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Article

Comparison of infrared thermal imaging with two canine pain assessment tools in dogs undergoing treatment for chronic back pain.

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Abstract: Historically, the evaluation and assessment of the clinical response to treatment for canine back pain is subjective and relies on owner and clinician assessment of pain. This study evaluated the use of sequential infrared thermal images as a measure of the response of canine patients with back pain to a prescribed series of photobiomodulation therapy (PBMT) treatments. Qualifying participants had histories of pain and dysfunction associated with spinal osteoarthritis or intervertebral disk disease, or of non-specific uni- or bilateral back pain along the paravertebral epaxial muscles. Each patient was initially thermally imaged prior to PBMT treatment and then received multiple PBMT treatments delivered to the appropriate spinal area on days 1, 2, 3, and 4. Participants were reimaged on day 7. Thermal images provided an objective measure of superficial temperature changes over the area of PBMT treatment of each patient after the PBMT regimen. The temperature correlated with statistically significant changes in Colorado State University Canine Chronic Pain Scale scoring (CPS) and owner assessment using the Canine Brief Pain Inventory (CBPI), which includes a Pain Severity Score (PSS) and Pain Interference Score (PIS). The correlation of objective thermal imaging data with more subjective outcome measures suggests thermal imaging may be a valuable additional tool in monitoring therapy outcome.

Keywords: infrared thermal imaging; infrared thermography; veterinary thermal imaging; pain assessment; osteoarthritis; canine back pain; canine brief pain inventory; photobiomodulation therapy; laser therapy

1. Introduction

Non-specific back pain is a common condition seen in pet canines. Intervertebral disc disease is generally presumed to be the most common culprit, and one epidemiologic study suggests the prevalence of the disease in dogs <12 years of age to be 3.5% [1]. Epaxial muscle stress and repetitive injury are also causes of back pain seen in police and working dogs [2], and the diagnosis of degenerative lumbosacral stenosis is prevalent in medium to large breed dogs, especially German Shepherd and Retriever

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breeds [3]. Similarities to anatomical and physiologic characteristics of human spinal disease make spontaneous canine models a good source for translational research, with the goal of developing valid and effective prevention, evaluation, and treatments for both species [4].

Infrared thermal imaging provides a noncontact, non-invasive, non-irridating, accurate, and quantifiable graphic of the temperatures being radiated from the skin of the patient. The radiated energy correlates directly with blood flow beneath the skin [5-8]. Normal patients are thermally symmetrical when comparing contralateral anatomical areas [9,10]. Thermal asymmetry in contralateral anatomical areas results from an increase in underlying circulation caused by inflammation, infection, or neoplasia, or a decrease in circulation resulting from reduced sympathetic innervation of the area. [11-22].

Thermal imaging has been used in clinical veterinary applications for nearly 60 years. The first research paper assessing clinical veterinary applications of infrared thermal imaging was published in 1964 [23]. Thermal imaging is a screening tool with a high sensitivity and a low specificity that shows alterations in body surface temperatures secondary to changes in the physiology of underlying tissue applicable to a diversity of conditions [24-27]. Veterinary-specific guidelines for thermal imaging were established in 2019 [28].

Thermal images of the canine stifle show physiological changes in the stifle before the onset of structural changes when compared to X-ray, ultrasound, MRI, and CT scan [29] and differentiate between normal and cranial cruciate-deficient stifles [30]. Similarly, infrared imaging can differentiate between normal canine elbows and those with abnormal elbows (elbow dysplasia) as confirmed by arthroscopic examination [31].

Orthostatic analysis of thermal images of the paw prints can be utilized to screen for lameness in dogs [32]. Images of the paw prints are taken after the dog is kept in a static position on a foam mat for 30 seconds. The images show the change in the thermal pattern of the paw print in a lame limb compared to a non-lame limb.

Protocols for thermal screening have been developed for feline hyperthyroidism [33] and feline aortic thromboembolism [34]. By detecting increased surface temperatures secondary to increased circulation in malignant tissue, thermography is a fast, painless, contactless, and noninvasive imaging screen for canine mammary tumors [35], canine appendicular bone tumors [36], and skin and soft tissue tumors in cats [37].

Multiple clinical and diagnostic findings, including thermograhy, were used to evaluate police working dogs with hip osteoarthritis [38], examining breed, age, sex and OFA variation in mean thermography temperatures. Temperature data demonstrated some breed associated variation due to differences in hair coat. A significant variation between moderate and severe osteoarthritis was noted, with severe osteoarthritis showing decreased temperatures compared to moderate, presumably resulting from loss of muscle mass around the affected joints.

When using thermal imaging for patient assessment and monitoring response to therapy, the patient serves as its own control. Although factors such as breed and hair coat result in variations of body surface temperature from one patient to another, and should be considered when reviewing thermal images, an individual patient's temperatures

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should only be compared to their baseline or previous images, and the presence or lack of symmetry should be noted. Unexpected areas of increased or decreased temperature, changes in temperature over time from one imaging session to the next, and lack of thermal asymmetry indicate an alteration from normal.

