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Quantifying body surface temperature differences in canine coat types using infrared thermography

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ABSTRACT

Infrared thermography (IRT) has been used to assess the health of canines by measuring surface temperatures. However, little is known about the effect hair coat differences has on expected surface temperature in healthy canines under the influence of hair coat differences. The aim of this study was to identify the influence of coat characteristics in body surface temperature (BST) in canines (*Canis lupus familiaris*). To determine the changes in BST, an infrared thermal imaging camera (i.e. FLIR B400) was used. Thermal images of the left and right sides of privately-owned dogs (n = 50) were acquired. Each animal acclimated in an indoor environment away from direct sunlight (23 ± 2.0 °C) for 15 min, and images were taken at a distance 0.67 ± 0.24 m. Regions of interest (ROIs) of mean surface temperatures were examined across the lateral surface of each animal. No statistical differences were detected based on laterality ($P = 0.08$). Mean BSTs were categorized by each dog's hair coat type: short coat (SC), curly coat (CC), long coat (LC), and double coat (DC). These BSTs were then analyzed using two-way analysis of variance, or ANOVA, (Shapiro-Wilk) and pairwise comparison. SC animals had the highest BST (31.77 ± 0.19 °C; $P < 0.001$) whereas LC (28.14 ± 0.31 °C; $P < 0.001$) and DC animals (28.25 ± 0.23 °C; $P < 0.001$) were lower in BST. CC animals portrayed intermediate BST (29.85 ± 0.33 °C; $P < 0.001$). The Pearson correlation and one-way ANOVA between rectal temperature and BST and coat type were not statistically significant ($r = -0.24$ and $P = 0.07$, respectively). Results indicate that short-haired dogs exhibit a more drastic increase in BST (approximately 2 °C) in comparison to other dogs and this should be considered in future clinical applications.

1. Introduction

The regulation of body temperature in homeotherms is ensured by mechanisms of thermolysis and thermogenesis. Thermoregulatory adjustments can be induced not only by changes in environmental temperature but also by a variety of physiological situations including age, fasting, and food intake inducing changes in internal temperature (Arfuso et al., 2016). Thermographic studies have shown an increase in surface area with the consequential decrease in body size leads to a reduction in thermoregulatory capabilities to dissipate heat which can lead to heat gain (McNicholl et al., 2016). The evaluation of body temperature represents a valuable tool to monitor the physiologic status, welfare and the stress responses of animals (Refinetti and Piccione, 2003; Piccione et al., 2012; Rizzo et al., 2017). In place of more intrusive measurements of temperature, infrared thermography (IRT) is an alternative, non-invasive method that allows for the detection of real-time changes in body surface temperature (BST) (Schaefer et al., 2004). Immediate visualization of animal BST gives insight on the physiological responses of the body and its thermoregulatory status. BST relies on the synergistic properties that arise from fluctuations in peripheral blood flow underneath the skin. It is also affected by the interaction between the surface and external environment, such as the thermal gradient produced from the thermal properties of the hair coat (Turner, 2001; Soroko et al., 2017; Rizzo et al., 2017). Previous studies have been performed in dogs (Grossbard et al., 2014; Biondi et al., 2015; Pavelski et al., 2015). However, these studies were conducted without comparing different coat characteristics. Unlike BST in humans, BST in canines is often not a direct measure of skin temperature as hair acts as another layer of insulation (Zaproudina et al., 2008; Vainionpää et al., 2012).

Variables that effect BST can be categorized as environmental, subject, or technology factors (Fernández-Cuevas et al., 2015). Limited IRT references exist for BST measurement based in part on the range of variables that come with using IRT (Greer et al., 2007). Therefore, identification and standardization of these variables are imperative to produce accurate thermal results (Rekant et al., 2016). Environmental

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variables (e.g. ambient temperature, relative humidity, and other external sources of radiation) have been tested in a few studies. In human IRT, the ideal ambient temperature ranges from 18 °C to 25 °C; a warmer ambient temperature range of 22–24 °C is recommended for extremities of the body (Ring and Ammer, 2000). Previous equine IRT studies recommend ambient temperature ranges of less than 30 °C (Turner, 1991; Eddy et al., 2001; Autio et al., 2006). Not accounting for environmental factors that might affect BST can lead to the misinterpretation of that normal BST range, decreasing the utility of thermal imaging in healthy animals (Vainionpää et al., 2012; Rekant et al., 2016).

