



VNIVERSITAT
ID VALÈNCIA  Facultat de Medicina i Odontologia

Department of Physiology
PhD Program in Physiology

Veterinary thermography: detection and prognosis of pathophysiology in small animals

Doctoral Thesis

Presented by Irene
Díez Artigao

Directed by Dr. Sergio
Díez Domingo

July 2025





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Termografía en veterinaria: detección y pronóstico de patofisiología en pequeños animales

Doctoral thesis presented by Irene Díez Artigao.

Directed by Dr. Sergio Díez Domingo

Valencia, July 2025



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CERTIFICA:

Que la presente memoria, titulada **“Veterinary Thermography: Detection and Prognosis of Pathophysiology in Small Animals” / “Termografía en Veterinaria: detección y pronóstico de patofisiología en pequeños animales”**, corresponde al trabajo realizado bajo su dirección por Dña. Irene Díez Artigao, para su presentación como Tesis Doctoral en el Programa de Doctorado en Fisiología de la Universidad de València.

Y para que conste firman el presente certificado en Valencia, en julio de 2025.

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Abbreviations

ANOVA	Analysis of variance	MRI	Magnetic resonance imaging
AUC	Area Under the Curve	NSAID	Non-steroidal anti-inflammatory drug
CRT	Capillary refill time	OA	Osteoarthritis
CT	Computed tomography	ROC	Receiver Operating Characteristic
FATE	Feline aortic thromboembolism	ROI	Region of interest
HCM	Hypertrophic cardiomyopathy	SD	Standard deviation
IRT	Infrared thermography	Dif_Temp	Temperature difference
IVDD	Intervertebral Disc Disease	TM_Dif	Mean temperature difference

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Publications



Presentation: *Detection of pathology of horse extremities using thermography.*

XIV Congress of the European Association of Thermology. July 4-7, 2018. London, United Kingdom.



Presentation: *Use of thermography in fracture management in small animal clinics: a clinical case report.*

XIV Congress of the European Association of Thermology. July 4-7, 2018. London, United Kingdom.



Poster: *Thermography: an emerging tool for clinical use.*

XIX Congress of Veterinary Specialties, GTA. April 17-18, 2020.



Poster: *Infrared thermography for rapid detection of feline aortic thromboembolism in emergencies.*

XX Congress of Veterinary Specialties, GTA. May 11-13, 2021.



Poster: *Thermography as an indicator of tissue damage after laparoscopic ovariectomy vs. laparotomy.*

AVEPA SEVC. October 20-22, 2022.



Presentation and practical workshop: *thermography applied to animal production.*

XIII Veterinary Medicine Conference of AEICBAS, Abel Salazar Institute of Biomedical Sciences, University of Porto. March 23, 2024. Porto, Portugal.



Poster: *Thermography for evaluating the effects of rehabilitation in a patient with deforming spondylosis.*

XXIII Congress of Veterinary Specialties, GTA. April 12-13, 2024. Valencia, Spain.



Presentation: *Enhancing veterinary sports medicine: thermographic patterns in athlete dogs.*

5th Scientific Meeting of ECVSMR. October 16-18, 2024. Córdoba, Spain.



Poster: *Assessment by thermography of the variation in surface temperature in the carpus after applying laser therapy vs infrared lamp.*

XXIV Congress of Veterinary Specialties, GTA. April 25-26, 2025. Valencia, Spain.

1. Abstracts

1.1. Abstract (English)

Since ancient times, body heat has been a key indicator of health status. Throughout technological evolution, the way of measuring temperature has progressed from touch to more advanced methods such as the thermometer and the thermal camera, which allow for an objective, non-invasive, and contactless assessment. Infrared thermography (IRT) is based on physical principles that explain the emission of thermal energy by living organisms and has been widely used in human medicine and in production animals. However, its application in dogs and cats remains limited.

The application of IRT in small animal veterinary medicine is an emerging field with great diagnostic, prognostic, and clinical monitoring potential, especially in dogs and cats. In this context, the main objectives of this thesis were: 1) To establish a clinical protocol for image acquisition, 2) To define the most relevant Regions of Interest (ROI) in a healthy subject in a reproducible manner, 3) To determine the most appropriate variables for studying these ROIs, 4) To establish normal thermal patterns in healthy dogs, 5) To establish normal thermal patterns in canine athletes, and 6) To study thermal changes in patients with various pathologies and compare them with the healthy subject's pattern.

One of the conceptual cornerstones of this technique is thermal symmetry: a healthy body presents a symmetrical temperature distribution between contralateral areas (for example, both knees). The loss of this symmetry is indicative of pathological processes such as inflammation, infection, vascular disturbances, or neurological disorders. In this regard, thermography becomes an especially valuable tool for detecting illnesses before they become clinically apparent, allowing for early intervention. Moreover, it is a non-invasive

technique that can be performed without manipulating the animal, and it is harmless as it does not emit ionizing radiation, making it ideal for repeated use, especially in situations of stress or in pediatric or geriatric patients.

This work includes, on the one hand, statistical analyses to determine the significance of thermal differences between affected and healthy areas in healthy patients, athletes, and patients with various pathologies, as well as to evaluate the reliability and reproducibility of the results. On the other hand, it includes the study of several clinical cases in canine and feline patients and the application of IRT in their assessment. High-precision thermal cameras were used under controlled conditions, following a standardized protocol for image acquisition and ROI selection.

The results validate the usefulness of IRT as a complementary method in veterinary diagnosis, establishing that a contralateral thermal difference greater than 0.5°C in the general dog population can be considered pathological, while in athletes this range increases to 0.7°C due to their special status as sporting animals and the physiological adaptations this entails.

Several clinical cases demonstrate the usefulness of the technique. In the case of a bone fracture, a localized thermal increase was detected before the lesion became evident on radiographs. In cats suspected of presenting a feline aortic thromboembolism (FATE), IRT enabled the early detection of reduced blood flow in the hind limbs. In a dog with deforming spondylosis, thermal analysis was used to monitor the progression of rehabilitation, showing gradual improvements in thermal symmetry and distribution. The thermal effects of laparoscopic ovariectomy versus laparotomy were also

compared, demonstrating less disruption in thermal distribution in the first group, suggesting a lower tissue impact.

In conclusion, it is emphasized that infrared thermography is a safe, objective, cost-effective, rapid, and repeatable technique, ideal for use in veterinary clinical practice as a diagnostic and monitoring tool. It does not replace other imaging methods such as radiography or ultrasound but can serve as an excellent complementary technique, especially for early diagnosis, post-operative monitoring, evaluation of physiotherapeutic treatments, and rehabilitation monitoring. Its limitations are also identified, including the need for standardized acquisition protocols, the influence of environmental conditions, camera specifications, and operator experience.

Future lines of research are proposed, including the integration of artificial intelligence for automated thermal pattern analysis to further improve diagnostic precision.

This work not only provides a solid scientific foundation for implementing thermography in small animal veterinary medicine, but also represents an important step towards the integration of advanced, non-invasive technologies in routine clinical practice.

1.2. Abstract (Spanish)

Desde la antigüedad, el calor corporal ha sido un indicador clave del estado de salud. A lo largo de la evolución tecnológica, la forma de medir la temperatura ha avanzado desde el tacto hasta sistemas como el termómetro y la cámara térmica, que permiten una evaluación objetiva, no invasiva y sin contacto. La termografía infrarroja (TI) se fundamenta en principios físicos que explican la emisión de energía térmica por los organismos vivos, y se ha utilizado ampliamente en medicina humana y en animales de producción. Sin embargo, su aplicación en perros y gatos sigue siendo escasa.

La aplicación de la TI en medicina veterinaria de pequeños animales representa un campo emergente con un gran potencial diagnóstico, pronóstico y de seguimiento clínico, especialmente en perros y gatos. En este contexto, los objetivos principales de esta tesis fueron los siguientes: 1) Establecer un protocolo clínico de adquisición de imágenes, 2) definir las regiones de interés (ROI) más relevantes en un sujeto sano de manera reproducible, 3) determinar las variables de estudio de las ROI más apropiadas, 4) establecer patrones térmicos normales en perros sanos, 5) establecer patrones térmicos normales en perros atletas; 6) Estudiar alteraciones térmicas en pacientes con diversas patologías y compararlas con el patrón del sujeto sano.

Uno de los pilares conceptuales de esta técnica es la **simetría térmica**: un cuerpo sano presenta una distribución de temperatura simétrica entre partes contralaterales (Por ejemplo, ambas rodillas). La pérdida de esa simetría es indicativa de procesos patológicos como inflamaciones, infecciones, alteraciones vasculares o trastornos neurológicos. En este sentido, la termografía se convierte en una herramienta especialmente útil para detectar

enfermedades antes de que se manifiesten clínicamente, permitiendo un abordaje precoz. Además, es una técnica no invasiva, permitiendo su uso sin manipulación del animal, e inocua al no emitir radiación ionizante, permitiendo su uso repetido sin efectos adversos, especialmente interesante en situaciones de estrés o en pacientes pediátricos o geriátricos.

