FULL PAPER *Physiology*

Comparison of Three Thermal Cameras with Canine Hip Area Thermographic Images

Mari VAINIONPÄÄ[1)]*, Marja RAEKALLIO[1)], Elina TUHKALAINEN[1)], Hannele HÄNNINEN[1)], Noora ALHOPURO[1)], Maija SAVOLAINEN[1)], Jouni JUNNILA[2)], Anna HIELM-BJÖRKMAN[1)], Marjatta SNELLMAN[1)] and Outi VAINIO[1)]

[1)]*Department of Equine and Small Animal Medicine, Pharmacology and Toxicology, Faculty of Veterinary Medicine, University of Helsinki, Koetilantie 7, Finland*
[2)]*4Pharma Ltd, Espoo, Finland*

(Received 19 April 2012/Accepted 25 June 2012/Published online in J-STAGE 9 July 2012)

ABSTRACT. The objective of this study was to compare the method of thermography by using three different resolution thermal cameras and basic software for thermographic images, separating the two persons taking the thermographic images (thermographers) from the three persons interpreting the thermographic images (interpreters). This was accomplished by studying the repeatability between thermographers and interpreters. Forty-nine client-owned dogs of 26 breeds were enrolled in the study. The thermal cameras used were of different resolutions—80 × 80, 180 × 180 and 320 × 240 pixels. Two trained thermographers took thermographic images of the hip area in all dogs using all three cameras. A total of six thermographic images per dog were taken. The thermographic images were analyzed using appropriate computer software, FLIR QuickReport 2.1. Three trained interpreters independently evaluated the mean temperatures of hip joint areas of the six thermographic images for each dog. The repeatability between thermographers was >0.975 with the two higher-resolution cameras and 0.927 with the lowest resolution camera. The repeatability between interpreters was >0.97 with each camera. Thus, the between-interpreter variation was small. The repeatability between thermographers and interpreters was considered high enough to encourage further studies with thermographic imaging in dogs.
KEY WORDS: canine, comparison, thermal camera, thermographic image, thermography.

doi: 10.1292/jvms.12-0180; *J. Vet. Med. Sci.* 74(12): 1539–1544, 2012

Thermography (also known as infrared thermography and infrared imaging) is a noninvasive and safe method of detecting changes in superficial temperature in animals [15, 16, 23, 28] and humans [20, 26]. A change in superficial temperature may be an indicator of several illnesses and pain [10, 13]. Although this method could be useful as a diagnostic tool in everyday veterinary medicine, its clinical utility has rarely been studied, especially in small animals. In recent years, the technology of the cameras has improved, prices have gone down and the equipment has become easy to transport, which makes bedside use feasible.

The normal temperature of an area of the body is a product of cell metabolism and local blood flow [9]. Inflammation in subcutaneous and deeper tissues can be reflected by superficial tissue temperature changes of ≥1°C. In the inflammatory process, skin temperature rises due to changes in the diameter of blood vessels and the rate of blood flow as well as increased capillary permeability, which can be seen with thermography [29, 30]. The human hand and fingers can detect a ≥2°C difference in temperature on a patient's skin [11], whereas modern infrared cameras have been claimed to be more than 10 times more sensitive in detecting temperature changes. Thermography can be used to detect changes in peripheral blood flow from the resulting changes in heat loss [25].

The objective of this study was to compare three different resolution thermal cameras in investigating the amount of variance caused by thermographers and interpreters of thermal camera images (thermographic images). In addition, we visually observed the appearance of varying hair coats in different breeds of dogs. Our aim was to show that the variance caused by these two random components would be small enough to be considered negligible in clinical use. None of the thermal cameras were made for medical purposes, and by comparing different resolutions in an animal study, we also set out to determine which resolution, if not all of them, would be best suited for veterinary purposes.

MATERIALS AND METHODS

Thermal cameras: Three types of thermal cameras were used for this study. The resolutions of the cameras were 80 × 80 pixels (i5, FLIR Systems, Inc., Danderyd, Sweden), 180 × 180 pixels (b60, FLIR Systems, Inc.) and 320 × 240 pixels (T425, FLIR Systems, Inc.). The thermal sensitivities of the cameras were 0.10, 0.07 and 0.05°C for i5, b60 and T425, respectively. The cameras were selected to have a variety of different resolutions. The freeware FLIR QuickReport 2.1 [5] facilitated the processing of thermographic images taken with all three cameras.

