Article

Current trends in the management of canine traumatic brain injury: An Internet-based survey

Emma Kathryn Evans, Alberto L. Fernandez

Abstract — This study characterized trends in management of canine traumatic brain injury (TBI) among 182 small animal veterinarians grouped as follows: Board-certified specialists at a veterinary teaching hospital (BCS-VTH), Board-certified specialists in private practice (BCS-PP), non-specialists at a teaching hospital (DVM-VTH), and non-specialists in private practice (DVM-PP). The BCS-VTH, BSC-PP, and DVM-VTH groups were more comfortable using the modified Glasgow Coma Scale (MGCS) than the DVM-PP group ($P < 0.001$, $P < 0.001$, and $P = 0.009$, respectively). All respondents chose the following diagnostics most frequently: packed cell volume/total solids (95.6%), blood glucose (96.7%), and blood pressure (95.0%). The DVM-VTH group chose the following more frequently than the DVM-PP group: computed tomography (19.4% *versus* 4.5%; $P = 0.027$), venous or arterial blood gas (83.9% *versus* 46.3%; $P < 0.001$), electrocardiography (71.0% *versus* 44.8%; $P = 0.018$), lactate (87.1% *versus* 59.7%; $P = 0.009$), and brief thoracic ultrasound (87.1% *versus* 62.7%; $P = 0.017$). BCS-PP chose hypertonic saline more frequently than DVM-PP (94.1% *versus* 74.6%; $P = 0.005$). The DVM-PP group chose corticosteroid therapy and anticonvulsant therapy more frequently than BCS-PP (10.4% *versus* 0.0%; $P = 0.019$; 73.1% *versus* 43.1%; $P = 0.004$, respectively). This study highlights variability in management of canine TBI.

Résumé — Tendances actuelles dans la gestion des traumatismes cérébraux canins : sondage sur Internet. Cette étude a caractérisé les tendances dans la gestion des traumatismes cérébraux canins (TC) parmi 182 médecins vétérinaires pour petits animaux regroupés de la façon suivante : spécialistes agréés par un conseil dans un hôpital d'enseignement vétérinaire (BCS-VTH), spécialistes agréés en pratique privée (BCS-PP), non-spécialistes dans un hôpital d'enseignement vétérinaire (DVM-VTH) et non-spécialistes en pratique privée (DVM-PP). Les BCS-VTH, les BSC-PP et les DVM-VTH étaient plus à l'aise lors de l'utilisation de l'échelle de Glasgow modifiée (MGCS) que les DVM-PP ($P < 0{,}001$, $P < 0{,}001$ et $P = 0{,}009$, respectivement). Tous les répondants ont choisi les diagnostics suivants le plus fréquemment : valeur d'hématocrite/solides totaux (95,6 %), glycémie (96,7 %) et tension artérielle (95,0 %). Le groupe DVM-VTH a choisi les éléments suivants plus fréquemment que le groupe DVM-PP : tomodensitométrie (19,4 % *contre* 4,5 %; $P = 0{,}027$), gaz du sang veineux ou artériel (83,9 % *contre* 46,3 %; $P < 0{,}001$), électrocardiographie (71,0 % *contre* 44,8 %; $P = 0{,}018$), lactate (87,1 % *contre* 59,7 %; $P = 0{,}009$) et une brève échographie thoracique (87,1 % *contre* 62,7 %; $P = 0{,}017$). Le groupe BCS-PP a choisi la solution saline hypertonique plus fréquemment que le groupe DVM-PP (94,1 % contre 74,6 %; $P = 0{,}005$). Le groupe DVM-PP a choisi la thérapie corticostéroïde et une thérapie anti-convulsivante plus fréquemment que le groupe BCS-PP (10,4 % contre 0,0 %; $P = 0{,}019$; 73,1 % contre 43,1 %; $P = 0{,}004$, respectivement). Cette étude souligne la variabilité dans la gestion des TC canins.

(Traduit par Isabelle Vallières)

Can Vet J 2019;60:73–79

Cape Cod Veterinary Specialists, 11 Bourne Bridge Approach Street, Bourne, Massachusetts, USA.

Address all correspondence to Dr. Emma Evans; e-mail: ekevans88@gmail.com

Use of this article is limited to a single copy for personal study. Anyone interested in obtaining reprints should contact the CVMA office (hbroughton@cvma-acmv.org) for additional copies or permission to use this material elsewhere.