In dogs, initial and subsequent pain assessments are helpful to qualify and quantify the extent of pain, as well as to monitor response to therapeutics. [39]. There are multiple metrology tools that have been developed for the assessment of chronic canine pain, and the Colorado State University Canine Chronic Pain Scale (CPS) is commonly used by veterinary staff to evaluate patients. While this tool enjoys frequent use in clinical practice and has been used as an assessment tool when evaluating therapy after back surgery [40], it has no published validation study. Assessment by the owner/caregiver also provides valuable insight, and the standard metrology tool utilized for canines is the Canine Brief Pain Inventory (CBPI). The CBPI evaluates the magnitude of pain via the Pain Severity Score (PSS), and the overall impact of that pain by measuring the Pain Interference Score (PIS). The CBPI has been validated for dogs where a ≥1 change for PSS and ≥2 change for PIS is considered significant [41].

In the first study of which we are aware comparing the results of thermal imaging to monitor treatment response with an objective measure and two clinic metrics, treatment response was monitored in police working dogs with bilateral hip osteoarthritis [42]. This study showed a correlation of the thermal imaging results with results of weight distribution (stance analysis) and clinical metrology instruments, including CBPI, that assess pain and function.

The mechanisms of photobiomodulation therapy are well established in peer-reviewed publications [43-52]. Photobiomodulation therapy (PBMT) delivers visible or near-infrared photons that produce a biochemical cascade of events in cells and tissues. Photobiomodulation induces autocrine signaling within cells, resulting in modulation of cell physiology and function and paracrine cell-to-cell signaling resulting in modulation of tissue physiology and function. Photoreceptor molecules within the cell absorb photonic energy, resulting in increased release of adenosine triphosphate, reactive oxygen species, and nitric oxide. These bioactive substances incite a biochemical cascade of events that lead to increased circulation, reduced pain, modulation of inflammation, and acceleration of healing.

The use of PBMT for treatment of pain and inflammation associated with neuromusculoskeletal disorders and osteoarthritis has been well documented in multiple species [53-58].

Our hypothesis was that there would be a correlation between patient response to PBMT, pre- and post-treatment thermal images, and patient pain assessment metric tools.

2. Methods

2.1. Qualifying Participants

Study participants were a convenience sample composed of patients of a rehabilitation center that met the inclusion criteria of a history of back pain, short to medium haircoat, body weight of 15-55 kg., and no current dermatological disorders.

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To be included, the patient's initial physical exam had to reveal palpable back pain along the thoracic and/or lumbar spine in the epaxial and paravertebral muscles. Preference was given to patients with diagnostic evidence of age-related degenerative osteoarthritis of the thoracic and/or lumbar spine. The attending veterinarian for each participant prescribed PBMT of the musculature of the back. Any previously prescribed pharmaceutical, nutraceutical, or holistic treatment protocols were maintained during the study. Pet owners were instructed to suspend any/all therapeutics prescribed on an 'as needed' basis for the duration of the study.

Participants could not receive PBMT, extracorporeal shock wave therapy (ESWT), or transcutaneous pulsed electromagnetic field therapy (tPEMF) for seven days prior to entering the study. Patients could not receive ESWT or tPEMF at any time during the study. Participants had to discontinue any underwater treadmill sessions, therapeutic exercises, or massage techniques for four days prior to, and during the study.

Owners were given a summary of the design and intent of the study and required to sign a participant release. The release included the provision that patients would be withdrawn from the study if examination revealed continuation might have any negative effects on the patient.

2.2. Study Design

2.2.1. Day One

Initial clinical evaluation of each qualifying participant included a patient history, physical exam, body condition score (BCS), CPS, and owner completion of a CBPI worksheet.

Patients were led into a room with an ambient temperature of 20° C followed by 15 minutes of inactivity to allow for equilibration to room temperature. Patients were positioned in a standing position for thermal imaging. Animal handlers were not allowed to touch the dorsum of the patient's back during the equilibration time or during imaging. Hair was not clipped from the patient since hair removal can affect the surface temperature of the area being imaged for as long as 60 minutes after removal [59].

A dorsal thermal image of the back was taken. A ghosted outline of the patient in the thermal imaging device software allowed repeatability when framing the image. In each thermal image, an anatomical area from T6-7 to S1-3, including all paravertebral epaxial musculature, was defined as the region of interest (ROI). This ROI also defined the treatment area for PBMT in each patient.

The thermal imaging system used has a 640 X 512 high-resolution medical-grade detector with a <.02°C sensitivity and accuracy of +/- 1°C. Temperature data were collected from 327,680 points and compiled using calibrated veterinary-specific software (Digatherm IR 640, Infrared Cameras Inc, Beaumont, TX, United States).