Animals: A total of 49 client-owned dogs were enrolled in the study. The dogs were recruited by a public call, and

*CORRESPONDENCE TO: VAINIONPÄÄ, M., Department of Equine and Small Animal Medicine, Pharmacology and Toxicology, Faculty of Veterinary Medicine, University of Helsinki, Koetilantie 7, Finland.
e-mail: mari.vainionpaa@helsinki.fi

Table 1. Demographic data of the dogs included in the study (mean ± SD)

Breed	Dogs	Age	Weight
Akita	2	4 ± 1.4	24 ± 0.8
American cocker spaniel	3	4 ± 1.5	1 ± 2.2
Australian kelpie	1	6	22
Australian shepherd	1	1	17
Border collie	8	4 ± 3.2	18.9 ± 2.5
Border terrier	1	8	9
Caucasian shepherd dog	1	6	91
Central Asian shepherd dog	1	6	61
Doberman pinscher	2	5 ± 2.1	32 ± 1.4
Dogo Argentino	2	8 ± 0.7	46 ± 3.5
Finnish Lapphund	2	3 ± 3.5	15 ± 0.4
German shepherd dog	8	4 ± 2.5	35.8 ± 6.8
Giant schnauzer	1	3	38
Golden retriever	1	1	29
Hovawart	1	8	28
Labrador retriever	3	7 ± 2.5	32 ± 3.6
Lagotto Romagnolo	1	3	12
Lancashire heeler	1	5	11
Mixed-breed dog	1	5	33
Nova Scotia duck-tolling retriever	1	9	15
Old English sheepdog	1	2	33
Rough collie	2	3.5 ± 0.7	30.4 ± 0.6
Samoyed	1	2	33
Smooth collie	1	6	22
Staffordshire bull terrier	1	1	18
Welsh springer spaniel	1	7	22

dogs with all hip joint area conditions were included in the study. All dogs were adults aged 1–10 years, with 16 males, 25 females, five castrated males and three sterilized females. The dogs were of 26 different breeds (Table 1) with different types of hair coats. Their weights varied from 9 to 91 kg.

Thermographic imaging: The dogs were allowed to walk around and adjust to the room temperature in a calm manner for approximately 30 min before imaging. They were then positioned standing in an upright position, as symmetrically as possible, without the owner or thermographer touching the dog's torso. Owners were allowed to touch the head or the collar of the dog in order to keep the dog in the required position (Fig. 1). If needed, the owner could help the position of the dog by holding the dog under the abdomen. The dogs were examined in a room with a steady temperature.

Since the area of interest was the hip area, each thermographic image included the area from the last lumbar vertebra to the first coccygeal vertebra at a minimum. All images were taken from a distance of 60 cm to simulate a clinical setting where the space around the patient could be limited (Fig. 1). The distance was chosen from the average of the natural positions of the three thermographers when holding the camera. The distance was measured with a tape measure before each thermographic image.

The thermographic images were first taken by one thermographer with all three cameras, one thermographic image per camera. The same procedure was then immediately repeated by another thermographer. This resulted in six thermographic images per dog. Since the same distance was used with all cameras, the cameras were focused before taking the thermographic images. The dogs were not allowed to move during this time. The thermographers were trained in using all three cameras before the beginning of the study.

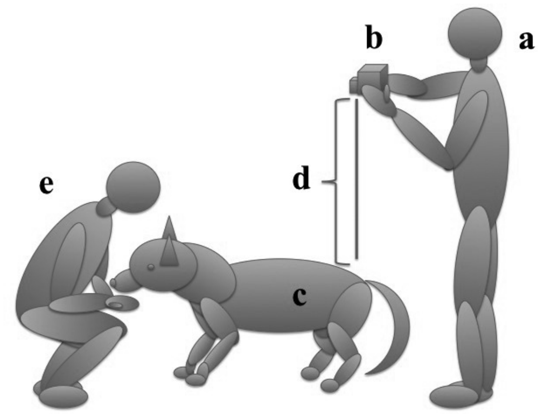

Fig. 1. Thermographer (a) standing behind the dog taking a thermographic image with the thermal camera (b) of the dog's (c) lumbar area from a distance of 60 cm (d). Owner (e) is holding the dog from the front.