ARTICLE

Introduction

Canine traumatic brain injury (TBI) presents a therapeutic challenge to the veterinary practitioner. Moderate to severe TBI requires prompt recognition and therapeutic intervention to prevent rapid neurologic deterioration or death. Recommendations for the optimal management of human TBI patients are evolving and consensus guidelines for the management of canine TBI patients are lacking. Review articles describing the pathophysiology of canine TBI (1) and summarizing current recommendations for the management of small animal neurologic trauma (2) underscore the complexity of brain injury. As the pathophysiology is better elucidated, an increasing number of diagnostic and therapeutic targets have been identified. The utility of these diagnostics and the efficacy of specific therapies remain controversial, however. For example, veterinary studies that have evaluated the prognostic utility of advanced imaging [magnetic resonance imaging (MRI)] in canine head trauma suggest that there are significant associations between intraparenchymal lesions and prognosis (3). However, the cost, anesthetic risks, and availability of advanced imaging must be measured against its prognostic value. Further, both traditional and novel treatments for TBI continue to be debated and investigated. The human literature provides conflicting results regarding the superiority of hypertonic saline or mannitol for the treatment of intracranial hypertension, for example (4). Moreover, while human and canine head trauma patients appear to be at increased risk for post-traumatic seizures (5,6), the benefit of implementing prophylactic anticonvulsant therapy is unclear (2).

This Internet survey-based study was conducted as a preliminary step towards a larger goal: to initiate the development of formal and more widely available treatment guidelines for canine TBI. Surveys of current clinical practice can provide the foundation for the development of consensus guidelines for case management. In addition to identifying areas of clinical equipoise for further investigation, a thorough understanding of current clinical practice is necessary to identify barriers to implementation of guidelines and is a prerequisite for any study of the improvement of quality of care (7). The primary objective of this study was to characterize the current diagnostic and therapeutic strategies employed in the management of canine traumatic brain injury (TBI). The authors speculated that diagnostic and therapeutic preferences would be heterogeneous among practitioners surveyed.

Materials and methods

An Internet-based survey was used to interview practicing veterinarians regarding their management of canine TBI. The survey was conducted over a 3-month period (June to August 2016). The survey was constructed with the assistance of an Internet-based continuing education platform (VETgirl: Veterinary Continuing Educations Podcasts and Webinars) and distributed through social media as well as by e-mail. E-mail invitations were sent to veterinary professional list server groups [American College of Veterinary Emergency and Critical Care (ACVECC) and American College of Veterinary Internal Medicine (ACVIM) discussion list servers]. There was a total of 182 veterinarian respondents. The survey required that all questions be completed before submission, precluding the inclusion of incomplete surveys in data analysis. Responses from veterinary students and veterinary technicians were not included in final data analysis.

Survey characteristics

The survey contained 24 questions on diagnostic and therapeutic preferences in canine TBI cases. The questions were a combination of multiple-choice questions that permitted a single response, multiple choice questions that allowed for multiple responses, and a small number of open-ended questions. The questionnaire is available on request from the corresponding author. Respondents were divided into 4 categories: Board-certified specialists at a veterinary teaching hospital (BCS-VTH), Board-certified specialists in private practice (BCS-PP), non-specialists affiliated with a teaching hospital (DVM-VTH), and non-specialists in private practice (DVM-PP). The Board-certified specialists were individuals with diplomate status in American College of Emergency and Critical Care, American College of Veterinary Internal Medicine, American College of Veterinary Surgeons, or American College of Veterinary Anesthesia and Analgesia.

Statistical analysis

The survey questions were analyzed as a multinomial random variable when the survey question allowed the respondent to only choose a single response from a list. When respondents could choose multiple responses from a list, the data were analyzed per response category as a binomial random variable. Under the multinomial response paradigm, the multinomial relative frequency distributions of the BCS-VTH, the BCS-PP, the DVM-VTH, and the DVM-PP were compared by the conventional likelihood Chi-squared test when all of the multinomial categories were non-sparsely populated, and by the Pearson Chi-squared exact test when 1 or more of the multinomial cell frequency categories was sparsely populated. Under the binomial response paradigm, the binomial relative frequency distributions of the BCS-VTH, BCS-PP, DVM-VTH, and DVM-PP were compared by the conventional Fishers exact test. For hypothesis testing, a $P \leq 0.05$ decision rule was used as the null hypothesis rejection criterion for all between-group comparisons. A commercial statistical analysis program (SAS version 9.4; SAS Institute, Cary, North Carolina, USA) was used to conduct all statistical analyses.

Results

Respondent characteristics

A total of 182 respondents was included in the analysis. Respondents were placed in 1 of 4 categories for analysis: BCS-VTH: 33 respondents; DVM-VTH: 31 respondents; BCS-PP: 51 respondents); and DVM-PP: 67 respondents. The most frequent workplace categories cited were private practice specialty hospital (39.0%), private practice emergency practice (31.9%), and veterinary teaching hospital (35.2%). All respondents selected small animal as at least part of their patient population.