Este trabajo incluye, por un lado, un análisis estadístico para determinar la significancia de las diferencias térmicas entre zonas afectadas y sanas en pacientes sanos, atletas y con diversas patologías, así como para evaluar la fiabilidad y reproducibilidad de los resultados. Por otro lado se incluye el estudio de varios casos clínicos con pacientes caninos y felinos y la aplicación de la TI para su desarrollo. Se utilizaron cámaras térmicas de alta precisión bajo condiciones controladas, siguiendo un protocolo estandarizado para la toma de imágenes y la selección de ROI.

Los resultados validan la utilidad de la TI como método complementario en el diagnóstico veterinario, estableciendo que una diferencia térmica contralateral mayor a 0.5 °C en perros de población general puede considerarse patológica, mientras que en atletas este rango aumenta a 0.7°C dada su condición especial como deportistas y las adaptaciones fisiológicas que ello conlleva.

En diversos casos clínicos se demuestra la utilidad de la técnica. En caso de **fractura ósea**, se detectó un aumento térmico localizado antes de que la lesión fuese evidente en radiografías. En felinos con sospecha de presentar un **tromboembolismo aórtico felino (FATE)**, la TI permitió la identificación precoz de una reducción de flujo sanguíneo en miembros posteriores. En un perro con **espondilosis deformante**, se monitoriza la evolución de la rehabilitación mediante análisis térmico, observando mejoras progresivas en

la simetría y distribución térmica. También se compararon los efectos térmicos de la **ovariectomía laparoscópica versus laparotomía**, demostrando una menor alteración en la distribución térmica en el primer grupo, lo que sugiere un menor impacto tisular.

En conclusión, se resalta que la termografía infrarroja es una técnica **segura, objetiva, económica, rápida y repetible**, ideal para el uso en clínica veterinaria como herramienta diagnóstica y de seguimiento. No reemplaza otros métodos de imagen como la radiografía o la ecografía, pero puede ser una excelente técnica complementaria, especialmente para el diagnóstico precoz, el monitoreo postoperatorio, la evaluación de tratamientos fisioterapéuticos y el control de rehabilitación. También se identifican sus limitaciones, como la necesidad de estandarización en protocolos de adquisición, la influencia del entorno ambiental, el tipo de cámara y la experiencia del operador.

Se proponen futuras líneas de investigación, así como la incorporación de inteligencia artificial para automatizar el análisis de patrones térmicos y mejorar la precisión diagnóstica.

Este trabajo no sólo proporciona una base científica sólida para la implementación de la termografía en la medicina veterinaria de pequeños animales, sino que también representa un importante paso hacia la integración de tecnologías no invasivas y avanzadas en el diagnóstico clínico cotidiano.

1.3. Abstract (Valencian)

Des de l'antiguitat, la calor corporal ha sigut un indicador clau de l'estat de salut. Al llarg de l'evolució tecnològica, la manera de mesurar la temperatura ha avançat des del tacte fins a sistemes com el termòmetre i la càmera tèrmica, que permeten una avaluació objectiva, no invasiva i sense contacte. La termografia infraroja (TI) es fonamenta en principis físics que expliquen l'emissió d'energia tèrmica pels organismes vius, i s'ha utilitzat àmpliament en la medicina humana i en animals de producció. No obstant això, la seua aplicació en gossos i gats segueix sent escassa.

L'aplicació de la TI en la medicina veterinària de xicotets animals representa un camp emergent amb un gran potencial diagnòstic, pronòstic i de seguiment clínic, especialment en gossos i gats. En este context, els objectius principals d'aquesta tesi son els següents: 1) Establir un protocol clínic d'adquisició d'imatges, 2) definir les regions d'interés (ROI) més rellevants en un subjecte sa de manera reproduïble, 3) determinar les variables d'estudi de les ROI més apropiades, 4) establir patrons tèrmics normals en gossos sans, 5) establir patrons tèrmics normals en gossos atletes, 6) estudiar alteracions tèrmiques en pacients amb diverses patologies i comparar-les amb el patró del subjecte sa.

Un dels pilars conceptuals d'esta tècnica és la simetria tèrmica: un cos sa presenta una distribució de temperatura simètrica entre parts contralaterals (per exemple, els dos genolls). La pèrdua d'aquesta simetria és indicadora de processos patològics com ara inflamacions, infeccions, alteracions vasculars o trastorns neurològics. En este sentit, la termografia es convertix en una ferramenta especialment útil per a detectar malalties abans que es manifesten clínicament, facilitant un abordatge precoç. A més, és una tècnica no invasiva,

possibilitant el seu ús sense manipulació de l'animal, i innòcua al no emetre radiació ionitzant, fet que permet repetir-la sense efectes adversos, especialment interessant en situacions d'estrés o en pacients pediàtrics o geriàtrics.

Aquest treball inclou, per una banda, una anàlisi estadística per a determinar la significació de les diferències tèrmiques entre zones afectades i sanes en pacients sans, atletes i amb diverses patologies, així com per a avaluar la fiabilitat i reproductibilitat dels resultats. Per altra banda, s'inclou l'estudi de diversos casos clínics amb pacients canins i felins i l'aplicació de la TI per al seu desenvolupament. Es van utilitzar càmeres tèrmiques d'alta precisió en condicions controlades, seguint un protocol estandarditzat per a la presa d'imatges i la selecció de ROI.

Els resultats validen la utilitat de la TI com a mètode complementari en el diagnòstic veterinari, establint que una diferència tèrmica contralateral superior a 0,5 °C en gossos de població general pot considerar-se patològica, mentre que en atletes aquest rang augmenta a 0,7 °C donada la seua condició especial com a esportistes i les adaptacions fisiològiques que això comporta.

En diversos casos clínics es demostra la utilitat de la tècnica. En cas de fractura òssia, es va detectar un augment tèrmic localitzat abans que la lesió fora evident en radiografies. En felins amb sospita de presentar un tromboembolisme aòrtic felí (FATE), la TI va permetre la identificació precoç d'una reducció de flux sanguini en els membres posteriors. En un gos amb espondilosi deformant, es va monitoritzar l'evolució de la rehabilitació mitjançant anàlisi tèrmica, observant-se millores progressives en la simetria i la distribució tèrmica. També es van comparar els efectes tèrmics de

l'ovariectomia laparoscòpica versus laparotomia, demostrant-se una menor alteració en la distribució tèrmica en el primer grup, la qual cosa suggerix un menor impacte tissular.

En conclusió, es destaca que la termografia infraroja és una tècnica segura, objectiva, econòmica, ràpida i reproducible, ideal per a l'ús en clínica veterinària com a ferramenta diagnòstica i de seguiment. No reemplaça altres mètodes d'imatge com la radiografia o l'ecografia, però pot ser una excel·lent tècnica complementària, especialment per al diagnòstic precoç, la monitorització del postoperatori, l'avaluació de tractaments fisioterapèutics i el control de la rehabilitació. També s'identifiquen les seues limitacions, com la necessitat d'estandardització de protocols d'adquisició, la influència de l'entorn ambiental, el tipus de càmera i l'experiència de l'operador.

Es proposen futures línies d'investigació, així com la incorporació de la intel·ligència artificial per a automatitzar l'anàlisi de patrons tèrmics i millorar la precisió diagnòstica.

Aquest treball no només proporciona una base científica sòlida per a la implementació de la termografia en la medicina veterinària de xicotets animals, sinó que també representa un pas important cap a la integració de tecnologies no invasives i avançades en el diagnòstic clínic quotidià.

1.4. Extended summary (Spanish)

Introducción:

La termografía infrarroja (TI) es una técnica no invasiva y sin contacto que permite visualizar la distribución de temperatura en la superficie de un objeto o ser vivo mediante la detección de la radiación infrarroja que emite. Utilizando cámaras térmicas, esta tecnología genera imágenes llamadas termogramas, donde los colores representan diferentes rangos de temperatura. Su aplicación se ha extendido a múltiples campos como la industria, la medicina y la seguridad, permitiendo detectar anomalías térmicas asociadas a fallos mecánicos, pérdidas energéticas o procesos patológicos.

En medicina humana o veterinaria, la TI permite identificar patrones térmicos anormales en el cuerpo humano o animal, facilitando el diagnóstico precoz de enfermedades sin necesidad de contacto físico ni radiación ionizante.

El interés por la temperatura corporal como indicador clínico se remonta a la antigüedad. La historia moderna de la TI comienza con el descubrimiento de la radiación infrarroja por William Herschel en 1800, y su desarrollo tecnológico se aceleró durante el siglo XX, especialmente con fines militares. A partir de la década de 1950, se introdujo en el ámbito médico con dispositivos como el bolómetro de Schwamm y Reeh, y más tarde con el radiómetro sin contacto de Benzinger.

Actualmente, la termografía infrarroja es una herramienta consolidada en diversas disciplinas, valorada por su capacidad para detectar alteraciones térmicas de forma rápida, segura y precisa.

