Relationship between the ratio of optic nerve sheath diameter to eyeball transverse diameter and morphological characteristics of dogs

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OBJECTIVE
To assess the feasibility of ocular ultrasonography for measurement of the ratio of optic nerve sheath diameter (ONSD) to eyeball transverse diameter (ETD) in dogs with various morphologies and to evaluate the interobserver reliability of the ONSD/ETD ratio and its correlation with various morphological variables.

ANIMALS
45 healthy dogs of various breeds.

PROCEDURES
Height, head circumference, body weight, body condition score, intraocular pressure, and blood pressure were recorded for each dog. Unsedated dogs underwent bilateral ocular ultrasonography once. A veterinarian and board-certified ophthalmologist who were unaware of subject signalment independently reviewed the ultrasonographic videos and selected 1 image for each eye on which the ETD and ONSD were measured. The ONSD/ETD ratio was calculated and compared between the 2 observers. Correlations between the ONSD/ETD ratio and various physiologic and morphological variables were assessed.

RESULTS
172 ONSD/ETD ratios were recorded. The ONSD/ETD ratio was calculated for at least 1 eye for 44 of the 45 (98%) dogs. Mean ± SD time required to complete the ultrasonographic examination was 90 ± 30 seconds (range, 15 seconds to 3 minutes). The mean ± SD ONSD/ETD ratio was 0.17 ± 0.01 (range, 0.15 to 0.20). The ONSD/ETD ratio did not differ significantly between the left and right eyes or the 2 observers and was not correlated with any of the variables assessed.

CONCLUSIONS AND CLINICAL RELEVANCE
Ocular ultrasonography was a rapid, noninvasive, and reliable method for measurement of the ONSD/ETD ratio. The ONSD/ETD ratio did not appear to be influenced by dog morphology. (*Am J Vet Res* 2021;82:667–675)

Prompt identification of ICH is paramount for the management of various neurologic and systemic diseases because the consequences of rising ICP can lead to catastrophic events such as brain herniation, respiratory failure, and death.[1–3] An elevated ICP is often suspected in patients with altered mentation, deficits in brainstem reflexes including changes in pupil size and reactivity, cardiovascular changes suggestive of a Cushing reflex (reflex bradycardia and systemic hypertension secondary to an elevated ICP), or history of recent head trauma.[1,4] However, those findings are neither specific nor sensitive for the detection of ICH,[5] and an altered state of consciousness may be observed with disruption of the reticular activating system unrelated to ICH.[6]

Current modalities for objective measurement of ICP do not allow the rapid assessment necessary for timely and potentially life-sparing interventions. Intracranial pressure is measured by subdural or intraparenchymal transducers, both of which are invasive techniques and are not commonly performed in veterinary clinics,[7] owing to the technical nature, time, and neurosurgical skills necessary for transducer placement and the risk of infection and hemorrhage for the patient.[8] Noninvasive techniques to detect ICH include assessment of transcranial blood flow[9] and evaluation of MRI sequences for evidence of hypertension[10]; however, the technology necessary for those techniques is not widely available for use in veterinary emergency practice.

ABBREVIATIONS

BCS	Body condition score
DAP	Diastolic arterial pressure
ETD	Eyeball transverse diameter
ICH	Intracranial hypertension
ICP	Intracranial pressure
IOP	Intraocular pressure
MAP	Mean arterial pressure
ONS	Optic nerve sheath
ONSD	Optic nerve sheath diameter
SAP	Systolic arterial pressure

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An increase in the ONSD identified on MRI or ocular ultrasonographic images is considered an indicator of elevated ICP in human patients[11] and dogs.[12,13] The optic nerve is an outgrowth of the diencephalon, and the ONS is in the continuum of the meninges that surround the brain.[14] As ICP increases, the CSF confined in the intracranial meninges is pressurized to the subarachnoid space in the periorbital region and distends the ONS.[15]

In clinically normal individuals, the ONSD is positively correlated with body weight,[16] limiting the specificity of a single reference range for various breeds of dogs with different morphologies. For example, a small-breed dog with an enlarged ONSD might be incorrectly classified as clinically normal and a large-breed dog with a physiologically normal ONSD might be misclassified as having an enlarged ONSD if a single reference range is used to interpret ONSD values. A diagnostic tool that allows rapid assessment of ICP with the inherent ability to account for the size and morphological characteristics of a dog would increase the usefulness and precision of that measurement.

In dogs, globe (eyeball) size is positively correlated with body size and weight[17] and can be represented as the ETD. In human medicine, the ONSD/ETD ratio has been successfully used to identify elevations in ICP in individuals of diverse populations including pediatric patients.[18,19] The ONSD/ETD ratio has not been investigated in dogs and warrants consideration as a means to independently control for the morphological diversity of dogs and provide a rapid, straightforward cage-side tool for identifying an abnormally increased ICP in critically ill dogs.

The objectives of the study reported here were to assess the feasibility of ocular ultrasonography as a portable method for measuring the ONSD/ETD ratio in dogs of various sizes and with various morphological characteristics, to evaluate the interobserver reliability of the ultrasonographically determined ONSD/ETD ratio, to assess the respective relationships between various morphological characteristics and the ONSD and ONSD/ETD ratio, and to derive a de novo ONSD/ETD ratio reference interval for the study population. We hypothesized that the ONSD/ETD ratio would not be significantly associated with dog size or ultrasonographer experience.