Interpretation of the thermographic images: Data (thermographic images) from each camera were analyzed with the freeware FLIR QuickReport 2.1 [5]. This software was chosen in order to get easily repeatable results and to establish whether it is practical and easy enough to be used in a clinical setting by a general practitioner. The interpreters were trained in using the software before the beginning of the study.

The thermographic image rainbow colour palette was used for viewing and analyzing the images. This color palette was chosen because all three cameras could be set to this palette. All cameras were also set to a fixed temperature interval, thereby minimizing the possible changes in the image layout during analysis. The emissivity was set to 1 in all of the cameras as well as in analyzing the images.

The area of interest was the anatomical hip joint area. Mean temperatures in both hips were evaluated with the software by placing temperature boxes of equal size on the areas of interest in the thermographic images (Fig. 2a–c). The analysis was performed for all cameras separately and by three different interpreters independently.

Written informed consent for participation in the study was requested from all dog owners. This study was approved by the Ethical Committee of the Viikki Campus, University of Helsinki.

Statistical methods: A one-arm cross-sectional experimental design was used in this study. The analysis dataset included values from three cameras, two thermographers and three interpreters for both the left and right hip joint areas for each dog. The random variation caused by the interpreters and thermographers was assessed in two different ways. First, random effects models were constructed.

Random effects models were selected because different thermographers and interpreters are assumed to create only random variation in the data, i.e., the mean differences between thermographers and interpreters are assumed to be zero.

To estimate the variance component of interpreter, a random effects model was constructed. Only the effect of the dog was included as a random factor in the model. The response of the model was calculated as the mean of the two images taken by two thermographers on the same dog for each interpreter. In this model, the residual variance component estimates the variation between interpreters for a given dog. The random effects models were constructed separately for the different cameras and for the left and right legs.

As said, a random effects model was also constructed for estimating the variance component related to the thermographer. Here, the response was calculated as the mean of the three interpreters for each image. In these models, the random effect of the dog was included as the only factor in the model. The residual variance of these models estimated the variation between thermographers for a given dog. The random effects models were constructed separately for the different cameras and for the left and right legs. Estimates and 95% confidence intervals (CI) were provided for all of the random effects models.

Another approach in evaluating the importance of the differences between interpreters and thermographers was also applied. Here, we calculated a repeatability statistic between interpreters and thermographers with one-way analysis of variance (ANOVA) in which the effect of the dog was used as a fixed effect. In these models, the within-group variation describes the variation between interpreters and thermographers, respectively. The repeatability statistic was calculated based on the within group and between group mean squares of the ANOVA models.

All statistical analyses were performed using the SAS® System for Windows, version 9.2 (SAS Institute Inc., Cary, NC, U.S.A.).

RESULTS

Repeatability between interpreters was at least 0.974 for camera i5, 0.989 for camera b60 and 0.991 for camera T425. Repeatability between thermographers varied depending on the camera used: it was 0.927 with the i5 and 0.976 and 0.981 with the b60 and T425, respectively.

The results of the random effects models were similar to those of the repeatability statistics for the left and right leg, respectively. The between-interpreter variation was small: the estimates were 0.04 (95% CI 0.03–0.06) with camera T425, 0.05 (95% CI 0.04–0.07) with camera b60 and 0.13 (95% CI 0.1–0.17) with camera i5. With cameras T425 and b60, the variation between thermographers also seemed to be minor (estimates 0.09 [95% CI 0.06–0.14] and 0.11 [95% CI 0.07–0.17] respectively). With camera i5, the variation between thermographers was almost 0.4 (95% CI 0.27–0.6). These estimates, excluding the between-thermographer variation with camera i5, seem negligible compared with the variation caused by the dogs. The between-dog variation varied from 4.6 to 5.2 depending on the fitted model.

Thermographic images of dogs with certain different hair types and lengths are shown in Fig. 3.

DISCUSSION

This study examined the reliability of thermography by studying the variation and repeatability of different resolution cameras, different thermographers and different interpreters, using basic software for analyzing the images. It was executed by employing two investigators for taking the images and three investigators for analyzing them.