Table 1. Responses to the survey question: What is your comfort level using the modified Glasgow Coma Scale (MGCS)?

	Percent (%) of responses within each group		
Group	Not comfortable	Moderately comfortable	Very comfortable
BCS-VTH	9.1	33.3	57.6
BCS-PP	9.8	39.2	51.0
DVM-VTH	22.6	32.2	45.2
DVM-PP	40.3	32.2	17.9

BCS-VTH — Board-certified veterinarians working at a veterinary teaching hospital; BCS-PP — Board-certified veterinarians working in private practice; DVM-VTH — non-Board-certified veterinarians working at a veterinary teaching hospital; DVM-PP — non-Board-certified veterinarians working in private practice.

Incidence of canine TBI and preliminary clinical criteria used to further evaluate canine TBI cases

All respondents most frequently indicated that they saw or treated 1 to 5 cases of canine TBI per month (including polytrauma cases suspected to have TBI). The clinical criteria most often selected to further evaluate canine TBI cases included changes in mentation/responsiveness (98.4%), changes in pupil size, symmetry, responsiveness, or other cranial nerve deficits (97.8%), and hypertension/bradycardia (92.9%). Additional criteria, including evidence of external trauma (88.5%), evidence of seizures (86.8%), and changes in posture or ability to ambulate (82.4%), were also frequently chosen. Overall, 73.6% of respondents identified the modified Glasgow Coma Scale (MGCS) as part of the clinical criteria. The BCS-VTH practitioners were more likely to include the MGCS as part of their clinical criteria than were DVM-PP practitioners ($P = 0.013$). Similarly, BCS-PP practitioners were more likely to include the MGCS than were DVM-PP practitioners ($P = 0.004$).

Modified Glasgow Coma Scale: Utility of the MGSC and comfort level using the MCGC

Most practitioners indicated that the MGCS was moderately useful (62.6% of respondents). The majority of respondents were either moderately comfortable (37.9%) or very comfortable (39.0%) using the MGCS (Table 1). The DVM-VTH practitioners were more comfortable using the MGCS than were DVM-PP practitioners ($P = 0.009$). The BCS-VTH and BCS-PP practitioners also indicated they were more comfortable using the MCGS than were DVM-PP practitioners (both $P < 0.001$).

When asked about the frequency with which the MGCS is used in canine TBI patients, 48.4% of DVM-VTH practitioners responded that they used the MGCS in all patients while 23.9% of DVM-PP practitioners responded that they used the MGCS in all patients ($P = 0.020$). The DVM-PP practitioners were more likely to never use the MGCS (23.9%) compared with the BCS-PP practitioners (5.9%; $P = 0.011$). There were no significant differences among the responses of Board-certified specialist groups ($P > 0.05$).

Among all groups, 34.6% of survey respondents indicated that they repeat the MGCS in fewer than 50% of cases. Additional responses were as follows: the MGCS is never repeated at regular intervals (22.0%), the MGCS is repeated at regular intervals in > 50% but not all patients (22.5%), and the MGCS is repeated at regular intervals in all TBI patients (20.9%).

Table 2. Responses to the survey question: What initial diagnostics do you perform (within 4 hours of admission) on a canine traumatic brain injury patient?

	Percent (%) of responses within each group			
Diagnostic test	BCS-VTH	BCS-PP	DVM-VTH	DVM-PP
PCV/TS	100	98.0	100	89.6
Blood glucose	100	98.0	93.5	95.5
Lactate	93.9	68.6	87.1	59.7
CBC	48.5	74.5	45.2	70.1
Serum chemistry	45.5	78.4	41.9	76.1
Blood pressure	97.0	100	93.5	91.0
Coagulation testing	9.1	2.0	25.8	20.9
Pulse oximetry	81.8	80.4	67.7	73.1
ECG	75.8	41.2	71.0	44.8
Survey radiographs	33.3	70.6	35.5	71.6
Brief abdominal ultrasound	97.0	84.3	87.1	71.6
Brief thoracic ultrasound	81.8	58.8	87.1	62.7
CT	18.2	3.9	19.4	4.5
MRI	0	0	3.2	4.5
EEG	0	0	3.2	3.0
Measurement of intracranial pressure	0	0	0	1.5
Venous or arterial blood gas	81.8	60.8	83.9	46.3
Other	15.2	2.0	9.7	3.0

BCS-VTH — Board-certified veterinarians working at a veterinary teaching hospital; BCS-PP — Board-certified veterinarians working in private practice; DVM-VTH — non-Board-certified veterinarians working at a veterinary teaching hospital; DVM-PP — non-Board-certified veterinarians working in private practice; PCV/TS — packed cell volume and total solids; CBC — complete blood (cell) count; ECG — electrocardiography; CT — computed tomography; MRI — magnetic resonance imaging; EEG — electroencephalography.

