Computed tomographic findings in dogs with head trauma and development of a novel prognostic computed tomography–based scoring system

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OBJECTIVE
To characterize CT findings and outcomes in dogs with head trauma and design a prognostic scale.

ANIMALS
27 dogs admitted to the Koret School Veterinary Teaching Hospital within 72 hours after traumatic head injury that underwent CT imaging of the head.

PROCEDURES
Data were extracted from medical records regarding dog signalment, history, physical and neurologic examination findings, and modified Glasgow coma scale scores. All CT images were retrospectively evaluated by a radiologist unaware of dog status. Short-term (10 days after trauma) and long-term (≥ 6 months after trauma) outcomes were determined, and CT findings and other variables were analyzed for associations with outcome. A prognostic CT-based scale was developed on the basis of the results.

RESULTS
Cranial vault fractures, parenchymal abnormalities, or both were identified via CT in 24 of 27 (89%) dogs. Three (11%) dogs had only facial bone fractures. Intracranial hemorrhage was identified in 16 (59%) dogs, cranial vault fractures in 15 (56%), midline shift in 14 (52%), lateral ventricle asymmetry in 12 (44%), and hydrocephalus in 7 (26%). Hemorrhage and ventricular asymmetry were significantly and negatively associated with short- and long-term survival, respectively. The developed 7-point prognostic scale included points for hemorrhage, midline shift or lateral ventricle asymmetry, cranial vault fracture, and depressed fracture (1 point each) and infratentorial lesion (3 points).

CONCLUSIONS AND CLINICAL RELEVANCE
The findings reported here may assist in determining prognoses for other dogs with head trauma. The developed scale may be useful for outcome assessment of dogs with head trauma; however, it must be validated before clinical application. (*Am J Vet Res* 2017;78:1085–1090)

Injury to the skull or brain caused by an external force (ie, head trauma) is common in dogs, identified in 25% of dogs with severe blunt trauma.[1] Causes include road traffic accidents, falls from heights, dog fights, assaults by humans or other animals, and crushing or missile injuries.[1–8] Reported mortality rates of 15% to 24%[1,3,4] indicate a poor prognosis for affected dogs, compared with prognoses for other traumatic injuries.[1,5] The diversity in causes of head trauma is reflected in the variety of associated clinical signs, which range from minor neurologic deficits to life-threatening and possibly irreversible neurologic impairment due to brain damage.[4,6] As a result, various treatment options may be pursued and accurate prognosis is often difficult.

In veterinary medicine, valid prognostic indicators for survival after head trauma are limited in number. Reported indicators include the MGCS,[3,4] which is based on clinical evaluation on admission. A few laboratory findings have been associated with outcomes, such as venous blood base excess and bicarbonate and potassium concentrations, BUN concentration, and plasma lactate concentration[4] as well as certain MRI characteristics (eg, degree of midline shift, high percentage of intraparenchymal lesions, brain herniation, and MRI grade).[7,8] Nevertheless, a readily available tool that enables accurate prognostication for dogs with head trauma is needed for better treatment planning and management.

Neuroimaging of patients with head trauma allows anatomic characterization of fractures, hematomas, contusions, herniations, diffuse axonal injury, brain swelling, and cerebral ischemia and, thereby, facilitates appropriate treatment selection.[9–11] Computed tomography is the modality of choice for imaging humans with acute head injury,[9–12] offering the advantages of short scanning time, detailed images,

ABBREVIATIONS

KCTS	Koret CT score
MGCS	Modified Glasgow coma scale

and high equipment availability. A scoring method based on changes seen on CT scans is reportedly correlated with outcome in humans with head trauma and is hence routinely used to determine prognosis in that species.[12–16] However, information regarding CT findings in dogs with head trauma is limited,[15] and a scoring system that allows association of these changes with prognosis is notably lacking. The purpose of the study reported here was to characterize CT findings in a cohort of dogs with head trauma and identify potential short- and long-term prognostic indicators, with the aim of developing a CT-based scoring system to predict prognosis.

