Infrared thermography as a diagnostic tool to detect cranial cruciate ligament deficiency in dogs

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Abstract

Cranial cruciate ligament (CCL) disease is the leading cause of canine lameness. Diagnosis is based on physical examination and diagnostic imaging findings. Limitations of diagnostic modalities, including patient temperament, cost, availability, and need for general anesthesia, preclude their use for many patients. Infrared thermography is an easy, non-invasive diagnostic screening technique with use in both human and veterinary musculoskeletal conditions. The objective of this study was to investigate the utility of infrared thermography to diagnose CCL disease in a large population of client-owned dogs and investigate for correlations between ability of thermography to diagnose CCL deficiency and recorded explanatory factors. A commercial grade thermal imaging camera was used to collect preoperative images of both stifles in 50 dogs with surgically confirmed CCL rupture in one stifle and a normal opposite stifle. The average maximum temperatures of the affected and unaffected stifles were collected from these images and used for statistical analysis. Infrared thermography was not successful in differentiating between CCL-deficient and unaffected stifles in this cohort. No significant differences in average maximal temperature were observed between stifles when comparing to explanatory factors or variables. Use of infrared thermography should not be relied upon to diagnose canine CCL disease.

Résumé

La pathologie du ligament croisé crânien (CCL) est la principale cause de boiterie canine. Le diagnostic repose sur l'examen physique et les résultats de l'imagerie diagnostique. Les limites des modalités de diagnostic, y compris le tempérament du patient, le coût, la disponibilité et la nécessité d'une anesthésie générale, empêchent leur utilisation pour de nombreux patients. La thermographie infrarouge est une technique de dépistage diagnostique simple et non invasive, utilisable dans les conditions musculosquelettiques humaines et vétérinaires. L'objectif de cette étude était d'étudier l'utilité de la thermographie infrarouge pour diagnostiquer les problèmes de CCL dans une grande population de chiens appartenant à des clients et d'étudier les corrélations entre la capacité de la thermographie à diagnostiquer une déficience du CCL et les facteurs explicatifs enregistrés. Une caméra d'imagerie thermique de qualité commerciale a été utilisée pour collecter des images préopératoires des deux grassets chez 50 chiens avec une rupture du CCL confirmée chirurgicalement dans un grasset et un grasset opposé normal. Les températures maximales moyennes des grassets affectés et non affectés ont été recueillies à partir de ces images et utilisées pour l'analyse statistique. La thermographie infrarouge n'a pas réussi à différencier les grassets avec atteintes du CCL des grassets non affectés dans cette cohorte. Aucune différence significative dans la température maximale moyenne n'a été observée entre les grassets lors de la comparaison avec des facteurs ou variables explicatifs. L'utilisation de la thermographie infrarouge ne doit pas être utilisée pour diagnostiquer les pathologie du CCL canin.

(Traduit par Docteur Serge Messier)

Introduction

For centuries, changes in body surface temperature (BST) have been used in consideration of underlying physiologic functions as local variations in temperature have shown to be indicative of disease in deeper tissues (1,2). The first recorded use of BST to diagnose disease was seen in the 400 B.C. writing of Hippocrates, in which physicians applied a thin mud slurry spread over a patient and observed for areas that dried first, indicating underlying organ pathology (3). Since the creation of primeval thermometers in the 16th century and the foundation of clinical thermometry 200 y later, there have been tremendous developments in methods of thermal measurement and imaging (4).

All living objects emit radiation at levels determined by the surface skin temperature. In the recent century, infrared thermography (IRT) has gained traction in the medical community as a non-invasive, non-radioactive diagnostic tool to measure and display a visual image of the infrared radiation. This radiation can be

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measured, displayed as a color map of an animal's body, and used to detect a change in the local skin temperatures which are affected by vasoconstriction, vasodilation, or infarction as well as inflammation or underlying metabolic rate (2,5,6). Although its practice does not afford the ability to identify specific anatomic abnormalities, IRT has described utility in both human and veterinary medicine to investigate many musculoskeletal conditions including joint inflammation and rheumatoid arthritis in children, muscle injuries in humans, foot dermatitis in cattle, and lameness in horses (2,7–9). In cats, thermography has been used in detection of pain, aortic thromboembolism, and hyperthyroidism (10–12). In addition, several studies have documented the diagnostic utility of thermal imaging for several musculoskeletal disease in canines including osteosarcoma, elbow dysplasia, and intervertebral disc disease (13–15).

