



CT findings and the prognostic value of the Koret CT score in cats with traumatic brain injury

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Abstract

Objectives The aims of this study were to evaluate associations between abnormal head CT findings and outcome, and to examine the prognostic value of the Koret CT score (KCTS) in cats sustaining acute traumatic brain injury (TBI).

Methods The medical records of cats hospitalised with TBI that underwent head CT scans within 72 h of admission were retrospectively reviewed. CT scans were evaluated independently by a radiologist and a neurologist who were blinded to the outcome. A KCTS and modified Glasgow Coma Scale (MGCS) were assigned to each cat and the association between abnormal CT findings, KCTS, MGCS and outcome were analysed.

Results Fourteen cats were included in the study: nine (64.2%) survivors and five (35.7%) non-survivors. Of the nine cats that were discharged, one was a short-term survivor (10 days) and eight (57.1%) were long-term survivors (≥ 6 months). Abnormal CT findings included lateral ventricle asymmetry/midline shift (42.8%), intracranial haemorrhage (35.7%), caudotentorial lesions (14.2%) and cranial vault fractures (14.2%), all of which were depressed. Intracranial haemorrhage was found to be significantly and negatively associated with short-term ($P=0.005$) and long-term ($P=0.023$) survival. KCTS was significantly associated with short-term survival ($P=0.002$) and long-term survival ($P=0.004$). A KCTS cut-off value of 2 yielded a 100% sensitivity and 100% specificity for short-term survival and 100% sensitivity and 80% specificity for long-term survival. An MGCS cut-off value of ≥ 13 was associated with a 100% sensitivity and 100% specificity for short-term survival, and with a 100% sensitivity and 80% specificity for long-term survival.

Conclusions and relevance KCTS, performed up to 72 h from injury, can be used as an additional diagnostic tool for the prediction of survival in cats with TBI.

Keywords: CT; traumatic brain injury; prognosis; intracranial haemorrhage

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Introduction

Traumatic brain injury (TBI) is defined as structural injury and/or physiological disruption of brain function induced by an external force, leading to neurological deficits immediately following the event.¹ Common causes of TBI in cats include road traffic accidents, falls from a height, bite wounds, assaults by humans, crushing and shooting injuries.^{2–5} The diversity of causes and the variability in the extent of trauma is reflected by a wide range of clinical signs, from minor neurological deficits to life-threatening and irreversible brain damage.^{6,7} Of cats with head trauma that present with skull fractures, nearly 30% will display neurological abnormalities.⁷ Despite the high prevalence of head trauma in cats,^{3,7} little is known about the nature of the resulting brain injury in this species and its association with neurological signs and prognosis.⁶

In a study by Caine et al,⁸ MRI findings of bilateral or multifocal T2 hyperintensities, mass effect and caudal transtentorial herniation were found to be significantly associated with a poor outcome.

In human medicine, CT is the imaging modality of choice in acute TBI^{9–11} because it allows rapid identification of life-threatening conditions. Furthermore, several classification methods based on the initial CT findings are routinely used for predicting prognosis.^{12–14}

Recently, a prognostic CT-based scoring index for dogs with TBI was introduced.¹⁵ This score, named the Koret CT score (KCTS), was based on abnormal findings on CT scans obtained within 72h of admission in 27 dogs with TBI. Specifically, haemorrhage and ventricular asymmetry were significantly and negatively associated with short- and long-term survival, respectively, in dogs with TBI.¹⁵ A similar scoring system for cats with TBI may be useful in clinical practice for better treatment planning and evaluation of prognosis. Therefore, this study aimed to provide a detailed description of abnormal CT findings and to evaluate the prognostic value of these findings and the KCTS in cats with TBI.

Materials and methods

The radiology archive of the Koret School Veterinary Teaching Hospital was searched for cats that underwent a head CT within 72h of a known TBI between 2008 and 2019. Data collected from the medical records included signalment, history (including the cause of injury), clinical signs, neurological findings, modified Glasgow Coma Scale (MGCS) on admission, CT findings, treatment and outcome. TBI was determined based on history and clinical evaluation, and was considered only if neurological impairment, which was judged to be secondary to brain injury, was observed. Cats that died for reasons unrelated to TBI and cats that underwent decompressive surgery were excluded.

