclear whether some of the patients enrolled in our study developed seizures at some later point in time. As did dogs, cats showed a low incidence of seizures at presentation, approximately 2.1%. To the best of our knowledge, immediate post-traumatic seizures have not been reported previously in cats. Additional studies will be required to determine the actual incidence during early and late-onset phases. Also in our study, not all of the animals likely had TBI, and some merely may have had fractures in the face and no neurological deficits.

Fluid in the frontal sinus was commonly encountered in both dogs and cats with TSF in our study. However, whereas evidence of fracture of the frontal bone was found in all affected dogs, no signs of bony involvement were found in approximately 50% of affected cats. The frontal sinus is a highly vascularized region. Vessels can be damaged by trauma, and secondary fluid leakage or hemorrhage may occur. We hypothesized that frontal sinuses may be more protected in dogs than in cats (eg, higher bone thickness, better muscle coverage), and therefore requiring more severe trauma or physical disruption of the sinus to cause fluid or blood accumulation.

Another interesting finding was the presence of pneumocephalus. It was observed in 6.6% of dogs and 4.2% of cats with TSF. Pneumocephalus always was associated with a fracture of the cranial vault in which bony displacement occurred. This low incidence is similar to that found in humans.<sup>24</sup> An incidence of 9.7% was found in

human patients with trauma affecting the head.<sup>24</sup> Interestingly, some of these human patients did not have any evidence of skull fracture. Air may originate from outside of the patient if the fracture is open, or from the sinus, nasal cavity, pharynx, or ear.<sup>24</sup> Although this air could be reabsorbed spontaneously in many cases, if the amount of air is sufficient to cause compression of brain tissue, surgical suction may be required. In our study, no reports of surgical decompression for this reason were identified, and it was considered an incidental finding.

In our study, at least 5% of animals with TSF had vertebral fractures, luxations, or both in the cervical region. This finding emphasizes the importance of imaging this region in animals with a history of head trauma, because lesions affecting multiple neuroanatomical sites may be present and difficult to identify clinically.

The analysis of 186 CT scans for our study confirmed that the proposed classification system was easy to use, because it is based on a simple assessment of fracture lines and the position of the fragment in relation to the surrounding bone. However, most difficult was the detection of bony margins, especially when the fracture affected the suture lines. Also, the transition between different bones (eg, maxillary to lacrimal) may be subjective in some cases, because a definitive suture line may not be present depending on CT slice thickness. Another problem we experienced was related to the anatomic variation. The inclusion of brachycephalic, mesocephalic, and dolichocephalic breeds resulted in differences among patients. Thorough knowledge of skull anatomy is necessary to identify each bone precisely. However, CT still provides excellent bony resolution and facilitates identification of the bone that is affected in most of cases.

Our study had several limitations inherent to its retrospective nature. The lack of complete medical history and follow-up may have resulted in underestimation of the clinical consequences of these traumatic events. The cause of the trauma could not always be

**TABLE 6** Risk factors for the occurrence of neurological signs in dogs and cats with TSF

Risk factor	Category	n (%) of dogs with neurological signs among animals of a particular category	P value	OR (CI 95%)	n (%) of cats with neurological signs among animals of a particular category	P value	OR (CI 95%)
Region affected							
Cranial vault	Yes	50/72 (69.4)	.009	3.9 (1.4, 11.2)	35/56 (62.5)	.002	3.8 (1.6, 8.9)
	No	7/19 (36.8)			12/39 (30.8)		
Base of cranium	Yes	13/18 (72.2)	.3	-	31/70 (44.3)	.09	-
	No	44/73 (60.3)			16/25 (64.0)		
Only face region	Yes	4/14 (28.6)	.004	0.2 (0.1, 0.6)	2/8 (25.0)	.1	-
	No	53/77 (68.8)			45/87 (51.7)		
Type of fracture of vault region							
Fragmented	Yes	29/47 (61.7)	.8	-	27/42 (64.3)	.01	3.0 (1.3, 6.9)
	No	28/44 (63.6)			20/53 (37.7)		
Displaced but no depressed	Yes	40/58 (69.0)	.1	-	15/28 (53.6)	.6	-
	No	17/33 (51.5)			32/67 (47.8)		
Depressed	Yes	30/38 (79.0)	.007	3.6 (1.4, 9.3)	10/13 (76.9)	.03	4.1 (1.1, 15.8)
	No	27/53 (50.9)			37/82 (45.1)		

ascertained. Some of the medical records had only a brief description of the animal's neurological signs. Therefore, it was not always clear whether or not the remainder of the neurological examination was unremarkable or if a full neurologic examination was not performed for medical (eg, suspected spinal fracture) or other reasons (eg, aggressive animal). Furthermore, evaluation of gait and proprioception in cats can be more challenging than in dogs. This difference could have caused less than ideal evaluation of cats, and potentially underestimation of the prevalence of some neurological deficits. For this reason, prospective studies are necessary to completely characterize the neurological presentation of animals with TSF, ideally using a standardized examination and record sheet.

In conclusion, dogs and cats showed differences in TSF distribution and patterns, with the cranial vault more commonly involved in dogs, and the face and base of the cranium more commonly involved in cats. Neurological signs were common in both species and more frequent in fractures of the cranial vault. The proposed TSF classification was easy to use and simplifies the classical description of skull fractures. The mere presence of TSF should not be considered a negative prognostic factor. Patients with fragmented or displaced fractures affecting the cranial vault seemed to have a worse prognosis, but further prospective studies are warranted.

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#### CONFLICT OF INTEREST DECLARATION

Authors declare no conflict of interest.

#### OFF-LABEL ANTIMICROBIAL DECLARATION

Authors declare no off-label use of antimicrobials.

#### INSTITUTIONAL ANIMAL CARE AND USE COMMITTEE (IACUC) OR OTHER APPROVAL DECLARATION

Authors declare no IACUC or other approval was needed.

#### HUMAN ETHICS APPROVAL DECLARATION

Authors declare human ethics approval was not needed for this study.

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### SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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