Cranial cruciate ligament disease (CCLD) is one of the leading causes of pelvic limb lameness in dogs and results in pain and osteoarthritis (16,17). Physical examination findings in CCL deficient dogs include pain upon stifle flexion and extension, quadriceps muscle atrophy, medial periarticular fibrosis or buttress, stifle joint effusion, positive sit test, cranial drawer, and tibial compression (18). However, the accuracy of these tests is affected by the temperament of the patient, presence of concurrent tarsal or coxofemoral disease, degree of CCL damage, amount of periarticular fibrosis as well as muscle contraction and wasting (18–21).

Survey radiography is routinely performed to support the diagnosis of CCL deficiency and rule out other traumatic or neoplastic disorders (22). However, in some cases, diagnosis may be challenging in absence of a translational device in patients with subtle periarticular changes, as its use in assessing intraarticular ligamentous structure is limited (23). As such, computed tomography (CT) and arthrography, magnetic resonance imaging (MRI), ultrasound, and arthroscopy have been investigated for their utility in diagnosing canine CCL insufficiency (24–26). Limitations of these diagnostic modalities, including patient temperament, cost, availability, and need for general anesthesia, preclude use for many canine patients.

Infrared thermography (IRT) as a diagnostic screening technique for CCLD in canines could provide an easy, noninvasive way to support the diagnosis in challenging cases for which physical examination findings are not conclusive. Infernuso *et al* (27) performed thermographic studies of 6 Labrador retrievers with normal stifles and 10 dogs with a CCL-deficient stifle both before and after clipping of fur. However, information regarding the use of IRT to detect CCL-deficiency in canine populations with broad variations in weight and breed is absent from current literature.

In the present study, an industrial grade thermal imaging camera (FLIR T620) was evaluated for its ability to detect a difference in maximum temperatures between normal stifles and those with CCL-deficiency in a large population of client-owned dogs. The hypothesis was that CCL-deficient stifles would have a higher maximal temperature than that of the contralateral normal stifle and that the FLIR camera would be able to reliably detect which stifle had the injury. In addition, hair coat length, duration of lameness, BCS, radiographic evidence of osteoarthritis, preoperative use of NSAIDs, presence of a meniscal tear, and presence of a complete *versus* partial tear were recorded to assess for correlation of these variables with imaging results.

Materials and methods

Animals

Dogs that were presented to the Red Bank Veterinary Hospital, Tinton Falls, New Jersey, over an 8-month period (May to December 2019) were eligible for inclusion in the study. All subjects had a surgically confirmed CCL rupture in one stifle with a normal opposite stifle (no palpable effusion, pain, instability, or previous surgical procedures) based on history and physical examination performed by a Diplomate of the American College of Veterinary Surgeons. Dogs were excluded if there was evidence of concurrent dermatologic, metabolic, neurologic, or orthopedic disease. Data recorded from each patient included signalment, hair coat length (long *versus* short), duration of lameness ($<$ 30 d *versus* $\geq$ 30 d), body condition score (BCS) ($<$ 6/9 *versus* $\geq$ 6/9), degree of radiographic osteoarthritis in the operated leg (minimal *versus* moderate or severe), and pre-operative use of NSAIDs.

Thermographic imaging and surgery

All dogs had limited exercise the day of the examination and were housed in a temperature and humidity-controlled environment prior to image collection. Pre-operative thermal images of both stifles were taken from lateral, medial, cranial, and caudal views while the dog was in a standing position with a hand-held T-620 Forward-Looking Infrared (FLIR) thermal imaging camera positioned 12 to 24 inches from the stifle. The camera has a resolution of 640 $\times$ 480 pixels and is equipped with a focal plane array amorphous silicon microbolometer. Using FLIR imaging software (FLIR Systems, Wilsonville, Oregon, USA), the outline of the stifle joint was identified as defined by the distal third of the femur and the proximal third of the tibia for all views, the cranial aspect of the patella to the caudal aspect of the gastrocnemius muscle for the medial and lateral views, and the medial and lateral boundaries of the proximal tibia and distal femur for the cranial and caudal views. The program was used to calculate the maximum temperature within the region of interest (ROI) overlying the stifle joint for all views; the maximum temperature for each stifle was recorded (Figure 1).

