

Effect of brachycephaly and body condition score on respiratory thermoregulation of healthy dogs

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OBJECTIVE

To evaluate the effect of brachycephaly and body condition score on respiratory thermoregulation of healthy dogs.

DESIGN

Prospective study.

ANIMALS

52 brachycephalic and 53 nonbrachycephalic dogs.

PROCEDURES

All dogs were exposed to a cool treatment (temperature, $21.8 \pm 1.7^\circ\text{C}$ [$71.2 \pm 3.1^\circ\text{F}$]; relative humidity, $62.2 \pm 9.7\%$; and ambient enthalpy, 47.7 ± 6.6 kcal/kg) and then a hot treatment (temperature, $32.9 \pm 1.7^\circ\text{C}$ [$91.2 \pm 3.1^\circ\text{F}$]; relative humidity, $51.9 \pm 9.8\%$; and ambient enthalpy, 74.8 ± 8.7 kcal/kg; heat stress) at least 1 hour later. For each treatment, dogs were allowed to acclimatize to the environment for 15 minutes and then were placed in a sealed whole-body plethysmograph for continuous measurement of the respiratory pattern for 10 minutes. Treatment was discontinued if a dog developed signs of respiratory distress. Respiratory variables and body temperature were compared between the 2 breed types (brachycephalic and nonbrachycephalic) and between treatments.

RESULTS

Body condition score was positively associated with body temperature independent of environmental conditions or breed type and negatively associated with tidal volume. Brachycephalic dogs had a greater increase in respiratory rate in response to heat stress than did nonbrachycephalic dogs.

CONCLUSIONS AND CLINICAL RELEVANCE

Results indicated that brachycephalic dogs had decreased capacity for thermoregulation, compared with nonbrachycephalic dogs, but body condition score was a greater determinant of body temperature than breed type. Nevertheless, both upper airway conformation and body condition score should be considered when evaluating whether an individual dog is capable of tolerating heat stress. (*J Am Vet Med Assoc* 2017;251:1160–1165)

Mammals often must dissipate excess metabolic heat to maintain the desired body temperature, typically by use of conduction and evaporation to transfer heat to the surrounding environment. Some mammals, such as humans, horses, sheep, and goats, rely on evaporation of sweat for heat dissipation, and this potent mechanism can dissipate 2.2 kJ (0.525 kcal) of heat/mL of water evaporated.¹ Dogs lack extensive sweat glands and must rely on evaporation of water from moist mucous membranes of the respiratory tract for thermoregulation and dissipation of excess heat. Although respiratory evaporative cooling is just as effective as sweating on the basis of the amount of heat/mL of water evaporated, thermoregulation by respiratory evaporation of water is less efficient than sweating for several reasons. To increase the amount

of water evaporated (and thus the amount of heat dissipated), dogs must increase the amount of air that passes over the nasal or oral mucosa by increasing ventilation, which is an active process that increases metabolic rate and heat production. Furthermore, the increase in ventilation needed for thermoregulation must be balanced against the closely regulated need for gas exchange. As a result, dogs use very low tidal volumes at a very rapid rate (ie, panting) to increase fresh air movement over the mucosal surfaces of the upper respiratory tract while controlling alveolar ventilation.

Brachycephalic dogs are particularly susceptible to hyperthermia during periods of heat stress,² presumably because of the anatomy of their upper airway. Brachycephalic dogs have greater respiratory tract resistance to airflow (airway resistance) than similarly sized dogs of nonbrachycephalic breeds likely owing to the compressed facial structures (nares, nasal passages, nasal turbinates, and larynx) through which they must move air.³ Airway resistance is dependent

ABBREVIATIONS

BAOS Brachycephalic airway obstruction syndrome
BCS Body condition score
bpm Breaths per minute

on the radius of the airway (ie, $R = 8\eta l/\pi r^4$, where R is airway resistance, η is the dynamic viscosity of air, l is the length of the airway, and r is the radius of the airway), and small changes in the airway radius can cause large changes in airway resistance. Thus, when brachycephalic dogs attempt to increase airflow, such as in response to heat stress, it requires more effort and generates more metabolic heat per unit of air moved.