Physical characteristics associated with the subject (e.g. coat length, color, and shape) are possible additional confounding variables (Tunley and Henson, 2004). Thermographic studies in equines have established expected normal thermal patterns (Eddy et al., 2001; Redaelli et al., 2014; Soroko et al., 2017). Standardized procedures such as brushing excess dirt from a hair coat, rid the coat of additional thermal interference, and provides a uniform image of its thermal pattern (Eddy et al., 2001; Autio et al., 2006; McCafferty, 2007). Difficulties in the interpretation of thermal patterns arise when using multiple canine breeds, especially when the hair coat is highly variable (McCafferty, 2007). Clipping hair to reduce this variation in BST can lead to an increase in stress levels (Yarnell et al., 2013), which changes BST as a result of the changes in sympathetic influence of peripheral blood stimulated by sympathetic nervous system activation (Travain et al., 2015). Alternatively, it has been noted by two canine studies that clipping of the fur is not necessary to produce accurate thermal patterns in both healthy and injured dogs (Marino and Loughin, 2010; Infernuso et al., 2010). The importance of hair coat remains a topic of debate.

In small animal medicine, canine thermography has potential as a diagnostic tool as shifts in BST due to changes in blood circulation may indicate inflammation or disease (Travain et al., 2015). A difference of less than 1 °C was considered statistically significant in identifying systemic infection and inflammation in calves and horses (Turner, 2001; Schaefer et al., 2004). To date canine thermoregulation studies have evaluated BST differences on limited aspects of the body in response to clinical conditions such as the stifles (Infernuso et al., 2010).

The aim of our study was to determine the influence of hair coat variation on body BST in healthy canines via infrared thermal imaging via infrared thermal imaging. BSTs were derived from regions of interest that cover the torso. Previous equine studies have shown that there are differences based on breed coat characteristics using temperatures of extremities of the body and the eyes (Bartolomé et al., 2013; Yanmaz and Okumus, 2014). However, there is little to no information on non-extremities or thermal windows of the body in equine and canine thermography studies (Johnson et al., 2006; Travain et al., 2015; Soroko et al., 2017). Our goal was to establish standards for dogs to aid future research in canine thermal imaging.

2. Materials and methods

2.1. Sample population

A total of 50 client-owned dogs were analyzed for this study. There were 29 females and 21 males. The dogs represented 17 different breeds with diverse types of hair coats (Table 1). Their weights varied from 2.7 to 47.6 kg. The mean age was consistent across all age groups 4.99 ± 2.87 years. Dogs were confirmed to be healthy by the most recent veterinary examination. Overweight or chronically-ill dogs were excluded from the study.

This research was approved by the California State Polytechnic University, Pomona Animal Care and Use Committee (ACUC), 17.023.

2.2. Data collection and infrared thermal imaging camera

Dogs were acclimated without restraint to indoor enclosures with a stable ambient temperature range of 21–25 °C for a minimum of 15 min prior to imaging; the relative humidity levels were also recorded in conjunction with the ambient temperature readings with an outdoor temperature thermometer (AcuRite Digital Weather Station). Dogs fasted for at least four hours before thermal images were taken. These images were taken from 14:00 to 16:00. Pearson correlation analyses were used to assess the correlation between relative humidity levels and ambient temperatures with BST. The emissivity value was set at 0.97 based on previous literature (Rizzo et al., 2017). At the end of the acclimation period, dogs were positioned without touching their coat to take images of their lateral surfaces while standing. After images of both sides of the dog were taken, a rectal temperature was obtained with a digital thermometer (Vicks SpeedRead™ Digital Thermometer); rectal temperatures of two dogs were unable to be taken. The distance between the dog and the camera was 0.67 ± 0.24 m to ensure full body images. The maximum angle from the lens of the camera to the body of the canine was no more than 17° (McCafferty, 2007). The same thermographer was used for all imaging to reduce user-error variability. Full lateral left-and-right-side images were taken for each dog. The left and right lateral of the FLIR B400 thermal camera were used for this study. The resolution of the camera is 320 × 240 pixels (B-series, FLIR Systems, Inc., Wilsonville). The thermal sensitivity (NETD) of this camera is < 0.08 °C (< 0.14°F) @ + 30 °C (+86°F). The field of view (FOV) is 25° × 18.75°. Data (thermal images) were analyzed with the FLIR Tools software (FLIR, Wilsonville).