PBMT was administered at a fluence of 20 joules/cm^2, using continuously delivered blended wavelengths of 650, 810, and 980 nm, 10 watts of power, spot size 4.91 cm^2, and power density of 2.04 W/cm^2 (Companion Therapy Laser CTX-15, LiteCure, Wilmington, DE, United States). The total dosage in Joules was calculated based on the treatment area for each patient using a dose (fluence) of 20 J/cm^2. Since the same power (10 watts) was

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used for all patients, the treatment time for patients varied as a function of the total area (cm^2) being treated. The delivery handpiece was kept in-contact with the hair and skin and moved uniformly over the ROI. All thermal imaging and PBMT treatments were performed by the same person on each patient throughout the study.

The PBMT treatment parameters and application protocol were similar to those previously reported for treatment of osteoarthritis and neuromusculoskeletal disorders in dogs [57-58, 60]. Information about device specifications, application method, and treatment parameters previously established as important [61] is in Table 1.

Table 1. Photobiomodulation Treatment Parameters**.**

Photobiomodulation Therapy Device Information
Manufacturer: Companion Animal Health
Model: CTX-15
Year Manufatured: 2018
Number of Emitters: One
Beam Delivery: Fiberoptic, On-contact, Rollerball Handpiece
Irradiation Parameters
Wavelength/Beam Percentage: 980 nm/57%, 810 nm/38%, 650 nm/5%
Operation Mode: CW
Power Output: 10W (+/-5%)
Spot Size: 4.91 cm^2
Beam Shape: Circular
Fluence: 20 J/cm^2
Application technique: On-contact,light pressure, scanned uniformly over the ROI at 3-5cm/sec.

Patient	Total Area (sq. cm)	Total Time (minutes)	Total Joules Administered
1	672	22.4	13440
2	260	8.7	5200
3	360	12	7200
4	384	12.8	7680
5	480	16	9600
6	456	15.2	9120
7	264	8.8	5280
8	588	19.6	11760
9	560	18.7	11200
10	270	9	5400
11	532	17.7	10640
12	456	15.2	9120

2.2.2. Days 2, 3, and 4

On days 2, 3, and 4 PBMT was administered using the same protocol and delivery as the day 1 treatment.

2.2.3. Day 7

The patient was given a physical examination followed by 15 minutes of inactivity to equilibrate to the ambient room temperature. A dorsal thermal image was taken of the patient's back, using the same framing as previous images.

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2.3. Data Collection

On days 1 and 7, data were collected from each participant. This data included the thermographic measurement of the minimum, maximum, and average temperature in each ROI, a CPS, an owner assessment of improvement or no improvement using a "better", "worse", or "same," an owner generated CBPI worksheet and an owner evaluation of the quality of life (QOL) using a scale of "poor", "fair", "good", "very good", or "excellent". For each patient, the changes in temperatures in the region of interest (minimum, average, and maximum) (ΔTmin, ΔTave, ΔTmax) for days 1 and 7 were calculated. These calculations were performed by the thermal imaging device software.

A timeline of the sequence of initial patient evaluation, owner assessments, photobiomodulation therapy treatments, and thermal imaging is in Figure 1.

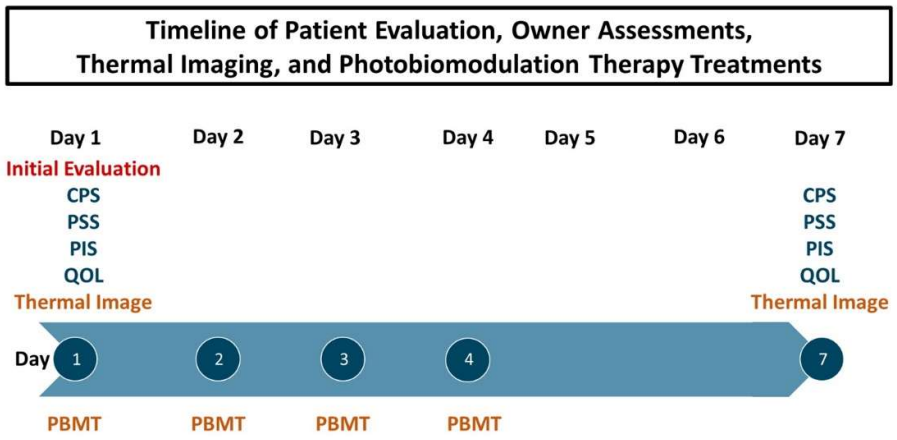

Figure 1. Timeline of Patient Evaluation, Owner Assessments, Thermal Imaging, and Photobiomodulation Therapy Treatments.