Following thermographic evaluation, dogs were anesthetized, and both stifles were palpated to confirm instability in the affected stifles and no palpable pathology of any kind in the contralateral stifle. The CCL-deficient stifle was explored *via* arthrotomy before placement of a fabellar-tibial suture or performance of a tibial plateau leveling osteotomy (TPLO). Data including presence of a meniscal tear and degree of CCL tear (complete *versus* partial) were recorded at time of surgery.

Descriptive statistics and statistical analysis

Descriptive statistics were obtained for cranial, caudal, medial, lateral, and average of all 4 projections for the maximum skin surface temperature of the CCL-deficient stifles, maximum skin surface temperature of the unaffected stifles, and for the temperature difference between the stifles. Furthermore, descriptives were obtained for the average maximum temperature of the CCL-deficient and unaffected stifles and for the temperature difference between the stifles in regard to all explanatory variables. Bootstraps of 5000 re-samples

Measurements

El1	Max	79.4°F
	Min	70.5°F
	Average	74.0°F

Parameters

Emissivity	0.95
Refl. temp.	68°F

Geolocation

Compass	39° NE	

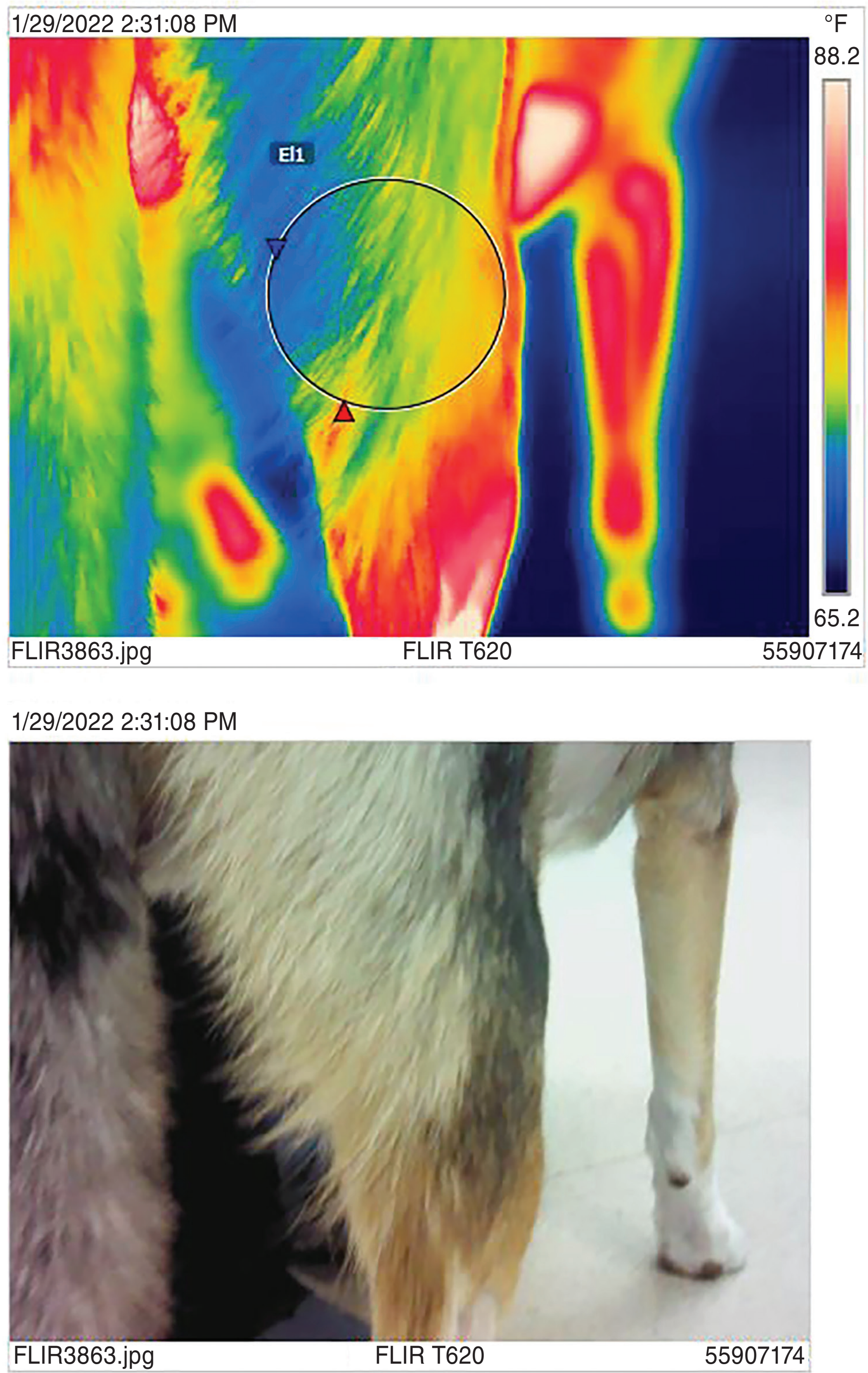

Figure 1. Cranial view of a dog's stifle using the FLIR thermal imaging camera with thermal and traditional pictures as well as recorded maximal temperature within the outlined region of interest (ROI) of the stifle joint.