Table 1
Demographic of dogs by breed.

Type of breed	Number of dogs
Chihuahua Mix	10
Terrier Mix	2
Miniature Pinscher	1
Pit Bull Mix	2
Papillon	5
Shih-tzu	3
Cocker Spaniel	1
Poodle Mix	4
Miniature Schnauzer	1
German Shepherd	2
Shepherd Mix	3
Australian Shepherd Mix	3
Labrador Mix	2
Hound Mix & Pointer	5
Akita	3
Pomeranian	1
Yorkshire Terrier Mix	2

2.3. Statistical analysis

ROIs were drawn across the lateral torso of each dog (Fig. 1). Mean BSTs and standard error of the mean (SEM) of the rectangular-shaped ROIs were then analyzed as mean temperature values through the FLIR Tools software program. In placing ROIs, "anchor points" were determined at the: 1) cranial aspect of the ischium and 2) coccygeal vertebrae to account for the differences in pixel area ratio attributed by canine size variation. A second ROI was drawn to cover the expanse of the torso. Averages of both ROIs were taken to evaluate mean BST and bilateral symmetry. A *t*-test was used to test for laterality. These characteristics and length were defined as the following: short coat (SC), long coat (LC), curly coat (CC), and double coat (DC). A two-way ANOVA was performed with the subsequent Holm-Sidak method for comparisons using the statistical software package, SigmaSTAT (SYSTAT, CA, USA), to determine the effect of coat type through mean temperatures of the ROIs. Pearson correlation analyses were used to assess the correlation between relative humidity levels and ambient temperatures with BST. Normal distribution was tested in all data using the Shapiro-Wilk normality test. In instances where normality failed, a

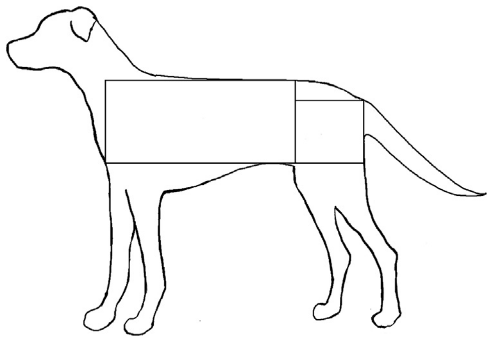

Fig. 1. Designated points (i.e. anchor points) ensured standardization of the rectangular boxes. The first point is cranial to the ischium at the end of the thoracolumbar vertebral section whereas the second point ends at the cranial aspect of the coccygeal vertebrae. The parts of the ROI of that does not include the dog was not included in the mean temperature values.

Mann-Whitney Rank Sum test or Kruskal–Wallis one-way ANOVA on ranks was run.

3. Results

The mean age of the dogs in this study was 4.99 ± 2.87 years and mix of small to large breeds. Age was not statistically different between coat categories ($P = 0.094$).

SC dogs had the highest mean BST with the lowest SEM (31.77 ± 0.19 °C) whereas LC animals had the lowest mean BST with the highest SEM (28.14 ± 0.31 °C) (Table 2). The lowest mean BST of dogs was in the LC dogs which had the smallest range in comparison to SC, CC, and DC dogs (Fig. 2). CC dogs had intermediate BST (29.85 ± 0.33 °C) and DC dogs had a lower intermediate BST (28.25 ± 0.23 °C). LC and DC dogs were more similar in mean BST (28.14 °C and 28.25 °C, respectively). Distributions of individual mean ST in DC dogs were larger than those of LC dogs. Comparison between each hair coat category were statistically significant ($P < 0.001$), with an overall significance of $P < 0.05$, except for the comparison of mean BST between DC and LC ($P = 0.79$) (Table 2). There was not a statistical difference in mean BST values between both ROI 1 and ROI 2. The mean BST values were therefore combined to determine mean full torso BST for each animal. There was not a statistically significant difference in mean BST based on laterality ($P = 0.92$); a Mann-Whitney test was run in place of a normality test when comparing laterality with mean BST. Rectal temperatures were negatively correlated with BST but were not significant (r = -0.24). A one-way ANOVA did not show a statistical difference between rectal temperatures and mean BST based on coat type.