Materials and Methods

Animals

Owners of dogs with head trauma admitted to the Koret School Veterinary Teaching Hospital between January 2010 and January 2015 were offered CT examination of the head as part of the clinical workup for their dogs. Medical records of dogs that had undergone CT examination were analyzed retrospectively. Dogs that had been injured ≥ 72 hours prior to hospital admission were excluded from the study. Dogs that died during treatment were excluded from the analysis if the cause of death was unrelated to the traumatic head injury. All dogs were hospitalized in the intensive care unit and received treatment according to clinical indications.

Medical records review

Data were collected from the medical records regarding signalment, medical history (including the cause of trauma), physical and neurologic examination findings, MGCS score[3] on admission, CT findings, and outcome. The MGCS score was calculated by scoring motor activity, brainstem reflexes, and level of consciousness on a scale of 1 to 6, wherein a score of 6 represented unremarkable findings and a score of 1 represented severe impairment, for a total possible score ranging from 3 (least likely to survive) to 18.[3] Intervals from trauma to hospital admission were categorized as < 8 hours, 8 to 24 hours, or > 24 to 72 hours. Dog breed was categorized as mixed, pure toy breed,[17] and other pure breed. Body weight was categorized as < 5 kg, 5 to 10 kg, 10.1 to 20 kg, and > 20 kg. The occurrence and frequency of seizures were recorded, and occurrence was categorized as ≤ 24 hours, 1 to 7 days, and > 7 days following initial head trauma.

For evaluation of outcomes, short-term survival was defined as survival for 10 days after initial head trauma and long-term survival as survival for at least 6 months after trauma. Cause of death was recorded for nonsurvivors as spontaneous or euthanasia. Long-term outcome was determined by a follow-up telephone interview by one of the investigators (OC) at least 6 months after trauma. Owners were asked to grade their dog's quality of life subjectively on a scale from 1 (poor) to 5 (excellent).

CT examination

A CT scan of the head was performed within 72 hours after trauma with 1 of 2 CT scanners.[a,b] Slice thickness ranged from 0.75 to 2.7 mm, depending on skull size and scanner used. A radiology specialist (DP), who was blinded to the clinical status and outcome of the dogs, retrospectively reviewed the images and later compared her findings with those recorded in the independently written report of the attending neurologist. Brain and bone windows in transverse and reconstructed planes were used to evaluate lesions. Examined abnormalities included the presence of lesions; location (intra-axial or extra-axial) and number (single or multiple) of intracranial hemorrhages, which were diagnosed by areas of hyperdensity; presence, location, number (single or multiple), and displacement (ie, depressed or not) of cranial vault fractures; presence and location of facial bone fractures[6]; presence of midline shift, lateral ventricle asymmetry, and hydrocephalus; and presence of parenchymal hypodensity, which was considered to be consistent with brain edema. All scans were performed without contrast medium administration and with the dogs sedated or anesthetized. All dogs recovered from CT-associated sedation or anesthesia without complication. The CT findings had no effect on the treatment provided to each dog.

Statistical analysis

Statistical software[c] was used for all analyses. Associations were examined between specific CT findings and dog age, sex, breed, and body weight; interval between trauma and initial evaluation; cause of trauma; and concurrent injuries. Associations were also examined between these variables and the outcomes of interest (short- and long-term survival). The χ^2 test was used to examine associations between categorical variables, the Mann-Whitney nonparametric test was used to compare quantitative variables between 2 independent groups, and the Kruskal-Wallis nonparametric test was used to compare quantitative variables between ≥ 3 independent groups. All tests were 2-tailed, and values of $P < 0.05$ were considered significant.

Development of a prognostic scoring system

To provide qualitative outcome assessment for head trauma in dogs, a scoring system, termed the KCTS system, was developed on the basis of significant associations identified between abnormal CT findings and both short- and long-term survival during statistical analysis. The inclusion of specific CT findings and the score assigned to them were decided on the basis of the estimated effect on the outcome. Because of the small number of dogs in the study, CT findings were also included regardless of whether they lacked a significant association with outcome if they were already known or logically presumed to influence the probability of survival.