2.4. Statistical Analysis

Descriptive statistics were calculated. Normally distributed continuous variables were expressed as mean and standard deviation and non-normal distributed variables were expressed as median and range. To determine the correlation between two independent variables (ROI ΔT and CBPI and ROI ΔT and CPS) for each subject who received photobiomodulation, paired t-tests and the Mann-Whitney U-test were used to compare the change in CPS, PSS and PIS scores with the change in ROI thermal temperatures from day 1 to day 7. Two-tailed assessments were used and P values <.05 were considered significant. Because the outcome measurements were independent, Benjamini-Hochberg correction was also calculated for P values, where the false discovery rate was set at 15%. All analyses were performed using a statistical program (IBM SPSS Statistics for Windows, Version 25.0, IBM Corp, Armonk, New York).

3. Results

3.1. Patients

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Twelve dogs meeting the inclusion criteria participated in the trial. All patients completed day 1 and day 7 pain assessment. All twelve dogs had a history of generalized lower back pain.

Four of the twelve had a diagnosis of chronic back pain combined with multi-joint osteoarthritis. One dog had a known adrenal tumor. Two dogs had a history of ataxia and weakness. Although the laser therapist was not blinded to which animals had multiple joint osteoarthritis, there was no attempt to provide PBMT to anywhere on the patient other than the specified ROI (in this case the thoracolumbar epaxial muscles.) All owners completed the CBPI on days 1 and 7. All dogs completed thermography studies specifically as outlined. Baseline characteristics of all 12 dogs are presented in Table 2.

Table 2. Baseline characteristics of 12 dogs with non-specific back pain enrolled in an open study evaluating the correlation between pain scores, thermal data, and response to PBMT.

Number of participants:	12
Age in years median (range):	12 (7-15)
Weight in kg median (range):	24.1 (7.7-33.5)
Body Condition Score (BCS/10) median (range):	5.5 (4-7)
PSS Day 1 median (range):	4.625 (2.0-7.0)
PIS Day 1 median (range):	5.835 (2.67-7.33)
CPS Score Day 1 median (range):	1.5 (0.75-3.0)

3.2. Qualitative Analysis of Thermal Images and Correlation to Pain Scores

For each dog, the thermal images were paired - with days 1 and 7 presented on the same page. Three veterinarians, experienced with thermal imaging, and blinded to patient signalment, history, and pain scores, evaluated the twelve pair of images qualitatively and recorded improvement or no improvement on a scale of “better”, “worse”, or “same”. These results were compared to the owner assessment of QOL on days 1 and 7. Any improvement of QOL was tallied as “better”, any worsening of QOL was reported as “worse” and no change in QOL was reported as “same”. Figure 2 includes paired thermal images of three patients for qualitative interpretation.

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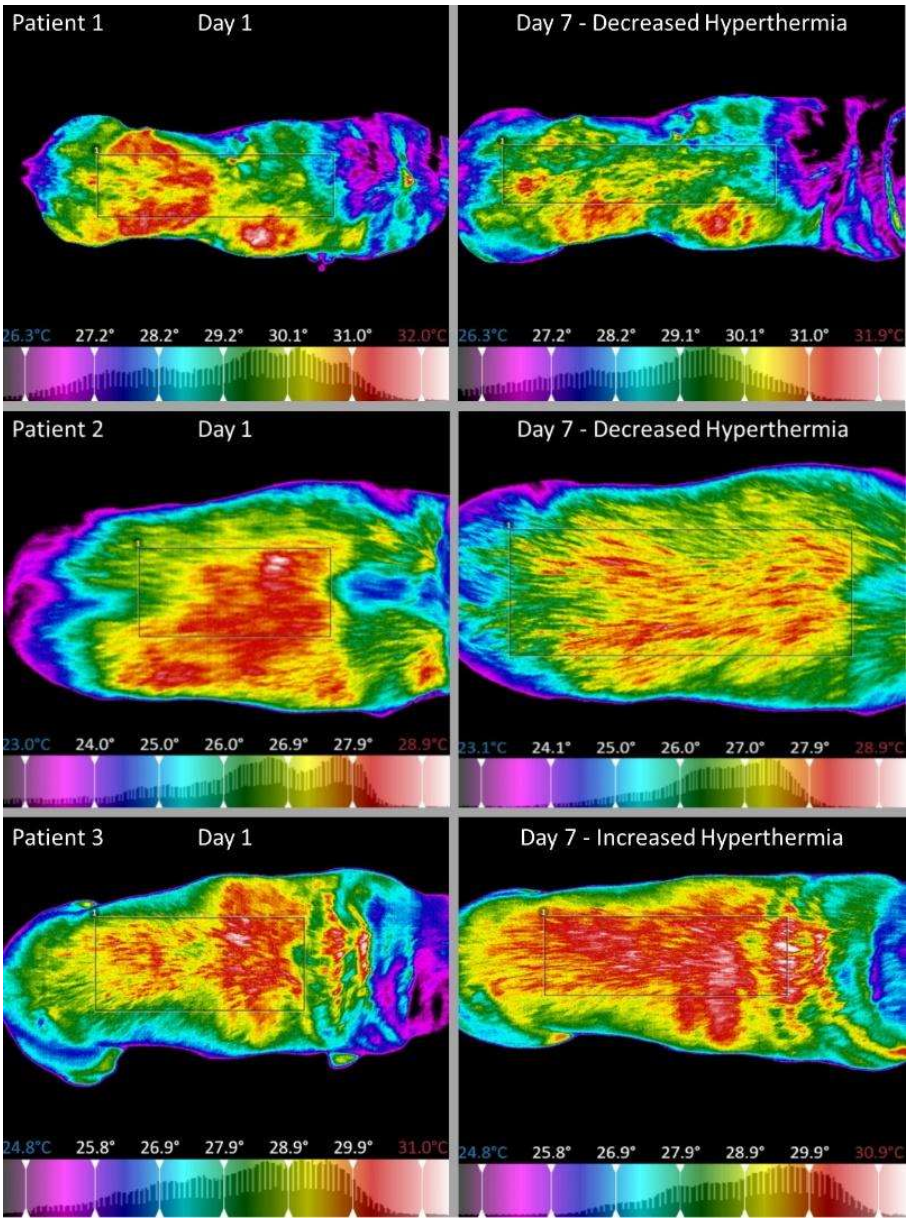