Materials and Methods

Animals

All study procedures were reviewed and approved by the University of Saskatchewan Animal Research Ethics Board (AUP No. 20200007). Dogs owned by staff and students of the Western College of Veterinary Medicine were prospectively recruited for the study from January through April 2020. To be eligible for study enrollment, each dog had to be between 5 months and 13 years old and free of systemic disease, ophthalmic abnormalities, and previous or current neurologic disease as determined on the basis of the owner-provided medical history and results of complete physical, neurologic, biomicroscopic[a] ophthalmic, and indirect ophthalmoscopic examinations. Consent was obtained from the owner of each dog prior to study enrollment.

Data collection

For each dog, sex, age, height, head circumference, body weight, BCS, IOP, SAP, MAP, and DAP were recorded at the time of examination. The IOP was approximated by use of a tonometer.[b] Blood pressure was measured noninvasively with an oscillometric monitor.[c]

Ocular ultrasonographic examinations were performed by either a veterinarian (AD) with no previous training in ocular ultrasonography or a board-certified veterinary ophthalmologist (SO). All ultrasonographic recordings were standardized in the vertical transverse plane, with a depth of 50 mm, focus point of 25 mm, and gain of 60 dB. To perform the ocular ultrasonographic examination, each dog was restrained in a sitting position on an examination table in a room with dimmed lighting. Each dog was gently restrained manually with one of the restrainer's hands under the dog's chin and the other at the back of its head. One drop (approx 0.05 mL) of topical 0.5% proparacaine solution[d] was instilled in each eye. Ultrasound gel was copiously placed on a 15-MHz B-scan probe[e] that was then gently applied over the superior aspect of an eyeball and stabilized by resting a finger over the face of the dog. Vertical sections of the eyeball were successively scanned by fanning and sliding the transducer until the orbit and optic nerve were clearly visualized. The process was repeated for the contralateral eye. For each eye, the video of the ocular ultrasonographic examination was terminated at the discretion of the sonographer once the ONS and ETD were visualized in the same frame **(Figure 1)**. The time required to obtain the video was recorded. The video of each examination was saved and archived for review.

All videos of the ocular ultrasonographic examinations were independently reviewed by the veterinarian and veterinary ophthalmologist who performed the examinations. All identifying information was removed from the video files so that the observers remained unaware of (were blinded to) the subject's signalment during the review and measurement processes. For each eye, each observer independently selected 1 image from the video on which to measure the ONSD and ETD. All measurements were performed by use of the electronic caliper feature within a computer software program.[e] The ETD was measured at the widest aspect of the eyeball transverse to its axis **(Figure 2)**. The optic nerve was identified as a slightly curved hypoechoic strip caudal to the eye, and the ONS was identified as the hyperechoic strip on both sides of the optic nerve.[20,21] The borders of the hyperechoic strips furthest from the optic

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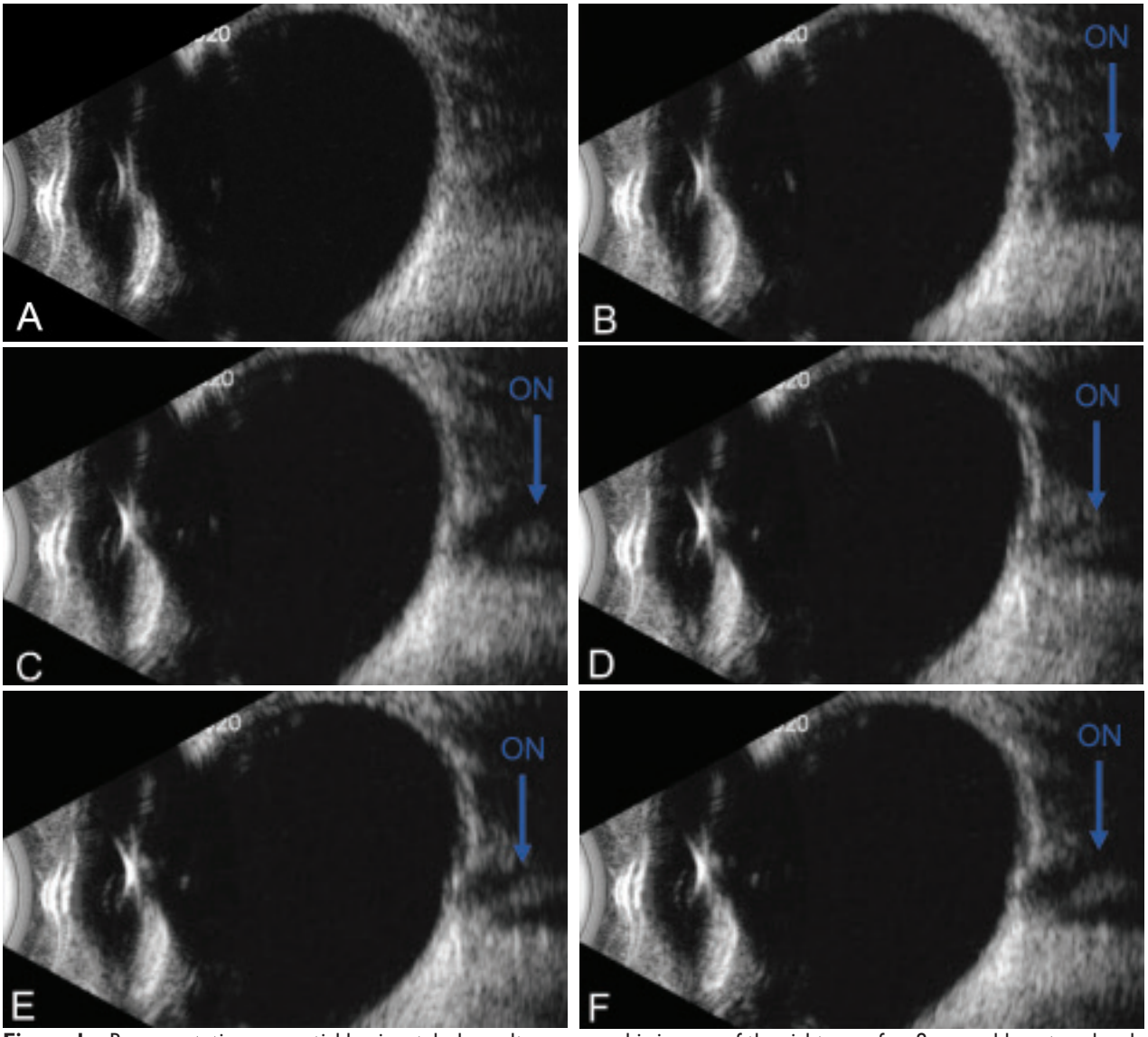