The variation between thermographers depended on the resolution of the camera used. Cameras b60 and T425 were found to have equal repeatabilities, whereas the repeatability was poorer and not directly correlative with camera i5. This can be explained by the fact that thermography is a physiological diagnostic tool and falls in the category of functional imaging techniques [3] in which small changes in the subject or the angle of the camera can be significant. In a low-resolution camera, such as the i5, small changes in image cannot be interpreted and put into perspective due to the lack of resolution. The present results indicate that a resolution of 180 by 180 pixels, such as in the b60, is enough to provide reliable results. A higher resolution means smaller detectable changes.

The repeatability between interpreters was high, which indicates that the basic FLIR QuickReport 2.1 freeware [5] can be used to interpret thermographic images. More meticulous software might be needed to interpret smaller details and areas. The results also indicate that this method could easily be applied to clinical practice with relatively minor training in using infrared cameras and interpreting thermographic images.

The recruited dogs were of varying breeds and, more importantly, had different kinds of fur. As a result, we observed that different hair coats differ markedly in appearance, which can, at times, complicate locating the area of interest. This is especially true when the hair is very long and/or thick [19]. Furthermore, curly hair can make estimation of the mean temperature difficult despite the computer software selected. The study material proved challenging for the interpreters due to the different breeds of dogs and varying kinds of hair coats, which affected the amount of heat emitted from dogs, thus influencing the thermographic images [19]. With humans, the heat emitted from the body is not trapped inside insulating fur as in dogs, and direct measurement of skin temperature is possible [7, 21]. Further studies are needed to define the hair length limits for thermography in dogs. Marking the area of interest would have been extremely helpful in recognizing the anatomical structures, but as demonstrated in a study in humans [3], any interference with the area of interest would have impacted the thermographic images. Exercise has also been shown to affect thermographic images [24], and the 30-min period for the dogs to adjust to the room temperature in a calm way and a symmetrical body position were probably factors

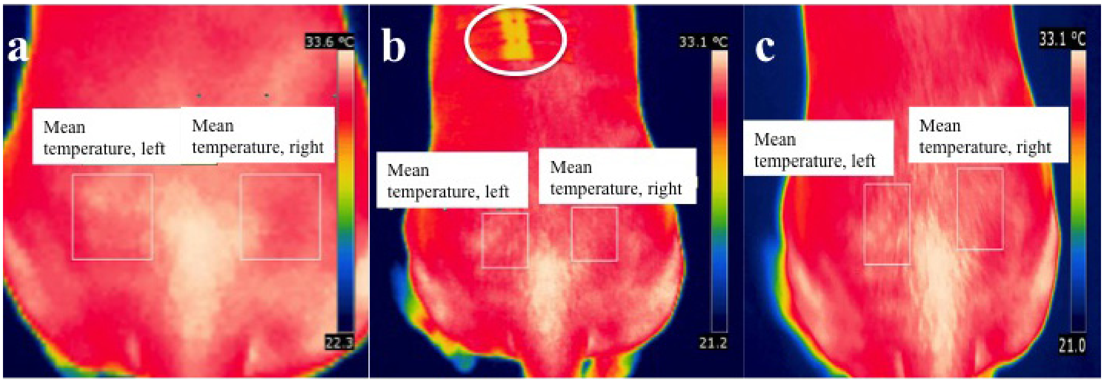

Fig. 2. In all thermographic images, the area of interest is marked with a white rectangle (mean temperature). The same dog is presented in all thermographic images. The thermographic images are taken with a) camera i5, b) camera b60 and c) camera T425. In b), the thermometer site (oval) is also visible. The results of thermometer measurements are not reported in this article.