Figure 2. Paired thermal images (Day 1 vs Day 7) of three patients for qualitative interpretation. Patients 1 and 2 show qualitatively decreased hyperthermia in the region of interest. Patient 3 shows qualitatively increased hyperthermia in the region of interest.

Of the 12 patients, while the paired thermal images of three patients showed a qualitative visual increase in hyperthermia, no owner reported that the QOL was worse. Four paired thermal images were visually the same, and five owners reported that the QOL was the same. Five paired thermal images showed a visual decrease in hypothermia, and seven owners reported improved QOL. The results are represented by the bar graph in Figure 3.

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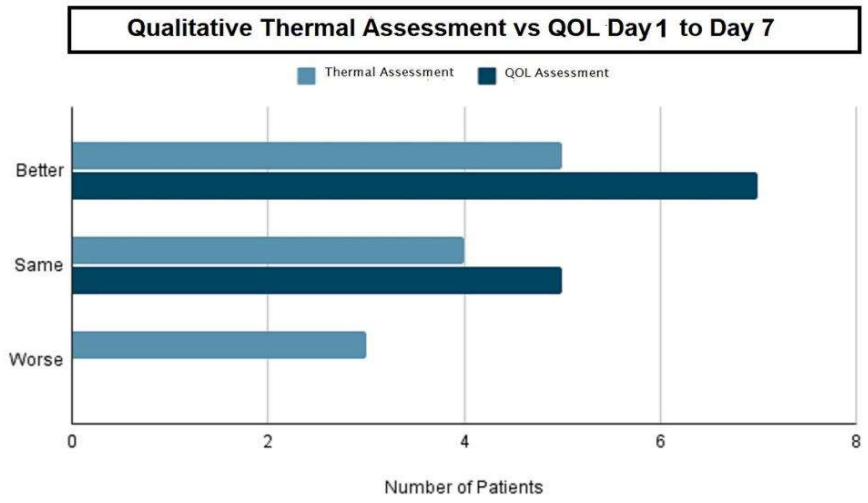

Figure 3. Qualitative Thermal Assessment versus QOL Day 1 to Day 7.

3.3. Ability of Pain Scores and ROI Temperatures to Detect Response to PBMT

From day 1 to day 7, ten of the twelve dogs' clinician pain assessment scores improved as measured by the CPS. The remaining two dogs' CPS scores stayed the same. The owner assessments performed on days 1 and 7 were more variable, with eight owners reporting improvement in PSS (six were considered clinically significant with improvements in scores ≥1) , and ten owners reporting improvement in PIS (eight were clinically significant with score improvement ≥2). Minimum, maximum and average pain scores on days 1 and 7 are depicted in Figure 4.