Figure 1—Representative sequential horizontal-plane ultrasonographic images of the right eye of an 8-year-old neutered male Labrador Retriever obtained by successively fanning and sliding a 15-MHz B-scan probe over the superior aspect of the eyeball until the orbit and optic nerve (ON; blue arrow) were clearly visualized. A to C—Initially, the ON fibers appear hypoechoic within the hyperechoic retrobulbar fat and become progressively defined, forming a curved hypoechoic strip. D to F—The ON was followed until it reached the caudal aspect of the eyeball.

nerve were used as landmarks for measurement of the ONSD, which was measured perpendicular to the focal axis of the optic nerve 3 mm caudal to the optic disc. That 3-mm distance was measured by drawing a straight line caudally from the optic disc parallel to the focal optic nerve axis. Each observer measured the ONSD and ETD once for each eye and used those measurements to calculate the ONSD/ETD ratio for that eye.

Statistical analysis

The data distributions for continuous variables were evaluated for normality by visual assessment of histograms and quantile plots and results of skewness-kurtosis and Shapiro-Wilk tests. Graphic evaluation of scatterplots, box plots, and q-q plots was used to search the data for potential outliers. Because no significant outliers were identified relative to the fairly small sample size, all values were retained in the data analyses. All continuous variables were determined to be normally distributed, and results for those variables were summarized as the mean ± SD. The primary outcomes of interest were the ONSD, ETD, and ONSD/ETD ratio. The respective correlations between each outcome of interest and dog age, height, head circumference, body weight, BCS (analyzed as a continuous variable), IOP, SAP, MAP, and DAP were assessed by calculation of the Pearson correlation coefficient (r). The respective correlations between each outcome variable and sex were assessed by calculation of the Spearman correlation coefficient (r_S). Paired t tests were used to compare

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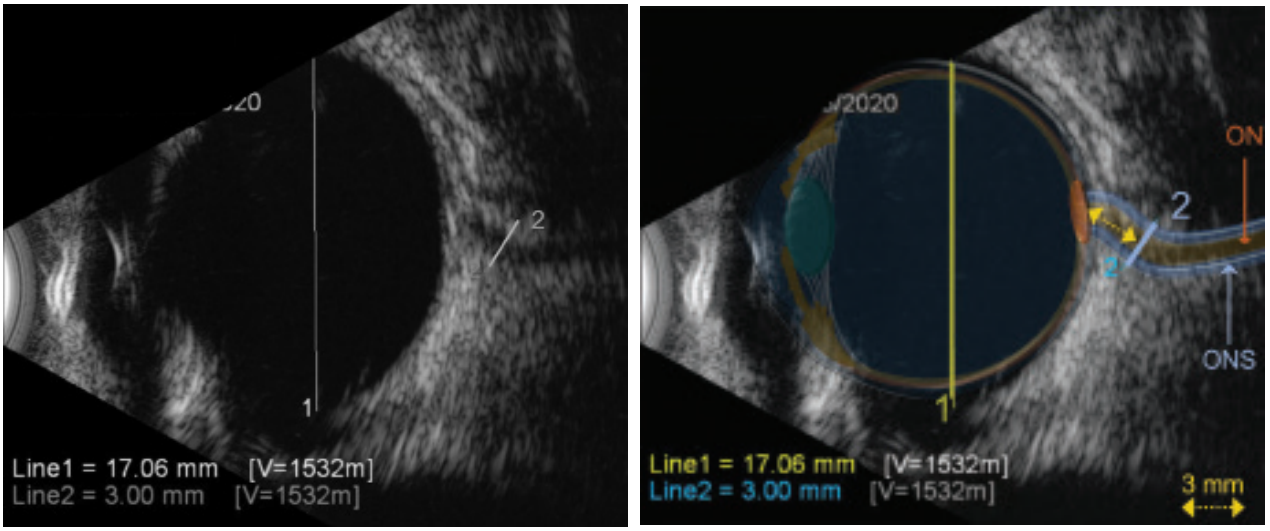