To assess the effect of relative humidity levels and ambient temperature on BST, Pearson coefficient and one-way ANOVA analyses were used. Relative humidity levels were negatively correlated with BST, but the correlation coefficient was not significant (r = -0.11). In contrast, ambient temperatures were positively correlated with BST (r = 0.26). In addition, ambient temperature was not significant in comparison to coat category ($P = 0.49$).

Table 2
Mean BST based on hair coat category (DC = double coat, SC = short coat, LC = long coat, and CC = curly coat). A multiple comparison procedure (Holm-sidak method) of breed type categories was performed (overall significance level = 0.05).

Group	Mean	SEM
DC	28.246	0.232
SC	31.768	0.189
LC	28.144	0.306
CC	29.849	0.327
Comparison	***P***	***P* < 0.050**
SC vs. DC	< 0.001	Yes
SC vs. LC	< 0.001	Yes
SC vs. CC	< 0.001	Yes
CC vs. DC	< 0.001	Yes
CC vs. LC	< 0.001	Yes
DC vs. LC	0.791	No

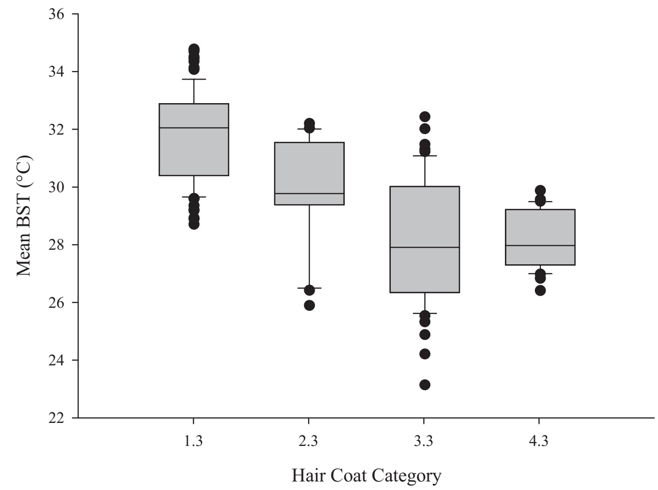

Fig. 2. Box-and-whisker plot of mean BSTs from the ROIs based on breed type categories: short coat (SC), curly coat (CC), long coat (LC), and double coat (DC).

4. Discussion

SC dogs had the highest mean BST that surpassed 31 °C as they have the least amount of insulation interference in comparison to LC, CC, and DC dogs. Elevated rate of heat loss through thermoregulatory mechanisms (i.e. convection and conduction) have been apparent in smooth, short-haired Holstein cows in contrast to wild-type Holstein cows in similar regions examined in this study (Dikmen et al., 2008). In contrast, dogs in this study did show differences in BST based on hair coat type. LC and DC dogs had low mean BST (~28 °C) in comparison to the canines characterized as SC and CC, which had mean BSTs greater than 29 °C. Fig. 3

Radiative temperature decreases in coats with a crimped, wavy texture with angles greater than 45° in two types of domesticated sheep (i.e. Dorset Down and Clum Forest) (Cena and Clark, 1973). Therefore, animals with a straighter hair release heat more easily and more quickly than those with hair that lays flat against the surface of their bodies. In