Initial diagnostic testing performed in canine TBI cases

The diagnostic tests most frequently performed on a TBI patient within the first 4 h of admission by all respondents included packed cell volume/total solids (PCV/TS) (95.6%), blood glucose (96.7%), and blood pressure (95.0%) (Table 2). Practitioners at a teaching hospital (BCS-VTH and DVM-VTH) indicated that they use lactate (93.9% *versus* 68.6%; $P = 0.005$), electrocardiogram (ECG) (75.8% *versus* 41.2%; $P = 0.003$), and brief thoracic ultrasound (81.8% *versus* 58.8%; $P = 0.032$) more frequently than did their private practice counterparts (BCS-PP and DVM-PP). When DVM-VTH and DVM-PP groups were compared, DVM-VTH practitioners chose computed tomography (CT) (19.4% *versus* 4.5%; $P = 0.027$), venous or arterial blood gas (83.9% *versus* 46.3%; $P < 0.001$), ECG (71.0% *versus* 44.8%; $P = 0.018$), lactate (87.1% *versus* 59.7%; $P = 0.009$), and brief thoracic ultrasound (87.1% *versus* 62.7%; $P = 0.017$) more frequently than did their private practice counterparts. Conversely, DVM-PP practitioners more frequently chose complete blood (cell) count (CBC) (70.1% *versus* 45.2%; $P = 0.025$), serum chemistry (76.1% *versus* 41.9%; $P = 0.001$), and survey radiographs (71.6% *versus* 35.5%; $P = 0.001$) as part of their initial diagnostic plan than did DVM-VTH practitioners.

Table 3. Responses to the survey question: What initial therapeutics do you consider in canine traumatic brain injury cases?

	Percent (%) of responses within each group			
Therapeutic	BCS-VTH	BCS-PP	DVM-VTH	DVM-PP
Mannitol	84.8	94.1	93.5	85.1
Hypertonic saline	87.9	94.1	90.3	74.6
Crystalloid fluid therapy	84.8	96.1	96.8	88.1
Colloid fluid therapy	27.3	21.6	6.5	20.9
Elevation of head (incline board)	97.0	88.2	93.5	95.5
Oxygen therapy	93.9	96.1	87.1	94.0
Corticosteroid therapy	3.0	0	3.2	10.4
Non-steroidal anti-inflammatory therapy	0	0	3.2	7.5
Opioid therapy	87.9	90.2	83.9	79.1
Anticonvulsant therapy	54.5	47.1	58.1	73.1
Therapeutic hypothermia	18.2	9.6	12.9	17.9
Mechanical ventilation	45.5	21.6	22.6	20.9
Hyperventilation	9.1	9.8	0	3.0
Antibiotic therapy	18.2	15.7	25.8	25.4
Insulin therapy	0	7.8	3.2	3.0
Antioxidant/ Free-radical scavenging therapy	9.1	19.6	3.2	14.9
Other	15.2	3.9	6.5	1.5

BCS-VTH — Board-certified veterinarians working at a veterinary teaching hospital; BCS-PP — Board-certified veterinarians working in private practice; DVM-VTH — non-Board-certified veterinarians working at a veterinary teaching hospital; DVM-PP — non-Board-certified veterinarians working in private practice.

Initial therapeutic interventions used in canine TBI cases

The initial therapeutic interventions chosen for TBI are summarized in Table 3. The most frequently selected treatments among all respondents included mannitol (89.0%), hypertonic saline (85.1%), crystalloid fluids (91.2%), elevation of the head (93.4%), oxygen therapy (93.4%), and opioid analgesia (84.6%).

The BCS-PP practitioners were more likely to choose hypertonic saline than were the DVM-PP practitioners; 94.1% BCS-PP practitioners chose hypertonic saline compared with 74.6% DVM-PP practitioners ($P = 0.005$). While 10.4% of DVM-PP practitioners chose corticosteroids as part of their initial treatment plan, none of the BCS-PP clinicians selected corticosteroid therapy ($P = 0.019$). Moreover, 73.1% DVM-PP clinicians chose anticonvulsant therapy compared to 47.1% of BCS-PP practitioners ($P = 0.004$).

Treatment(s) of choice for intracranial hypertension

Hyperosmolar agents were the initial therapy of choice for intracranial hypertension (ICH). Mannitol was chosen by 73.0% of participants and hypertonic saline was chosen by 73.6% of participants. Corticosteroid therapy (0.03%), colloid therapy (0.05%), and decompressive craniectomy (0.02%) were chosen much less frequently (Table 4). According to most respondents, mannitol and hypertonic saline were both available for use at all times (90.7%).