Se basa en la radiación térmica que emiten todos los cuerpos con temperatura superior al cero absoluto. Esta energía, captada por cámaras térmicas, permite visualizar la temperatura superficial sin contacto. La radiación infrarroja forma parte del espectro electromagnético y su análisis se rige por leyes físicas como las de Planck, Stefan-Boltzmann y Wien, que relacionan temperatura y emisión de energía. La emisividad, o capacidad de un cuerpo para emitir radiación, es clave para obtener mediciones precisas.

En biología, la termorregulación es el mecanismo por el que el cuerpo mantiene una temperatura estable, y cualquier alteración física puede reflejarse térmicamente. Por ello, la termografía es útil en medicina y veterinaria ya que es capaz de detectar inflamaciones, problemas circulatorios o metabólicos, y evaluar tratamientos de forma objetiva y no invasiva.

La piel, formada por epidermis, dermis e hipodermis, es un órgano clave en la termorregulación. En animales, su grosor y proporción varían según la edad y la zona corporal. La dermis, rica en vasos, y el pelaje influyen directamente en la regulación térmica. El tipo, densidad y color del pelaje afectan la capacidad de disipar calor, siendo un reto para la termografía, especialmente en animales con pelo largo o rizado. Aunque no es necesario rasurar para obtener imágenes útiles, el pelaje puede dificultar la precisión del análisis térmico e incluso impedirlo.

En condiciones normales, se ha visto que existe simetría térmica entre partes contralaterales del cuerpo. En humanos, los estudios indican que diferencias mayores a 0,5 °C pueden indicar patología; en perros y caballos se observan patrones similares.

Hay diversos estudios que caracterizan esta técnica como una herramienta útil en diversas ramas de la medicina, como para valoración de inflamaciones,

infecciones, neuropatías, lesiones musculares y articulares, así como para el seguimiento postquirúrgico.

En medicina deportiva, se emplea para evaluar daño muscular y efectos de terapias rehabilitadoras. En el ámbito articular, ha demostrado eficacia en el seguimiento de la osteoartritis y patologías neurológicas periféricas. En oncología, permite detectar tumores y monitorizar la perfusión durante cirugías. También se ha aplicado en la detección de fracturas, especialmente en pediatría, y en reproducción para evaluar fertilidad y detectar gestación.

Además, es una herramienta valiosa para el estudio del bienestar animal, al permitir la evaluación del estrés sin contacto físico. Su uso se ha extendido a múltiples especies, aunque aún se requieren estudios adicionales para estandarizar su aplicación. Los resultados actuales respaldan su potencial como técnica diagnóstica complementaria, segura y eficaz.

Hipótesis y objetivos:

La **hipótesis** de este estudio plantea que la TI podría ser una herramienta útil en la práctica clínica diaria de pequeños animales, tanto como método diagnóstico en patologías con alteraciones vasculares, como predictor precoz antes de la aparición de signos clínicos, como técnica complementaria a otras pruebas de imagen, y como herramienta de seguimiento en la evolución de enfermedades o intervenciones quirúrgicas.

El **objetivo** principal de esta tesis es validar la termografía infrarroja (TI) como una herramienta útil en la práctica clínica diaria de la medicina veterinaria de pequeños animales. Para ello, se plantean varios objetivos específicos:

- Establecer un protocolo de imagen que no requiera una posición estándar del paciente, considerando que los animales no siempre mantienen una postura fija y suelen moverse durante el estudio.
- Definir las regiones de interés (ROI) para analizar el mapa térmico de forma reproducible.
- Determinar las variables de estudio más adecuadas dentro de las ROI para su correcta caracterización.
- Establecer el patrón térmico en animales sanos, evaluando la simetría térmica entre partes contralaterales del cuerpo.
- Establecer el patrón térmico del perro atleta como caso particular del animal sano, y definir las diferencias esperadas entre regiones contralaterales.
- Estudiar las alteraciones térmicas en pacientes con diversas patologías y compararlas con el patrón térmico de los sujetos sanos.

Metodología:

Este estudio es de **tipo** prospectivo y se ha llevado a cabo en animales procedentes de distintos centros de la zona de Valencia. Todos los pacientes recibieron atención veterinaria completa, incluyendo exploración clínica y pruebas diagnósticas complementarias según el caso, y las patologías detectadas fueron tratadas. Las imágenes termográficas se contrastaron con otras técnicas de imagen como radiografía, ecografía y tomografía computarizada.

En cuanto a los criterios de **inclusión**, se consideraron todos los pacientes, sanos o enfermos, que acudieron a consulta y completaran tanto el protocolo

diagnóstico como el de seguimiento. Esta decisión se toma debido a las dificultades para obtener casos que cumplieran todos los requisitos, ya que en medicina privada no siempre es posible realizar todos los seguimientos necesarios por limitaciones económicas o falta de colaboración de los tutores. Por ello, aunque la muestra total es amplia, se encuentra dividida en subgrupos con diferentes patologías y no en una sola enfermedad con gran número de casos.

Los criterios de **exclusión** incluye a aquellos pacientes que no completaron el protocolo diagnóstico o no acudieron a los controles programados, así como aquellos que estaban sucios o mojados y no fue posible limpiarlos y/o secarlos adecuadamente antes del estudio, ya fuera por falta de tiempo o por comportamiento del animal.

La **muestra** del estudio incluye 148 perros de entre 2 meses y 11 años de edad, con pesos entre 2,5 y 35 kg, pertenecientes a diversas razas y evaluados en clínicas veterinarias y centros deportivos caninos de Valencia. Se han analizado distintas regiones de interés (ROI) según el grupo de estudio:

- 44 perros sanos.
- 46 perros atletas (considerados sanos pero con características fisiológicas particulares por su alto nivel de actividad física).
- 58 perros con patologías diversas (24 con dolor agudo postraumático, 22 con dolor crónico como artrosis, 5 con enfermedad de disco intervertebral y 11 con neoplasias).

En los grupos de perros sanos y atletas se midieron ROI comunes como falanges, carpo, antebrazo, codo, hombro (sólo en sanos), tarso,

gastrocnemio, cuádriceps y bíceps femoral. Se han comparado temperaturas entre zonas homólogas dentro de cada animal, o con zonas de referencia cuando no era posible. Además, se han seleccionado casos clínicos individuales de especial interés por sus características particulares, con el fin de realizar un análisis más detallado.

Las imágenes se adquieren con dos cámaras diferentes de distintos fabricantes: Fluke Ti125 y FLIR I7. Se procesaron utilizando los softwares Smart View 3.2 (para la cámara Fluke) y Quick Report (para la FLIR i7), y en caso necesario, se empleó el programa ImageJ para análisis adicionales.

Los pacientes clasificados como sanos o con patologías específicas fueron incorporados al estudio tras acudir al centro veterinario sin una condición previa relacionada con la investigación. A sus tutores se les ofreció participar voluntariamente, y aquellos que aceptaron iniciaron el proceso. Sólo se incluyeron en el estudio final los animales que cumplían con los criterios establecidos. Las citas se programan con antelación y se siguió un protocolo diagnóstico adaptado a cada caso.

Para estudiar a los perros atletas, la doctoranda contactó con varios centros de entrenamiento de Agility, seleccionando los más representativos y coordinando las sesiones con los entrenadores. Los tutores fueron informados detalladamente sobre los objetivos, metodología y beneficios del estudio, incluyendo la duración de las sesiones y el uso de los datos para mejorar la salud y el rendimiento de sus perros. Se garantizó la confidencialidad de la información y se ofreció acceso a los resultados. La colaboración entre los centros deportivos y el equipo de investigación fue fundamental para lograr una recolección de datos amplia, representativa y eficaz.

La recolección de datos de los pacientes se realizó siguiendo un orden estandarizado para optimizar el tiempo de consulta y garantizar la eficiencia diagnóstica. La visita comenzaba con la identificación del paciente y la firma del consentimiento informado, seguida de una anamnesis completa que incluía historial médico y estilo de vida. Sin manipular al animal, se realiza primero el estudio termográfico, capturando imágenes térmicas y convencionales. Posteriormente, se llevaba a cabo el examen físico tradicional, incluyendo constantes fisiológicas, exploración específica, como traumatológica y neurológica, y pruebas complementarias cuando eran necesarias, para establecer un diagnóstico definitivo o presuntivo y prescribir el tratamiento correspondiente.

Se establece un **protocolo** estandarizado para la toma de imágenes térmicas. En casos excepcionales, se realizaron en diferentes instalaciones, procurando mantener condiciones similares (temperatura y manejo).

- La cámara térmica se enciende 10 minutos antes del estudio.
- Los pacientes se aclimatan durante 15 minutos en una sala a 20–25 °C, sin correas, contacto humano ni dispositivos electrónicos.
- Deben presentarse limpios y cepillados
- El estudio se realiza antes de cualquier manipulación física.
- Si se requiere rasurado, se hace con margen suficiente para la observación de la ROI y se deja aclimatar la piel 15 minutos.
- No deben comer en exceso ni hacer ejercicio al menos dos horas antes del estudio.