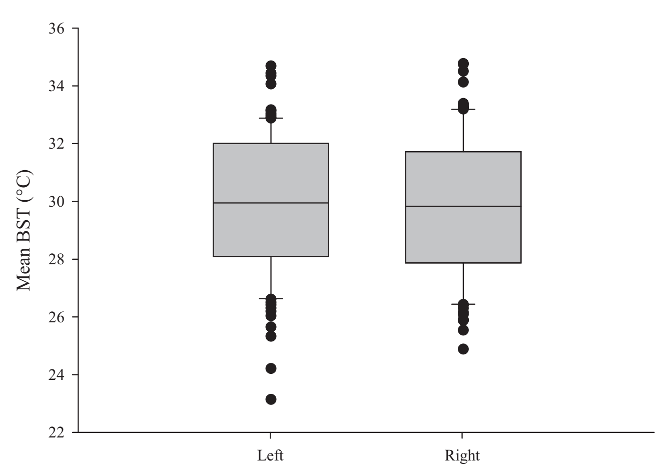

Fig. 3. Box-and-whisker plot showing laterality or the left and right sides of the ROIs.

addition, asymmetrical patterning of curly coats can expose parts of the skin that the more evenly covered LC and DC animals do not expose. This may be a possible reason why mean BST of curly hair coats exceeded mean BST of LC and DC animals in this study.

Thicker coats reduce the dissipation of heat and thus is interpreted as a lower mean BST as observed in the LC animals (Johnson et al., 2006). When looking at the effects of hair coat pattern by seasons in horses, researchers suggest that hair coat weight has an inverse effect regarding heat loss (Autio et al., 2006). Differences in hair growth phase can also contribute to the variation in thermal loss. Most dog breeds have a higher telogen phase of up to 34%; the ratio between the telogen and the kenogen phase in breeds acclimated to colder climates are more synchronous than breeds originating in warmer climates (Welle and Wiener, 2016). Unevenness in the level of thickness of the coat could contribute to the variability of BST readings, as both ROIs showed higher standard deviations in DC dogs than those of SC and CC animals. In contrast, a previous study which tested the usage of different thermal cameras suggested diverse types of hair coat were not an issue with respect to within-dog variation in the 26 different breeds of dogs (Vainionpää et al., 2012). Further research should be conducted to gauge hair weight, length, and width to specify their insulative properties (Osthaus et al., 2018).

The purpose of obtaining rectal temperatures was to appreciate whether differences in BST could be explained by changes in body temperature. In this study, rectal temperatures were independent of mean BST. Regions with sparse hair such as the eye and tympanic membrane have shown correlation with rectal temperature in canines (Zanghi, 2016). These areas are commonly known as thermal windows since blood perfusion is greatest in these areas, thus providing a scope into core body temperature (Soerensen and Pedersen, 2015). The effect of different hair coat types on rectal temperature has not been studied as well. The results of this study indicate that different hair coat types do not have a significant influence on rectal temperature ($r = -0.24$) and therefore, may not need to be considered when measuring BSTs or when evaluating anatomical regions with even more hair than found around the ears and eyes. Without a layer of insulation provided by a substantial amount of hair, heat is lost directly from the surface of the skin through thermoregulatory processes.

Ambient temperature and relative humidity levels are known to influence thermoregulatory capacities (McCafferty, 2007). In this study, relative humidity levels did not have a significant effect on mean BST. Ambient temperature did not correlate with coat category but had a significant effect on mean BST. Narrowing the range of ambient temperature in the study may decrease variation in mean BST. In terms of camera angles, it has been reported in an equine study that BSTs are unaffected by an angle less than 20 °C (Soroko and Howell, 2018).

The limbs were not analyzed in this study due to the highly variable characteristic of the BST across the limbs and should be considered in future research studies. A study of ten Labrador Retrievers showed that variation was still found in BST after the hair coat had been clipped from distal portions of the limb when image acquisition took place after 60 min (Loughin and Marino, 2007). Skin areas near major blood vessels such as cephalic and saphenous veins appear warmer whereas areas distant from blood supply at the dorsal metacarpus and pastern display cooler temperatures (Eddy et al., 2001). In order to reduce complications in coat evaluation and appreciate coat differences, the torso was chosen due to its homogeneity. Possible dissimilar effects on BST on other parts of the canine body. Temperature ranges of more than 1 °C are generally considered abnormal in equine thermography when evaluating the limbs. However, when observing opposing sides of limbs, BSTs varied over 5 °C without the presence of clinical inflammation (Soroko et al., 2017). In contrast, BSTs differed approximately 2 °C between SC and LC dogs, which is between the range reported in equine thermographic studies, possibly showing signs of inflammation. This would suggest that coat type is an important consideration when evaluating inflammation.

