Results of magnetic resonance imaging performed within 48 hours after head trauma in dogs and association with outcome: 18 cases (2007–2012)

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Objective—To review results of MRI performed within 48 hours after head trauma in dogs and identify associations between MRI findings and outcome.

Design—Retrospective case series.

Animals—18 dogs that underwent MRI within 48 hours after known head trauma.

Procedures—Medical records were reviewed for information on signalment, history, clinical findings, MRI findings, treatment, and outcome.

Results—2 dogs were euthanized, 1 died, and 1 had major persistent deficits. The remaining 14 dogs had a good outcome, including 9 that recovered completely and 5 that had minor persistent deficits. The most common MRI abnormalities were intra-axial changes (n = 13) and extra-axial hemorrhage (13). Intra-axial changes were best seen on T2-weighted and fluid attenuation inversion recovery (FLAIR) images. A mass effect was detected in 9 dogs, 6 of which had a midline shift (mean, 2.18 mm). Three dogs had transtentorial herniation, and 2 had transcranial herniation. Extra-axial hemorrhage was best seen on FLAIR images. The most common location was subdural, with subdural extra-axial hemorrhage most often seen on the same side as the injury. Epidural hemorrhage was seen in 2 dogs. The affected area was larger in these dogs than in dogs with subdural hemorrhage. One dog required surgery and the other was euthanized.

Conclusions and Clinical Relevance—Results suggested that in dogs with acute (< 48 hours' duration) head trauma, T2-weighted and FLAIR images provided the most diagnostic information. Dogs with injuries affecting the caudal fossa or affecting both the rostral and caudal fossae typically had poorer outcomes. (*J Am Vet Med Assoc* 2015;246:1222–1229)

Because it can determine the presence and extent of pathological changes, neuroimaging plays a key role in the evaluation and treatment of TBI.[1] During the period immediately after an injury, for example, imaging may be helpful in distinguishing between the need for minimally invasive treatment versus surgical intervention. If surgery is required, imaging can aid in surgical planning.[2] Many studies involving human patients have been conducted in an attempt to establish which cross-sectional neuroimaging techniques have the highest sensitivity for detection of specific types of lesions, taking into consideration safety, radiation dose, cost, and the time it takes to obtain images.[3] Several studies in the human literature evaluated which criteria to use to determine the need for cross-sectional neuroimaging, including the GCS, clinical signs (eg, vomiting, headache, amnesia, and intoxication), and patient age.[2] However, these criteria have not been found to be completely reliable.

In veterinary medicine, there are few data available to guide practitioners as to when cross-sectional neuroimaging is recommended for patients suspected or known to have undergone head trauma. Some general comments in the literature suggest that such imaging is indicated in patients that fail to respond to aggressive medical management, that deteriorate after an initial response to medical treatment, or that have focal or asymmetric neurologic signs.[4]

Studies involving human patients have also been performed to determine whether results of cross-sectional neuroimaging can be used to help predict functional outcome or likelihood of death. A study[1] of patients undergoing surgery because of TBI, for example, identified 7 factors related to the likelihood of death during the perioperative period: patient age, extent of the lesion, bilateral absence of pupillary light response, GCS score prior to surgery, extent of midline shift measured on CT images, type of surgery (craniotomy or craniectomy), time between injury and surgery, and the presence of acute brain swelling at the time of surgery.

Intracranial changes associated with head trauma can be divided into primary and secondary injuries.

ABBREVIATIONS

FLAIR	Fluid attenuation inversion recovery
GCS	Glasgow coma scale
TBI	Traumatic brain injury

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Primary injuries occur as a direct result of the initial trauma and can include contusion or hemorrhage in the intra-axial or extra-axial tissues and diffuse axonal injury in the parenchymal tissues. Secondary injuries include changes due to swelling and inflammation that occur within the brain as a response to the initial injury and changes that develop as a consequence of elevated intracranial pressure.[1,5]

Even though TBI is frequently seen in a small animal practice, few reports describing results of imaging of these patients have been published,[6] and those that have been published have often consisted of individual case reports,[7] reviews of the pathophysiology of neurologic trauma,[4] or evaluations of the longer-term consequences of TBI, such as seizure activity.[8]

The present study was designed to obtain more information on the results of cross-sectional neuroimaging in dogs with head trauma. Specifically, the purposes of the study reported here were to review results of MRI performed within 48 hours after head trauma in dogs, determine the MRI sequences that provided the greatest diagnostic information, and identify associations between MRI findings and outcome.

Materials and Methods

Medical records of the Department of Diagnostic Imaging at Dick White Referrals for 2007 through 2012 were searched to identify dogs that had undergone MRI within 48 hours after known head trauma. Information obtained from the medical records of dogs eligible for inclusion in the study consisted of signalment, history (including cause of injury), results of other diagnostic imaging tests, clinical signs, neurologic findings, MRI sequences obtained, MRI findings, treatment, and long-term outcome.