Transportation of live-animal cargo by commercial airlines is regulated by the USDA APHIS. Part 3.15 of the *Animal Welfare Act and Animal Welfare Regulations*⁴ stipulates that dogs and cats transported by commercial carriers must not be exposed to temperatures $> 29.4^\circ\text{C}$ (85°F) for > 4 consecutive hours, and commercial carriers are obligated to provide whatever environmental modifications are necessary to meet that requirement. Currently, most airlines have enacted either a partial or complete ban on the transportation of dogs and cats of brachycephalic breeds on the basis of the perceived increase in risk of heat stress for those animals during air travel.^{5,6} Widespread adoption of specific regulations for brachycephalic dogs and cats by individual airlines was undoubtedly driven by the disproportionate representation of those breeds in official incident reports for US domestic airlines. For example, “brachycephalic” was the primary cause reported for almost half (14/30 [47%]) of animal deaths during commercial air transport in 2007.⁷ Despite those observations, there is no direct evidence that brachycephaly specifically affects the ability of dogs to thermoregulate. Therefore, the purpose of the study reported here was to compare respiratory thermoregulation between healthy brachycephalic dogs and dogs of nonbrachycephalic breeds. Our hypothesis was that the respiratory thermoregulatory capacity of brachycephalic dogs would be less than that of nonbrachycephalic dogs, especially during a heat-stress challenge.

Materials and Methods

Animals

Fifty-two dogs of brachycephalic breeds (brachycephalic dogs) and 53 dogs of nonbrachycephalic breeds (nonbrachycephalic dogs) were enrolled in the study. The nonbrachycephalic dogs were purposely selected to approximate the body size distribution for the brachycephalic dogs. All dogs were privately owned, considered healthy on the basis of results of a physical examination, and assigned a BCS on a scale of 1 to 9 as described.⁸ Dogs with clinically apparent disease or that had resting dyspnea at room temperature ($< 22^\circ\text{C}$ [72°F]) were excluded from the study. Study procedures were approved by the Oklahoma State University Institutional Animal Care and Use Committee, and informed consent was obtained from all dog owners prior to enrollment of their pets into the study.

Study design

For each dog, the respiratory pattern and body temperature were measured under 2 conditions or

treatments: cool (temperature, $21.8 \pm 1.7^\circ\text{C}$ [$71.2 \pm 3.1^\circ\text{F}$]; relative humidity, $62.2 \pm 9.7\%$; and ambient enthalpy, 47.7 ± 6.6 kcal/kg) and hot (temperature, $32.9 \pm 1.7^\circ\text{C}$ [$91.2 \pm 3.1^\circ\text{F}$]; relative humidity, $51.9 \pm 9.8\%$; and ambient enthalpy, 74.8 ± 8.7 kcal/kg). Environmental conditions were established by use of the laboratory climate control system and verified with a handheld meteorology device.^a For each treatment, dogs were allowed to acclimatize to the environment for 15 minutes and then were placed in a sealed whole-body plethysmograph^b ($98 \times 73.5 \times 71$ cm) for continuous measurement of the respiratory pattern for 10 minutes. Tidal volume (measured in milliliters) and breathing cycle duration (measured in seconds) were measured on a breath-by-breath basis, and plethysmograph software^c was used to calculate the respiratory frequency (60 s/breathing cycle duration) and minute ventilation (tidal volume \times respiratory frequency) for each breath. Detected breaths were automatically rejected by the software if the expiratory time was > 20 seconds, inspiratory time was < 0.1 second, or inspired and expired volumes differed by $> 40\%$.

Each dog was exposed to the cool treatment first as a safety measure to ensure that it would tolerate the data measurement process and then exposed to the hot treatment. Dogs were maintained at room temperature for at least 1 hour between treatments. Examination or treatment was discontinued if a dog developed signs of respiratory distress. Owners were not allowed to be present for any of the plethysmographic examinations so that variable (owner presence) could be eliminated from the experiment.