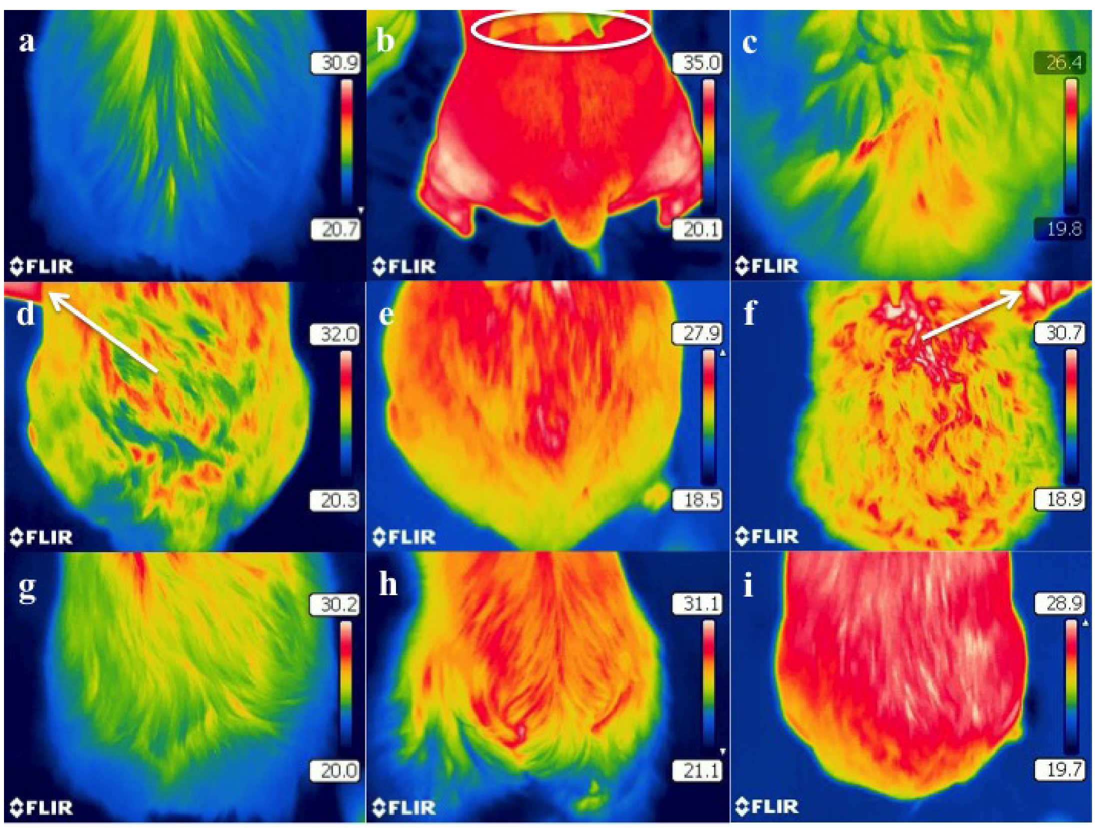

Fig. 3. Thermographic images of different breeds of dogs with different types of hair coats taken with camera T425: a) Finnish Lapphund, b) Staffordshire bull terrier, c) Samoyed, d) Labrador retriever, e) German shepherd dog, f) Lagotto Romagnolo, g) Border collie, h) American cocker spaniel, and i) Smooth collie. Arrows point to the owner's hand holding the dog from the ventral side. The oval indicates the thermometer site (measurements not reported in this article).

affecting in the results. A study on horses suggested that no adjustment or equilibration time is required for performing thermographic imaging [27], but this could be due to the fact that a horse is a much bigger and more even heat source than a dog. In the present study, however, we were only interested in within-dog variation.

The emissivity was set to one (e=1) in all thermographic images. This setting was selected in the absence of further information. An emissivity of one is the emissivity of a theoretical black body that represents perfect absorption of light

[14]. This means that an assumption of not reflecting but only emitting heat radiation is made for the subject. Although this is not true with dogs, this emissivity is commonly used to make thermographic images comparable, since there have been no studies on the emissivity of animals to date. Another option would have been to use an emissivity of 0.98, which is the emissivity of human skin [22], or 0.95, which has been used in a study on horses [1], but these alternatives did not seem appropriate in the present context due to the different types of hair coats of the dogs because thicker hair serves as a better isolator [4]. The ability of a subject—in this case, a dog—to emit or reflect heat should be considered in the interpretations of thermographic images [2], and this requires further study. Fur clipping has not been proven necessary for thermographic evaluation of structures in studies performed on dogs [12, 17, 18] and could actually be harmful due to the microtrauma caused by the clippers and the corresponding circulatory change.