Figure 2—Representative horizontal-plane ultrasonographic images of the left eye of a 1-year-old neutered male mixed-breed dog obtained as described for the dog of Figure 1 that depict measurement of the ETD and ONSD without and with a colored overlay of the canine eye to highlight landmarks. The ETD (line 1) was measured at the widest diameter of the eyeball transverse to its axis. The ONSD (line 2) was the distance between the outer borders of the hyperechoic rim (ie, subarachnoid space that contained CSF) that surrounded and defined the optic nerve (ON) and was measured perpendicular to the focal axis of the ON 3 mm caudal to the optic disc. In both images, the ON appears as a curved hypoechoic strip within the ONS. Rostral to the eyeball, there is an anechoic-hypoechoic area produced by multiple reverberations and mirror images from the ultrasound transducer to the ocular acoustic interfaces including the lens and sclera. This area contains curvilinear hyperechoic lines that are reflections from the anterior and posterior lens capsule.

the outcome variables between left and right eyes and between the 2 observers (veterinarian and veterinary ophthalmologist). Independent *t* tests were used to assess the effect of sex on each of the outcome variables. All *t* tests were 2-sided, and values of $P < 0.05$ were considered significant. For each outcome variable, the Bland-Altman method was used to investigate potential repartitions of differences around the mean and to calculate the 95% limits of agreement for measurements between left and right eyes and between the 2 observers. For the study population, a de novo reference interval for the ONSD/ETD ratio was derived from the 2.5th and 97.5th percentiles and their respective 95% CIs as described[22] by use of the ONSD/ETD ratio values determined by the 2 observers on the mean measurement for both eyes of each dog. All analyses were performed by use of a commercially available statistical software program.[f]

Results

Dogs

Forty-seven dogs were recruited for study enrollment. Two dogs were subsequently excluded from the study because of abnormal findings on the retinal examination. The remaining 45 dogs were enrolled in the study and included 18 males (2 sexually intact and 16 castrated) and 27 females (9 sexually intact and 18 spayed). There were 18 (40%) mixed-breed dogs, 4 Labrador Retrievers, 3 Golden Retrievers, 2 Greyhounds, 2 Dachshunds, 2 Chihuahuas, and 1 each of the following breeds: American Staffordshire Terrier, Border Terrier, Boxer, Cairn Terrier, Cocker Spaniel, French Bulldog, German Shepherd Dog, Jack Russell Terrier, Papillon, Parson Russell Terrier, Saint Bernard, Shetland Sheepdog, Standard Poodle, and Yorkshire Terrier. The study population had a mean ± SD age of 5 ± 4 years, height of 48.6 ± 16 cm, head circumference of 46.4 ± 10 cm, and body weight of 20.5 ± 12 kg.

Ultrasonographic measurements

The veterinarian and veterinary ophthalmologist performed the ocular ultrasonographic examination for 23 and 22 dogs, respectively. The mean ± SD time required to complete the examination and acquire satisfactory videos was 90 ± 30 seconds (range, 15 seconds to 3 minutes).

A total of 172 ONSD/ETD ratios were recorded by the 2 observers. Occasionally, ultrasonographic artifacts adversely affected measurement of the ONSD on the same image as the ETD. For example, a linear hypoechoic artifact caused by differences in wave sounds penetrating the lamina cribrosa cranially to the head of the optic nerve could be mistaken for the ONS and lead to overestimation of the ONSD. Extraocular muscles also appear as hypoechoic structures in the retrobulbar region and could be mistaken for the ONS and lead to overestimation of the ONSD. The ONSD could also be overestimated if the hypoechoic rim of the dura mater appeared very thin, making it difficult to differentiate the border between the hyperechoic ONS and the hyperechoic periorbital fat **(Figure 3)**.

The ONSD/ETD ratio could not be calculated by either observer for a total of 4 eyes (both eyes of 1 dog, the right eye of 1 dog, and the left eye of 1 dog) owing to inadequate visualization of the ONS during