Statistical analysis

Post hoc manipulation of the plethysmographic data was not performed to avoid introduction of investigator bias. Tidal volume and minute ventilation data for each dog were corrected for body weight. Dependent variables of interest included body temperature at the end of each 10-minute plethysmographic measurement session (ie, end of each treatment), respiratory rate, tidal volume, and minute ventilation. Each dependent variable was compared between brachycephalic and nonbrachycephalic dogs (breed type) and between cool and hot treatments (treatment) by use of ANCOVA. The analysis was blocked by dog to facilitate the use of each dog as its own control and sex (sexually intact male, castrated male, sexually intact female, or spayed female) to control for its effect on the data. Other independent variables included in each model were BCS and age. Values of $P < 0.05$ were considered significant, and results were reported as mean \pm SD.

Results

Dogs

The 52 brachycephalic dogs included 10 Boston Terriers, 10 Boxers, 10 Shi Tzus, 8 French Bulldogs, 8 Pugs, 3 English Bulldogs, 2 Japanese Chins, and 1 English Mastiff.

The 53 nonbrachycephalic dogs included 10 Miniature Schnauzers, 8 Pembroke Welsh Corgis, 7 Border Collies, 5 Labrador Retrievers, 4 Beagles, 4 Golden Retrievers, 4 Miniature Poodles, 3 Jack Russell Terriers, 3 Yorkshire Terriers, 2 Weimaraners, 1 Brittany Spaniel, 1 Cocker Spaniel, and 1 Rat Terrier. The mean age, body weight, body temperature, and resting tidal volume did not differ between brachycephalic and nonbrachycephalic dogs

(**Table 1**). The mean \pm SD resting respiratory rate for the nonbrachycephalic dogs (86 ± 74 bpm) was greater than that for brachycephalic dogs (62 ± 54 bpm), but that difference was not significant ($P = 0.06$).

Treatment response

All dogs completed the cool treatment, but the hot treatment had to be discontinued for 5 brachycephalic

Table 1—Comparison of mean \pm SD age, body weight and temperature, and resting respiratory rate and tidal volume between 53 healthy nonbrachycephalic and 52 healthy brachycephalic dogs prior to exposure to cool (temperature, $21.8 \pm 1.7^\circ\text{C}$ [$71.2 \pm 3.1^\circ\text{F}$]; relative humidity, $62.2 \pm 9.7\%$; and ambient enthalpy, 47.7 ± 6.6 kcal/kg) and hot (temperature, $32.9 \pm 1.7^\circ\text{C}$ [$91.2 \pm 3.1^\circ\text{F}$]; relative humidity, $51.9 \pm 9.8\%$; and ambient enthalpy, 74.8 ± 8.7 kcal/kg; B) treatments.

Variable	Nonbrachycephalic dogs	Brachycephalic dogs	P value
Age (y)	4.6 ± 2.4	4.4 ± 2.0	0.65
Weight (kg)	16.0 ± 11.0	13.4 ± 9.8	0.19
Temperature ($^\circ\text{C}$)	38.4 ± 0.38	38.4 ± 0.38	0.33
Respiratory rate (bpm)	86 ± 74	62 ± 54	0.06
Tidal volume (mL/kg)	8.2 ± 4.5	9.2 ± 5.9	0.31

Nonbrachycephalic dogs were selectively chosen to approximate the body condition distribution for brachycephalic dogs. All dogs were exposed to the cool treatment first. For each treatment, dogs were allowed to acclimatize to the environment for 15 minutes and then were placed in a sealed whole-body plethysmograph for continuous measurement of respiratory pattern for 10 minutes. Dogs were maintained at room temperature for at least 1 hour between treatments. Treatment was discontinued if a dog developed signs of respiratory distress.