It is crucial to bear in mind the physical conditions such as room temperature as well as the laws of radiation and wave physics. Most importantly, the room temperature should be even, as it was in this study. Drafts from windows or doors and strong spotlights might have a significant effect on thermographic images [8], especially if the room in question is small. Converting a thermographic image into other physiological function images, or properly interpreting them, requires the elimination of environmental influences and variations [6]. The veterinarian interpreting the thermographic images should also have a strong knowledge of the anatomy and physiology of the animal being imaged. In the present study, emphasis was placed on the anatomical structures and physiologies of different breeds of dogs. Since marking of the anatomical structures is impossible, knowledge of anatomy is necessary. Thermography is a physiological diagnostic tool, and therefore, mastering the physiology and anatomy is required in order to obtain valuable and correct information from the thermographic images.

Based on this study, we can conclude that the variation introduced by trained thermographers and interpreters is negligible when evaluating thermal camera images that have been taken with the cameras b60 and T425. Camera i5 was more sensitive to variations between thermographers.

The study also showed that it is possible to use a thermal camera and software for interpreting thermographic images with proper training. This includes an understanding of the possible challenges of the method. The clinical implication is that noninvasive thermography could be used as a diagnostic tool, bearing in mind that the method has limitations, as do all diagnostic methods.

The results of the current study indicate that the investigated method is potentially practical and reliable in clinical use. However, clinical studies are needed to specify the resolution required in clinical practice and the usefulness of the method for different medical conditions. Further studies are also needed to establish the usability of thermography on dogs with illness or pain.

ACKNOWLEDGMENT. FLIR Sweden and Infradex Oy Finland (Seppo Vihinen) made this study possible by providing the cameras.

REFERENCES

1. Autio, E., Neste, R., Airaksinen, S. and Heiskanen, M.L. 2006. Measuring the heat loss in horses in different seasons by infrared thermography. *J. Appl. Anim. Welf. Sci.* **9**: 211–221. [Medline] [CrossRef]
2. Eddy, A. L., Van Hoogmoed, L. M. and Snyder, J. R. 2001. The role of thermography in the management of equine lameness. *Vet. J.* **162**: 172–181. [Medline] [CrossRef]
3. Denoble, A. E., Hall, N., Pieper, C. F. and Kraus, V. B. 2010. Patellar skin surface temperature by thermography reflects knee osteoarthritis severity. *Clin. Med. Insights Arthritis Musculoskelet. Disord.* **3**: 69–75. [Medline] [CrossRef]
4. Dikmen, S., Alava, E., Pontes, E., Fear, J. M., Dikmen, B. Y., Olson, T. A. and 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. [Medline] [CrossRef]
5. Systems, F.L.I.R. Inc. 1999–2012. FLIR QuickReport Software [cited 2012 April 18]. http://www.flir.com/cs/emea/en/view/?id=42406
6. Fujimasa, I., Chinzei, T. and Saito, I. 2000. Converting far infrared mage information to other physiological data. *IEEE Eng. Med. Biol.* **19**: 71–76. [CrossRef]
7. Gazerani, P. and Arendt-Nielsen, L. 2011. Cutaneous vasomotor reactions in response to controlled heat applied on various body regions of healthy humans: evaluation of time course and application parameters. *Int. J. Physiol. Pathophysiol. Pharmacol.* **3**: 202–209. [Medline]
8. Gebremedhin, K. G. and Wu, B. 2001. A model of evaporative cooling of wet skin surface and fur layer. *J. Therm. Biol.* **26**: 537–545. [CrossRef]
9. Head, M. J. and Dyson, S. 2001. Talking the temperature of equine thermography. *Vet. J.* **162**: 166–167. [Medline] [CrossRef]
10. Head, J. F. and Elliott, R. L. 2002. Infrared imaging: Making progress in fulfilling its medical promise. *IEEE Eng. Med. Biol. Mag.* **21**: 80–85. [Medline] [CrossRef]
11. Holmes, L. C., Gaughan, E. M., Gorondy, D. A., Hogge, S. and Spire, M. F. 2003. The effect of perineural anesthesia on infrared thermographic images of the forelimb digits of normal horses. *Can. Vet. J.* **44**: 392–396. [Medline]
12. Infernuso, T., Loughin, C. A., Marino, D. J., Umbaugh, S. E. and Solt, P. S. 2010. Thermal imaging of normal and cranial cruciate ligament-deficient stifles in dogs. *Vet. Surg.* **39**: 410–417. [Medline] [CrossRef]
13. Jiang, L. J., Ng, E. Y. K., Yeo, A. C. B., Wu, S., Pan, F., Yau, W. Y., Chen, J. H. and Yang, Y. 2005. A perspective on medical infrared imaging. *J. Med. Eng. Technol.* **29**: 257–267. [Medline] [CrossRef]
14. Kastberger, G. and Stachl, R. 2003. Infrared imaging technology and biological applications. *Behav. Res. Methods Instrum. Comput.* **35**: 429–439. [Medline] [CrossRef]
15. Kízková, I. and Kunc, P. 2007. Applications of infrared thermography in animal production. *J. Fac. Agric.* **22**: 329–336.
16. Levet, T., Mertens, A., Devisscher, L., Duchateau, L., Bogaert, L. and Vlaminck, L. 2009. Distal limb cast sores in horses: Risk factors and early detection using thermography. *Equine Vet. J.* **41**: 18–23. [Medline] [CrossRef]