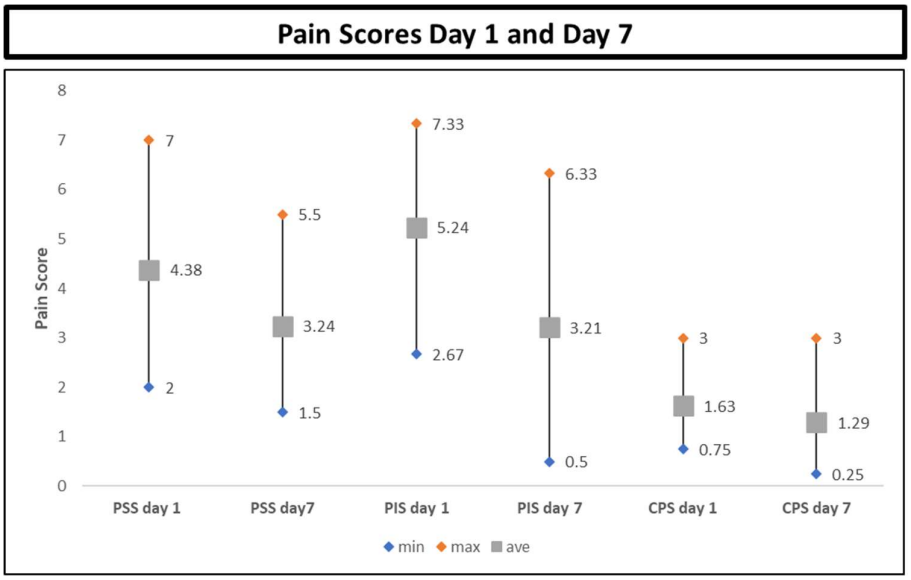

Figure 4. *Pain Scores Day 1 and Day 7*

Each thermal image was evaluated to determine ΔTmin, ΔTave, and ΔTmax in the ROI between days 1 and 7. Eight patients showed a decrease in ΔTmin, 6 showed a

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decrease in ΔTmax and 7 showed a decrease in ΔTave. Median and mean results are shown in Table 3.

Table 3. Comparison of response to treatment outcomes using the owner-completed CBPI, the clinician-completed CPS, and the change in ROI ΔT.

Change in CPS	Change in PSS	Change in PIS	Change in ROI ΔTmin	Change in ROI ΔTmax	Change in ROI ΔTave
Median/Range	Median/Range	Median/Range	Mean+sd	Mean+sd	Mean+sd
-0.25 (-1.25-0)	-1.0 (-3.5-0.75)	-2.0 (-4.67-0.67)	-0.392 ± 0.916	0.142 ± 0.797	-0.225 ± 0.926

The graph in Figure 5 demonstrates the minimum, maximum and average ΔTmax results on days 1 and 7.

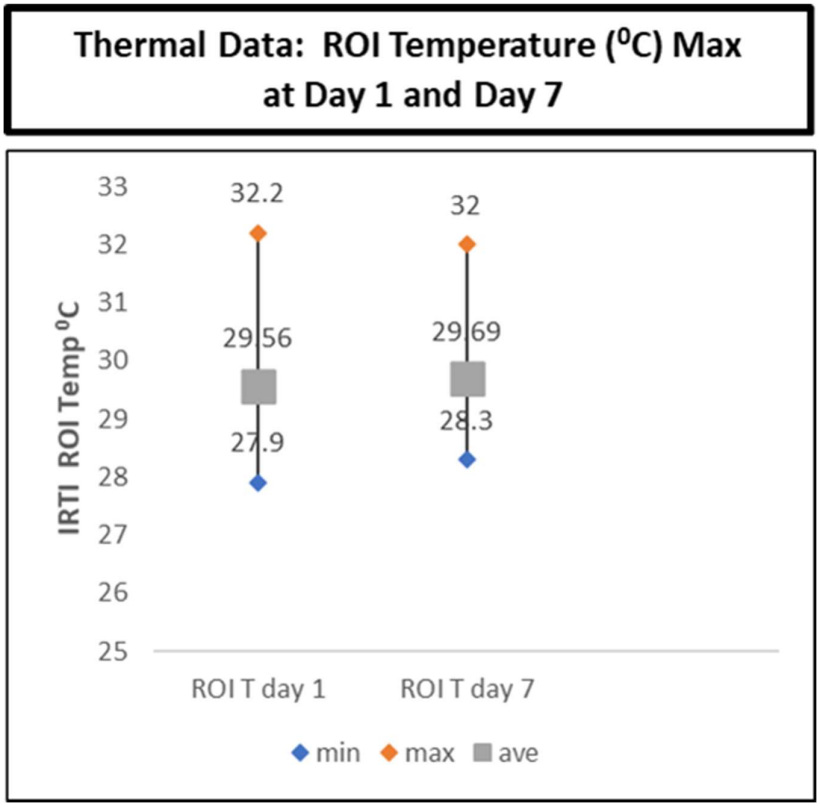

Figure 5. ROI temperature ΔTmax results on days 1 and 7

Our objective was to determine if changes in ROI temperatures correlated with changes in pain scores, therefore we used two statistical comparison tests to evaluate the results. Paired T-tests showed a significant correlation between all three ΔT measurements and owner assessment of PIS (P= .001, .006, .009) as well as between the PSS score and the CPS score versus ΔTmax (P= .018). Upon application of the Benjanimi-Hochberg correction factor for two independent variables, we were still able to conclude significance of these correlations, outlined in Table 4.