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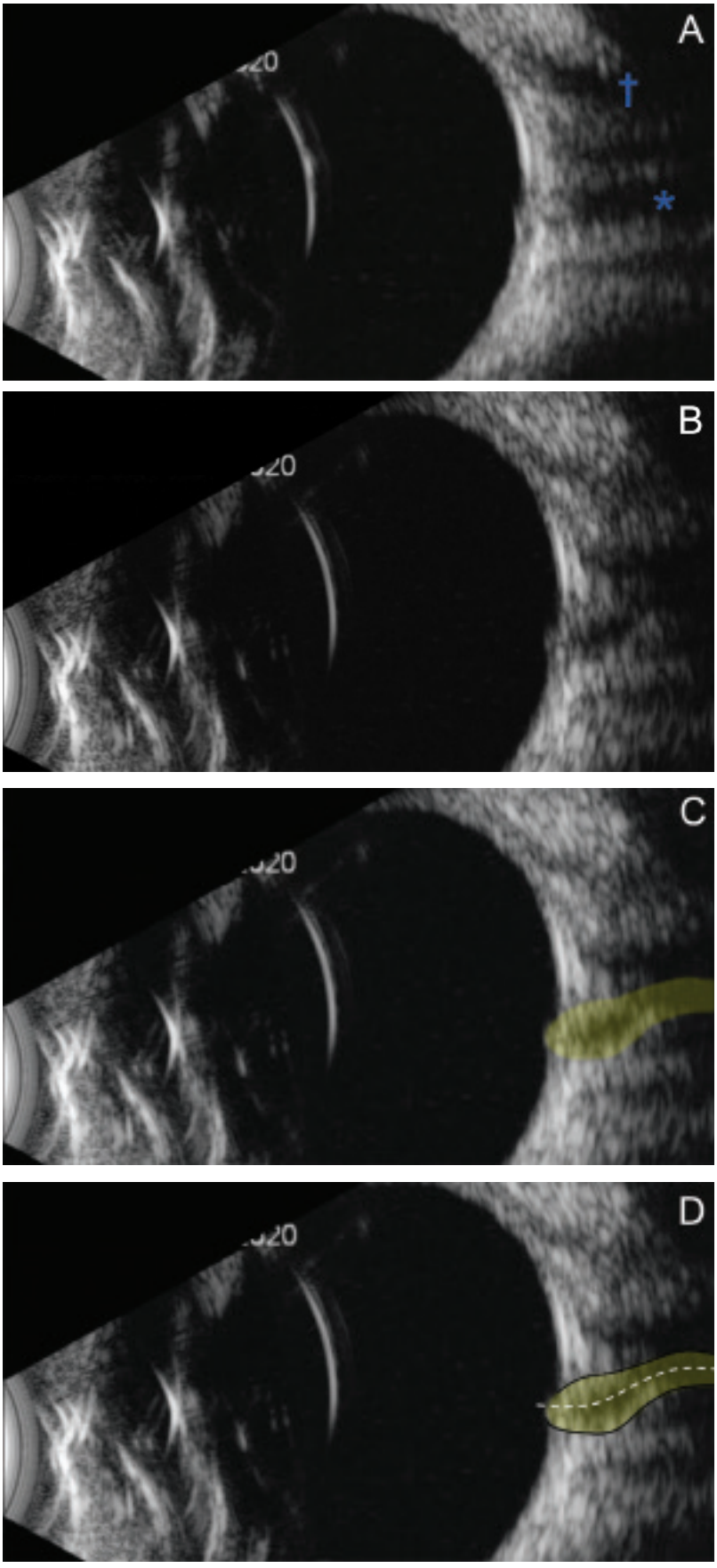

Figure 3—Representative horizontal-plane ultrasonographic images of the left eye of a 10-month-old neutered male mixed-breed dog that depict various artifacts and limitations associated with measuring the ONSD on the same image as the ETD. A—A retrobulbar linear hypoechoic artifact (asterisk) can be mistaken as the ONS and lead to overestimation of the ONSD. This type of artifact is caused by differences in wave sounds penetrating through the lamina cribrosa cranially to the optic nerve head. Extraocular muscles (dagger) also appear as hypoechoic structures in the retrobulbar region. B—Slight lateral fanning of the ultrasound probe allows visualization of the hypoechoic optic nerve, which curves as it approaches the caudal aspect of the eyeball. C—In this image, the ONS is highlighted in yellow to demonstrate that the ONSD might be underestimated if the measure is based solely on the curved hypoechoic fibers of the optic nerve without including the hyperechoic subarachnoid space. D—In this image, the optic nerve (white dashed line), thin hypoechoic dura mater (black line), and ONS (yellow shaded area) have been highlighted and intensified to allow comparison with the image in panel B. The ONSD can be overestimated if the hypoechoic rim representing the dura mater appears very thin, making it difficult to differentiate the border between the hyperechoic ONS and hyperechoic periorbital fat. Notice that the entire eyeball is not visible in any of these images.

review of the ultrasonographic videos. Thus, the ONSD/ETD ratio was successfully calculated for at least 1 eye for 44 of the 45 (98%) dogs and for both eyes of 42 (93%) dogs.

Descriptive statistics for the ONSD, ETD, and ONSD/ETD ratio were summarized **(Table 1)**. The ONSD (P = 0.329), ETD (P = 0.087), and ONSD/ETD ratio (P = 0.050) did not differ significantly between the left and right eyes. When the Bland-Altman method was used to compare the ONSD/ETD ratio between the left and right eyes, all but 1 difference were within the 95% limits of agreement (–0.03 to 0.02), and the differences were scattered evenly above and below 0. This suggested that the ONSD/ETD ratio did not differ between the 2 eyes or there was consistent bias in the ONSD/ETD ratio of one eye relative to the other. For this study population, the derived reference interval for the ONSD/ETD ratio had a lower limit of 0.16 (95% CI, 0.15 to 0.16) and upper limit of 0.20 (95% CI, 0.19 to 0.20).

Sex was not significantly correlated with the ONSD (P = 0.564), ETD (P = 0.518), or ONSD/ETD ratio (P = 0.763).

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Table 1—Descriptive statistics for the ONSD, ETD, and ONSD/ETD ratio for 45 healthy dogs of various breeds and morphologies as determined by measurements obtained from horizontal-plane ultrasonographic images.