Restrictions to this study include the dissimilarity in canine routine and management as the participating canines were privately owned which may have affected mean BST. Although an indoor environment reduced environmental factors such as direct sunlight, which influence the thermal signature of the body. Intrinsic factors such as differences in adult dogs and the presence of mixed-breed dogs may have further complicated accurate obtainment of BST based on variation of thermoregulatory capabilities (Larson and Carithers, 1985); in this study, age was not considered to be significant when evaluating coat categories. Most dogs used in this research were mixed-breed; it would be useful to perform a similar study on purebred dogs to minimize potential discrepancy due to further variation of the hair coat (Czyż et al., 2012).

5. Conclusion

When evaluating BSTs using IRT, it is important to consider breed coat characteristics for veterinary clinicians to more accurately interpret BST values. Canines with short hair are consistent in expressing BSTs up to 2 °C warmer than dogs with longer and more diverse coat lengths and properties. Further research can include looking at individual properties of the hair and their potential impact on BSTs in pure-bred dogs.

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Declaration of Interest

None.

References

Arfuso, F., Fazio, F., Rizzo, M., Marafioti, S., Zanghì, E., Piccione, G., 2016. Factors affecting the haematological parameters in different goat breeds from italy. Ann. Anim. Sci. https://doi.org/10.1515/aoas-2015-0094.

Autio, E., Neste, R., Airaksinen, S., Heiskanen, M.L., 2006. Measuring the heat loss in horses in different seasons by infrared thermography. J. Appl. Anim. Welf. Sci. 9, 211–221. https://doi.org/10.1207/s15327604jaws09033.

Bartolomé, E., Sanchéz, M.J., Molina, A., Schaefer, A.L., Cervantes, I., Valera, M., 2013. Using eye temperature and heart rate for stress assessment in young horses competing in jumping competitions and its possible influence on sport performance. Animal 7, 2044–2053. https://doi.org/10.1017/S1751731113001626.

Biondi, F., Dornbusch, P.T., Sampaio, M., Montiani-Ferreira, F., 2015. Infrared ocular thermography in dogs with and without keratoconjunctivitis sicca. Vet. Ophthalmol. 18, 28–34. https://doi.org/10.1111/vop.12086.

Cena, K., Clark, J.A., 1973. Thermal radiation from animal coats: coat structure and measurements of radiative temperature. Phys. Med. Biol. 18, 432–443. https://doi.org/10.1088/0031-9155/18/3/008.

Czyż, K., Patkowska-Sokoła, B., Filistowicz, A., Janczak, M., Bodkowski, R., 2012. Analysis of hair coat of dachshund of longhaired, shorthaired, and wirehaired variety. Bull. Vet. Inst. Pulawy. 56, 643–647. https://doi.org/10.2478/v10213-012-0113-2.

Dikmen, S., Alava, E., Pontes, E., Fear, J.M., Dikmen, B.Y., Olson, T.A., Hansen, P.J., 2008. Differences in thermoregulatory ability between slick-haired and wild-type lactating holstein cows in response to acute heat stress. J. Dairy Sci. 91, 3395–3402. https://doi.org/10.3168/jds.2008-1072.

Eddy, A., Van Hoogmoed, L., Snyder, J., 2001. The role of thermography in management of equine lameness. Vet. J. 162, 172–181. https://doi.org/10.1053/tvjl.2001.0618.

Fernández-Cuevas, I., Bouzas Marins, J.C., Arnáiz Lastras, J., Gómez Carmona, P.M., Piñonosa Cano, S., García-Concepción, M.Á., Sillero-Quintana, M., 2015. Classification of factors influencing the use of infrared thermography in humans: a review. Infrared Phys. Technol. 71, 28–55. https://doi.org/10.1016/j.infrared.2015.02.007.

Greer, R.J., Cohn, L.A., Dodam, J.R., Wagner-Mann, C.C., Mann, F.A., 2007. Comparison of three methods of temperature measurement in hypothermic, euthermic, and hyperthermic dogs. J. Am. Vet. Med. Assoc. 230, 1841–1848. https://doi.org/10.2460/javma.230.12.1841.