For MRI, dogs were anesthetized with propofol, with anesthesia maintained with isoflurane and oxygen. Images were acquired with a 0.4-T permanent magnet,[a] with the dogs positioned in sternal recumbency. Sequences, planes, and mean scanning times were as follows: sagittal T2-weighted images, 3.56 minutes; dorsal T2-weighted images, 4.26 minutes; transverse T2-weighted images, 4.2 minutes; transverse FLAIR images, 5.29 minutes; transverse T2* gradient echo images, 3.5 minutes; and transverse T1-weighted images, 4.28 minutes. All sequences were acquired in all dogs. In addition, transverse T1-weighted images were obtained following administration of gadopentetate dimeglumine[b] (0.2 mg/kg [0.09 mg/lb], IV) in select dogs.

For the present study, all MRI images were reviewed retrospectively with a DICOM (Digital Imaging and Communications in Medicine) viewer[c] by a board-certified radiologist blinded to the history and outcome of the patients. Specific features examined were based on the classification of primary and secondary injuries observed in human patients with TBI. Primary intracranial changes were classified as intra-axial or extra-axial. For intra-axial changes, details of the location (gray vs white matter and rostral vs caudal fossa) of any parenchymal brain lesions were recorded, noting whether there was evidence of any signal void on T2* gradient echo images. Extra-axial changes considered most likely to be extra-axial hemorrhage were classified on the basis of anatomic location as epidural (lentiform and ellipsoid), subdural (crescentic and concave), or subarachnoid (linear or convoluted and extending into the sulci). In addition, extra-axial hemorrhage was identified as occurring on the same side as the blunt trauma, as determined on the basis of location of the soft tissue trauma (coup), or on the opposite side (contrecoup).

To identify secondary changes, images were evaluated for the presence of a mass effect. Mass effects were categorized as a rostrocaudal shift (including either rostral or caudal transtentorial herniation and foramen magnum herniation), subfalcine or midline shift, and herniation through a skull defect. If present, the size of any midline shift was measured on transverse T2-weighted images **(Figure 1)** in a manner similar to that described for human patients.[1]

Outcome was classified as complete recovery, partial recovery with minor ongoing deficits (ie, persistent neurologic deficits evident during clinical examination that did not substantially affect quality of life), partial recovery with major ongoing deficits (ie, persistent deficits evident during clinical examination that substantially affected quality of life), or death (ie, died or was euthanized). Imaging findings were examined to determine whether any particular findings were associated with a better or poorer outcome. Sequences on which specific findings were most commonly seen were also identified.

Results

Eighteen dogs met the criteria for inclusion in the study. Age at the time of initial examination ranged from 9 weeks to 10 years (mean, 2.4 years). Body weight ranged from 0.8 to 29 kg (1.8 to 63.8 lb; mean,

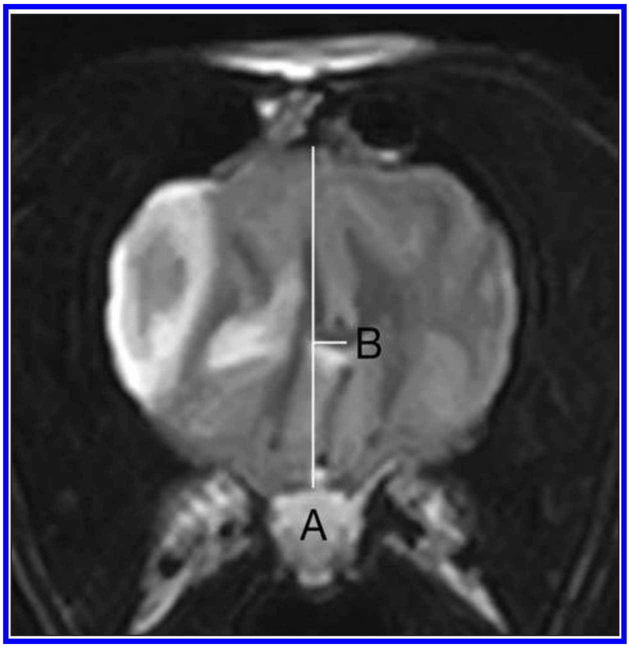

Figure 1—Transverse T2-weighted MRI image of a dog with a midline shift due to an epidural hematoma. The size of the midline shift was measured as displacement of the midline structures (line B) from the actual midline, represented as the longitudinal fissure from the falx dorsally to the ventral midline (line A). The patient underwent surgery to evacuate the epidural hematoma and made a full recovery.

8.7 kg [19.1 lb]). Twelve were male and 6 were female. There were 4 mixed-breed dogs, 2 Chihuahuas, 2 Jack Russell Terriers, 2 Yorkshire Terriers, 2 Greyhounds, and 1 each of Maltese Terrier, Tibetan Terrier, Miniature Dachshund, Cavalier King Charles Spaniel, Norfolk Terrier, and Miniature Schnauzer.