were used for each Student's *t*-test to account for the failure of descriptive data to meet the assumption of normality. The significance level, *alpha,* was set at 0.5 for all statistical tests with Holm correction used for all *t*-tests to account for *alpha* inflation.

Statistics analyses were performed using *R* statistical programming software version 1.3.1093 (R Foundation for Statistical Computing, Vienna, Austria). A 1-sample *t*-test was used to examine the temperature difference between stifles with the null hypothesis being that the average maximum temperature difference between the affected and unaffected stifle is zero. Two sample *t*-tests were used to analyze the mean temperature difference between stifles regarding each of the explanatory factors: hair coat length, duration of lameness, BCS, degree of radiographic osteoarthritis, preoperative use of NSAIDs, presence of meniscal tear, and degree of CCL tear. The null hypothesis was that there was no variation in the mean temperature difference between the levels of each explanatory variable. In addition, 2 sample *t*-tests were used to compare the average maximum affected stifle temperatures to the explanatory variables: hair coat length, complete or partial tear, presence of meniscal tear, and preoperative use of NSAIDs. The null hypothesis was that the average maximum affected stifle temperature of dogs would not differ between the levels of each explanatory variable. Lastly, a repeated measures analysis of variance was used to examine the average maximum temperature difference between the affected and unaffected stifles for comparing the use of NSAIDs with a complete or partial CCL rupture, with or without a meniscus tear, and with a chronic or acute lameness.

Results

Animals

Fifty dogs were examined at Red Bank Veterinary Hospital, Tinton Falls, New Jersey over the 8-month study period which met the criteria for inclusion. Fifteen different pure breeds were represented, with the 3 most common being Labrador retriever ($n = 12$), Doberman pincher ($n = 4$), and Rottweiler ($n = 2$). Seventeen mixed breed dogs were also included. Mean age at time of IRT was 6.6 y old (range: 2 to 12.5 y). There were 28 female dogs (25 spayed, 1 intact) and 22 male dogs (17 neutered, 5 intact). Median body weight was 31.2 kg (range: 6.2 to 56.4 kg); 22 dogs weighed < 30 kg, whereas the remaining 28 were ≥ 30 kg. Mean BCS was 5.7/9 with 40% ($n = 20$) of dogs having a BCS ≥ 6/9. Some dogs had a short-haired coat ($n = 37$) and others had a long-haired coat ($n = 13$). Some dogs were lame for < 30 d ($n = 25$) and others were lame ≥ 30 d ($n = 25$). Some dogs had a complete CCL tear ($n = 43$), whereas others ($n = 7$) had partial CCL tears. Nineteen dogs sustained a meniscal tear and 31 had a healthy, intact meniscus. Some dogs had minimal ($n = 38$) and some ($n = 12$) had moderate to severe degrees of radiographic osteoarthritis. Some dogs were receiving an NSAID (Rimadyl $n = 28$, Galliprant $n = 1$, Deramaxx $n = 1$, Metacam $n = 1$) ($n = 31$) at time of IRT, whereas others were not receiving an NSAID ($n = 19$).

Statistical analysis

The mean maximum temperature of the CCL-deficient stifles was 33.20°C, whereas the mean of the average maximum temperatures of the unaffected stifles was 33.34°C. There was insufficient evidence to confirm the hypothesis that the difference of the average maximum temperature between the CCL deficient and unaffected stifle is significant (95% CI: −0.57 to 0.1; $P = 0.15$). However, a non-statistically significant mean temperature difference of 0.14°C was observed between the stifles, such that on average, the unaffected stifle had a higher temperature than the affected stifle.