Patient factors appeared to influence the choice of first-line therapy for ICH more so than specific characteristics of hypertonic saline *versus* mannitol. The patient's volume status and/or hemodynamic stability appeared to influence initial therapeutic choices most often (82.4%). Comorbidities were also frequently considered when choosing a therapy (75.8%). DVM-VTH practitioners were more likely to indicate that "results of advanced imaging" guided first-line therapy for ICH than did their DVM-PP counterparts (16.1% *versus* 1.5%; $P = 0.012$).

The physical properties of mannitol and hypertonic saline as hyperosmolar agents, their effects on inflammation, and their ability to modulate oxidative injury were chosen with a similar frequency (33.5%, 27.4%, and 26.9% of all respondents, respectively). The rheological effects of hypertonic saline and mannitol were considered by 25.2% of all respondents.

Improved mentation or responsiveness was the most important clinical criterion used to guide treatment for TBI, chosen with a frequency of 99.4%. The following clinical criteria were also frequently considered: resolution of the hemodynamic changes associated with intracranial hypertension (90.6%) and improvement of pupil size, symmetry, and reactivity (93.4%). Control of clinical seizures was chosen by 76.3% of respondents, while improvement of the MGCS score was chosen by 64.2% of all respondents. Improvement of ventilation parameters, normolactatemia, and normoglycemia were chosen by 47.8%, 42.3%, and 41.7%, respectively. Achieving a normal EEG was rarely chosen to guide continued therapy (0.04% of all respondents; Table 5).

Pathophysiology of secondary brain injury

Most practitioners were either very familiar (42.3%) or somewhat familiar (43.4%) with the pathophysiology of secondary brain injury. Board-certified specialists were more likely to be very familiar with secondary brain injury than non-Board-certified specialists of either group: 63.6% BCS-VTH practitioners and 66.7% BCS-PP practitioners indicated they were very familiar with secondary brain injury, whereas 38.7% DVM-VTH practitioners and 14.9% DVM-PP practitioners indicated that they were very familiar with secondary brain injury. The DVM-VTH practitioners were more likely to indicate that they were very familiar with secondary brain injury than were the DVM-PP practitioners (DVM-VTH 38.7% *versus* DVM-PP 14.9%; $P = 0.017$).

Availability and accessibility of canine TBI treatment guidelines and comfort level treating canine TBI

According to most respondents, guidelines for canine TBI are somewhat clear (68.1%) and moderately available and accessible (67.6%). Among all groups, 54.4% of respondents felt very comfortable treating TBI. A substantial number of respondents indicated they were moderately comfortable (40.7%), and a lesser number indicated they were not comfortable treating TBI (4.9%). Board-certified specialists of both groups were

Table 4. Responses to the survey question: What is your first-line therapy of choice for intracranial hypertension?

	Percent (%) of responses within each group					
Group	Mannitol	Hypertonic saline	Colloid	Corticosteroids	Decompressive craniectomy	Other
BCS-VTH	57.6	84.8	3.0	0	3.0	0
BCS-PP	68.6	72.5	3.9	0	2.0	3.9
DVM-VTH	93.5	87.1	3.2	6.5	6.5	3.2
DVM-PP	74.6	62.7	7.5	6.0	0	6.0

BCS-VTH — Board-certified veterinarians working at a veterinary teaching hospital; BCS-PP — Board-certified veterinarians working in private practice; DVM-VTH — non-Board-certified veterinarians working at a veterinary teaching hospital; DVM-PP — non-Board-certified veterinarians working in private practice.

Table 5. Responses to the survey question: What clinical criteria do you use to guide therapy in canine traumatic brain injury?

	Percent (%) of responses within each group			
Clinical criterion	BCS-VTH	BCS-PP	DVM-VTH	DVM-PP
Improved mentation/responsiveness	97.0	100	100	100
Improved MGCS score	75.8	72.5	61.3	53.7
Normotension and normal heart rate	87.9	92.2	90.3	91.0
Normal pupil size, symmetry, and reactivity	78.8	96.1	93.5	98.5
Eupnea	72.7	80.4	67.7	80.6
Normocapnia	69.7	37.3	54.8	41.6
Normoglycemia	51.5	39.2	32.3	43.3
Normolactatemia	57.6	35.3	51.6	35.8
Control of clinical seizures	72.7	70.6	71.0	85.1
Normal EEG	0	2.0	3.2	7.5
Other	3.0	2.0	0	1.5

BCS-VTH — Board-certified veterinarians working at a veterinary teaching hospital; BCS-PP — Board-certified veterinarians working in private practice; DVM-VTH — non-Board-certified veterinarians working at a veterinary teaching hospital; DVM-PP — non-Board-certified veterinarians working in private practice; MGCS — modified Glasgow Coma Scale score; EEG — electroencephalography.

more likely to indicate they were very comfortable treating TBI than were non-specialists of either of the non-specialist groups (79.7% BCS *versus* 32.6% DVM). The DVM-VTH practitioners were more likely to indicate that they were very comfortable treating canine TBI than were their DVM-PP counterparts (48.4% *versus* 25.4%; $P = 0.047$).