Short-term survival was defined as survival for at least 10 days after the initial trauma and long-term survival was defined as survival for at least 6 months. A telephone survey with the owners was conducted to ascertain long-term survival. During the conversation, owners were asked to grade their cat's quality of life subjectively on a scale from poor to excellent (poor = unable to perform basic daily tasks such as ambulation or owner recognition; inadequate = needs assistance to perform daily tasks; fair = still disabled but needs no assistance to perform basic tasks; good = minor residual deficits; excellent = complete recovery of neurological function).

CT scans were performed using one of two CT scanners (Elscent Twin or 16-slice Philips MX 8000 IDT) with a slice thickness of 1 mm for all cats; all scans were conducted without intravenous contrast medium administration. Brain, lung and bone CT windows in transverse and additional reconstructed planes were used to evaluate lesions. All scans were reviewed retrospectively and independently by the same radiology specialist (DP) and a board-certified neurologist (OC), who were blinded to the cats' clinical status and outcome.

CT abnormalities recorded for each cat included location (intra- or extra-axial) and number (single or multiple) of intracranial haemorrhages; cranial vault fractures and displacement (ie, depressed or not); midline shift, lateral ventricle asymmetry and hydrocephalus; parenchymal hypodensity; and the presence and location of bone fractures.

The calculation of the KCTS in each cat was based on the presence of the relevant CT abnormalities (Table 1); the total score ranged from 0 to 7.

The MGCS¹⁶ was calculated by evaluating motor activity, brainstem reflexes and level of consciousness on a scale of 1–6, wherein a score of 6 represented normal findings, and a score of 1 represented severe impairment. The total possible score ranged from 3 (least likely to survive) and 18.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics version 24. Association between CT findings and survival was assessed by Fisher's exact test

Table 1 Scoring values of the Koret CT score system

Parameter	Score
Haemorrhage	1
Midline shift/lateral ventricle asymmetry	1
Any caudotentorial lesion (hypodensity, haemorrhage, fracture)	3
Cranial vault fracture	1
Depressed fracture	1
Total score	0–7

of independence, with a 95% confidence interval (CI). Differences in KCTS between survivors and non-survivors (both short- and long-term) was assessed by the Mann–Whitney U-test. Receiver–operating characteristic (ROC) curve analysis was conducted to find the optimal cut-off point of the scoring index that would offer the best combination of sensitivity and specificity. The reported sensitivity and specificity were calculated using the recommended cut-off point. The relationship between MGCS and KCTS was determined by Spearman's rank correlation coefficient. Categorical variables (ie, CT findings) are presented as percentages and frequencies, while quantitative variables are presented as medians and ranges.

Results

Animals

Fourteen cats met the inclusion criteria of this study, of which nine (64.2%) were male (six castrated, three sexually intact), and five (35.7%) were female (four spayed and one sexually intact). Eleven cats were domestic short- or longhairs, and there was one each of Persian, Siamese and Ragdoll breeds. Mean age was 3.7 years (median 1.75 years, range 3 months to 15 years).

The most common cause of TBI was road traffic accidents ($n = 7$; 50%) followed by falls from a height ($n = 3$; 21.4%), dog bites ($n = 2$; 11%) or traumatic injury caused by an object ($n = 2$; 11%). Concurrent injuries were documented for all cats and included facial bone fractures in nine (64.3%), epistaxis and mouth bleeding in eight (57.1%), ocular injuries and lower airway injuries in six ($n = 42.8\%$) and bone or rib fractures in three (21.4%) cats.