In addition, no significant difference in average maximum temperatures between CCL-deficient and unaffected stifles was observed when comparing dogs

- receiving NSAIDs and dogs not receiving NSAIDs (95% CI: −1.29 to 0.03; $P = 0.062$),
- with short *versus* long hair (95% CI: −0.81 to 0.98; $P = 0.84$),
- with complete *versus* partial CCL tear (95% CI: −1.32 to 0.61; $P = 0.6$),
- with acute *versus* chronic lameness (95% CI: −0.59 to 0.75; $P = 0.84$),
- with or without a meniscal tear (95% CI: −0.51 to 1.01; $P = 0.52$),
- with a BCS of < 6 *versus* ≥ 6 (95% CI: −0.68 to 0.78; $P = 0.94$), and
- with mild *versus* moderate or severe radiographic osteoarthritis of the CCL-deficient stifle (95% CI: −0.98 to 0.77; $P = 0.86$).

Furthermore, there was no significant difference in average maximum temperatures of CCL-deficient stifles of dogs on an NSAID compared with dogs not receiving an NSAID (95% CI: −3.66 to 0.88; $P = 0.23$).

When comparing the average maximum temperature of the CCL-deficient stifle in dogs with a complete CCL tear and dogs with a partial tear, there was no significant difference (95% CI: −6.87 to 0.82; $P = 0.25$). However, it was noted that there was a non-statistically significant average maximum temperature difference of 1.66°C between dogs with a complete CCL tear and dogs with a partial tear such that on average, dogs with a complete tear had a higher average maximum stifle temperature than those with a partial tear. Notably, there was a non-statistically significant average maximum temperature difference in the CCL-deficient stifle of 1.26°C (95% CI: −0.58 to 5.21; $P = 0.13$) and of 1.21°C (95% CI: −0.82 to 5.17; $P = 0.16$) in the unaffected stifle between dogs with short *versus* long hair and on average, dogs with short hair had a higher average maximum stifle temperature than dogs with long hair. In addition, there was a non-statistically significant average maximum temperature difference between CCL-deficient stifles with and without a meniscal tear of 1.10°C (95% CI: −1.19 to 3.81; $P = 0.31$) such that on average, dogs with a meniscal tear had a higher average maximum stifle temperature than dogs with an intact, healthy meniscus. Lastly, no significant differences or interactions were observed when analyzing temperature differences between CCL-deficient and unaffected stifles for comparing the use of NSAIDs in the presence of a complete or partial CCL tear, with or without a meniscal tear, or when there is a chronic or acute lameness.

Discussion

The utility of a commercial grade FLIR camera and thermography used to diagnose CCLD in a cohort of 50 dogs of various sizes, degree of CCL deficiency and concurrent meniscal disease, duration of clinical signs, and hair coat length was investigated. There was no significant evidence that IRT can differentiate between CCL-deficient and unaffected stifles when comparing the maximum stifle temperatures from 4 different projections and from the average of all measurements in this population of dogs. Infrared thermography, therefore, should not be relied upon when diagnosing cruciate ligament disease in dogs.

Results of this study provide contradictory information to that previously reported regarding the use of IRT for diagnosing canine CCLD. Infernuso *et al* (27) concluded that thermography was successful in differentiating CCL-deficient stifles from those with an intact CCL with success rate of 75 to 85% when thermal imaging pattern analysis performed. In addition, authors concluded that there were no significant differences in regional average temperatures between normal canine stifles and those with CCL ruptures. There are several possible explanations for the discrepancy in study conclusions including the respective study populations as well as image collection and processing techniques. The cohort of dogs in the aforementioned study was a small population of Labrador retrievers ($n = 6$) with normal stifles (controls) and adult dogs ($n = 10$) with CCL rupture of 5 breeds and similar weight (range: 26.1 to 45 kg), whereas the present study had a more than 3-fold increase in population size ($n = 50$) and a wider variety of weights (range: 6.2 to 56.4 kg), breeds ($n = 15$), hair coat lengths, and body condition scores. In addition, Infernuso *et al* (27) used a stand-mounted Meditherm Med2000 IRIS camera for image acquisition, whereas a hand-held FLIR T620 was used herein. Although both cameras have FDA approval for medical application, the stand-mounted and hand-held nature of the cameras as well as differences in thermal sensitivity, focus distance, and resolution between cameras may have contributed to contradictory conclusions. The present study also focused on comparing the maximal temperatures of CCL-deficient and normal stifles and did not include image pattern recognition analysis. Comparison of the maximal temperatures, rather than mean temperatures, of CCL-deficient and normal stifles was made to limit inherent variability introduced by ROI selection, positional view, and angle inconsistencies previously described as possible sources of analysis impedance (26,27). Performance of image pattern recognition and analysis may have resulted in similar conclusions.