Results

Animals

Of all dogs admitted with head trauma to the Koret School Veterinary Teaching Hospital between 2010 and 2015, 27 had owner permission to perform a CT examination during the first 72 hours after the traumatic incident, and all 27 dogs were included in the study. Sixteen (59%) dogs were male (3 castrated, 12 sexually intact, and 1 of unknown reproductive status), and 11 (41%) were female (3 spayed and 8 sexually intact). Breeds included mixed (n = 6), Yorkshire Terrier (4), Chihuahua (3), Maltese (2), Toy Poodle (2), and Border Collie, American Staffordshire Bull Terrier, Bichon Frisé, Cavalier King Charles Spaniel, Golden Retriever, Labrador Retriever, Pekingese, Shih Tzu, Pug, and Vizsla (1 each). Sixteen (59%) dogs were classified as toy breeds. Mean age was 4.1 years (SD, 4.4 years; median, 2.0 years; range, 3 months to 15 years), and 21 (78%) dogs were < 5 years of age. Median body weight was 5.55 kg (range, 1.22 to 35 kg), and 19 (70%) dogs weighed ≤ 10 kg.

The most common cause of head trauma was road traffic accident (n = 13 [48%]). Other causes included fall from height (5 [19%]), dog fight (4 [15%]), physical abuse by the owners (2 [7%]), hit by a falling object (2 [7%]), and unknown (1 [4%]). All dogs were admitted within 72 hours after initial head trauma, with 21 (78%) admitted within 8 hours, 3 (11%) within 8 to 24 hours, and 3 within > 24 to 72 hours. Concurrent injuries were documented for only 6 (22%) dogs and included lung contusion (3), humeral fracture (1), corneal perforation (1), and C6 transverse process fracture (1).

Mental status and MGCS score

Mental status and MGCS score were recorded at hospital admission for 26 (96%) dogs. The remaining dog had arrived under general anesthesia administered by the referring veterinarian. Mental status was categorized as unremarkable for 1 (4%) dog, depressed for 5 (20%) dogs, delirium for 7 (27%) dogs, stupor or semicomatose for 9 (34%) dogs, and comatose for 4 (15%) dogs. Mean MGCS score was 11.9 (SD, 4.1; median, 12.5 [range, 4 to 17]) and was assessed as mild (total score, 15 to 18) in 10 of the 26 (38%) dogs, moderate (total score, 9 to 12) in 10 (38%) dogs, and severe (total score, 3 to 8) in 6 (23%) dogs.

Median MGCS score at hospital admission was 14 for dogs that survived for 10 days and 14.5 for dogs that survived ≥ 6 months after initial head trauma; for nonsurvivors, these numbers were 7 and 9, respectively. The MGCS score was significantly associated with short-term (P = 0.006) and long-term (P = 0.01) survival.

Seizures

Seizures were recorded for 8 (30%) dogs. Seven dogs had seizures only during the first 24 hours after initial head trauma, whereas 1 dog had seizures from 1 to 7 days after initial trauma. Antiepileptic treatment was initiated in all 8 dogs with seizures and included phenobarbital (n = 4) or phenobarbital and levetiracetam (4). Seizures were not associated with short- or long-term survival or MGCS score.

CT characteristics

All dogs had abnormal CT findings. Cranial vault fractures (n = 15 [56%]), abnormalities of the parenchyma (23 [85%]), or both were identified in 24 (89%) dogs, whereas 3 (11%) dogs had only facial bone fractures. The most common CT abnormality was areas of hypodensity in the brain, which was identified in 19 (70%) dogs **(Figure 1)**. These involved the cerebral hemisphere or cerebellum as a single lesion (13 [48%]) or multiple lesions (5 [19%]) or a unilateral area in the brainstem (1 [4%]).