Six of the 18 dogs had been injured in road traffic accidents, 8 had been injured as a result of blunt object trauma or head compression (1 had been stepped on by the owner, 1 had had a door shut on its head, and 6 had been hit by an object such as a ball or plank), 2 had been injured in dog fighting, 1 had run head first into a post, and 1 had been kicked by a horse. At the time of initial examination, 11 of the 18 dogs were obtunded or stuporous, 5 were lethargic, and 2 had no central neurologic deficits but underwent MRI because of visible head trauma or peripheral neurologic deficits. Other clinically important systemic abnormalities included respiratory distress (n = 4), concurrent spinal fractures (2), nonambulatory tetraparesis (8), concurrent orthopedic injury requiring surgical intervention (2), severe epistaxis (4), and hemoperitoneum requiring surgery (1). One dog was pregnant. Surgery was performed in 4 dogs and included intracranial decompression (n = 1), spinal fracture stabilization (1), and orthopedic fracture repair (2). One of the dogs that underwent fracture repair also required splenectomy owing to profuse bleeding following trauma. All 4 dogs that underwent surgery survived to discharge from the hospital. The remaining dogs received only medical treatment. In only 1 dog was the concurrent injury thought to have influenced the outcome. In the other dogs, all concurrent injuries were treated successfully.

Follow-up information was available for all 18 dogs. Eleven dogs were examined 2 weeks after hospital discharge, 4 were examined 6 weeks after discharge, 4 were examined 10 weeks after discharge, and 1 was examined 16 weeks after discharge. Three dogs did not survive: 1 died during recovery from general anesthesia for imaging, 1 was euthanized after 6 days of treatment because it was not showing any improvement, and 1 was euthanized at the owners' request immediately following imaging (combined severe head injury and spinal fracture). One dog had partial recovery with major persistent deficits, including ambulatory tetraparesis and circling that persisted for several months after discharge from the hospital. These 4 dogs (3 that died and 1 with major persistent deficits) were defined as having a poor outcome.

The remaining 14 dogs had a good outcome, including 9 that recovered completely and 5 that had persistent deficits characterized by the owners as having a minor impact on the dogs' quality of life that persisted beyond discharge from the hospital (eg, thoracic limb hypermetria, pelvic limb ataxia, and ataxia in all 4 limbs). These 14 dogs were categorized as having a good outcome.

For the 16 dogs with central neurologic deficits, GCS score at the time of initial examination ranged from 4 to 18 (mean, 12.75; potential scores ranged from 3 to 18, with higher scores representing better condition). In the 3 dogs that died, GCS scores were 4, 4, and 10; in the dog with major persistent deficits, GCS score was 12; in the 5 dogs with minor persistent deficits, GCS score ranged from 8 to 18 (mean, 14); and in the 9 dogs with complete recovery (excluding the 2 dogs without central neurologic deficits on initial examination), GCS scores ranged from 11 to 18 (mean, 14.8).

Seventeen dogs had evidence of intracranial trauma on MRI images.

Intra-axial changes—Intra-axial (ie, parenchymal) changes were identified in 13 dogs. These changes were best seen as hyperintensity on T2-weighted and FLAIR images. There was no abnormal contrast enhancement. Changes were seen as a signal void (solid or onion skin–like layers) on T2* gradient echo images in 7 of the 13 dogs (**Figure 2**).

Parenchymal signal changes were identified in the gray matter in 7 of the 13 dogs (4 recovered completely and 3 had minor deficits), in the white matter in 1 dog (recovered with minor deficits), and in both the gray and white matter in 5 dogs (2 died, 1 had major deficits, and 2 recovered completely). One of the dogs that died had no visible parenchymal change on MRI images. The location of parenchymal signal changes (ie, gray vs

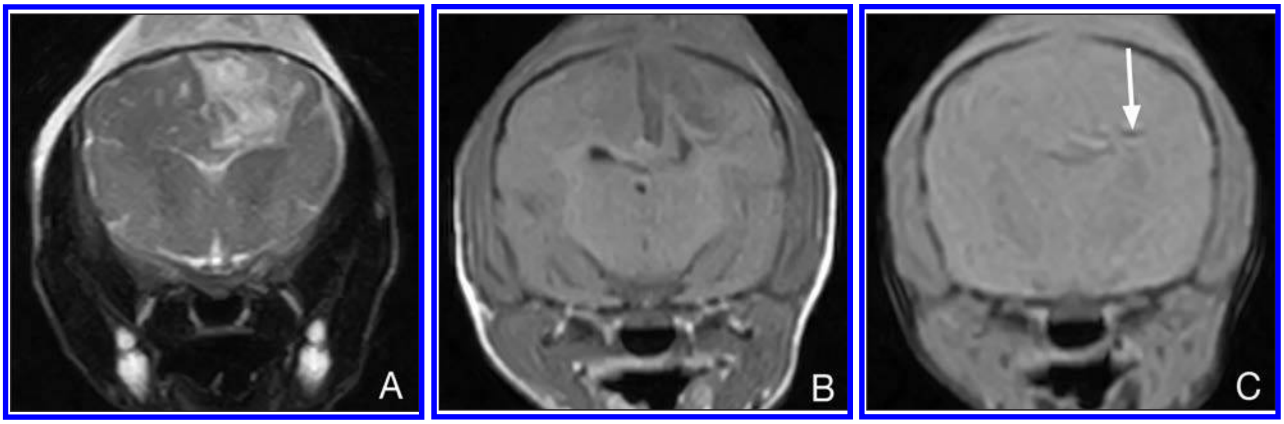

Figure 2—Transverse MRI images of the brain of a dog with a contusion affecting both the gray and white matter. A—T2-weighted image; parenchymal changes were evident as hyperintense cortical contusions within the gyri. B—T1-weighted image; parenchymal changes were difficult to identify. C—T2* gradient echo image; characteristic signal void crescents at the margin of the lesion confirmed the presence of hemorrhage. On admission, the patient was obtunded, nonambulatory, and tetraparetic. Following medical treatment, the patient was ambulatory, with minimal ataxia at the time of discharge from the hospital.