Infrared imaging systems detect body surface temperature as it relates to local dermal microcirculation regulated by the sympathetic autonomic nervous system and do not detect heat emanating from deeper tissues. The basis of medical IRT is for correlation of temperature changes with various disease states as they relate to autonomic driven changes corresponding to deeper structures and functions (28–30). Infrared thermography has demonstrated useful in evaluation of multiple disease processes in human subjects of all sizes, regardless of body fat percentage. To the authors' knowledge, this is the first study investigating the correlation between body weight and BCS and the ability of IRT to diagnose CCLD in the dog. No correlation was determined between patient weight or BCS and ability of IRT to diagnose CCLD.

This study is the first to investigate what correlations, if any, exist between the ability of FLIR camera to diagnose a CCL deficient stifle and presence of a complete or partial CCL tear, presence of a meniscal tear, and pre-operative use of non-steroidal anti-inflammatories (NSAIDs). Although not significant, there were several trends noted which may warrant further investigation or may have been significant with a larger sample size. Dogs with a complete CCL tear had an average maximum temperature 2.73°C higher than dogs with a partial tear. The increased instability of a complete tear may have caused more joint inflammation and effusion than a partial tear resulting in a higher surface skin temperature over the stifle. Similarly, there was a non-significant maximum temperature difference between CCL-deficient stifles with and without a meniscal tear of 1.10°C such that on average, dogs with a meniscal tear had a higher maximum stifle temperature than dogs with an intact, healthy meniscus. The canine menisci provide stifle joint stability and function in load bearing, load distribution, and shock absorption. The increase in articular cartilage contact pressure following meniscal injury contributes to cartilage degeneration and subsequent inflammation, which may have resulted in higher surface skin temperature over the stifle (31). In addition, the average maximal temperature difference between affected stifles and unaffected stifles was higher in short-haired *versus* long-haired dogs (1.26 *versus* 1.21°C, respectively). This finding may correlate with the insulating properties of a longer hair coat. However, the impact of hair coat length and thickness on temperature scale remains unknown, and future studies are warranted.

This study had several limitations. Time to acclimation to temperature and humidity-controlled environment varied between patients in the study. Several studies investigating infrared thermography evaluation of different regions of the horse (back, forelimb) have concluded variable ideal stay time within controlled environment ranging from 10 to 31 min, depending on the nature of the study (7,9). Also, the hand-held nature of the camera invariably lead to subtle changes in angle between the camera and patients. However, a study investigating the effects of infrared camera angle and distance on measurement and reproducibility of thermographically determined temperatures of the distolateral aspects of equine forelimbs were unaffected by a camera angle less than 20° or a 0.5-m increase in camera distance from the forelimb (7). Although there were no control dogs, prior studies investigating thermographic patterns and mean temperatures of clinically normal equine and canine limbs have reported bilateral symmetry between various ROI's suggesting contralateral ROI may be used for comparative control imaging when evaluating patients with unilateral disease for altered thermographic patterns (28,30,32–34). As such, the contralateral, unaffected stifle was used as a control group in this study. However, as CCL rupture is now recognized as a disease, it is possible that the contralateral joint of patients with a CCL rupture may exhibit simultaneous disease which is not overtly clinical (35). As such, it is possible that the control stifle may be affected by some degree of primary osteoarthritis and thus exhibit higher temperatures, making the differences in temperature smaller. In retrospect, collection of radiographs of the control stifles would have further confirmed a disease-free state of the controls *versus* physical examination alone. The dogs included in this study were of varying breeds, size, and hair coats which made the standardization of hair length and size of the measured stifle area impossible.

Results indicate that IRT should not be relied upon as a screening tool when diagnosing cruciate ligament disease in dogs. This study did not control for weight, breed, coat length, *etc.* which may have contributed to the inability of IRT to detect a temperature difference between CCL-deficient stifles with or without meniscal tears. Although CCL ruptures are the most common disease process affecting canine stifles, other diseases including meniscal only tears, patella luxations, inflammatory disease, immune-mediated disease, other ligamentous injuries, and osteoarthritis can affect the stifle. Further work should investigate diagnostic utility of IRT to screen for meniscal tears, as well as other stifle pathologies, and assessment of long-term response to surgery.

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