Intracranial hemorrhage was identified in 16 (59%) dogs and was intra-axial in 12 and extra-axial in 4. Eleven of these dogs had a single hemorrhage, and 5 had multiple hemorrhages. Cranial vault fractures were detected in 15 (56%) dogs, and 12 of these dogs had multiple fractures. In 8 dogs with cranial vault fracture, the fracture was depressed. Facial bone fractures were identified in 14 (52%) dogs. Midline shift was evident in 14 (52%) dogs, lateral ventricle asymmetry in 12 (44%) dogs, and hydrocephalus in 7 (26%) dogs.

In 24 (89%) dogs, ≥ 1 abnormality was detected via CT. Of the 15 dogs with cranial vault fracture, 12 had parenchymal hypodensity, 11 had hemorrhage, 9 had midline shift, and 8 had ventricular asymmetry. Of the 24 dogs with parenchymal abnormalities, the rostrotentorial area alone was affected in 20 (83%) dogs, the infratentorial area in 2 (8%) dogs, and both

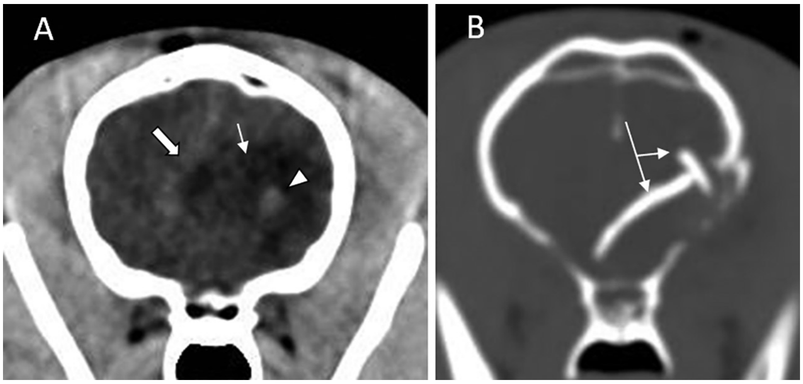

Figure 1—Transverse unenhanced CT images of the head of an 11-year-old sexually intact male mixed-breed dog following head trauma. A—At the level of the optic canal, a focal hyperattenuating lesion (arrowhead) surrounded by a larger hypoattenuated area (thin arrow), consistent with acute intraparenchymal hemorrhage, and surrounding brain edema are visible. Rightward deviation of the falx cerebri (thick arrow) and mild subcutaneous gas are also evident. B—A more rostral (8 mm), wide-windowed image at the level of the frontal lobes shows fractures of the left wing of the basisphenoid bone, with large intracranially depressed fragments (arrows) and mild subcutaneous gas.

areas in 2 (8%) dogs. No associations were identified between specific CT findings and dog age, sex, breed, and body weight; interval between trauma and hospital admission; cause of trauma; or concurrent injuries.

Outcome

None of the dogs underwent cranial surgery during hospitalization. Nineteen (70%) dogs survived for at least 10 days after initial head trauma, all of which were discharged from the hospital before day 10. Of the 8 nonsurvivors, 6 were euthanized and 2 died during hospitalization. The median hospitalization period for survivors was 3 days (range, 1 to 17 days). Sixteen of the 19 remaining dogs survived for at least 6 months after trauma. Of the other 3 dogs, 2 were euthanized 7 and 14 days after trauma owing to a lack of improvement in neurologic status. One dog was lost to follow-up but was considered neurologically normal at hospital discharge 7 days after trauma. Owner assessment of their dog's quality of life at 6 months was excellent for 13 of 16 dogs and good for the remaining 3 dogs.

KCTS system

Analysis of the CT data revealed that hemorrhage (intra-axial or extra-axial) was significantly ($P = 0.008$) and negatively associated with short-term survival, whereas ventricular asymmetry was significantly ($P = 0.04$) and negatively associated with long-term survival. The OR for short-term survival for dogs without evidence of hemorrhage on CT was 23.0 (95% confidence interval, 1.2 to 456.0). The OR for long-term survival for dogs without ventricular asymmetry was 7.0 (95% confidence interval, 1.2 to 41.0). Therefore, both of these variables were included in the prognostic scoring (KCTS) system, and each was assigned a score of 1 point. All other CT abnormalities, namely hemorrhage site location and number, areas of hypodensity, midline shift, cranial vault, and facial bone fracture, were not associated with short- or long-term survival. Although midline shift was not associated with survival, this variable is similar to ventricular asymmetry in that it indicates a mass effect; therefore, presence of either of these findings was assigned a score of 1 point in the KCTS system.