Variable	Eye	Mean ± SD	95% CI	Minimum value	Maximum value
ONSD (mm)	Left	2.90 ± 0.26	2.82–2.98	2.41	3.58
	Right	2.94 ± 0.25	2.86–3.01	2.48	3.59
	Both eyes	2.92 ± 0.22	2.85–2.99	2.48	3.49
ETD (mm)	Left	16.90 ± 0.87	16.63–17.18	14.55	18.26
	Right	16.76 ± 0.91	16.47–17.04	14.60	18.35
	Both eyes	16.83 ± 0.85	16.56–17.10	14.64	18.21
ONSD/ETD ratio	Left	0.17 ± 0.01	0.17–0.18	0.15	0.20
	Right	0.18 ± 0.01	0.17–0.18	0.15	0.20
	Both eyes	0.17 ± 0.01	0.17–0.18	0.15	0.20

For each dog, each variable was independently measured once for each eye by a veterinarian and a board-certified veterinary ophthalmologist. The measurements from both observers were combined for the calculation of the statistics presented in this table. The ONSD (P = 0.329), ETD (P = 0.087), and ONSD/ETD ratio (P = 0.050) did not differ significantly between the left and right eyes.

Table 2—Respective correlations of the ONSD, ETD, and ONSD/ETD ratio with various morphological and physiologic variables as determined from data obtained for the dogs described in Table 1.

	ONSD		ETD		ONSD/ETD ratio	
Variable	*r*	*P*	*r*	*P*	*r*	*P*
Age	0.051	0.742	–0.015	0.921	0.067	0.666
BCS	–0.11	0.478	–0.013	0.934	–0.13	0.399
Body weight	0.404	0.007	0.759	< 0.001	0.600	0.540
Height	0.447	0.002	0.809	< 0.001	–0.077	0.620
Head circumference	0.413	0.005	0.763	< 0.001	–0.103	0.507
MAP	0.045	0.772	–0.047	0.761	0.085	0.585
SAP	0.167	0.277	0.122	0.429	0.122	0.432
DAP	–0.018	0.907	–0.128	0.406	0.66	0.66
IOP left eye	0.206	0.191	0.258	0.099	0.063	0.694
IOP right eye	0.103	0.515	0.284	0.068	–0.058	0.716

Values of $P < 0.05$ were considered significant.

The ONSD was significantly correlated with height (r = 0.447; P = 0.002), head circumference (r = 0.413; P = 0.005), and body weight (r = 0.404; P = 0.007; **Table 2**). The ETD was also significantly correlated with height (r = 0.809; $P < 0.001$), head circumference (r = 0.763; $P < 0.001$), and body weight (r = 0.759; $P < 0.001$). Conversely, the ONSD/ETD ratio was not significantly correlated with any of the morphological and physiologic variables assessed. Thus, the ONSD/ETD ratio appeared to be fairly tightly conserved regardless of the size of the dog **(Figure 4)**. There was a significant positive correlation between ONSD and ETD (r = 0.600; $P < 0.001$) and the ONSD/ETD ratio (r = 0.768; $P < 0.001$).

The ONSD measurements differed significantly (P = 0.018) between the 2 observers (veterinarian and veterinary ophthalmologist) by a mean of 0.15 mm. However, the ETD (mean difference, 0.17 mm; P = 0.147) and ONSD/ETD ratio (mean difference, 0.007; P = 0.066) measurements did not differ significantly between the 2 observers. When the Bland-Altman method was used to compare the ONSD/ETD ratio between the 2 observers, all but 1 difference were within the 95% limits of agreement (–0.04 to 0.05). The calculated ONSD/ETD ratio ranged from 0.014 to 0.21 for one observer and 0.13 to 0.22 for the other observer.

Discussion

Results of the present study indicated that, in dogs, the ONSD was significantly correlated with ETD and that the ONSD/ETD ratio was not correlated with dog height, head circumference, body weight, BCS, age, or sex. Similarly, the ONSD/ETD ratio is not significantly correlated with height in human subjects.[23] For dogs, normative values for ONSD are generally derived from a complex model in which body weight plays an important role and range from 1.0 to 3.55 mm depending on body weight.[16] Because the ultrasonographically determined ONSD/ETD ratio was not associated with dog size in the present study, it might be a clinically useful measure for dogs regardless of morphology. In human medicine, the ONSD/ETD ratio is not correlated with age and it is universally used as an indicator of ICP in patients of all age groups.[19]

The ONSD/ETD ratio for the dogs of the present study ranged from 0.15 to 0.20 (mean, 0.17), which was similar to that reported for human subjects (range, 0.14 to 0.23; mean, 0.18).[23] For human

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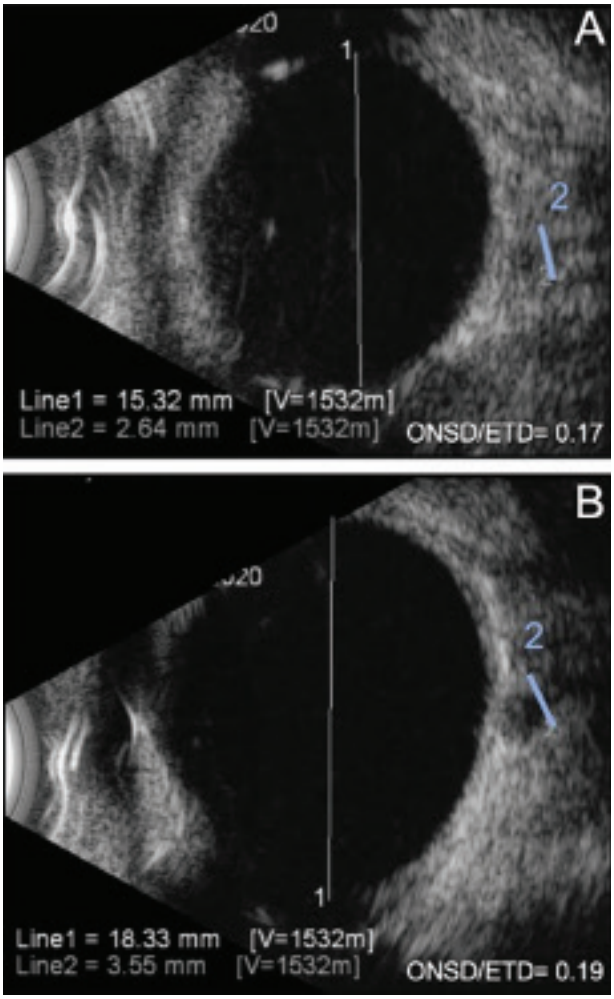