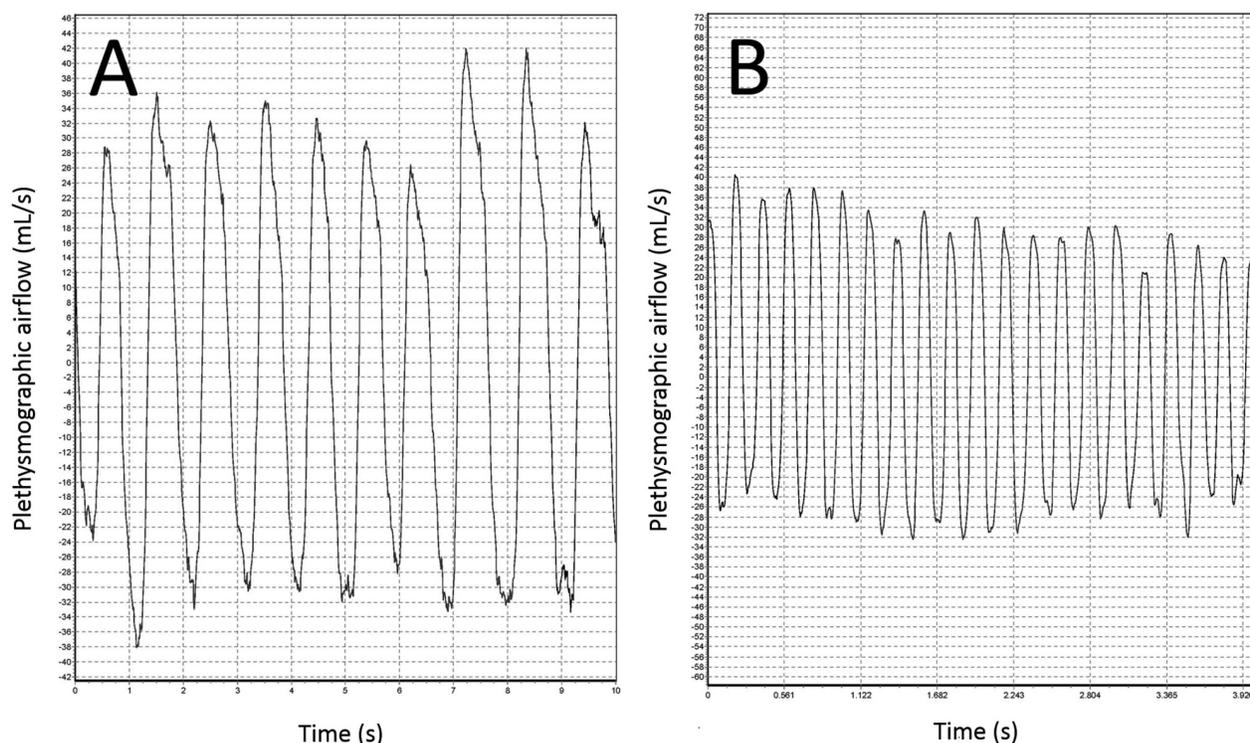


Figure 1—Representative whole-body plethysmographic tracings for an 8-year-old spayed female Brittany Spaniel during exposure to a cool treatment (temperature, $21.8 \pm 1.7^\circ\text{C}$ [$71.2 \pm 3.1^\circ\text{F}$]; relative humidity, $62.2 \pm 9.7\%$; and ambient enthalpy, 47.7 ± 6.6 kcal/kg; A) and a 7-year-old sexually intact female Boston Terrier during exposure to a hot treatment (temperature, $32.9 \pm 1.7^\circ\text{C}$ [$91.2 \pm 3.1^\circ\text{F}$]; relative humidity, $51.9 \pm 9.8\%$; and ambient enthalpy, 74.8 ± 8.7 kcal/kg; B). Dogs were exposed to the cool treatment first. For each treatment, dogs were allowed to acclimatize to the environment for 15 minutes and then were placed in a sealed whole-body plethysmograph for continuous measurement of respiratory pattern for 10 minutes. Dogs were maintained at room temperature for at least 1 hour between treatments. Treatment was discontinued if a dog developed signs of respiratory distress. The respiratory rate is approximately 60 bpm in panel A and 300 bpm in panel B. Notice that the scales for the x- and y-axes differ between the 2 panels.

dogs (3 French Bulldogs and 2 Pugs) because of signs of respiratory distress. For those 5 dogs, the values for respiratory rate, tidal volume, and minute ventilation for the hot treatment were obtained during the last minute before the treatment was discontinued.

In general, dogs responded to an increase in ambient temperature by increasing their respiratory rate (Figure 1). Moreover, that increase in respiratory rate was accompanied by a concurrent decrease in tidal volume and increase in minute ventilation (Figure 2). For both brachycephalic and nonbrachycephalic dogs, the mean \pm SD body temperature increased only slightly, albeit significantly ($P = 0.002$), between the cool ($38.4 \pm 0.4^\circ\text{C}$ [$101.1 \pm 0.7^\circ\text{F}$]) and hot ($38.5 \pm 0.5^\circ\text{C}$ [$101.3 \pm 0.9^\circ\text{F}$]) treatments.