white matter) seemed to have less of an association with outcome than the extent of the affected parenchyma. Hence, dogs with both gray and white matter affected typically had a poorer outcome.

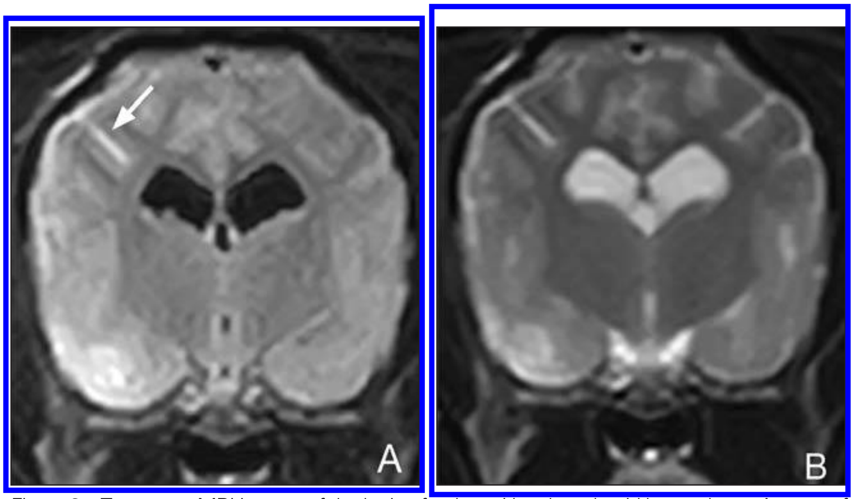

Figure 3—Transverse MRI images of the brain of a dog with subarachnoid hemorrhage. An area of hyperintensity extending into a sulcus was more evident on a FLAIR image (A) than on a T2-weighted image (B). Notice the concurrent cortical contusion in the right piriform lobe. On initial evaluation, the patient was lethargic and nonambulatory and developed seizures soon after hospitalization. Following medical management for the intracranial injury, the patient made a full recovery.

Extra-axial changes—Evidence of extra-axial hemorrhage was seen in 13 dogs. This was best seen on FLAIR images as a layer of hyperintensity surrounding the parenchyma **(Figure 3)**. Hemorrhage was described as subdural in 9 dogs (4 recovered completely, 4 had minor deficits, and 1 had major deficits), subarachnoid in 2 (1 recovered completely and 1 had minor deficits), and epidural in 2 (1 recovered completely [after surgery] and 1 died). The 2 dogs with epidural hemorrhage had a greater amount of bleeding and greater mass effect than did dogs with extra-axial hemorrhage in other locations, suggesting location might have been less important to outcome than extent of bleeding.

Other intracranial changes—There was a mass effect with associated midline shift in 6 dogs; the mass effect was caused by intra-axial or extra-axial changes or both. Five dogs recovered (of which 1 required surgery) and 1 died. The degree of midline shift ranged from 1.7 to 4 mm (mean, 2.18 mm). The 2 dogs that were euthanized or underwent surgical intervention had the largest midline shift at 4 mm.

Five dogs had evidence of herniation. Transtentorial herniation was seen in 3 dogs. Two dogs had rostral transtentorial herniation, one of which also had evidence of foramen magnum herniation; both were euthanized **(Figure 4)**. One dog had caudal transtentorial herniation and recovered completely. Two dogs (both Chihuahuas) had parenchymal herniation through a calvarial defect, regarded as most likely to be a preexisting fontanelle. Both of these patients survived to hospital discharge without major persistent deficits.

Parenchymal changes affected the rostral fossa in 12 dogs (all recovered completely or had mild deficits). Parenchymal changes affecting the caudal fossa were seen in 1 dog, which died. Changes to both the rostral and caudal fossae were seen in 4 dogs, of which 2 died, 1 had major persistent deficits, and 1 (with very minor caudal fossa changes only) recovered fully **(Table 1)**.

Intracranial changes (intra-axial or extra-axial changes) affected the same (coup) side as the soft tissue injuries (and presumed site of impact) in 15 dogs **(Figure 5)**. One dog had subdural hemorrhage opposite (contrecoup) to the apparent site of trauma. One dog had forebrain lesions on the same side as the soft tissue trauma and a caudal fossa lesion on the opposite side (but also concurrent cervical injury).