- La cámara se coloca perpendicular a la región de interés (ROI), manteniendo la misma distancia dentro de cada paciente (1 m para zonas grandes, 0,5 m para pequeñas).
- Tras el estudio termográfico, se realiza el examen físico convencional y se mide la temperatura rectal basal.

El **análisis** de las imágenes termográficas se basa en la comparación de regiones contralaterales del cuerpo para detectar asimetrías térmicas asociadas a diversas patologías. Aunque el protocolo general podía variar levemente según el paciente o la zona de estudio, se mantuvieron constantes las condiciones de captura (distancia y posición) dentro de cada paciente. Las regiones de interés (ROI) fueron definidas y analizadas por la autora para garantizar la coherencia, seleccionando siempre las mismas ROI en cada paciente para asegurar la continuidad de las mediciones. En casos específicos, las ROI se ajustaron según criterios clínicos, como en la evaluación de áreas hipotérmicas en espacios intervertebrales para localizar neuropatías o en pacientes oncológicos.

De cada ROI se obtuvieron varias mediciones: temperatura media, máxima y mínima, todas en grados Celsius (°C).

Las imágenes se analizaron en sus formatos originales (.IS2 para FLUKE y RJPJ para FLIR), que contienen datos térmicos precisos por píxel, requiriendo software especializado para su interpretación. En cuanto a la paleta de colores, se utilizaron representaciones visuales que asignan colores a rangos de temperatura para facilitar la interpretación.

Se elige una paleta de alto contraste, ya que permite identificar con mayor claridad asimetrías térmicas sutiles, especialmente útiles en el contexto

médico. No obstante, es importante recalcar que los colores son relativos y no representan datos absolutos, por lo que el análisis cuantitativo debe basarse en los valores numéricos proporcionados por la cámara.

Tras la captura, las imágenes termográficas fueron descargadas y procesadas en ordenador utilizando los softwares correspondientes, ajustando parámetros como la temperatura de fondo y la emisividad para garantizar lecturas térmicas precisas.

Un paso clave es la estandarización de las temperaturas máxima y mínima en todas las imágenes, lo que permite mantener una escala de colores uniforme y facilitar la comparación visual. El ajuste automático de la escala térmica por parte de la cámara puede generar imágenes de bajo contraste, dificultando la identificación de diferencias térmicas relevantes. En cambio, el ajuste manual de la escala, mejora el contraste, elimina información térmica irrelevante (como el fondo) y resalta la silueta del paciente. Este ajuste uniforme entre imágenes permite que los colores representen los mismos valores de temperatura en todas ellas, facilitando la inspección visual inicial y la comparativa entre zonas contralaterales, así como la identificación de patrones térmicos específicos. Por tanto, el ajuste manual es esencial para lograr coherencia y precisión en estudios comparativos con múltiples imágenes.

Para el **análisis estadístico** se utilizó el software SPSS® (versión 21.0).

Dado el tamaño y las características de la muestra, se han aplicado estadísticas paramétricas, calculando la media, desviación estándar e intervalo de confianza del 95 % para las variables termográficas en las regiones de interés (ROI) de cada grupo (sanos, atletas y patológicos).

Para comparar medias entre dos grupos se ha empleado la prueba t de Student, y se aplica un ANOVA para comparaciones entre tres o más grupos, aplicando los tests de Scheffé, Games-Howell o Bonferroni según la homogeneidad de varianzas. Se consideraron significativos los resultados con $p < 0.05$.

La simetría térmica se ha evaluado comparando las medias de las ROI contralaterales mediante t de Student y líneas de regresión, aceptando simetría si el intervalo de confianza del 95 % de la pendiente incluye 1 y el de la ordenada al origen incluye 0.

Para definir criterios diagnósticos mediante termografía, se utilizaron curvas ROC, que permiten evaluar la capacidad del modelo para distinguir entre pacientes sanos y patológicos. La métrica empleada fue el AUC-ROC, donde un valor de 1 indica un rendimiento perfecto y 0.5 equivale al azar. Se aplica el índice de Youden para determinar el umbral óptimo de clasificación.

Se han realizado cuatro curvas ROC:

- ROC1: comparativa entre perros sanos con patológicos para identificar qué diferencia térmica contralateral sugiere patología.
- ROC2: agrupa sanos y atletas frente a patológicos, para evaluar la influencia del ejercicio en la clasificación.
- ROC3: comparativa entre sanos con atletas, analizando si ambos presentan simetría térmica similar.
- ROC4: comparativa entre atletas con patológicos, para definir un umbral diagnóstico considerando el efecto del entrenamiento físico.

Resultados y conclusiones:

En los capítulos 5.8 y 5.9 se ha establecido un protocolo detallado para la adquisición y procesamiento de imágenes termográficas, cumpliendo así el **primer** objetivo del estudio.

El **segundo** objetivo se obtiene mediante la definición de regiones de interés (ROI) para el análisis térmico, que encontramos en el capítulo 5.3, reproducible en perros sanos, atletas y enfermos.

El **tercer** objetivo consiste en identificar las variables más relevantes dentro de las ROI para caracterizar mejor las alteraciones térmicas. Se ha observado que no todas las regiones responden térmicamente de igual manera ante una patología: por ejemplo, lesiones en músculos extensores del tarso muestran variaciones térmicas más marcadas que alteraciones en el hombro en fases iniciales. Esta diferencia se debe a la naturaleza de las patologías, ya que las lesiones musculares tienden a generar inflamación más evidente que las tendinopatías.

Tras definir las regiones de interés (ROI), se analiza la temperatura media como métrica principal, ya que en un estudio piloto se ha comprobado que las temperaturas máxima y mínima eran menos fiables debido a la presencia de valores atípicos en áreas pequeñas.

Tanto en el histograma (Figura 6.1), como en los diagramas de dispersión (Figura 6.2) muestran que tanto en perros sanos como en atletas existe simetría térmica entre zonas contralaterales, con diferencias centradas en torno a 0 °C. Sin embargo, los perros atletas presentan mayor dispersión, lo que indica una mayor variabilidad térmica.

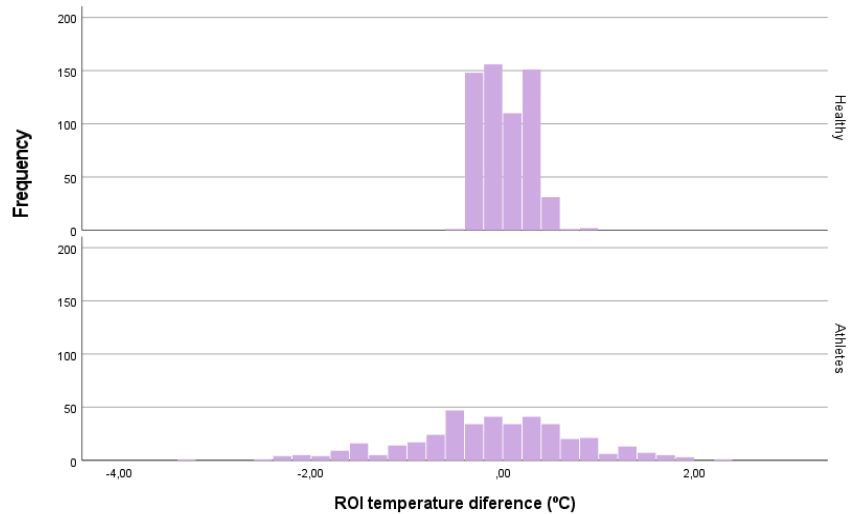


Figura 6.1: Histograma que muestra la frecuencia de ocurrencia de diferentes valores de Diferencia de Temperatura en la Región de Interés (ROI) estudiada en perros sanos y atléticos