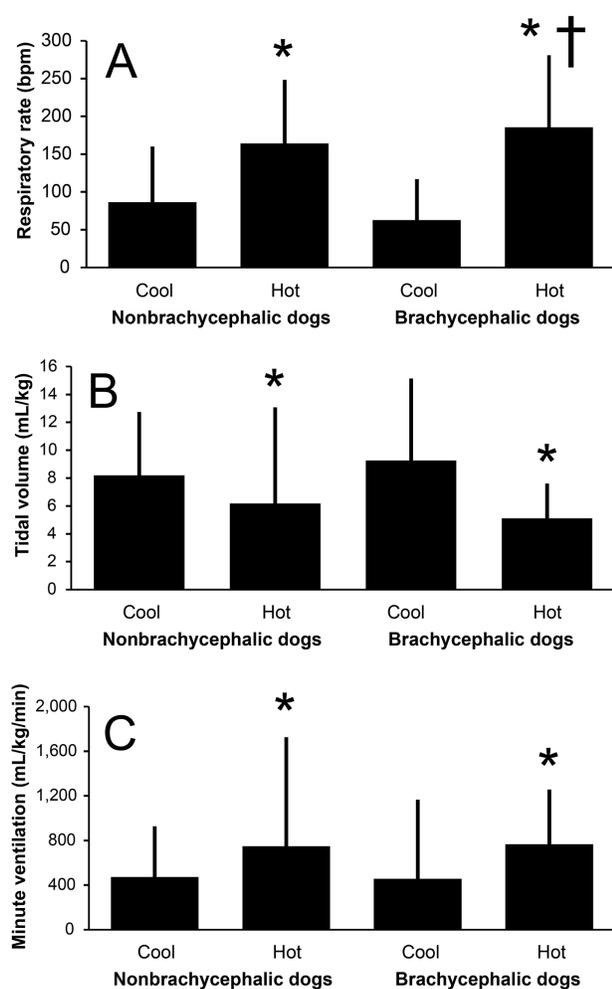


Figure 2—Mean respiratory rate (A), tidal volume (B), and minute ventilation (C) for 53 healthy nonbrachycephalic and 52 healthy brachycephalic dogs when exposed to the cool and hot treatments described in Figure 1. Bars delimit the SD. *Within breed type (brachycephalic or nonbrachycephalic), the mean for the hot treatment differs significantly ($P < 0.05$) from that for the cool treatment. †Mean for brachycephalic dogs differs significantly ($P < 0.05$) from the corresponding treatment for nonbrachycephalic dogs. See Figure 1 for remainder of key.

Body condition score had the largest effect on the respiratory patterns and thermoregulation of the study dogs regardless of treatment or breed type. Body condition score was positively associated with body temperature ($P = 0.007$) and negatively associated with tidal volume ($P = 0.008$).

The interaction between breed type and treatment was significantly ($P = 0.012$) associated with respiratory rate, with brachycephalic dogs increasing their respiratory rate to a greater extent than nonbrachycephalic dogs in response to the hot treatment (ie, heat stress). Breed type was not significantly associated with changes in tidal volume ($P = 0.106$) or minute ventilation ($P = 0.845$) in response to heat stress.

The interaction of BCS, breed type, and treatment was complex. When that interaction was included in the model, neither it ($P = 0.333$) nor the fixed effect for breed type ($P = 0.890$) was significantly associated with body temperature. However, when all interactions were excluded from the model, breed type was significantly ($P = 0.004$) associated with body temperature, with the increase in body temperature in response to heat stress for brachycephalic dogs being significantly greater than that for nonbrachycephalic dogs.

Discussion

To our knowledge, the present study was the first to find a significant difference between brachycephalic and nonbrachycephalic dogs in regard to respiratory response to heat stress. Furthermore, BCS had an important effect on the respiratory patterns and thermoregulation of the dogs regardless of breed type (brachycephalic or nonbrachycephalic), with body temperature increasing and tidal volume decreasing as BCS increased.