Cranial vault fractures were identified in 6 of the 8 nonsurvivors and 9 of 19 short-term survivors. These fractures were characterized as depressed in 4 of 6 nonsurvivors and 4 of 9 survivors. Therefore, detection of either injury was also assigned 1 point in the KCTS system. Finally, an infratentorial lesion was identified in half of the nonsurvivors and in none of the survivors. In previous reports[7,8] of MRI findings in dogs with head trauma, infratentorial or brainstem lesions were correlated with an adverse outcome and, in one of those reports,[7] were classified as the highest (ie, most severe) MRI grade. Because of the clear contribution of infratentorial lesion to nonsurvival, both in our study and in the literature,[7,8,18–20] 3 points were allotted for its detection.

In summary, a score of 1 in the developed KCTS system is assigned for each presence of the following: hemorrhage, midline shift or lateral ventricle asymmetry, cranial vault fracture, and depressed fracture. Presence of any infratentorial lesion (hypodensity, hemorrhage, or fracture) is assigned a score of 3. This system allows for a total possible score range from 0 to 7, with 7 indicating the poorest prognosis.

Discussion

In human medicine, neuroimaging and imaging-based scoring methods are routinely used in the diagnosis of and prognostication for head trauma patients.[12–16,19] However, owing to inherent differences in anatomy and image resolution between humans and dogs, these scales cannot be applied to dogs. To the authors' knowledge, the present study provided the first detailed description of CT abnormalities in dogs with head trauma.

Detection of abnormal findings in all 27 dogs (each scanned within 72 hours after initial head trauma) indicated that CT scanning was a suitable diagnostic tool for this purpose. We were unable to determine conclusively that all dogs included in the cohort had concurrent traumatic brain injury; however, in most (89%) dogs, either the brain parenchyma or cranial vault was involved. Abnormalities included cranial vault fractures, facial bone fractures, regional brain hypodensity consistent with edema, areas of brain hyperdensity consistent with hemorrhage, and a mass effect, as represented by midline shift or ventricular asymmetry. Hydrocephalus, which was detected in 7 dogs, can be an incidental finding[21–24] and therefore did not necessarily represent brain injury.

Results suggested that cranial vault fracture in dogs will likely be accompanied by brain parenchyma abnormalities such as hypodensity, hemorrhage, midline shift, and ventricular asymmetry. Accordingly, careful evaluation of CT data for those abnormalities is recommended as well as treatment for brain edema, high intracranial pressure, and hemorrhage when indicated.

Most dogs with head trauma receive medical care soon after the traumatic event, as do dogs with general trauma.[1,7] In the present study, almost 80% of the dogs with head trauma were brought to the hospital < 8 hours after initial trauma, and almost 90% arrived within 24 hours after initial trauma. Head trauma patients are often unstable at hospital admission, have a high risk of rapid deterioration, and require close monitoring. A CT examination of the head can be performed quickly, providing sufficient resolution to identify hemorrhage, brain edema, mass effect, and fractures at a fairly low cost. This makes CT the imaging modality of choice for the characterization of head trauma in humans in the acute care setting.[9–12] In addition, in comatose or semicomatose dogs, general anesthesia is often unnecessary for CT scanning, unless positive pressure ventilation is indicated for permissive hypocapnea.

Magnetic resonance imaging of the brain in dogs provides a wealth of information and is, therefore, an obvious alternative to CT in the assessment of head trauma. However, notwithstanding this established merit, it is unclear whether information obtained via MRI is useful for treatment planning and prognosis in dogs with head trauma. Moreover, the requirement for prolonged anesthesia limits the use of MRI for brain injury. Interestingly, a modified human grading system in which the severity and location of the lesions are taken into account was used in a study[11] of the prognostic value of MRI. Because MRI provides detailed information about brain parenchymal changes in both human and dogs, that modification was possible. However, a similar degree of anatomic accuracy is not likely to be achieved with CT.