Neurological examination findings and MGCS

All 14 cats had abnormal mentation, including depression ($n = 7/12$), semi-coma ($n = 5/12$) and stupor ($n = 2/12$). Cranial nerve abnormalities included anisocoria ($n = 8/14$; 57.1%), absent or diminished pupillary light reflex ($n = 7/14$; 50%), absent or diminished palpebral reflex ($n = 3/14$; 21.4%), absent gag reflex ($n = 1/14$; 7.1%), quadriparesis ($n = 1/14$; 7.1%) and head tilt ($n = 1/14$; 7.1%). Other neurological abnormalities included absent menace response ($n = 6/14$; 42.8%), head turn ($n = 3/14$; 21.4%), miosis ($n = 3/14$; 21.4%) and third eyelid protrusion ($n = 2/14$; 14.3%). The three cats with miosis were different from the cats with third eyelid protrusion and they displayed other neurological signs; therefore, these cats were not suspected as having Horner's syndrome. Seizures were documented in one cat.

An MGCS was recorded for all cats. Five cats were scored 15–18, seven 9–14 and two 3–8. Mean MGCS was 13.14 (median 14, range 7–17).

Outcome

Ten (71.4%) cats survived for at least 10 days after the initial TBI and nine (64.3%) survived for at least 6 months. One cat was euthanased after 14 days owing to severe

lower airway complications. Of the five (35.7%) non-survivors, one was euthanased and four died during hospitalisation. The median hospitalisation period for survivors was 4 days (range 2–14) and for non-survivors it was 2 days (range 1–2).

In the nine long-term survivors, the owner's assessment of their quality of life at 6 months post-injury was subjectively categorised as excellent for five cats (55.5%), good for one cat (11.1%) and fair for three cats (33.3%).

CT characteristics and KCTS

Thirteen cats (92.8%) had abnormal findings identified on the CT scan, all demonstrating multiple lesions. These included cranial vault fractures or brain parenchymal changes ($n = 11/14$; 78.6%), abnormalities of the brain parenchyma ($n = 9/14$; 64.3%), lateral ventricle asymmetry/midline shift ($n = 6/14$; 42.8%), intracranial parenchymal haemorrhage ($n = 5/14$; 35.7%) and epidural haemorrhage in one (Figure 1). Brain parenchymal hypodensity was also recorded ($n = 3/14$; 21.4%), likely consistent with brain oedema. Cranial vault fractures ($n = 2/14$; 14.3%) were both complex and depressed temporal bone fractures. Caudotentorial lesions (brainstem haemorrhage and brainstem oedema) were also recorded ($n = 2/14$; 14.3%) (Figure 2), as were facial bone fractures ($n = 8/14$; 57.1%).

A KCTS was calculated for all 14 cats with a mean score of 1.5 (median 1, range 0–5). The median KCTS for cats surviving ≤ 10 days was 0 (range 0–2, interquartile

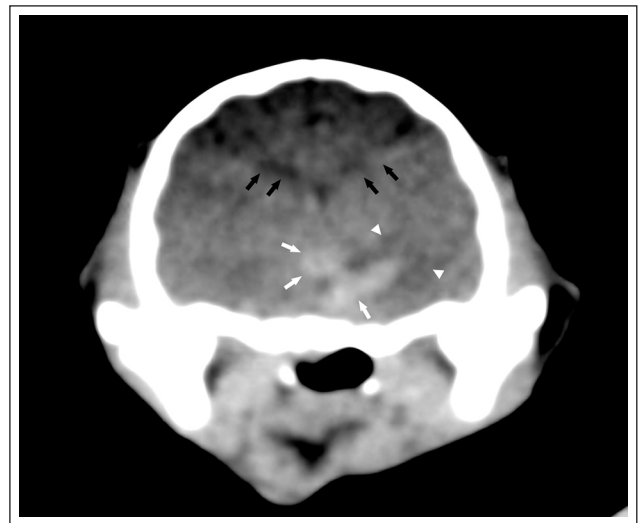


Figure 1 Transverse unenhanced CT image of the head of a 2-year-old castrated male domestic shorthair cat following traumatic brain injury. A brain-windowed image at the level of the interthalamic adhesion shows a hyperattenuating lesion (white arrows) surrounded by a hypoattenuating area (white arrowheads) consistent with acute parenchymal haemorrhage with surrounding parenchymal oedema; lateral ventricular asymmetry (black arrows) is also noted. The presence of haemorrhage and lateral ventricular asymmetry at this location each grants 1 point to the Koret CT score