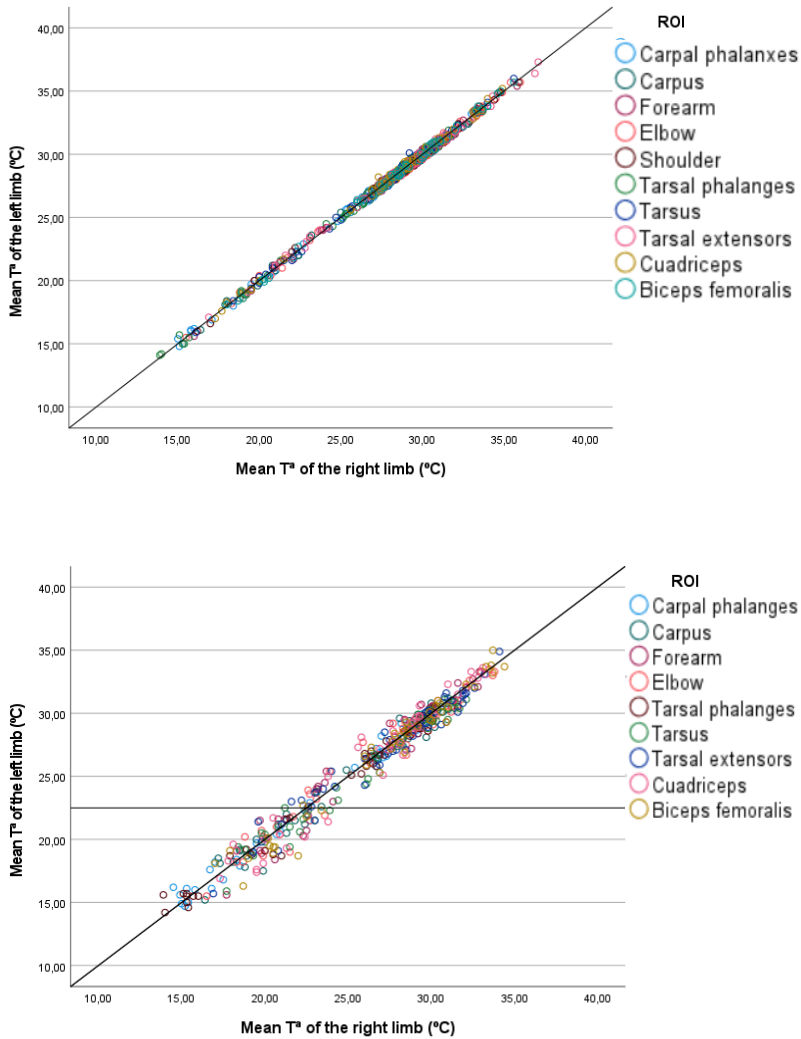


Figura 6.2: a) Comparación de la media de temperatura (°C) de las diferentes regiones de interés (ROI) de la extremidad izquierda con respecto a la extremidad derecha en perros sanos.
b) Comparación de la media de temperatura (°C) de las diferentes ROI de la extremidad izquierda con respecto a la extremidad derecha en perros deportivos. Mayor dispersión que en animales no deportivos.

Este estudio busca definir cuánto debe diferir la temperatura entre zonas homólogas para considerarse indicativa de lesión. En perros sanos y atletas se ha analizado la diferencia térmica absoluta, mientras que en casos patológicos se consideró también el signo, con el objetivo de definir aumento o disminución de temperatura.

En perros sanos, el análisis estadístico muestra que las diferencias de temperatura entre extremidades opuestas se agrupan alrededor de cero, indicando simetría. Los diagramas de dispersión confirman esta simetría, con una fuerte correlación entre temperaturas medias contralaterales. Al realizar la curva ROC1 para definir el criterio diagnóstico (Figura 6.5), se observa que una diferencia térmica de 0,45 °C es el umbral óptimo para discriminar entre individuos sanos y enfermos, cumpliendo con el **cuarto objetivo** de este trabajo. Este valor mejora la precisión diagnóstica y permite una detección precoz de patología.

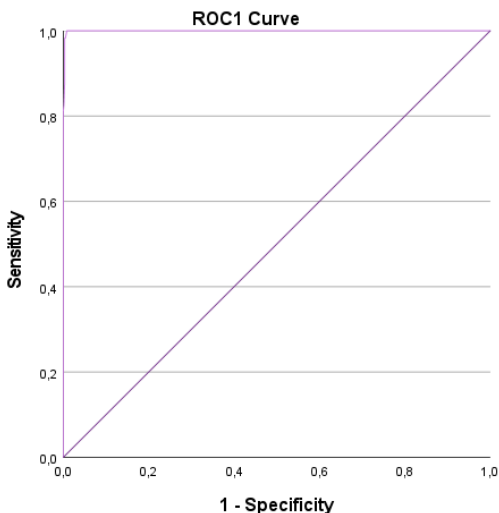


Figura 6.5: Curva ROC de pacientes sanos vs. patológicos

En perros atletas, aunque presentan simetría térmica similar a los perros sanos, muestran mayor dispersión en las mediciones. Esto puede deberse a la actividad metabólica elevada por el ejercicio, al aumento del flujo sanguíneo o a descompensaciones musculares crónicas no patológicas. También podrían influir microlesiones asociadas al entrenamiento, que generan zonas de hipertermia por inflamación y reparación tisular. La curva ROC4 indicó que una diferencia de 0,7 °C entre lados contralaterales permite distinguir claramente entre atletas y pacientes patológicos, lo que ayuda a evitar errores diagnósticos y a personalizar el manejo clínico y deportivo. Con esto, se cumple el **quinto objetivo** de este trabajo

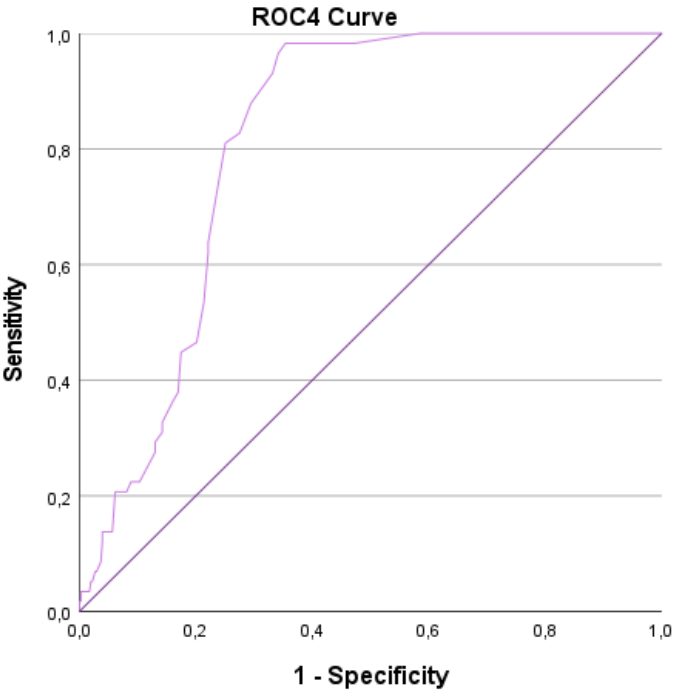


Figura 6.8: Curva ROC de pacientes deportivos vs. pacientes patológicos.

El **sexto objetivo** es analizar las alteraciones térmicas en pacientes con diversas patologías y compararlas con el patrón de los sujetos sanos. El análisis comparativo en animales con patologías entre zonas lesionadas y sus contralaterales sanas mostró que las regiones afectadas presentan una temperatura media 2,4 °C superior. Este aumento sugiere que las lesiones generan hipertermia local, probablemente por inflamación, y que dicha diferencia térmica puede ser un indicador útil de patología.

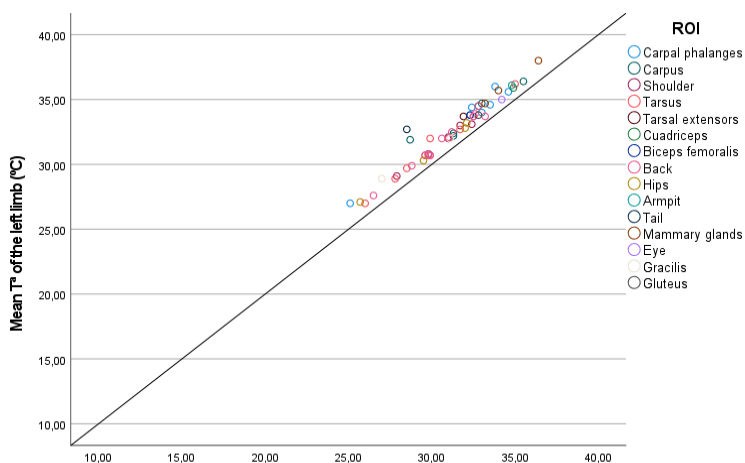


Figura 6.4: Comparación de los valores de temperatura media (°C) de las diferentes regiones de interés afectadas con respecto a la zona contralateral sana en perros patológicos. La temperatura media de la zona afectada es mayor que la de la zona contralateral sana.

Dentro de este grupo, se pudieron identificar cuatro subgrupos (Tabla 6.4): dolor agudo, dolor crónico, displasia de cadera y enfermedad discal, observando que cada uno presenta un gradiente térmico específico, lo que permite diferenciar, no solo el tipo de patología, si no también su intensidad. Las enfermedades con menor dolor muestran patrones térmicos similares a

los de perros atletas, mientras que las más severas, como el trauma agudo, se asemejan a los perfiles térmicos de pacientes oncológicos. Esto permite clasificar las patologías según su impacto fisiológico.

Tabla 6.4: Clasificación de los grupos de estudio, en la que se observa una clara diferencia entre sanos, deportistas y oncológicos, con la correspondiente gradación entre el resto de grupos.