Concurrent osseous and soft tissue injuries—Fractures of the cranial vault were seen in 9 of the 18 dogs. Concurrent head injuries consisted of orbital trauma (n = 2), frontal sinus trauma (7), nasal trauma (4; all patients with nasal trauma had some changes in

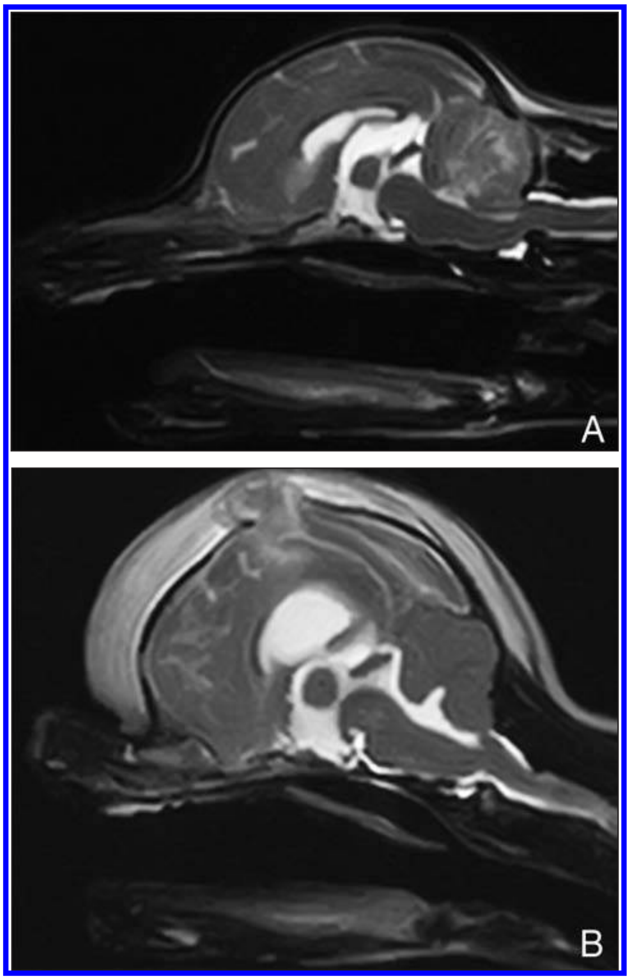

Figure 4—Sagittal MRI images of 2 dogs demonstrating different types of herniation following head trauma. A—T2-weighted image of a dog with a contusion in the cerebellum in conjunction with rostral transtentorial and caudal foramen magnum herniation. On initial evaluation, the patient was stuporous with respiratory stridor and was euthanized at the owner's request following MRI and neurologic assessment. B—T2-weighted image of a Chihuahua with herniation through a calvarial defect. On initial evaluation, the patient was obtunded, nonambulatory, and tetraparetic, with increased spinal segmental reflexes in all 4 limbs. Following medical management, the patient made a full recovery.

the frontal sinus), and mandibular or temporomandibular joint injuries (3). The presence or absence of identifiable cranial vault fractures was not associated with outcome. All 18 dogs had some evidence of soft tissue trauma. T2* gradient echo and T1-weighted sequences were most helpful in identifying bone trauma. Short tau inversion recovery sequences were most helpful in identifying soft tissue trauma.

Table 1—Imaging findings in 18 dogs that underwent MRI within 48 hours after known head trauma.

	Outcome	
Intracranial change	**Poor**	**Good**
Gray matter changes only (n = 7)	0	7
White matter changes only (n = 1)	0	1
White matter and gray matter changes (n = 5)	3	2
Extra-axial changes (n = 13)	2	11
Midline shift (n = 6)	1	5
Transtentorial herniation (rostral or caudal; n = 3)	2	1
Transcranial herniation (n = 2)	0	2
Changes affecting the rostral fossa only (n = 12)	0	12
Changes affecting the caudal fossa only (n = 1)	1	0
Changes affecting both the rostral and caudal fossae (n = 4)	3	1

Outcome was classified as good (complete recovery or partial recovery with minor persistent deficits) or poor (partial recovery with major persistent deficits, died, or euthanized).

Discussion

Results of the present study suggested that in dogs with acute (< 48 hours duration) head trauma, T2-weighted and FLAIR images provided the most diagnostic information. Dogs with injuries affecting the caudal fossa alone or affecting both the rostral and caudal fossae typically had poorer outcomes.

Primary intra-axial changes were seen in 13 of the 18 dogs in the present study. Given that images were acquired during the acute phase of injury, it was not surprising that these parenchymal lesions were best visible on T2-weighted images as hyperintense focal lesions. Surprisingly, although all of these patients had hyperintense changes on T2* gradient echo images, not all had characteristic signal voids on these images. This may have been due to the nature of the injury (eg, microbleeding and edema rather than hematoma), the timing of imaging early in the evolution of the traumatic lesions, or the inherently reduced visibility of susceptibility artifacts with low-field MRI.[9,10] Owing to the fact that we only included dogs that underwent MRI within 48 hours after the traumatic injury, hemorrhages were deemed to be in the peracute or acute stage. With peracute and acute injuries, RBCs and hemoglobin are isointense or have low signal intensity on T1-weighted images but have increased signal intensity on T2-weighted images.[11,12]

One goal of neuroimaging in humans is to distinguish gray matter from white matter injuries, because this distinction is associated with prognosis.[1] Seven of the 13 dogs in the present study with intra-axial changes had gray matter injuries, and all recovered completely or had minor deficits. These types of injuries can be referred to as cortical contusions, and human studies[9] suggest that they have a better prognosis than diffuse axonal injuries, unless associated with a mass effect or an injury to the brainstem.