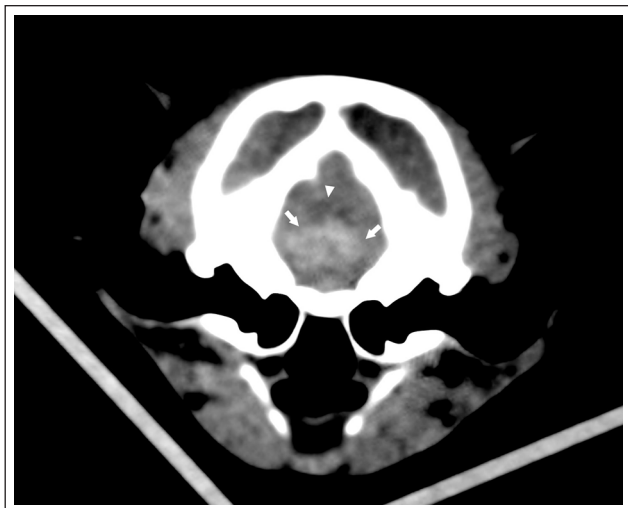


Figure 2 Transverse unenhanced CT image of the head of a 4.5-month-old intact female Ragdoll cat following traumatic brain injury. A brain-windowed image at the level of the tentorium shows a caudotentorial hyperattenuating lesion (white arrows) surrounded by mild hypoattenuating focal area (arrowhead) consistent with acute haemorrhage surrounded by mild oedema. On the Koret CT score, 3 points are granted for caudotentorial oedema and 1 point for parenchymal haemorrhage

range [IQR] 0–1) and 0 (range 0–2, IQR 0–1) for cats that survived 6 months after TBI. In the non-survivor group, the median score was 3 (range 1–5, IQR 1.5–4.5) (Table 2).

Association with outcome

Of all the CT abnormalities, intracranial haemorrhage was the only finding that was found to be significantly and negatively associated with short-term ($P = 0.005$) and long-term ($P = 0.023$) survival. A significant negative association was found between the KCTS and both short-term ($P = 0.002$) and long-term survival ($P = 0.004$). We conducted ROC curve analysis to determine the sensitivity and specificity of the KCTS. The results showed that the area under the curve (AUC) was 1 for short-term survival and 0.96 (95% CI 0.63–1.00) for long-term survival. A KCTS cut-off value of ≤ 2 was associated with a 100% sensitivity and 100% specificity for short-term survival, and with a 100% sensitivity and 80% specificity for long-term survival.

The median MGCS was 15 for cats that survived in the short term and in the long term (range 13–17; IQR 14–16 [for both]); for the non-survivors, median MGCS was 10 (range 7–15; IQR 8–12). MGCS was significantly and negatively associated with short-term ($P = 0.002$) and long-term survival ($P = 0.023$). ROC analysis to determine the sensitivity and specificity of MGCS showed that the AUC was 1 for short-term survival and 0.88 (95% CI 0.35–1.00) for long-term survival. An MGCS cut-off value of ≥ 13 was associated with a 100% sensitivity and 100% specificity for short-term survival and with a 100% sensitivity and 80% specificity for long-term survival. A moderate negative correlation was found between KCTS and MGCS ($R = -0.57$; $P = 0.032$).