Figure 4—Representative horizontal-plane ultrasonographic images of the left eye of a 10-year-old spayed female Jack Russell Terrier (A) and a 4-year-old neutered male Golden Retriever (B). The ETD (line 1), ONSD (line 2), and ONSD/ETD ratio measurements for each eye are provided in the respective images. Notice that the ONSD/ETD ratios are similar despite the difference in size between the 2 dogs. Both of these dogs were included in the data set used to calculate the ONSD/ETD ratio reference interval for the study population (lower limit, 0.16 [95% CI, 0.15 to 0.16]; upper limit, 0.20 [95% CI, 0.19 to 0.20]), which was derived from the 2.5th and 97.5th percentiles (and their associated 95% CIs) of the ONSD/ETD ratio data for 45 healthy dogs of various breeds and morphologies.

patients with an abnormally increased ICP, the diagnostic accuracy of the ONSD/ETD ratio and ONSD as determined from ultrasonographic images is 85.7% and 79.6%, respectively.[18] In dogs, the ONSD is positively correlated with the ICP measured by invasive manometry,[13] supporting the theory that the ONSD/ETD ratio might be a valuable and noninvasive indicator of elevated ICP independent of patient morphology. Further investigation of dogs with various pathological conditions is necessary to confirm the accuracy of the ONSD/ETD ratio for detection of patients with an abnormally increased ICP. On the basis of the ONSD/ETD ratio reference interval derived for the healthy dogs of the present study and until a more precise cutoff is established, an ONSD/ETD ratio > 0.20 might be indicative of an elevated ICP.

For the dogs of the present study, the ONSD and ETD were successfully measured on the same ultrasonographic image for 88 of the 90 eyes evaluated. Over half (23/45 [51%] dogs [46 eyes]) of the ocular ultrasonographic examinations were performed by a veterinarian who had no experience performing such examinations prior to this study. This suggested that ultrasonographic measurement of the ONSD and ETD can be easily implemented in clinical settings. Artifacts and limitations associated with measurement of the ONSD and ETD on the same ultrasonographic image (eg, hypoechoic lines in the retrobulbar space owing to differences in wave penetration through the lamina cribrosa cranially to the optic nerve head or the presence of extraocular muscles, impaired precision of the ONSD measurement when the hyperechoic ONS is indistinguishable from the hyperechoic retrobulbar fat, and failure to visualize the hyperechoic ONS surrounding the hypoechoic optic nerve fibers) were commonly present in the ultrasonographic videos but not in all still images obtained from those videos. Before this method is adopted for clinical practice, sonographers should receive training in ocular and orbital ultrasonographic examination to learn the proper technique, interpret orbital anatomy, and appreciate artifacts that can interfere with measurements to minimize errors associated with incorrect data collection.[24]

Results of the present study suggested that interobserver reliability of the ONSD/ETD ratio was good. Thus, the ONSD/ETD ratio should be an objective and nonbiased measurement that can be compared serially over time for individual dogs regardless of the sonographer performing the ultrasonographic examinations. In the present study, the ONSD was the only measurement that varied significantly between the 2 observers; however, that difference was not reflected in the ONSD/ETD ratio, likely owing to similar values between the 2 observers and the low SD for the ratio. The findings of this study indicated that the ONSD/ETD ratio was less variable than the ONSD, which further supported that the ONSD/ETD ratio might be a more precise indicator of ICP for serial assessment. When repeated at regular intervals, assessment of the ONSD/ETD ratio might benefit dogs with ICH caused by traumatic brain injury or other neurologic conditions as well as dogs with systemic disease that are at risk of developing an elevated ICP secondary to shock, hepatic encephalopathy, pyrexia, hypertension, hypercarbia, or hypoxemia. In human medicine, patients with decreasing ONSD (as measured on ultrasonographic images) over time tend to have a good outcome, whereas patients with an increasing ONSD over time often require further management.[25] Also in human medicine, a decrease in ultrasonographically measured ONSD is closely correlated with diminution of ICP on invasive moni-

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tors during osmotherapy.[26,27] Ocular ultrasonography is readily available and fairly inexpensive and can be performed in unsedated animals; thus, calculation of the ONSD/ETD ratio is an ideal tool for monitoring patient response to treatment.