Diffuse axonal injuries are injuries involving the white matter tracts. Three degrees of severity are described in human patients. Mild (grade I) diffuse axonal injury involves the gray matter–white matter junction of the lobar white matter only. Moderate (grade II) diffuse axonal injury involves the lobar white matter and the corpus callosum. Severe (grade III) diffuse axonal injury involves the same structures and additionally the dorsolateral midbrain structures.[9]

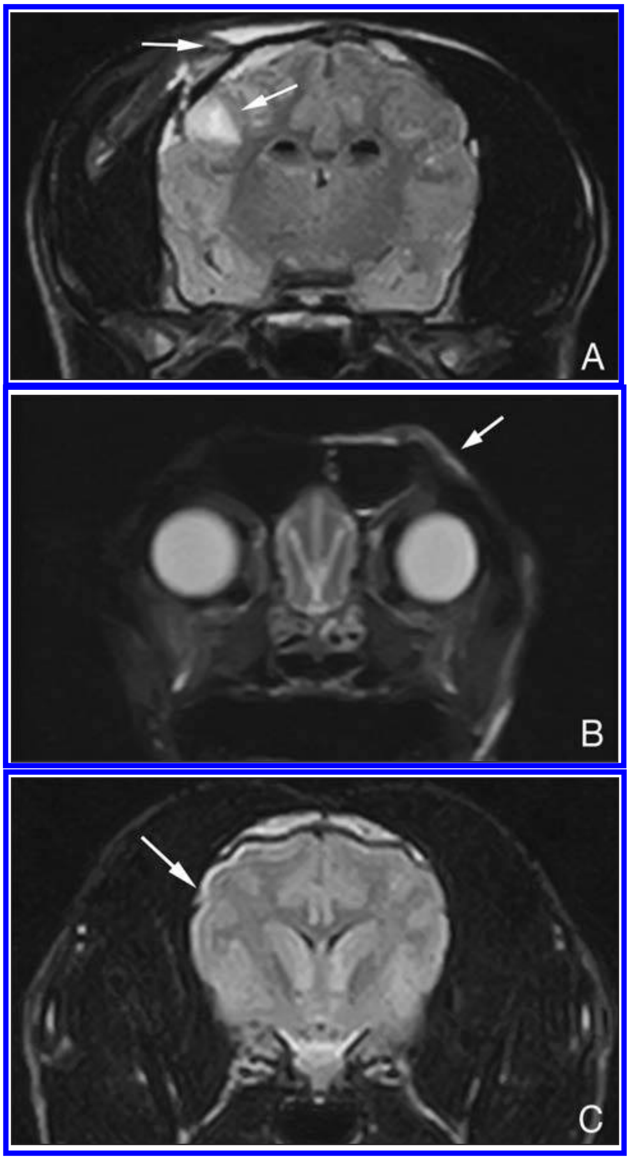

Figure 5—Transverse MRI images of 2 dogs, demonstrating a coup injury (A) and a contrecoup injury (B and C). A—Fluid attenuation inversion recovery image of a coup injury, with intra-axial and extra-axial changes seen on the same side as a cranial vault fracture and soft tissue injuries (arrows). The patient was stuporous, nonambulatory, and paraparetic. Following medical treatment and physiotherapy, the patient had persistent mild ataxia at the time of discharge from the hospital. B—Short tau inversion recovery image of the skull showing soft tissue and frontal sinus injuries on the left side of a dog (arrow). C—In the dog in B, extra-axial changes were seen on the right side (arrow), suggesting a contrecoup injury. The patient was lethargic on admission, but following several days of hospitalization, it recovered completely.

One dog in the present study had white matter changes alone, close to the gray matter–white matter junction. Thus, axonal injury in this dog, if present, was likely mild. However, a differential diagnosis for white matter hyperintensity is white matter contusion, and because axonal imaging was not available, the cause of the white matter hyperintensity in this dog was not determined. Three of the 5 dogs in the present study with both gray and white matter changes had a poor outcome, suggesting that white matter changes may have been associated with a poorer outcome than gray matter changes only. However, most dogs with gray and white matter changes had greater parenchymal involvement; therefore, the association of gray versus white matter distribution may have been less important than the extent of brain tissue affected.