Table 2 Koret CT score (KCTS), lesion types and modified Glasgow Coma Scale (MGCS) scores in the survivor and non-survivor groups

Variable	All patients (n = 14)	Non-survivors (n = 5)	Short-term survivors (n = 10)	Long-term survivors (n = 9)
CT findings				
Intracranial haemorrhage	5	4	1	1
Cranial vault fracture	2	2	0	0
Depressed fracture	2	2	0	0
Any caudotentorial lesion	2	2	0	0
Midline shift/lateral ventricle asymmetry	6	3	4	3
Median (IQR; range)		3 (1.5–4.5; 0–3)	0 (0–1; 0–2)	0 (0–1; 0–2)
KCTS				
0	6	0	6	6
1	3	1	3	2
2	1	0	1	1
3	2	2	0	0
5	2	2	0	0
Median (IQR; range)		10 (8–12; 7–15)	15 (14–16; 13–17)	15 (14–16; 13–17)
MGCS				
3–8	2	2	0	0
9–14	7	2	5	5
15–18	5	1	5	4

IQR = interquartile range

Discussion

In recent years, CT has become increasingly used as a diagnostic tool for assessing traumatic injuries in veterinary medicine.^{17–19} While CT scans require sedation in most patients, the use of head and whole body CT scanning following traumatic injuries provides detailed anatomical information at high resolution in a relatively short time. This wealth of cross-sectional data allows for accurate diagnosis and assists in treatment planning, including surgery. Furthermore, CT examination of the head can be performed quickly, providing sufficient resolution to identify haemorrhage, brain oedema, mass effect and fractures, thereby enabling rapid and potentially life-saving intervention.^{4,20} These advantages make CT imaging the diagnostic modality of choice in the acute care of patients with TBI.

The high prevalence (92.8%) of abnormal findings in head CT observed in our study and, particularly, the high prevalence (78.5%) of cranial vault fractures or brain parenchymal changes, support the use of CT scanning as an appropriate diagnostic tool following TBI in cats. These numbers are in line with similar publications on TBI in dogs, reporting 90–100% abnormal findings.^{15,21}

Intracranial haemorrhage was the only abnormal CT finding that was negatively associated with the outcome. This can be explained both by the traumatic force required to inflict bleeding and by the occurrence of secondary brain injuries, such as increased intracranial pressure, tissue hypoperfusion and severe tissue acidosis, all of which can be life threatening.²⁴ A similar association was found in dogs^{15,22} and cats.⁸ In our study, besides haemorrhage, no other abnormal CT findings were associated with the outcome. This lack of association probably reflects the combination of a large variety of detected abnormal findings and a relatively small number of cats, emphasising the necessity of a CT-based scoring system to consider multiple findings.

In humans, CT-based scoring systems for the prognosis of TBI have been used routinely for nearly 30 years.¹² To date, there are several CT scoring systems applied to human patients with TBI, namely the Marshall, Rotterdam, Helsinki and NeuroImaging Radiological Interpretation System CT scores.^{12–14,23} However, owing to inherent differences in anatomy and image resolution between humans and animals, these scales cannot be easily applied in veterinary medicine.

In this study, the KCTS was found to be a valid tool for predicting outcome in cats with a TBI. A statistically significant association was found between the KCTS and both short- and long-term survival. Furthermore, a KCTS cut-off score of 2 yielded sensitivities and specificities of 100% and 100% for short-term survival and 100% and 80% for long-term survival, respectively. This can aid clinical decisions, as it can support pursuing treatment in

cats with such a score, even when the clinical evaluation is discouraging.

A comparison of our abnormal CT findings and a study describing MRI findings in 30 cats with TBI⁸ reveals similar incidences of brain parenchymal lesions (64% vs 67%, respectively). Cranial vault fractures were noted in 14.2% in our study, all of which were depressed, compared with 40% fractures in the MRI study, of which only 16.6% were depressed. Caudotentorial lesion is less common in cats with TBI, as it was recorded only in 14.2% of the cats in our study and in 10% on MRI.⁸

One (7.1%) cat presenting with clinical neurological abnormalities did not have abnormalities on CT. We assume that this case could have suffered brain concussion without structural lesions, or that the brain parenchymal lesions were not detected by CT.²⁴