		N	Media	Desviación estándar	IC 95%	
					LI	LS
Sano		600	0,22 d	0,13	0,21	0,23
Atleta		407	0,69 c	1,10	0,88	2,91
Patológico	Dolor agudo	24	1,33 ab	0,57	0,63	0,74
	Dolor crónico	18	1,16 b	0,55	1,09	1,56
	Enfermedad discal	5	1,16 abc	0,29	0,99	1,33
	Displasia de cadera	4	1,03 abc	0,345	0,57	1,48
Oncología		7	1,9 a	0,34	0,74	1,58

N: Número de pacientes

IC: Intervalo de confianza (95%)

LI: Límite inferior del intervalo de confianza.

LS: Límite superior del intervalo de confianza.

a>b>c>d, diferencia estadísticamente significativa p>0,001.

En cuanto a los pacientes oncológicos, aunque no son directamente comparables con los otros grupos debido a que las zonas afectadas no coinciden con las estudiadas en los demás casos, presentan patrones térmicos únicos que requieren un análisis separado. Las regiones afectadas por el cáncer pueden mostrar alteraciones térmicas distintas, lo que refuerza la necesidad de adaptar el enfoque diagnóstico en estos casos.

A través del estudio de la simetría térmica en distintos grupos, se evidencia una relación directa entre la alteración térmica y el estado de salud. En animales con enfermedades oncológicas, las zonas afectadas muestran patrones térmicos distintos y no siempre comparables a zonas estándar, por lo que requieren un estudio individualizado.

Además del estudio estadístico, **se presentaron estudios específicos por su relevancia clínica**, los cuales son:

Evaluación térmica del desarrollo de una fractura

Se presenta el caso clínico de una perra mestiza de 8 años con una fractura oblicua desplazada en la tibia y el peroné. Inicialmente se trata la lesión inmovilizando la fractura con una férula durante tres semanas. Desde el primer día, se combina la termografía junto con radiografías para monitorizar el proceso inflamatorio y la evolución de la fractura.

El primer estudio térmico muestra un aumento de temperatura en la zona fracturada, reflejando una respuesta inflamatoria aguda esperable. Sin embargo, en los controles posteriores (días 5 y 15), en las radiografías no se observa formación de callo óseo, y la termografía en el día 15 revela una temperatura patrón térmico sin hipertermia local, indicando ausencia de respuesta inflamatoria, sugiriendo compromiso en la regeneración.

Ante la falta de progreso, se opta por una intervención quirúrgica. Siete días después de la cirugía, la termografía muestra un aumento generalizado de temperatura en la zona operada, esperable por la inflamación postoperatoria.

En este caso, se analiza cómo la termografía infrarroja puede detectar cambios fisiológicos asociados al desarrollo y evolución de una fractura ósea. La formación del callo óseo, esencial para la consolidación, depende en gran medida de la vascularización de la zona afectada. La angiogénesis, o formación de nuevos vasos sanguíneos, es clave en las primeras fases del proceso de curación, ya que permite el aporte de oxígeno y nutrientes necesarios para la regeneración ósea. Cuando esta vascularización es deficiente, como en fracturas desplazadas o de difícil localización, la curación puede retrasarse o incluso fracasar, dando lugar a complicaciones como la pseudoartrosis.

Durante la recuperación, se espera un aumento de la vascularización y, por tanto, de la temperatura en la zona lesionada, reflejo de la actividad metabólica e inflamatoria. En el caso estudiado, la integración de imágenes térmicas, radiografías y evaluación clínica permitió concluir que el proceso de curación se había paralizado o retrasado. A pesar de haber recibido tratamiento conservador (reducción manual y vendajes), no se observó formación de callo óseo ni respuesta térmica adecuada, lo que indica una falta de actividad inflamatoria y regenerativa.

La termografía ha sido clave para detectar esta ausencia de respuesta fisiológica, permitiendo un diagnóstico más preciso y la toma de decisiones clínicas fundamentadas. Ante la falta de progreso, se opta por resolución quirúrgica. Este caso destaca el valor de la termografía como herramienta complementaria a la radiografía y al seguimiento clínico, permitiendo una

evaluación más completa del estado de la fractura a nivel vascular y una intervención personalizada y tratamiento más eficiente.

La IRT como método predictivo del tromboembolismo aórtico felino.

El tromboembolismo arterial (TEA) ocurre cuando un trombo se desprende, convirtiéndose en un émbolo que bloquea una arteria periférica. Generalmente, se presenta de forma aguda o súbita, acompañado de signos clínicos intensos. Afecta comúnmente la arteria femoral, y suele estar asociado a enfermedades cardíacas como la miocardiopatía hipertrófica. Se manifiesta con parálisis súbita de las extremidades posteriores, dolor, cianosis y ausencia de pulso femoral. Su diagnóstico requiere técnicas de imagen como ecografía Doppler o tomografía computarizada.

Este estudio evalúa el uso de la termografía infrarroja (IRT) como herramienta de triaje rápido en gatos con parálisis del tercio posterior. Se compararon 16 gatos divididos en dos grupos: un grupo control de 11 gatos sanos y un grupo de estudio con 5 gatos con parálisis. De estos últimos, 2 fueron diagnosticados con FATE y 3 con patologías neurológicas (trauma o edema medular).

Los resultados muestran que los gatos con tromboembolismo aórtico felino presentan temperaturas significativamente más bajas en las extremidades posteriores en comparación con los gatos sanos o con lesiones medulares, reflejando la isquemia causada por el trombo.

Además, se observa una diferencia térmica media entre extremidades ipsilaterales de hasta 2,8 °C en gatos con TEA, frente a diferencias mínimas en los otros grupos ($\leq 0,9$ °C). Estas diferencias fueron estadísticamente significativas ($p < 0,01$), lo que respalda el valor diagnóstico de la termografía.

Estudios previos, como el de Pouzot-Nevoret, sugieren que una diferencia de 2,4 °C es indicativa de FATE. Aunque el número de casos en este estudio fue limitado, los resultados coinciden con dicha referencia. La termografía es hasta 10 veces más sensible que el tacto humano, lo que permite objetivar hallazgos clínicos y mejorar la precisión diagnóstica.

Esta técnica ha demostrado ser especialmente útil en contextos de urgencia, donde el tiempo es crítico. Permite diferenciar rápidamente entre TEA y otras causas de parálisis del tercio posterior, como traumatismos o edemas medulares, que presentan patrones térmicos distintos. Su uso en el triaje inicial permite priorizar pruebas confirmatorias como ecografía Doppler o tomografía, optimizando recursos y reduciendo el estrés del paciente.

La implementación de la termografía como herramienta de triaje mejora la capacidad del equipo veterinario para establecer diagnósticos diferenciales tempranos y precisos, lo que impacta directamente en la supervivencia y recuperación del paciente. No obstante, es importante considerar otras causas de enfriamiento de las extremidades posteriores, como la hipotermia o la hipovolemia, por lo que se recomienda una evaluación física completa y un estudio térmico integral del paciente.

Seguimiento de la evolución de un paciente con espondilosis deformante mediante termografía infrarroja

Acude a consulta una perra mestiza de 9 años, con antecedentes de displasia de cadera y espondilosis deformante grado 3. Presenta dolor muscular, rigidez, alteraciones en la marcha y dependencia de medicación para el control del dolor. Se combina el tratamiento médico suministrado con sesiones semanales de fisioterapia, incluyendo terapia manual, técnicas

osteopáticas, electroacupuntura y cuidados domiciliarios como masajes suaves y movilizaciones.

La termografía infrarroja se utiliza en este paciente para evaluar el estado inflamatorio de los músculos dorsales antes de cada sesión.

En la primera visita (día 0), se detecta una diferencia térmica de 1 °C entre partes contralaterales de la musculatura dorsal. Siete días después (día 7), al comenzar con las sesiones de fisioterapia, la paciente muestra una mejora notable clínica, presentando mayor energía, movilidad y flexibilidad. La termografía confirma la mejoría, mostrando una asimetría térmica reducida, con una diferencia de 0,3 °C entre partes contralaterales.

En la tercera sesión (día 22), la paciente presenta mejoría clínica con respecto a la sesión anterior. Se observa mayor elasticidad de los tejidos y ausencia de contracturas. La termografía muestra una diferencia térmica de 0,2 °C, compatible con la normalidad e indicando una disminución significativa de la inflamación con respecto a la primera visita.

El tratamiento fisioterapéutico permitió una mejora significativa en este caso, reduciendo la dependencia de medicación de la paciente. La termografía infrarroja fue clave para evaluar objetivamente la evolución de la misma, mostrando reducción de la inflamación muscular con el paso de las sesiones.

Aunque la termografía ha demostrado utilidad en el seguimiento de terapias, aún no se ha estudiado su aplicación específica en el diagnóstico y monitoreo de la espondilosis deformante, lo que representa una oportunidad para futuras investigaciones. En conjunto, este caso destaca la eficacia de un enfoque multidisciplinario y personalizado, apoyado en herramientas objetivas como la

termografía, para mejorar la calidad de vida en pacientes con patologías musculoesqueléticas crónicas.