Grossbard, B.P., Loughin, C.A., Marino, D.J., Marino, L.H., Sackman, J., Umbaugh, S.E., Solt, P.S., Afruz, J., Leando, P., Lesser, M.L., Akerman, A., 2014. Medical infrared imaging (thermography) of type I thoracolumbar disk disease in chondrodystrophic dogs (〈https://doi-org.proxy.library.cpp.edu/〉). Vet. Surg. 43 (7), 869–876. https://doi.org/10.1111/j.1532-950X.2014.12239.

Infernuso, T., Loughin, C.A., Marino, D.J., Umbaugh, S.E., Solt, P.S., 2010. Thermal imaging of normal and cranial cruciate ligament-deficient stifles in dogs: thermal imaging of canine stifles. Vet. Surg. 39, 410–417. https://doi.org/10.1111/j.1532-950X.2010.00677.

Johnson, S.I., McMichael, M., White, G., 2006. Heatstroke in small animal medicine: a clinical practice review. J. Vet. Emerg. Crit. Care 16, 112–119. https://doi.org/10.1111/j.1476-4431.2006.00191.

Larson, R.L., Carithers, R.W., 1985. A review of heat stroke and its complications in the canine. N. Z. Vet. J. 33, 202–206. https://doi.org/10.1080/00480169.1985.35236.

Loughin, C.A., Marino, D.J., 2007. Evaluation of thermographic imaging of the limbs of healthy dogs. Am. J. Vet. Res. 68, 1064–1069. https://doi.org/10.2460/ajvr.68.10.1064.

Marino, D.J., Loughin, C.A., 2010. Diagnostic imaging of the canine stifle: a review. Vet. Surg. 39, 284–295. https://doi.org/10.1111/j.1532-950X.2010.00678.

McCafferty, D.J., 2007. The value of infrared thermography for research on mammals: previous applications and future directions. Mammal Rev. 37, 207–223. https://doi.org/10.1111/j.1365-2907.2007.00111.

McNicholl, J., Howarth, G.S., Jazel, S.J., 2016. Influence of the environment on body temperature of racing greyhounds. Front. Vet. Sci. 3, 53. https://doi.org/10.3389/fvets.2016.00053.

Osthaus, B., Proops, L., Long, S., Bell, N., Hayday, K., Burden, F., 2018. Hair coat properties of donkeys, mules and horses in a temperate climate. Equine Vet. J. 50, 339–342. https://doi.org/10.1111/evj.12775.

Pavelski, M., Silva, D.M., Leite, N.C., Junior, D.A., de Sousa, R.S., Guérios, S.D., Dornbusch, P.T., 2015. Infrared thermography in dogs with mammary tumors and healthy dogs. J. Vet. Intern. Med. 29 (6), 1578–1583. https://doi.org/10.1111/jvim.13597.

Piccione, G., Casella, S., Panzera, M., Giannetto, C., Fazio, F., 2012. Effect of moderate treadmill exercise on some physiological parameters in untrained beagle dogs. Exp. Anim. 61, 511–515. https://doi.org/10.1538/expanim.61.511.

Refinetti, R., Piccione, G., 2003. Daily rhythmicity of body temperature in the dog. J. Vet. Med. Sci. 65 (8), 935–937. https://doi.org/10.1292/jvms.65.935.

Redaelli, V., Bergero, D., Zucca, E., Ferrucci, F., Costa, L.N., Crosta, L., Luzi, F., 2014. Use of thermography techniques in equines: principles and applications. J. Equine Vet. Sci. 34, 345–350. https://doi.org/10.1016/j.jevs.2013.07.007.

Rekant, S.I., Lyons, M.A., Pacheco, J.M., Arzt, J., Rodriguez, L.L., 2016. Veterinary applications of infrared thermography. Am. J. Vet. Res. 77, 98–107. https://doi.org/10.2460/ajvr.77.1.98.

Ring, E.F.J., Ammer, K., 2000. The technique of infra red imaging in medicine. Thermol. Int. 10, 7–14. https://doi.org/10.1088/978-0-7503-1143-4ch1.