In the study reported here, hemorrhage and ventricular asymmetry, which both reflect a direct impact on brain parenchyma, were associated with a poor outcome. Dogs without evidence of bleeding were 23 times as likely to survive and dogs without ventricular asymmetry were 7 times as likely to survive as were dogs with such evidence. However, ventricular asymmetry can also be an incidental finding,[25] particularly in toy breeds, which comprised 59% of dogs in the study. Because it was impossible to determine conclusively whether the ventricular asymmetry was incidental or secondary to the head trauma, and given the significance of its association with outcome, this finding was grouped with another clinical indication of a mass effect on the ventricle, namely midline shift, into 1 category in the developed KCTS system.

Because the small number of dogs included in the present study limited the statistical power to detect differences in the prevalence of CT findings between survivors and nonsurvivors, some CT abnormalities that appeared more common in nonsurvivors than in survivors were included in the developed KCTS system despite a lack of a significant association. Among these, infratentorial lesions are known to severely affect prognosis in dogs with head trauma[7,8]; thus, these abnormalities were given an exceptional weighting in the scoring system.

The MGCS is useful in the clinical evaluation of dogs with head trauma at hospital admission, and scores are linearly and positively correlated with the probability of survival.[3,4] However, results are affected by sedative, analgesic, and antiepileptic drugs, which are commonly used in dogs with head trauma. Another limitation of the MGCS is that its predictive value is restricted to the first 48 hours of hospitalization.[7] Indeed, in the present study, half of the dogs that failed to survive to hospital discharge were still alive 48 hours after admission, stressing the need for a scoring system that would predict outcome for a longer term.

The value and validity of the proposed KCTS system for predicting short- and long-term survival of dogs with head trauma remain to be evaluated, and such evaluation must be performed before the system can be clinically applied. The advantages of combined application of the MGCS and KCTS systems as well as of the modified MRI assessment system[7] for prognosis assessment in dogs with head trauma should be also examined.

In the study reported here, the potential value of the CT findings for treatment planning was not evaluated; therefore, the findings did not affect the treatment protocols. None of the dogs underwent surgical decompression to treat hematomas or to address depression fractures, and treatment was individually tailored on the basis of clinical assessment. Only 2 of the 19 dogs that survived in the short-term were subsequently euthanized because of unsatisfactory neurologic improvement. As perceived by the owners, the remaining dogs had a good to excellent quality of life ≥ 6 months after initial head trauma. Similar findings were obtained in another study,[7] in which 42 of 47 (89%) dogs with head trauma that survived the initial 48-hour period after trauma survived to at least the 6-month follow-up point and the owners' assessment of recovery was generally good. Taken together, these findings suggest that most dogs with head trauma that survive to hospital discharge will have a good quality of life in the long term.

The main limitation of the present study was the small sample size, which restricted the statistical power to detect significant associations between abnormal CT findings and outcomes. Another limitation was the less detailed images obtained by CT, compared with the detail provided by MRI, which reduced the ability to detect pathological changes following head trauma. In addition, the inherent beam-hardening artifacts in caudal fossa images may have interfered with the detection of lesions in this area or may have been confused with parenchymal hypodensity; however, we presume that this particular limitation is well recognized by clinicians who routinely evaluate CT images. Lastly, most nonsurviving dogs in the present study were euthanized, which means that the outcome could have been affected by the owners' decisions; nonetheless, this limitation is inherent to clinical studies involving assessment of prognosis.

Acknowledgments

The authors declare that there were no conflicts of interest.

Footnotes

a. Elscint Twin, Elscint, Haifa, Israel.
b. Philips MX 8000 IDT, Philips, Cleveland, Ohio.
c. SPSS software, version 21, SPSS Inc, Chicago, Ill.