MGCS has previously been shown to be significantly correlated with survival,²⁵ as was also found in our study. It has the advantage of not requiring chemical restraint or expensive equipment, and it can be performed repeatedly to monitor changes in the neurological status of a patient. However, the MGCS may be affected by various external factors, including the use of analgesia and sedatives, spinal cord injury and poor systemic conditions such as hypovolaemic shock. These limitations may reduce its prognostic accuracy in individual cases, which justifies the use of additional objective prognostic tools. Interestingly, our results showed only a moderate negative association between KCTS and MGCS, possibly reflecting the different parameters considered in each scoring method. An example of such discrepancy is two cats that had an MGCS of 13 and a KCTS of 0 – both survived for the long term. In those cats, the KCTS better predicted the positive outcome. These findings emphasise the necessity to consider both clinical assessment and diagnostic imaging findings to determine the prognosis for a cat with TBI.

The long-term quality of life (QoL) survey results suggest that 100% of cats that survived to discharge had a fair to excellent QoL. Similarly, high results have been reported previously in both dogs and cats that recovered from TBI.^{8,15,26}

In head trauma, clinical assessment of TBI vs conditions such as miosis due to traumatic uveitis or Horner's syndrome is challenging.⁴ In this study, we considered TBI only if neurological impairment was apparent and was assessed secondary to brain injury, and not to damage in peripheral nerves, ocular tissue or the spinal cord. Cases with neurological deficits that were considered unrelated to the TBI were excluded.

The main limitation of this study was the small number of cats that were included, which restricted the statistical power of the results. Thus, a larger-scale study is warranted to confirm our findings. Another limitation

was the CT inherent beam hardening artefact of the caudal fossa, which could be interpreted as hypodensity or obscure the lesion in that area. Lastly, the evaluation of the inter-observer reliability of the KCTS in an independent data set is warranted.

Conclusions

Head CT detected abnormal findings in most cats following acute TBI. Intracranial haemorrhage was the only abnormal finding that was negatively associated with outcome. The KCTS appears to be a useful prognostic tool, with a cut-off score of 2 predicting survival with high sensitivity and specificity.

Conflict of interest The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Ethical approval This work involved the use of non-experimental animals only (including owned or unowned animals and data from prospective or retrospective studies). Established internationally recognised high standards ('best practice') of individual veterinary clinical patient care were followed. Ethical approval from a committee was therefore not necessarily required.

Informed consent Informed consent (either verbal or written) was obtained from the owner or legal custodian of all animal(s) described in this work (either experimental or non-experimental animals) for the procedure(s) undertaken (either prospective or retrospective studies). For any animals or humans individually identifiable within this publication, informed consent (either verbal or written) for their use in the publication was obtained from the people involved.