Rizzo, M., Arfuso, F., Alberghina, D., Giudice, E., Gianesella, M., Piccione, G., 2017. Monitoring changes in body surface temperature associated with treadmill exercise in dogs by use of infrared methodology. J. Therm. Biol. 69, 64–68. https://doi.org/10.1016/j.jtherbio.2017.06.007.

Schaefer, A.L., Cook, N., Tessaro, S.V., Deregt, D., Desroches, G., Dubeski, P.L., Tong, A.K.W., Godson, D.L., 2004. Early detection and prediction of infection using infrared thermography. Can. J. Anim. Sci. 84, 73–80. https://doi.org/10.4141/A02-104.

Soerensen, D., Pedersen, L., 2015. Infrared skin temperature measurements for monitoring health in pigs: a review. Acta Vet. Scand. 57, 5. https://doi.org/10.1186/s13028-015-0094-2.

Soroko, M., Howell, K., Dudek, K., 2017. The effect of ambient temperature on infrared thermographic images of joints in the distal forelimbs of healthy racehorses. J. Therm. Biol. 66, 63–67. https://doi.org/10.1016/j.jtherbio.2017.03.018.

Soroko, M., Howell, K., 2018. Infrared thermography: current applications in equine medicine. J. Equine Vet. Sci. 60, 90–96. https://doi.org/10.1016/jevs.2016.11.002.

Travain, T., Colombo, E.S., Heinzl, E., Bellucci, D., Prato Previde, E., Valsecchi, P., 2015. Hot dogs: thermography in the assessment of stress in dogs (canis familiaris)—A pilot study. J. Vet. Behav. 10, 17–23. https://doi.org/10.1016/j.jveb.2014.11.003.

Tunley, B.V., Henson, F.M.D., 2004. Reliability and repeatability of thermographic examination and the normal thermographic image of the thoracolumbar region in the horse. Equine Vet. J. 36, 306–312. https://doi.org/10.2746/0425164044890652.

Turner, T.A., 1991. Thermography as an aid to the clinical lameness evaluation. Vet. Clin. N. Am. Equine Pract. 7, 311–338. https://doi.org/10.1016/S0749-0739(17)30502-3.

Turner, T.A., 2001. Diagnostic thermography. Vet. Clin. N. Am. Equine Pract. 17, 95–114. https://doi.org/10.1016/S0749-0739(17)30077-9.

Vainionpää, M., Tienhaara, E.P., Raekallio, M., Junnila, J., Snellman, M., Vainio, O., 2012. Comparison of three thermal cameras with canine hip area thermographic images. J. Vet. Med. Sci. 74, 1539–1544. https://doi.org/10.1292/jvms.12-0180.

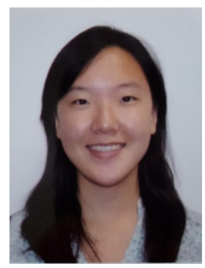
Welle, M.M., Wiener, D.J., 2016. The hair follicle: a comparative review of canine hair follicle anatomy and physiology. Toxicol. Pathol. 44, 564–574. https://doi.org/10.1177/0192623316631843.

Yanmaz, L.E., Okumus, Z., 2014. Using infrared thermography to detect corneal and extremity temperatures of healthy horses. Isr. J. Vet. Med. 69 (1), 20–23.

Yarnell, K., Hall, C., Billett, E., 2013. An assessment of the aversive nature of an animal management procedure (clipping) using behavioral and physiological measures. Physiol. Behav. 118, 32–39. https://doi.org/10.1016/j.physbeh.2013.05.013.

Zanghi, B.M., 2016. Eye and ear temperature using infrared thermography are related to rectal temperature in dogs at rest or with exercise. Front. Vet. Sci. 3, 111. https://doi.org/10.3389/fvets.2016.00111.

Zaproudina, N., Varmavuo, V., Airaksinen, O., Närhi, M., 2008. Reproducibility of infrared thermography measurements in healthy individuals. Physiol. Meas. 29, 515–524. https://doi.org/10.1088/0967-3334/29/4/007.



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