Discussion

This survey identified some conserved practices implemented by most practitioners, as well as specific differences in diagnostic and therapeutic approaches to canine TBI. While all respondents appear to rely heavily on the results of a complete neurologic examination, Board-certified specialists were more comfortable with the use of the MGCS and used it more frequently than did other groups. The explanations for these discrepancies were not addressed in this survey. A future survey could be constructed to more specifically interrogate clinicians about their familiarity with and exposure to the MGCS at varying levels of education and training. The Glasgow Coma Scale (GCS) has traditionally been considered the gold standard in human medicine for providing an objective neurologic assessment of the level of consciousness in human patients with severe brain injury (8). Initial as well as serial GCS scores can be used to guide therapy, compare treatment efficacies, and determine prognosis in human patients sustaining brain injury (8–10). Similar to the GCS in human comatose patients, the MGCS serves as an objective neurologic assessment that can be performed at the time of admission and repeated at intervals during hospitalization. Previous veterinary studies that have evaluated prognostic indicators in head trauma have found the MGCS to be a useful indicator of survival in the TBI patient population (11–14). Given its prognostic utility, concerted efforts to teach and to reinforce consistent use of the MGCS in canine TBI cases seem warranted.

Initial diagnostic tests performed in TBI cases help to guide therapeutic interventions and to provide prognostic information. Based on retrospective veterinary studies, neither blood pressure nor blood glucose at the time of admission is predictive of outcome in TBI, although hyperglycemia may indicate the severity of brain injury (12). While hyperglycemia has been associated with poor outcome in humans with TBI in clinical studies, some studies suggest that episodic hyperglycemia may improve cerebral metabolism and mitigate secondary brain injury (15). The effects of glucose control on neurologic outcome or survival in canine TBI patients have yet to be determined. Moreover, indicators of hypoperfusion or metabolic dysfunction, including increased lactate, decreased blood pH, increased base deficit, and decreased bicarbonate, have been shown to be predictive of non-survival in dogs with traumatic brain injury (12). The non-uniform pattern of diagnostic tests chosen by practitioners at a teaching hospital *versus* those in private practice in this survey suggests a lack of clarity regarding the utility — or necessity- of specific diagnostics. The disparity seen in responses should prompt the construction of a more formal diagnostic algorithm that can be applied to canine TBI cases.

Neuroimaging in the acute canine TBI patient was infrequently chosen as a diagnostic tool among all respondents in this survey. Neuroimaging allows for the identification of structural changes to brain and skull and may be used to guide therapy in the head trauma patient. In humans, CT remains the imaging modality of choice for head trauma within the first 24 h of injury, as it allows for rapid assessment for hemorrhage and fractures (16). As the sequelae of secondary brain injury develop, however, MRI becomes the superior imaging modality for detecting changes to the brain parenchyma and becomes the imaging modality of choice 24 h or more after the injury (16,17). A study evaluating MRI in dogs with head trauma demonstrated associations between MRI findings and prognosis (3). In veterinary patients, however, CT and MRI often require heavy sedation or anesthesia to obtain images of diagnostic quality, so in addition to cost, the risks and benefits of advanced imaging to the individual patient must be carefully considered (14). A follow-up survey could be designed to identify the reasons that clinicians infrequently pursue advanced imaging in the context of canine TBI (i.e., perceived value or necessity of information obtained, financial costs, anesthetic risks, accessibility, other reasons). Specific recommendations regarding neuroimaging in the canine TBI patient and the optimum time at which to perform imaging would be of value in the construction of treatment guidelines.

Therapeutic options for canine TBI are numerous and often controversial. Corticosteroid therapy was chosen by fewer than 5% of respondents; however, 10.4% of non-specialists in private practice indicated that they use corticosteroids in the management of TBI. A randomized control trial evaluating corticosteroid administration in human head trauma (CRASH study) found no clinical benefit to corticosteroid therapy and in fact showed increased early mortality rates in patients who received corticosteroids (18). Prior to this study, corticosteroids were more commonly used in the treatment of TBI. Although there are no studies that evaluate the use of corticosteroids in canine TBI, given the evidence for harm in the human population, the authors believe it is prudent to recommend against the use of corticosteroids in the treatment of TBI.