Many brachycephalic dogs develop BAOS, which is characterized by a constellation of anatomic and functional abnormalities such as stenotic nares and nasal turbinates, soft palate elongation, everted laryngeal sacculles, and tracheal hypoplasia.⁹ Collectively, those abnormalities increase upper airway resistance and tend to create a vicious cycle, in which the negative intraluminal pressure generated during forceful attempts to inhale exacerbates soft tissue deformities (eg, soft palate elongation and laryngeal sacculle eversion), thereby increasing airflow resistance and creating the need for even more forceful attempts to inhale (ie, greater negative intraluminal pressure) and maintain adequate air movement.² That cycle appears to provide a mechanism to support the theory that brachycephalic dogs are inherently susceptible to heat stress because of the conformation of their upper airways. However, in the present study, BCS, not brachycephaly, appeared to have the greatest effect on the respiratory response of dogs to heat stress, at least for dogs that did not have clinical signs of BAOS.

In the present study, BCS was positively associated with body temperature and negatively associated with weight-corrected tidal volume. Lean body mass was not assessed for the dogs of this study; therefore, it is unknown whether the low tidal volume for dogs with high BCSs was simply a reflection of a size-

appropriate tidal volume divided by the larger collective measure of lean body mass and excessive body fat in those dogs relative to that for dogs with lower BCSs. However, given that the body temperature measured at any moment represents the net balance between rate of heat generation and rate of heat dissipation and all dogs were evaluated at rest and presumed to have reasonably comparable rates of heat generation, the positive association between BCS and resting body temperature suggested that excessive weight inhibits heat dissipation. That finding was contradictory to results of another study¹⁰ in which obesity was inversely associated with body temperature in dogs. It is possible subcutaneous fat has an insulating effect that reduces heat loss through the skin. Also, obesity may impair air movement through the respiratory tract, and given that dogs rely on such air movement for heat dissipation, this impairment leads to retention of body heat. Regardless, BCS should be considered anytime a predictive assessment must be made, such as when planning air travel, as to whether a dog will tolerate heat stress.

For the dogs of the present study, brachycephaly had a direct effect on breathing pattern and possible effect on thermoregulation. Although the body temperature and respiratory rate of all dogs increased significantly when they were exposed to the hot treatment (heat stress), the magnitude of the increase in respiratory rate and possibly body temperature for brachycephalic dogs was significantly greater than that for nonbrachycephalic dogs. Additionally, during heat stress, the mean tidal volume for brachycephalic dogs was lower, albeit not significantly so, than that for nonbrachycephalic dogs, which suggested that the overall air movement (and perhaps heat dissipation) of brachycephalic dogs was not as efficient as that of nonbrachycephalic dogs. Moreover, all 5 dogs for which the hot treatment had to be discontinued were brachycephalic (3 French Bulldogs and 2 Pugs) and had BCSs of 5.5, 7, 7, 8, and 9. It could not be discerned whether their inability to tolerate the heat stress challenge was entirely caused by the conformation of their upper airways or excessive body condition. Nevertheless, it is likely that brachycephaly contributed to an increase in airway resistance, which caused a concurrent increase in the amount of work required for breathing. Collectively, those findings supported other observations that brachycephalic dogs are inherently less capable of thermoregulation during periods of heat stress than nonbrachycephalic dogs, regardless of BCS.^{2,11} Also, all 5 dogs that were unable to complete the heat stress challenge belonged to 2 breeds, which raises the question as to whether certain brachycephalic breeds are less capable than others of thermoregulation during periods of heat stress.

Differences in the respiratory patterns and thermoregulation between brachycephalic and nonbrachycephalic dogs are presumed to be associated with differences in the upper airway conformation between the 2 breed types. It has been suggested that brachycephalic dogs are more susceptible to overheating than nonbrachycephalic dogs because the relatively smaller surface area of their upper airways limits evaporative cooling.¹² How-

ever, evaporative cooling is not restricted to the upper airways. Evaporative cooling can occur at all moist surfaces provided a suitable enthalpy gradient exists. When circumstances preclude complete warming and humidification of inhaled air in the upper airways, such as in exercising horses¹³ and humans¹⁴ breathing cold air, further heat and water transfer occurs across the mucosa of the lower portion of the respiratory tract (lower respiratory tract). Although it is possible that considerable evaporative cooling takes place in the lower respiratory tract of brachycephalic dogs because of the limited time inhaled air is in contact with the upper airways, it is likely there is ample surface area and contact time in the lower respiratory tract to facilitate heat transfer if the volume of inhaled air is sufficient to receive that heat.