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Table 4: Paired t-Test to Compare pain scores to ROI ΔT

	mean	var	t stat	df	PC	t	p-value	B-H corrected p-value
PIS vs ΔTmax	-2.028	2.735	-5.07	11	0.447	2.2	.001	.009*
PIS vs ΔTave	-2.028	2.736	-3.444	11	0.119	2.2	.006	.027*
PIS vs ΔTmin	-2.028	2.735	-3.118	11	0.109	2.2	.009	.027*
PSS vs ΔTmax	-1.093	1.979	-2.791	11	0.138	2.2	.018	.041*
CPS vs ΔTmax	-0.333	0.106	-2.283	11	0.517	2.2	.043	.077*
PSS vs ΔTave	-0.225	0.935	1.577	11	-0.266	2.2	.143	.215
PSS vs ΔTmin	-1.093	1.979	-1.408	11	-0.031	2.2	.187	.24
CPS vs ΔTave	-0.333	0.106	-0.396	11	0.224	2.2	.699	.786
CPS vs ΔTmin	-0.333	0.106	0.242	11	0.52	2.2	.813	.813

The Mann-Whitney U-test showed a statistically significant correlation between all three ΔT measurements and owner assessment of PIS (P= .001, .008, .01). Both the PSS and the CPS showed statistically significant correlation only with ΔTmax (P=.03, .02). Table 5 summarizes the U-test results.

Table 5. Mann-Whitney U test Calculator to compare Pain Scores to ROI ΔT.

	U value	Critical Value of U at p<.05	z score	p-value
PSS vs ΔTmin	53.5	42	-1.03923	.15
PSS vs ΔTmax	37.5	42	-1.96299	.03
PSS vs ΔTave	47.5	42	-1.38564	.08
PIS vs ΔTmin	33	42	-2.2228	.01
PIS vs ΔTmax	21	42	-2.9156	.001
PIS vs ΔTave	29.5	42	-2.4249	.008
CPS vs ΔTmin	70	42	-0.0866	.46
CPS vs ΔTmax	36	42	-2.0496	.02
CPS vs ΔTave	72	42	0.0289	.49

The relationship between improvement in PSS, PIS and improvement in ROI ΔTmax is presented in Figure 6. The lower left quadrant represents dogs with combined pain score improvements and corresponding ΔTmax improvement. The upper right quadrant represents dogs with worsening pain scores and worsening ROI ΔTmax. The linear data

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suggests the correlation; when pain scores improved, ΔTmax reduced, and conversely, where pain scores worsened, ΔTmax increased.

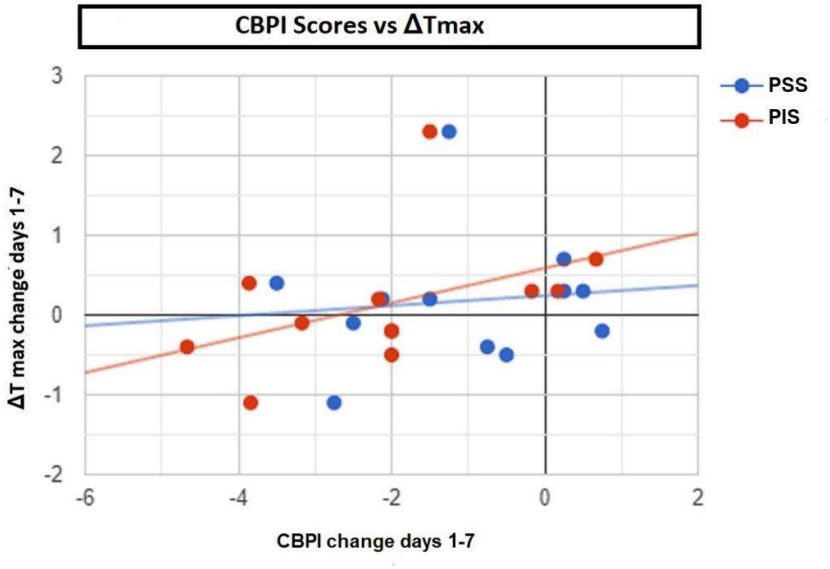

Figure 6: CBPI Scores versus ΔTmax.

4. Discussion

Infrared thermography has long been used in various industries to measure minute changes in surface temperature otherwise invisible to the naked eye. Veterinary medicine offers a unique opportunity to explore thermography as a screening tool to aid the clinician in evaluating non-verbal patients. The use of thermography in veterinary medicine was been reported for the evaluation of lameness in horses [62-64], companion animal clinical applications [14, 25-27, 29-37], and structural screening in working dogs [38,42]. When combined with palpation, thermal imaging has been shown to be a useful tool in differentiating painful cats from non-painful cats [22]. The objective of this study was to evaluate correlation between patient response to PBMT with pre- and post-treatment thermal images and patient pain assessment metric tools.

Research studies that evaluate pharmacologic or non-pharmacologic pain treatment modalities often use pain scores along with an objective measurement to evaluate success or failure of treatment. For example, force plate gait analysis, combined with owner pain assessment, has been used to evaluate the efficacy of carprofen in dogs [65]. While pain scoring of non-verbal patients is difficult, its use is critical in providing adequate and successful pain management for the patient [66,67]. Subjective pain scores, such as numerical rating or visual analogue scores, have been shown to have limited correlation with objective force plate data in dogs evaluated after knee surgery [68]. It is widely accepted that there is a significant caregiver placebo effect which can reach close to 40% in pet owners when compared to an objective outcome measurement and be even higher when veterinarians or veterinary staff perform pain assessment scoring [69]. Therefore,

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especially for chronic pain conditions, it is generally accepted practice to utilize a combination of pet owner scoring, objective measurement data, and clinician pain assessment to determine success or failure of a treatment protocol.