Primary extra-axial changes were seen in 13 dogs in the present study, and changes in all 13 dogs were classified as extra-axial hemorrhage. Intracranial bleeding in the extra-axial compartment is potentially life-threatening, even without concurrent parenchymal changes. The diagnosis of intracranial bleeding can be challenging, however, given that its appearance on MRI images depends on the extent of bleeding, the origin within the brain, and the time since the onset of bleeding.[11]

Extra-axial hemorrhage is traditionally classified as epidural, subdural, or subarachnoid.[13] Epidural hemorrhages develop between the inner surface of the skull and the dura mater. Owing to the attachments between the dura mater and the cranial sutures, epidural hemorrhages typically have a lentiform or ellipsoid shape. In humans, epidural hemorrhages typically develop on the coup side of injuries and rarely cross the cranial sutures. They can, however, cross the midline where the periosteum and sagittal suture are not firmly attached.[1] Most often, they are associated with cranial fractures. Findings that may indicate the need for surgical evacuation of an epidural hematoma include the thickness of the hematoma and a midline shift > 5 mm.[1] Only 1 dog in the present study had a midline shift secondary to epidural hemorrhage that was this severe (ie, 4 mm). This dog underwent successful decompressive surgery.

Subdural hematomas often develop from the cortical vein, but other origins include the pial vessels and the cerebral arteries.[9] Subdural hematomas can be found either on the coup or contrecoup side of the injury.[1] Subdural hematomas causing > 10 mm of displacement have been associated with significantly higher mortality rates in human patients than smaller displacements,[14] but none of the dogs described in the present report had displacements approaching 10 mm.

Subarachnoid hematomas, seen in 2 dogs in the present study, arise from damage to the pial blood vessels or as a result of intraventricular hemorrhage. They occur as a result of parenchymal hematomas extending into the ventricular system from the subependymal vessels and will usually occur on the opposite side to the injury.[9]

Most (15/18) dogs in the present study had intracranial (intra-axial or extra-axial) changes on the same (coup) side as the presumed site of impact, as determined on the basis of the most severe soft tissue trauma. One dog had subdural hemorrhage opposite (contrecoup) to the apparent site of trauma, and another dog had lesions on the same (coup) side as the injury but also had contrecoup epidural hemorrhage. These findings contrast with previous descriptions for human patients, in whom contrecoup injuries are more common and may be more severe than coup injuries.[15] In human patients, the contrecoup-coup phenomenon is believed to result from differences in the density of the cerebral parenchyma versus the CSF. It has been suggested that at the time of injury, CSF moves toward the site of impact, displacing the brain to the opposite side, so that the more severe trauma to the brain occurs on the side opposite to the impact site.[16] We speculate that the difference in prevalence of coup versus contrecoup injuries between dogs and human is due to anatomic differences, such as the more developed extracranial muscular mass surrounding the skull in dogs as well as the different shape of the canine skull, compared with the more rounded human skull. Another reason for this difference might be associated with differences in the types of injuries and the fact that dogs suffer fewer whiplash-type injuries.

Fluid attenuation inversion recovery sequences decrease the signal from the CSF, making meningeal lesions more perceptible.[17] Multiple studies[18–21] involving human patients have found FLAIR images to be more sensitive for detection of hemorrhage in the extra-axial compartment, compared with CT images and with T2-weighted spin echo images. The appearance may vary with time; however, all dogs in the present study were imaged within 48 hours after known trauma, so alterations in lesion appearance over time were not assessed. We found FLAIR images to be the best for identifying extra-axial hemorrhage. Of the 13 patients in the present study with extra-axial hemorrhage, 1 underwent decompressive surgery, but the rest did not require surgical intervention.

Secondary changes, such as a mass effect, were detected in several dogs in the present study. Traumatic brain herniation is secondary to mass effects,[5] and 9 dogs in the present study had a mass effect, including 6 with a midline shift and 3 with transtentorial (rostrocaudal) herniation. Whereas 5 of the 6 dogs with a midline shift had a good outcome (although 1 required surgical intervention), other studies have found that a midline shift on MRI images can negatively affect prognosis.[22] In human patients with TBI, midline shifts > 10 mm are associated with a greater prevalence of complications after discharge from the hospital.[23] Another study[13] found an increased perioperative mortality rate in patients with this degree of midline shift. A 2003 study[24] found that the degree of midline shift can be correlated with the severity of TBI. Similarly, the magnitude of the midline shift may be important in dogs. Two dogs in the present study had a midline shift of 4 mm, both with parenchymal changes. One was euthanized, and the other required decompressive surgery. On the other hand, dogs with smaller midline shifts had a good outcome.

Two dogs in the present study had parenchymal herniation through a calvarial defect, and both had a good outcome without surgical intervention, despite a considerable amount of cerebral parenchymal displacement. We suspected that the defect in these 2 patients represented a preexisting fontanelle, and given that the defect was already present, decompressive craniectomy was not considered necessary.

Trauma to the rostral fossa was observed in 12 dogs in the present study and was associated with a good prognosis. Five dogs had trauma to the cerebellum and brainstem structures within the caudal fossa, and of these, 3 died and 1 had major persistent deficits. Only 1 of the 5 dogs with caudal fossa changes recovered fully, and this dog had very minor caudal fossa changes. These findings suggested that a caudal fossa location may be associated with a poorer outcome, as is the case for human patients with trauma to the posterior fossa.[25] The changes observed included both intra-axial and extra-axial injuries.