References

1. Simpson SA, Syring R, Otto CM. Severe blunt trauma in dogs: 235 cases (1997–2003). *J Vet Emerg Crit Care (San Antonio)* 2009;19:588–602.
2. Friedenberg SG, Butler AL, Wei L, et al. Seizures following head trauma in dogs: 259 cases (1999–2009). *J Am Vet Med Assoc* 2012;241:1479–1483.

3. Platt SR, Radaelli ST, McDonnell JJ. The prognostic value of the modified Glasgow coma scale in head trauma in dogs. *J Vet Intern Med* 2001;15:581–584.
4. Sharma D, Holowaychuk MK. Retrospective evaluation of prognostic indicators in dogs with head trauma: 72 cases (January–March 2011). *J Vet Emerg Crit Care (San Antonio)* 2015;25:631–639.
5. Hall KE, Holowaychuk MK, Sharp CR, et al. Multicenter prospective evaluation of dogs with trauma. *J Am Vet Med Assoc* 2014;244:300–308.
6. Steinmetz S, Tipold A, Loscher W. Epilepsy after head injury in dogs: a natural model of posttraumatic epilepsy. *Epilepsia* 2013;54:580–588.
7. 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.
8. 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.
9. 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.
10. Kolias AG, Guilfoyle MR, Helmy A, et al. Traumatic brain injury in adults. *Pract Neurol* 2013;13:228–235.
11. Currie S, Saleem N, Straiton JA, et al. Imaging assessment of traumatic brain injury. *Postgrad Med J* 2016;92:41–50.
12. 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; discussion 646–637.
13. Marshall LF, Marshall SB, Klauber MR, et al. A new classification of head-injury based on computerized-tomography. *J Neurosurg* 1991;75:S14–S20.
14. Liesemer K, Riva-Cambrin J, Bennett KS, et al. Use of Rotterdam CT scores for mortality risk stratification in children with traumatic brain injury. *Pediatr Crit Care Med* 2014;15:554–562.
15. Platt SR, Radaelli ST, McDonnell JJ. Computed tomography after mild head trauma in dogs. *Vet Rec* 2002;151:243.
16. Evans HE, de Lahunta A. *Miller's anatomy of the dog*. 4th ed. Philadelphia: Saunders, 2012;88.
17. American Kennel Club. Toy breeds. Available at: www.akc.org/dog-breeds/groups/toy. Accessed Dec 4, 2016.
18. Hilario A, Ramos A, Millan JM, et al. Severe traumatic head injury: prognostic value of brain stem injuries detected at MRI. *AJNR Am J Neuroradiol* 2012;33:1925–1931.
19. Firsching R, Woischneck D, Klein S, et al. Classification of severe head injury based on magnetic resonance imaging. *Acta Neurochir (Wien)* 2001;143:263–271.
20. Maschke M, Mörsdorf M, Timmann M, et al. Posterior fossa trauma. In: Manto M, Gruol D, Schmahmann J, et al, eds. *Handbook of the cerebellum and cerebellar disorders*. New York: Springer, 2013;2055–2078.
21. Ryan CT, Glass EN, Seiler G, et al. Magnetic resonance imaging findings associated with lateral cerebral ventriculomegaly in English Bulldogs. *Vet Radiol Ultrasound* 2014;55:292–299.
22. Vullo T, Korenman E, Manzo RP, et al. Diagnosis of cerebral ventriculomegaly in normal adult beagles using quantitative MRI. *Vet Radiol Ultrasound* 1997;38:277–281.
23. Kii S, Uzuka Y, Taura Y, et al. Magnetic resonance imaging of the lateral ventricles in beagle-type dogs. *Vet Radiol Ultrasound* 1997;38:430–433.
24. Lu D, Lamb CR, Pfeiffer DU, et al. Neurological signs and results of magnetic resonance imaging in 40 Cavalier King Charles Spaniels with Chiari type 1-like malformations. *Vet Rec* 2003;153:260–263.
25. Pivetta M, De Risio L, Newton R, et al. Prevalence of lateral ventricle asymmetry in brain MRI studies of neurologically normal dogs and dogs with idiopathic epilepsy. *Vet Radiol Ultrasound* 2013;54:516–521.