17. Loughin, C. A. and Marino, D. J. 2007. Evaluation of thermographic imaging of the limbs of healthy dogs. *Am. J. Vet. Res.* **68**: 1064–1069. [Medline] [CrossRef]
18. Marino, D. J. and Loughin, C. A. 2010. Diagnostic imaging of the canine stifle: a review. *Vet. Surg.* **39**: 284–295. [Medline] [CrossRef]
19. McCafferty, D. J. 2007. The value of infrared thermography for research on mammals: previous applications and future directions. *Mammal Rev.* **37**: 207–223. [CrossRef]
20. Ng, E. Y. K. and Kee, E. C. 2008. Advanced integrated technique in breast cancer thermography. *J. Med. Eng. Technol.* **32**: 103–114. [Medline] [CrossRef]
21. Park, J., Jang, W. S., Park, K. Y., Li, K., Seo, S. J., Hong, C. K. and Lee, J. B. 2011. Thermography as a predictor of postherpetic neuralgia in acute herpes zoster patients: a preliminary study. *Skin. Res. Technol.* (in press).
22. Ring, E. F. J. 2006. The historical development of thermometry and thermal imaging in medicine. *J. Med. Eng. Technol.* **30**: 192–198. [Medline] [CrossRef]
23. Schweinitz von, D. G. 1999. Thermographic diagnostics in equine back pain. *Vet. Clin. N. Am.-. Equine* **15**: 161–177.
24. Simon, E. L., Gaughan, E. M., Epp, T. and Spire, M. 2006. Influence of exercise on thermographically determined surface temperatures of thoracic and pelvic limbs in horses. *J. Am. Vet. Med. Assoc.* **229**: 1940–1944. [Medline] [CrossRef]
25. Stewart, M., Webster, J. R., Verkerk, G. A., Schaefer, A. L., Colyn, J. J. and Stafford, K. J. 2007. Non-invasive measurement of stress in dairy cows using infrared thermography. *Physiol. Behav.* **92**: 520–525. [Medline] [CrossRef]
26. Tan, J.H., Ng, E. Y. K., Acharya, U. R. and Chee, C. 2009. Infrared thermography on ocular surface temperature: a review. *Infrared Phys. Technol.* **52**: 97–108. [CrossRef]
27. Tunley, B. V. and Henson, F. M. D. 2004. The liability and repeatability of thermographic examination and the normal thermographic image of the thoracolumbar region in the horse. *Equine Vet. J.* **36**: 306–312. [Medline] [CrossRef]
28. Turner, T. A. 2001. Diagnostic thermography. *Vet. Clin. N. Am. Equine* **17**: 95–113.
29. Varjú, G., Pieper, C. F., Renner, J. B. and Kraus, V. B. 2004. Assessment of hand osteoarthritis: correlation between thermographic and radiographic methods. *Rheumatology* **43**: 915–919. [Medline] [CrossRef]
30. Vianna, D. M. L. and Carrive, P. 2005. Changes in cutaneous and body temperature during and after conditioned fear to context in the rat. *Eur. J. Neurosci.* **21**: 2505–2512. [Medline] [CrossRef]