The GCS is used to classify TBIs in humans as mild, moderate, or severe. The modified GCS integrates data from examinations of motor activity, brainstem reflexes, and level of consciousness to yield a score from 1 to 6, part of a total score ranging from 3 to 18. Use of the modified GCS as a prognostic indicator in canine patients with head trauma has been studied previously. A study[26] in 38 canine patients, for instance, suggested that patients with a modified GCS score ≥ 8 have a 50% probability of surviving the first 48 hours after trauma. For dogs in the present study, GCS score appeared to be associated with outcome. Although this finding was consistent with findings of other studies,[27,28] the GCS score should be used for prognostic purposes in conjunction with other parameters such as results of cross-sectional imaging and pupil condition or as a method for assessing neurologic improvement.

In humans, there are specific recommendations for determining the need for cross-sectional neuroimaging that take into account the severity of injury and time since injury.[2] Cost and availability often mean that CT is used in the acute stage of injury in human patients, along with the fact that CT is capable of identifying intracranial hemorrhages and skull fractures. Magnetic resonance imaging is more often used in the subacute stage (48 to 72 hours after trauma) to diagnose ongoing damage, including axonal injury, although MRI is as sensitive as CT for identifying intracranial hemorrhage.[2] In small animal practice, the choice of advanced imaging is usually dependent on the modality available and, to some extent, cost. Some animal hospitals may be restricted to one particular imaging technique, making that modality the only option for use.

We make no recommendations as to which imaging technique is most appropriate for dogs with TBIs. The present study illustrated that MRI, when available, may be used. Furthermore, this study demonstrated that results of cross-sectional imaging should be used in conjunction with other assessment parameters. Often, imaging is resorted to only when a patient is not improving despite medical treatment. Frequently, this is the case once trauma patients arrive at a referral practice. Interestingly, the outcome for most patients in the present study was good, but this may have been due to skewing of the population at this referral center, in that many of the most severely affected TBI patients may not survive until referral.

One limitation of the present study was the lack of follow-up imaging to determine whether clinical improvement was accompanied by improvement in the MRI images. This was due to the retrospective nature of the case material but does not detract from the associations between outcome and initial MRI findings we identified.

In conclusion, although few cases were included, findings of the present study may, with further studies, lead to better guidelines on indications for imaging of dogs with head injuries and information on features of cross-sectional imaging that might be most helpful in determining prognosis. The patterns of intracranial trauma in dogs seemed to differ from those described in the human literature, indicating that further research involving veterinary patients is needed and that findings cannot be transferred directly from human patients. Both intra-axial and extra-axial changes were identified in the present study. The most common type of extra-axial hemorrhage was subdural hemorrhage, and extra-axial hemorrhages were seen most commonly on the coup side of injury, both of which differ from patterns seen in human patients. We recommend that when MRI is performed, FLAIR, T2-weighted, and T2* gradient echo sequences be included, on the basis of the fact that these images were found to be the most helpful in the present study.

Regarding outcome, our findings indicated that head trauma cases seen at a referral center have an overall good outcome. Features that could be linked to prognosis included injuries affecting the caudal fossa or causing a marked midline shift, which were associated with a higher mortality rate or higher rate of major persistent deficits or with a need for surgical intervention. Midline shift and transtentorial herniation were associated with variable outcomes, but herniation through a fontanelle was associated with a good outcome. Epidural hemorrhages were larger than other types of extra-axial hemorrhages, necessitating surgical decompression or euthanasia in the 2 dogs in which epidural hemorrhages were identified.

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From this month's *AJVR*

Measurement of intraocular pressure in healthy unanesthetized Inland bearded dragons (*Pogona vitticeps*)

Eva J. Schuster et al

June 2015

Objective—To evaluate the use of rebound and applanation tonometry for the measurement of intraocular pressure (IOP) and to assess diurnal variations in and the effect of topical anesthesia on the IOP of healthy Inland bearded dragons (*Pogona vitticeps*).

Animals—56 bearded dragons from 4 months to 11 years old.

Procedures—For each animal following an initial ophthalmic examination, 3 IOP measurements were obtained on each eye between 9 AM and 10 AM, 1 PM and 2 PM, and 5 PM and 7 PM by use of rebound and applanation tonometry. An additional measurement was obtained by rebound tonometry for each eye in the evening following the application of a topical anesthetic to evaluate changes in the tolerance of the animals to the tonometer. Descriptive data were generated, and the effects of sex, time of day, and topical anesthesia on IOP were evaluated.

Results—Bearded dragons did not tolerate applanation tonometry even following topical anesthesia. Median daily IOP as determined by rebound tonometry was 6.16 mm Hg (95% confidence interval, 5.61 to 6.44 mm Hg). The IOP did not differ significantly between the right and left eyes. The IOP was highest in the morning, which indicated that the IOP in this species undergoes diurnal variations. Topical anesthesia did not significantly affect IOP, but it did improve the compliance for all subjects.

Conclusions and Clinical Relevance—Results indicated that rebound tonometry, but not applanation tonometry, was appropriate for measurement of IOP in bearded dragons. These findings provided preliminary guidelines for IOP measurement and ophthalmic evaluation in bearded dragons. (*Am J Vet Res* 2015;76:494–499)

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