In this study, our objective measurement was temperature normalization over the assigned treatment area region of interest. Our results suggested that when we use an owner-reported, validated, canine chronic pain scoring tool, (CBPI), there was a statistically significant correlation between changes of temperature in the region of interest and the pain interference scores, while the pain severity scores were only significant when evaluating ΔTmax.

We expected that ΔTave measurements would be the most useful, however, in this sample population, ΔTmax correlated best with CBPI scores. When collecting temperature data, all data points in the ROI are used to calculate the minimum, maximum, and average temperatures. The number of temperature data points at the highest temperatures, ΔTmax, either increases or decreases as the circulation increases or decreases within that ROI. In this study, ΔTmax decreased in patients that responded to PBMT with a reduction in inflammation and a corresponding decrease in circulation.

In a previous publication evaluating the use of thermal images in monitoring response to therapy, maximum temperatures in ROIs showed greater correlation significance than average temperatures when compared to other metrics [42]. The authors of that study theorized that the maximum temperature may better reflect the changes in circulation in the underlying tissue than average temperature, and that using maximum temperature data in a ROI may eliminate variables in ROI average temperature calculation due to non-affected tissue inclusion in the ROI.

Not surprisingly, the use of the most basic assessment tool, the owner QOL score, was the least accurate outcome measurement. Inherent bias in reporting is a continual problem in evaluation of treatment success [70] and our study reinforced the issue. It is interesting to consider whether sharing the Day 7 images with the pet owners would have changed their opinion of treatment outcome.

Pain is multifactorial, complex, and in all species of animals, can be influenced by biological, psychological, and social factors [71, 72]. The successful use of any modality to treat pain can be difficult to assess as pain scoring and observational evaluation alone are often quite subjective. In this study we evaluated objective thermal imaging data as a therapy outcome measure, comparing it to more subjective pain and quality of life scoring. Comparing an objective measure of therapy outcome to subjective measures of outcome can only validate the objective measure as being as accurate as the subjective measure.

Thermal imaging is quick, non-invasive, and inexpensive. It requires no additional space in practice facilities, and since thermal imaging devices are mobile, the images can be captured in examination or treatment areas during patient assessment and examination. Data in this study suggest thermal imaging data correlates well with subjective pain and quality of life scoring. Because of the simplicity of thermal imaging, and the correlation with more subjective outcome measures, we suggest thermal imaging may be a valuable additional tool in monitoring therapy outcome.

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We acknowledge the limitations of this study, namely the small sample size, and the lack of a control subset of patients. Because the thermal imaging evaluation was not used to compare response between patients, we do not feel that the differences in patient size, coat color and length, and variety in disease pathologies posed significant variability to the data, as each patient behaved independently in their response to the prescribed therapy and that response was recorded via the collected thermal imaging surface temperature data.

5. Conclusions

Infrared thermal imaging proved a useful objective tool that correlated with subjective pain metrology tools and quality of life scores when used to monitor response to photobiomodulation treatment in canine patients with chronic generalized thoracolumbar back pain. Further studies comparing thermal imaging with other objective outcome measures are needed to validate whether thermography is a more accurate measure of therapy outcome than subjective pain and quality of life scoring.

Abbreviations

CPS: Colorado State University Canine Chronic Pain Scale
PBMT: Photobiomodulation Therapy
CBPI: Canine Brief Pain Inventory
PSS: Canine Brief Pain Inventory Pain Severity Score
PIS: Canine Brief Pain Inventory Pain Interference Score
QOL: Quality of Life

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available as they are part of the veterinary medical record.

Author Contributions: Conceptualization and methodology, E.F., J.J., J.G., and R.R.; validation, J.J., J.G., and R.R.; formal analysis, J.J., J.G., and R.R.; investigation, E.F. and R.R; original draft preparation, review, and editing, J.J., J.G., and R.R. All authors have read and agreed to the published version of the manuscript.

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Informed Consent and Ethical Review: In the United States where this study was conducted, there are no regulations or guide- lines that specifically apply to private practices that wish to conduct research [73]. This study was performed in a private clinical practice, using client-owned animals, where a valid veterinary-client-patient-relationship existed. The therapy treatments and data collection described (PBMT, medical thermal imaging, and the use of pain score questionnaires) are treatments and interventions that are within the normal scope of routine veterinary practice and considered standard of care. Informed client consent was obtained from each owner. A copy of the

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informed consent is in the supplemental material. The owners were fully informed that the research was to be published and there were no inherent risks to any data collection or treatment.

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