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References

- 1 Management of Concussion/mTBI Working Group. VA/DoD clinical practice guideline for management of concussion/mild traumatic brain injury. *J Rehabil Res Dev* 2009; 46: CP1–CP68.
- 2 Dewey CW. Emergency management of the head trauma patient. Principles and practice. *Vet Clin North Am Small Anim Pract* 2000; 30: 207–225.
- 3 Adamantos S and Garosi L. Head trauma in the cat. 1. Assessment and management of craniofacial injury. *J Feline Med Surg* 2011; 13: 806–814.
- 4 Kuo KW, Bacek LM and Taylor AR. Head trauma. *Vet Clin North Am Small Anim Pract* 2018; 48: 111–128.
- 5 Dewey CW, Downs MO and Aron DN. Acute traumatic intracranial haemorrhage in dogs and cats: a retrospective evaluation of 23 cases. *Vet Comp Orthop Traumatol* 1993; 6: 153–159.
- 6 Garosi L and Adamantos S. Head trauma in the cat. 2. Assessment and management of traumatic brain injury. *J Feline Med Surg* 2011; 13: 815–823.
- 7 Knight R and Meeson RL. Feline head trauma: a CT analysis of skull fractures and their management in 75 cats. *J Feline Med Surg* 2019; 21: 1120–1126.
- 8 Caine A, Brash R, Dennis R, et al. Magnetic resonance imaging in 30 cats with traumatic brain injury. *J Feline Med Surg* 2019; 21: 1111–1119.
- 9 Koliass AG, Guilfoyle MR, Helmy A, et al. Traumatic brain injury in adults. *Pract Neurol* 2013; 13: 228–235.
- 10 Currie S, Saleem N, Straiton JA, et al. Imaging assessment of traumatic brain injury. *Postgrad Med J* 2016; 92: 41–50.
- 11 Le TH and Gean AD. Neuroimaging of traumatic brain injury. *Mt Sinai J Med* 2009; 76: 145–162.
- 12 Marshall LF, Marshall SB, Klauber MR, et al. A new classification of head injury based on computerized tomography. *J Neurosurg* 1991; 75 Suppl 1: S1–S66.
- 13 Raj R, Siironen J, Skrifvars MB, et al. Predicting outcome in traumatic brain injury: development of a novel computerized tomography classification system (Helsinki computerized tomography score). *Neurosurgery* 2014; 75: 632–646.
- 14 Maas AIR, Hukkelhoven CWPM, Marshall LF, et al. Prediction of outcome in traumatic brain injury with computed tomographic characteristics: a comparison between the computed tomographic classification and combinations of computed tomographic predictors. *Neurosurgery* 2005; 57: 1173–1178.
- 15 Chai O, Peery D, Bdoalah-Abram T, et al. Computed tomographic findings in dogs with head trauma and development of a novel prognostic computed tomography-based scoring system. *Am J Vet Res* 2017; 78: 1085–1090.
- 16 Platt SR, Radaelli ST and McDonnell JJ. The prognostic value of the modified Glasgow coma scale in head trauma in dogs. *J Vet Intern Med* 2001; 15: 581–584.
- 17 Dozeman ET, Prittie JE and Fischetti AJ. Utilization of whole body computed tomography in polytrauma patients. *J Vet Emerg Crit Care (San Antonio)* 2020; 30: 28–33.
- 18 Dancer SC, Le Roux C, Fosgate GT, et al. Radiography is less sensitive relative to CT for detecting thoracic radiographic changes in dogs affected by blunt trauma secondary to a motor vehicle accident. *Vet Radiol Ultrasound* 2019; 60: 648–658.
- 19 Kirberger RM, Leisewitz AL, Rautenbach Y, et al. Association between computed tomographic thoracic injury scores and blood gas and acid–base balance in dogs with blunt thoracic trauma. *J Vet Emerg Crit Care* 2019; 29: 373–384.
- 20 Kim JJ and Gean AD. Imaging for the diagnosis and management of traumatic brain injury. *Neurotherapeutics* 2011; 8: 39–53.
- 21 Platt SR, Radaelli ST and McDonnell JJ. Computed tomography after mild head trauma in dogs. *Vet Rec* 2002; 151: 243. DOI: 10.1136/vr.151.8.243.

- 22 Beltran E, Platt SR, McConnell JF, et al. **Prognostic value of early magnetic resonance imaging in dogs after traumatic brain injury: 50 cases.** *J Vet Intern Med* 2014; 28: 1256–1262.
- 23 Wintermark M, Li Y, Ding VY, et al. **Neuroimaging radiological interpretation system for acute traumatic brain injury.** *J Neurotrauma* 2018; 35: 2665–2672.
- 24 Giannuzzi AP, De Simone A and Ricciardi M. **Spontaneous nervous system concussion in dogs: a description of two cases and a review of terminology in veterinary medicine.** *Open Vet J* 2017; 7: 306–312.
- 25 Lapsley J, Hayes GM and Sumner JP. **Performance evaluation and validation of the Animal Trauma Triage score and modified Glasgow Coma Scale in injured cats: a Veterinary Committee on Trauma registry study.** *J Vet Emerg Crit Care* 2019; 29: 478–483.
- 26 Yanai H, Tapia-Nieto R, Cherubini GB, et al. **Results of magnetic resonance imaging performed within 48 hours after head trauma in dogs and association with outcome: 18 cases (2007–2012).** *J Am Vet Med Assoc* 2015; 246: 1222–1229.