For the healthy dogs of the present study, the ONSD and ONSD/ETD ratio were not correlated with systemic blood pressure. Similarly, the ONSD is not significantly correlated with SAP and DAP in healthy human subjects, but it is positively correlated with SAP and DAP in hypertensive patients.[28] To our knowledge, the respective relationships between ONSD and SAP and DAP have not been investigated in dogs. Changes in systemic blood pressure associated with critical illness, such as sepsis, can lead to modification of cerebral perfusion and ultimately failure of the ICP autoregulatory mechanism.[29] Because cerebral perfusion pressure is the difference between MAP and ICP,[2,28] evaluation of the relationship between the ONSD/ETD ratio and blood pressure might provide valuable insight into the interactions between the cardiovascular system and cerebral perfusion.

It is indubitable that brain imaging has diagnostic value in patients with acute neurologic deterioration, and the ONSD can be measured on MRI and CT images.[12,30] However, both of those modalities are time consuming and expensive, are not readily available at most general veterinary practices and often necessitate transport of a patient to a specialty hospital, and require sedation or general anesthesia of a patient that may be critically ill. Results of the present study suggested that ocular ultrasonography is a readily available and rapid diagnostic imaging modality that can be used to measure the ONSD/ETD ratio in unsedated dogs. Assessment of the ONSD/ETD ratio by ultrasonography can help inform treatment, can be performed repeatedly with minimal risk to the patient, and is easy to do with a portable ultrasound unit in situations where transporting the patient is contraindicated.

In the present study, the transverse diameter of the eyeball was measured because the ETD and its correlation with ONSD have been successfully used for monitoring ICP in human medicine[18] and its borders are easily identified on ultrasonographic images. The ONSD was measured 3 mm caudal to the optic disc because it has been suggested that this location is where the ONSD is most sensitive to changes in ICP.[15] However, the optic nerve length might differ among dogs of different breeds. Results of another study[13] involving dogs suggest that measurement of the ONSD at its maximum diameter is a reliable indicator of increasing ICP. The maximum diameter of the ONSD was located 5 mm caudal to the optic disc for the dogs of that study.[13] The ONSD was measured 3 mm caudal to the optic disc for all dogs of the present study to ensure both consistency and reliability of the results.

For the dogs of the present study, the ONSD, ETD, and ONSD/ETD ratio of each eye were measured only once by each of the 2 observers to simulate how these measurements are most likely to be acquired and used in a clinical or emergent setting. None of those 3 measurements varied significantly between the left and right eyes of any dog, and the SD of the ONSD/ETD ratio for the study population was the same regardless of whether it was calculated on the basis of 1 eye/dog or the mean for both eyes of each dog.

The present study had several limitations. A meta-analysis[31] of the human medical literature suggests that measurement of ONSD may vary between institutions. The present study was conducted at 1 institution and by use of 1 ultrasound device. Ultrasound devices differ among veterinary clinics, and the quality of the device might affect the precision of the measurements. Meticulous assessment of specific landmarks and knowledge of the potential artifacts and misinterpretations that may occur during measurement of ONSD and ETD are necessary for accurate calculation of the ONSD/ETD ratio. For example, the eye is asymmetric, and its oblong shape might be exaggerated by ultrasonographic artifacts, making it difficult to determine the maximal ETD. Ultrasonographic artifacts were commonly encountered in the present study. Although the time required to obtain videos of the ocular ultrasonographic examinations was recorded, the time required to measure the ONSD and ETD was not recorded. The intraobserver repeatability of the ONSD, ETD, and ONSD/ETD ratio measurements was also not evaluated in this study. Each eye of each dog was ultrasonographically evaluated once by only 1 of 2 sonographers; therefore, comparison of video acquisition time between the 2 sonographers was not possible. As discussed in the aforementioned meta-analysis[31] of the human medical literature, we encourage personnel to become familiar with the image quality of the ultrasound device used at their institution and to validate their criteria for image acquisition and measurement of the ONSD/ETD ratio. The number of dogs evaluated in this study was fairly small, and the results should be interpreted cautiously. Finally, ultrasonographic determination of the ONSD/ETD ratio does not negate the benefits of measurement or continuous monitoring of ICP by invasive methods. However, it can be a valuable alternative when invasive manometric measurement of ICP is not an option or the risk of complications outweighs the benefits of invasive ICP monitoring.

Findings of the present study indicated that ocular ultrasonography was a rapid, noninvasive, and reliable method for measurement of the ONSD/ETD ratio in healthy dogs. Additionally, the ONSD/ETD ratio did not appear to be significantly correlated with physiologic (sex, age, blood pressure, and IOP) and morphological (height, head circumference, body weight, and BCS) characteristics of individual dogs. Ultrasonographic assessment of the ONSD/ETD ratio is also more readily available and less expensive than CT or MRI assessment of the ONSD/ETD ratio. The

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ONSD/ETD ratio reference interval derived for the healthy dogs of the present study had a lower limit of 0.16 (95% CI, 0.15 to 0.16) and upper limit of 0.20 (95% CI, 0.19 to 0.20). Further research is necessary to determine the accuracy of the ONSD/ETD ratio for prediction of ICH and how the ONSD/ETD ratio responds to changes in ICH and ICP.

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Footnotes

a. SL-17, Kowa American Corp, Torrance, Calif.
b. TonoVet, Icare Finland Oy, Vantaa, Finland.
c. SunTech Medical Inc, Morrisville, NC.
d. Alcaine, Alcon Canada Inc, Mississauga, Canada.
e. Accutome Inc, Malvern, Pa.
f. Stata, version 13, StataCorp LLC, College Station, Tex.

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