Evaluación del daño tisular con termografía infrarroja tras ovariectomía laparoscópica vs. laparotomía

Este estudio compara el impacto vascular de la cirugía laparoscópica frente a la convencional (laparotomía) en ovariectomías de 45 hembras (30 gatas y 15 perras), usando la termografía infrarroja (IRT) como herramienta objetiva para evaluar la temperatura cutánea en el área de incisión. Se realizaron tres imágenes térmicas por paciente: antes de la cirugía, tras el rasurado y aclimatación, y después de la intervención.

Los pacientes operados por laparoscopia muestran un patrón térmico más localizado, con zonas frías en los puntos de incisión y una diferencia térmica de $1,2^{\circ}\text{C} \pm 0,03^{\circ}\text{C}$ respecto al área control. En cambio, los pacientes operados por laparotomía presentan una diferencia mayor ($3,7^{\circ}\text{C} \pm 1,3^{\circ}\text{C}$), con un aumento generalizado de temperatura en el abdomen.

El análisis estadístico (T-Test) confirma que estas diferencias son significativas ($p < 0,05$).

Los resultados confirman que la laparoscopia, al ser menos invasiva, genera una menor alteración térmica en la zona de incisión, con diferencias de temperatura más cercanas al rango normal ($0,4^{\circ}\text{C} \pm 0,3^{\circ}\text{C}$), mientras que la laparotomía mostró diferencias significativamente mayores, reflejando mayor daño tisular e inflamación. Esto indica que la laparoscopia preserva mejor la circulación superficial y favorece una recuperación más rápida.

La termografía se destaca como una herramienta objetiva y precisa para evaluar el impacto fisiológico de las técnicas quirúrgicas, superando la

subjetividad de la inspección visual. Al proporcionar datos cuantificables sobre la respuesta vascular y térmica del tejido, permite optimizar el manejo postoperatorio y mejorar los resultados clínicos.

Limitaciones

Una limitación importante del estudio fue la dificultad para obtener una **muestra suficiente y homogénea** de pacientes con una sola patología, debido a la diversidad de casos en la práctica clínica veterinaria diaria y la falta de continuidad en el seguimiento.

La variabilidad de casos, la pérdida de pacientes en controles de seguimiento, y los estrictos criterios para incluir datos válidos complicaron la recolección de muestras representativas. Además, la diversidad entre razas de perros y el tamaño reducido de los centros veterinarios aumentan la heterogeneidad de la población.

Por ello, se ha decidido incluir varias patologías en el análisis. Aunque esto introduce variabilidad que dificulta comparaciones específicas, amplía el marco de referencia para identificar patrones generales, refleja mejor la realidad clínica y permite una exploración inicial de las capacidades de la termografía.

Para avanzar, se recomienda aumentar la muestra mediante colaboración entre clínicas, realizar estudios específicos para cada patología y crear bases de datos multicéntricas estandarizadas. Así, se combinarán estudios generales y focalizados para mejorar la comprensión y aplicación clínica de la termografía veterinaria.

La variabilidad en las características del **pelo** de los pacientes limita de forma importante la aplicación de la termografía infrarroja, especialmente a la hora

de seleccionar las Regiones de Interés (ROI). Propiedades como la longitud, textura y densidad del pelo afectan la precisión y consistencia de las mediciones térmicas.

- Pelo extremadamente largo: Actúa como una barrera térmica que dificulta la medición precisa de la temperatura cutánea y complica la selección de la ROI. Recortar o separar el cabello puede ayudar, pero es invasivo, lleva tiempo y no siempre resulta viable.
- Pelo rizado o rastas: Genera superficies irregulares que provocan sombras térmicas y variabilidad en las mediciones. La alta densidad del cabello dificulta la evaluación directa de la piel, limitando la utilidad de la termografía infrarroja o requiriendo algoritmos complejos que aumentan la dificultad y el coste del análisis.

Fortalezas:

La termografía infrarroja es una técnica completamente **no invasiva y segura**, ya que no utiliza radiación ionizante, eliminando riesgos para el paciente, el propietario y el personal veterinario, además de reducir costos en protección radiológica.

Su modalidad “**sin estrés**” permite realizar mediciones a distancia, sin contacto directo, minimizando el estrés en animales sensibles o difíciles de manejar, como especies exóticas o pacientes hospitalizados.

No requiere manipulación física, por lo que evita la necesidad de inmovilizar o sedar al animal, reduciendo riesgos de lesiones y alteraciones fisiológicas que podrían afectar el diagnóstico.

La termografía es **rápida** y fácil de implementar, con imágenes en tiempo real que facilitan la evaluación de múltiples pacientes sin comprometer la calidad.

Ofrece gran **versatilidad** diagnóstica, detectando anomalías térmicas relacionadas con inflamaciones, infecciones, problemas musculoesqueléticos, circulatorios o dolorosos, siendo una herramienta eficaz para el cribado inicial.

Finalmente, permite un **seguimiento** continuo y repetido sin causar molestias, ideal para monitorización de patologías crónicas o lesiones en recuperación.

Líneas futuras de estudio

Este trabajo demuestra que la termografía infrarroja tiene un gran potencial para la investigación y aplicaciones en medicina veterinaria, mejorando diagnóstico y bienestar animal, pudiendo abrirse diversas líneas de investigación a futuro:

- **Integración con otras técnicas diagnósticas:** combinar termografía con resonancia magnética, ecografía o tomografía para correlacionar patrones térmicos superficiales con hallazgos anatómicos internos, mejorando precisión diagnóstica.
- **Monitorización de enfermedades crónicas:** crear bases de datos térmicas para enfermedades como artritis o enfermedades renales, facilitando seguimiento temprano y control de inflamación.
- **Optimización de tratamientos:** evaluación en tiempo real la respuesta a terapias, ajustando tratamientos personalizados para acelerar la recuperación y minimizar efectos secundarios.

- **Bienestar animal en producción:** desarrollo de protocolos para detectar estrés térmico, deshidratación o infecciones en animales de granja, promoviendo salud y sostenibilidad.
- **Aplicaciones en oncología:** detectar tempranamente tumores mediante cambios térmicos relacionados con alteraciones metabólicas y circulatorias.
- **Automatización y análisis avanzado:** utilizar inteligencia artificial para interpretar imágenes térmicas, automatizar diagnósticos y monitorización en tiempo real, integrando sensores y dispositivos móviles para ampliar el acceso en clínicas pequeñas o rurales.

En resumen, la termografía en veterinaria tiene un futuro prometedor con múltiples aplicaciones que mejorarán la calidad de vida animal y el avance profesional mediante tecnologías modernas y sostenibles.

Resumen de puntos clave:

- La termografía infrarroja (TI) es una técnica no invasiva, segura y rápida, muy útil en medicina veterinaria para detectar anomalías térmicas, diagnosticar y monitorear diversas patologías en animales domésticos, de granja y silvestres, reduciendo el estrés al evitar manipulación directa.
- En perros sanos, existe simetría térmica entre extremidades contralaterales con una diferencia promedio $\leq 0,45$ °C, sirviendo como referencia para detectar desviaciones patológicas.

- Los perros atletas muestran mayor variabilidad térmica, estableciéndose un umbral de $0,7^{\circ}\text{C}$ para distinguir entre perros atléticos y enfermos.
- En animales con patologías, los gradientes térmicos ayudan a clasificar y evaluar la gravedad de las enfermedades.
- En fracturas, la ausencia de respuesta térmica indica problemas en la cicatrización, orientando hacia intervenciones quirúrgicas.
- En tromboembolismo aórtico felino, diferencias térmicas mayores a $2,2^{\circ}\text{C}$ entre extremidades respaldan el uso de TI como herramienta eficaz de triage en emergencias.
- Para la espondilosis deformans, TI identificó alteraciones térmicas asociadas a problemas circulatorios y musculares.
- Fortalezas de la TI incluyen la reducción del estrés animal, su versatilidad diagnóstica y utilidad para monitoreo continuo y personalizado.
- Limitaciones del estudio: dificultad para obtener muestras homogéneas debido a la variedad de patologías y la influencia del pelaje en las mediciones térmicas.
- La TI se posiciona como herramienta esencial en veterinaria moderna, permitiendo detección precoz, optimización terapéutica y mejora del bienestar animal.
- Futuras aplicaciones incluyen la integración con inteligencia artificial para automatizar análisis y ampliar su acceso, así como nuevas perspectivas en oncología y rehabilitación.

En definitiva, la termografía infrarroja mejora la calidad de vida animal y promueve prácticas veterinarias más modernas, sostenibles y centradas en el bienestar.

2. Introduction

2.1. History of Thermography. What is Infrared thermography?

Infrared thermography (IRT), also known as thermal imaging, is a non-contact testing technique used to detect and visualize the temperature distribution of an object or a scene based on the emitted or reflected thermal radiation. It involves using an infrared camera, which is capable of detecting and converting the infrared radiation emitted by an object or living being into a visual image that represents the temperature variations across the object's surface.