Anticonvulsant therapy was chosen by approximately 50% of respondents, which suggests a lack of consensus regarding the necessity of seizure prophylaxis. In humans, seizure prophylaxis is recommended in severe TBI patients (5,19,20). Studies evaluating EEG findings in human patients with moderate to severe TBI have shown that post-traumatic seizures occur in approximately 20% of the patient population; most of these seizures are non-convulsive and detected on EEG alone (19). Similarly, a study evaluating the incidence of post-traumatic seizures in dogs with head trauma revealed a greater incidence of seizures in trauma patients than in the general population (6). While prompt treatment of overt seizure activity in canine TBI patients is unlikely to be contested, the necessity for seizure prophylaxis remains controversial (1). Further, the anticonvulsant of choice for seizure prophylaxis, as well as the diagnostic modalities necessary to detect non-convulsive seizures, warrant further investigation before specific recommendations can be made.

While hyperosmolar agents have antioxidant properties, the addition of other antioxidants for the explicit purpose of scavenging reactive oxygen species was infrequently chosen as an initial therapeutic intervention for TBI. Studies evaluating the effect of specific antioxidants on outcome in human and veterinary TBI cases are lacking. It has been postulated that the mitigation of oxidative stress may be an important therapeutic target in TBI (21,22).

Intracranial hypertension is a severe complication of TBI and exacerbates cerebral ischemia and secondary brain injury (1,23). While surgical decompression *via* craniectomy may provide an acute reduction in intracranial pressure, intracranial hypertension is much more commonly treated with hyperosmolar therapies that target the reduction of interstitial edema within the brain (1,23). Mannitol and hypertonic saline are the 2 most widely used hyperosmolar agents in both human and veterinary medicine (1,4,23,24). In this survey, respondents chose mannitol and hypertonic saline as their first-line treatment of choice for intracranial hypertension with very similar frequencies. Beyond their hyperosmolar properties, the 2 therapies have varying effects on rheology, cerebral vasospasm, cardiac output, intravascular volume, and inflammation (4,24,25). Individual studies and meta-analyses in human medicine have sought to compare mannitol to hypertonic saline to determine whether there is a superior hyperosmolar therapy for the management of intracranial hypertension (4,26). While some studies suggest that hypertonic saline may more effectively reduce intracranial pressure compared with mannitol (1,4,26,27), these studies do not demonstrate that hypertonic saline improves survival or neurological signs relative to mannitol (27). Current guidelines for the treatment of severe TBI in humans do not recommend one hyperosmolar solution over the other, citing that there is insufficient evidence to do so (28). The relative benefits of hypertonic saline *versus* mannitol have not been investigated in naturally occurring TBI in the dog.

This study has several limitations. While the survey was distributed across 2 list servers and a veterinary continuing education social media platform for a 3-month period, the total number of respondents was small. The sample size was sufficient for the identification of statistically significant differences between groups; however, a larger number of participants would have increased the power to detect smaller differences. Furthermore, there was a limited number of questions that required clinicians to make diagnostic or therapeutic choices without case-specific information. As with any survey-based study, the construction of the questionnaire may have influenced survey results.

In conclusion, the results of this study suggest that significant heterogeneity exists in the assessment and treatment of canine TBI in the veterinary community. In particular, there is variation in the use of the MGCS, monitoring of oxygenation, ventilation and perfusion, and treatment with corticosteroids and hyperosmolar therapies, despite existing evidence for or against these interventions. This study highlights the need for evidence-based consensus guidelines for the treatment of TBI and identifies clinically relevant gaps in understanding that warrant further research.

Acknowledgments

The authors thank James Patrie for performing the statistical analyses, Cape Cod Veterinary Specialists for their financial support of the project, Dr. Louisa Rahilly for critical review of the survey, Dr. Shana O'Marra for critical review of the manuscript, and Dr. Justine Lee with VETgirl: Veterinary Continuing Education Podcasts and Webinars for critical review of the survey and assistance with survey distribution. The authors also thank those who responded to the survey questions. CVJ