The respiratory patterns of dogs with BAOS have been previously described following use of a system similar to that used in this study, but with somewhat different results. In a study¹⁵ of healthy nonbrachycephalic dogs versus dogs with BAOS, investigators did not find significant differences in any basic respiratory variables (respiratory rate, tidal volume, or minute ventilation), similar to the present study. An important difference between the 2 studies is that the previous study¹⁵ included dogs with clinical BAOS, whereas the present study did not. Dogs with BAOS are expected to have an increase in respiratory resistance and thereby compensatory tachypnea. The dogs of the present study did not have BAOS and therefore had normal respiratory rates.

For brachycephalic dogs, the risk and severity of BAOS, including clinical signs of exercise or heat intolerance, increase with age.⁵ Therefore, it was interesting that age was not retained in any of the statistical models for the dependent variables assessed (body temperature, respiratory rate, tidal volume, and minute ventilation). The reason for that was most likely because dogs with BAOS were excluded from the present study. This finding also suggested that age alone is not a risk factor for heat stress susceptibility in brachycephalic dogs.

Results of the present study indicated that both upper airway conformation and BCS affect thermoregulation, particularly in heat-stressed dogs. When exposed to a heat-stress challenge, the respiratory rate of healthy brachycephalic dogs was significantly greater than that of healthy nonbrachycephalic dogs. Body condition score was positively associated with body temperature and negatively associated with tidal volume regardless of breed type. Thus, thermoregulation may be substantially impaired in obese brachycephalic dogs, and both upper airway conformation and BCS should be considered when evaluating whether an individual dog is capable of tolerating heat stress.

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Footnotes

- a. Kestrel 4000 Pocket Weather Tracker, Nielsen-Kellerman Inc, Boothwyn, Pa.
- b. Buxco Whole Body Plethysmograph, Buxco Research Systems Inc, Wilmington, NC.
- c. BioSystem XA, Buxco Research Systems Inc, Wilmington, NC.

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From this month's AJVR

Evaluation of canine hepatic masses by use of triphasic computed tomography and B-mode, color flow, power, and pulsed-wave Doppler ultrasonography and correlation with histopathologic classification

Erin R. Griebie et al

OBJECTIVE

To determine clinical relevance for quantitative and qualitative features of canine hepatic masses evaluated by use of triphasic CT and B-mode, color flow, power, and pulsed-wave Doppler ultrasonography and to compare diagnostic accuracy of these modalities for predicting mass type on the basis of histopathologic classification.

ANIMALS

44 client-owned dogs.

PROCEDURES

Dogs with histopathologic confirmation (needle core, punch, or excisional biopsy) of a hepatic mass were enrolled. Triphasic CT and B-mode, color flow, power, and pulsed-wave Doppler ultrasonography of each hepatic mass were performed. Seventy quantitative and qualitative variables of each hepatic mass were recorded by 5 separate observers and statistically evaluated with discriminant and stepwise analyses. Significant variables were entered in equation-based predictions for the histopathologic diagnosis.

RESULTS

An equation that included the lowest delayed-phase absolute enhancement of the mass and the highest venous-phase mass conspicuity was used to correctly classify 43 of 46 (93.5%) hepatic masses as benign or malignant. An equation that included only the lowest delayed-phase absolute enhancement of the mass could be used to correctly classify 42 of 46 (91.3%) masses (with expectation of malignancy if this value was < 37 Hounsfield units). For ultrasonography, categorization of the masses with cavitations as malignant achieved a diagnostic accuracy of 80.4%.

CONCLUSIONS AND CLINICAL RELEVANCE

Triphasic CT had a higher accuracy than ultrasonography for use in predicting hepatic lesion classification. The lowest delayed-phase absolute enhancement of the mass was a simple calculation that required 2 measurements and aided in the differentiation of benign versus malignant hepatic masses. (*Am J Vet Res* 2017;78:1273–1283)



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