References

1. Sande A, West C. Traumatic brain injury: A review of pathophysiology and management. J Vet Emerg Crit Care 2010;20:177–190.
2. DiFazio J, Fletcher DJ. Updates in the management of the small animal patient with neurologic trauma. Vet Clin North Am Small Anim Pract 2013;43:915–940.
3. Beltran E, Platt SR, McConnell JF, Dennis R, Keys DA, De Risio L. Prognostic value of early magnetic resonance imaging in dogs after traumatic brain injury: 50 cases. J Vet Intern Med 2014;28:1256–1262.
4. Kamel H, Navi BB, Nakagawa K, Hemphill JC, 3rd, Ko NU. Hypertonic saline versus mannitol for the treatment of elevated intracranial pressure: A meta-analysis of randomized clinical trials. Crit Care Med 2011;39:554–559.
5. Annegers JF, Hauser WA, Coan SP, Rocca WA. A population-based study of seizures after traumatic brain injuries. N Eng J Med 1998;338:20–24.
6. Friedenberg SG, Butler AL, Wei L, Moore SA, Cooper ES. Seizures following head trauma in dogs: 259 cases (1999–2009). J Am Vet Med Assoc 2012;241:1479–1483.
7. Boller M, Kellett-Gregory L, Shofer FS, Rishniw M. The clinical practice of CPCR in small animals: An internet-based survey. J Vet Emerg Crit Care 2010;20:558–570.
8. Wijdicks EF. Clinical scales for comatose patients: The Glasgow Coma Scale in historical context and the new FOUR Score. Rev Neurol Dis 2006;3:109–117.
9. Marion DW, Carlier PM. Problems with initial Glasgow Coma Scale assessment caused by prehospital treatment of patients with head injuries: Results of a national survey. J Trauma Acute Care Surg 1994; 36:89–95.
10. Dolan R, Polito C, Isakov A, et al. Utility of pre-hospital Glasgow Coma Scale in predicting in-hospital mortality in patients with sepsis. Am J Resp Crit Care Med 2016:7619–7619.
11. 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.
12. Sharma D, Holowaychuk MK. Retrospective evaluation of prognostic indicators in dogs with head trauma: 72 cases (January–March 2011). J Vet Emerg Crit Care 2015;25:631–639.
13. Hall KE, Holowaychuk MK, Sharp CR, Reineke E. Multicenter prospective evaluation of dogs with trauma. J Am Vet Med Assoc 2014; 244:300–308.
14. Simpson SA, Syring R, Otto CM. Severe blunt trauma in dogs: 235 cases (1997–2003). J Vet Emerg Crit Care 2009;19:588–602.
15. Moro N, Ghavim S, Harris NG, Hovda DA, Sutton RL. Glucose administration after traumatic brain injury improves cerebral metabolism and reduces secondary neuronal injury. Brain Res 2013;1535:124–136.
16. Lee B, Newberg A. Neuroimaging in traumatic brain imaging. NeuroRx 2005;2:372–383.
17. Eierud C, Craddock RC, Fletcher S, et al. Neuroimaging after mild traumatic brain injury: Review and meta-analysis. Neuroimage Clin 2014;4: 283–294.
18. Roberts I, Yates D, Sandercock P, et al. Effect of intravenous cortico-corticosteroids on death within 14 days in 10008 adults with clinically significant head injury (MRC CRASH trial): Randomised placebo-controlled trial. Lancet 2004;364:1321–1328.
19. Vespa PM, Nuwer MR, Nenov V, et al. Increased incidence and impact of nonconvulsive and convulsive seizures after traumatic brain injury as detected by continuous electroencephalographic monitoring. J Neurosurg 1999;91:750–760.
20. Vespa PM, McArthur DL, Xu Y, et al. Nonconvulsive seizures after traumatic brain injury are associated with hippocampal atrophy. Neurology 2010;75:792–798.
21. Hall ED, Vaishnav RA, Mustafa AG. Antioxidant therapies for traumatic brain injury. Neurotherapeutics 2010;7:51–61.
22. Bains M, Hall ED. Antioxidant therapies in traumatic brain and spinal cord injury. Biochim Biophys Acta 2012;1822:675–84.
23. Rangel-Castillo L, Gopinath S, Robertson CS. Management of intracranial hypertension. Neurol Clin 2008;26:521–541.
24. Oddo M, Levine JM, Frangos S, et al. Effect of mannitol and hypertonic saline on cerebral oxygenation in patients with severe traumatic brain injury and refractory intracranial hypertension. J Neurol Neurosurg Psychiatry 2009;80:916–920.
25. Salim A, Hadjizacharia P, Dubose J, et al. Persistent hyperglycemia in severe traumatic brain injury: An independent predictor of outcome. Am Surg 2009;75:25–29.
26. Marko NF. Hypertonic saline, not mannitol, should be considered gold-standard medical therapy for intracranial hypertension. Crit Care 2012;16:113.
27. Mangat HS, Chiu YL, Gerber LM, Alimi M, Ghajar J, Hartl R. Hypertonic saline reduces cumulative and daily intracranial pressure burdens after severe traumatic brain injury. J Neurosurg 2014;122:1–9.
28. Carney N, Totten AM, O'reilly C, Ullman JS, et al. Guidelines for the management of severe traumatic brain injury. Neurosurgery 2017; 80:6–15.