IRT operates on the physical principle that objects with temperatures above absolute zero (0 K) emit infrared radiation. By capturing emitted or reflected infrared radiation, an infrared thermography camera generates a thermal image, also known as thermogram, that portrays the distribution of the temperature of an object, scene or being as distinct colours or shades, with each colour or shade corresponding to a specific temperature range.

This technique has been used extensively in diverse fields, such as building inspection, electrical systems inspection, mechanical systems inspection, industrial processes, medical diagnostics, and firefighting, among others. It serves as a means to detect anomalies like energy loss, water leaks, electrical hotspots, mechanical failures and, in medicine, certain thermal patterns are indicative of diseases or injuries. As a valuable tool for non-destructive testing and predictive maintenance, infrared thermography enables early detection of potential issues, facilitating timely corrective action to prevent costly failures or downtime.

IRT is now being utilized in clinical settings to measure the thermal distribution

of body heat using infrared cameras, followed by numerical analysis that allows extraction of physiological or pathological information, this being because living beings are emitters of this radiation and can be accurately measured by special devices (e.g. bolometers) that are built in thermographic cameras.

2.1.1. Heat as a relevant factor in medicine since the beginning of time

From the earliest days of clinical medicine, human body temperature has been used as a key diagnostic sign. Measure by hand has been a standard method to estimate skin temperature by physicians since the beginning of this knowledge.

Hippocrates, in the 5th century BC, was the first physician to study body heat. His method of assessing body temperature was based on applying mud to the patient's abdomen and observing the color changes that occurred when it dried.

The next important advance in the measurement of body temperature was made in 1612, when an Italian physician, Santoio Santorio, used the “thermometer”, based on the “thermoscope” developed by Galileo, and allowing the measurement of temperature with greater precision and quantitatively.

George Martine (1702–1741) proposed that the heat generated by animals was caused by the speed with which blood circulated through blood vessels [Haller.J-1985].

The Allbutt clinical thermometer was the first practical instrument to be commercially available (1866) [Editors.EB-2025].

It would not be until 1871 when Carl Wunderlich made a systematic record of temperature progression in a group of patients [Wunderlich.C-1871].

The medical use of infrared thermography started in 1952 in Germany. Eric Schwamm (physician) and Reeh (physicist) were the ones to develop a single-detector infrared bolometer to thermally measure specific regions of the human body surface for diagnostic purposes [Schwamm.E-1953], founding in 1954 the first medical thermography association, nowadays known as the German Society for Thermography and Regulation Medicine (Deutsche Gesellschaft für Thermographie und Regulationsmedizin e.V.).

In figure 2.1 we can see the thermographic device mentioned above:

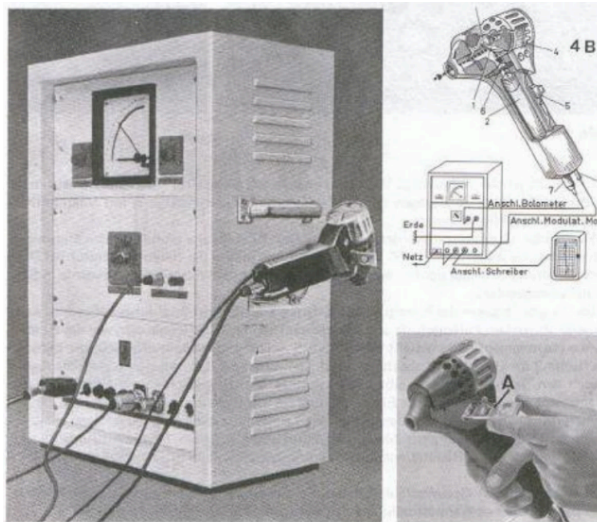


Figure 2.1: Ultrarot radiation meter for diagnostics and therapy monitoring, developed following the methods of Dr. Schwamm-Reeh.

In 1964, Theodor Benzinger invented the first non-contact radiometer to measure body temperature through the internal ear canal. While working at the U.S. Naval Medical Research Institute in Bethesda, Benzinger focused on human temperature regulation and created a small radiometer that allowed temperature measurements near the brain. The goal was to develop a non-invasive method that would eliminate the need to insert electrodes into the hypothalamus [Benzinger.M-1969].

2.1.2. Non-contact temperature measurement, the history of IRT

The history of infrared thermography begins with the finding of infrared radiation in the early 19th century. In 1800, astronomer Sir Frederick William Herschel made an important discovery while studying infrared radiation. Herschel used solar filters to measure the amount of heat that passed through different colours. He observed an increase in temperature from violet to red, and found that heat was most intense near red, even in the lack of visible light [Herschel.W-1800]. This experiment revealed the existence of energy that is invisible to the human eye, which Herschel called "heat rays." Today, this energy is called "infrared radiation".

John Federick William Herschel, who was the son of William Herschel, recreated his father's experiments on solar radiation. He was able to produce an image using this method, which he called a "thermogram". This term is still used to describe similar images today. Herschel used evaporography [Ring.EFJ-2006] to capture the image by focusing solar radiation through a lens onto a mixture of carbon particles in alcohol.

It wasn't until the mid-20th century that significant advances were made in the field of infrared thermography. During World War II, infrared cameras were

developed for military purposes, such as detecting enemy aircrafts at night. These early cameras were bulky and expensive, but they paved the way for further development in the field.

In the decades that followed, advances in technology made infrared cameras more affordable and accessible to a wider range of industries. Infrared thermography began to be used in a variety of applications. The ability to quickly and accurately measure temperature from a distance made infrared thermography an invaluable tool in many industries.

The year 1934 marked a turning point in the use of infrared radiation as a diagnostic tool in medical science. Researchers discovered that human skin was an excellent emitter of infrared radiation [Hardy.JD-1934]. This finding led to the exploration of IRT as a non-contact method for measuring skin temperature and eventually as a potential diagnostic imaging technique in medical science [Lahiri.BB-2012].

Today, infrared thermography is used in a wide range of applications, from medical diagnostics [Ring.EFJ-2012, Lahiri.BB-2012], to building inspection [Fox.M-2015]. It has proven to be a versatile and powerful tool for measuring temperature and detecting anomalies in a variety of materials and processes.

2.2. Physical principles of thermography

2.2.1. Heat transfer

Heat transfer is the process by which thermal energy is exchanged between objects or systems due to temperature differences. This energy exchange occurs spontaneously, moving from the area of higher temperature to the area of lower temperature, in accordance with the second law of thermodynamics. Heat transfer can occur through three fundamental mechanisms: conduction, convection and radiation, each of which is governed by different physical principles.

Conduction: Thermal conduction is the process by which heat is transferred from one part of an object to another or between objects in direct contact, without the material itself moving. This phenomenon occurs when the hottest particles (atoms or molecules) vibrate with greater energy due to the elevated temperature, and transmit part of that energy to neighboring particles that have lower energy, through their direct interactions. Conduction is most efficient in solid materials that have good thermal conductivity, such as metals, due to the easy transmission of energy between free electrons and atoms.

On the other hand, materials such as wood or plastic are thermal insulators because they have low thermal conductivity. How quickly conduction occurs depends on several factors, such as:

- The temperature difference between the two zones.
- The material in question, since its thermal conductivity influences the speed of the process.

- The contact area between the two bodies or surfaces that exchange heat.

Convection: Convection is the transfer of heat through a fluid (liquid or gas) due to the movement of molecules within that fluid. In this process, hot particles, by gaining thermal energy, expand and become less dense, which causes them to rise. Meanwhile, colder particles, which are denser, tend to sink, creating currents within the fluid. This cycle of ascent of hot molecules and descent of cold ones generates a movement that transports heat from one area to another.

There are two main types of convection:

- Natural convection: Occurs when fluid movement is generated due to temperature differences in the fluid, without the need for an external source of energy (for example, hot air rising and cold air descending spontaneously).
- Forced convection: Occurs when a fan, pump, or some other device forces fluid to move, speeding up the heat transfer process (such as when a computer fan moves hot air out of the system).

Radiation: Radiation is the process by which heat is transferred in the form of electromagnetic waves. Unlike conduction and convection, radiation does not require a material medium (solid, liquid, or gas) to propagate, allowing it to transfer heat even through a vacuum. All objects above 0 K emit thermal radiation, but the amount of energy emitted depends on the temperature of the object and its radiative properties.

Bodies with higher temperatures emit a greater amount of radiated energy,

and this radiation propagates in the form of electromagnetic waves at the speed of light. The amount of energy emitted by a body is related to its temperature through the Stefan-Boltzmann law, which will be explained later.

Temperature measurement scales are systems used to quantify temperature, that is, to measure the amount of heat present in an object or system. Temperature is a fundamental physical quantity that is related to the movement of particles in a material: the higher the temperature, the greater the average kinetic energy of the particles. There are several scales for measuring temperature, but the most common are the Celsius scale ($^{\circ}\text{C}$), the Fahrenheit scale ($^{\circ}\text{F}$), and the Kelvin scale (K).

The Celsius scale is the most used in most countries in the world, especially in scientific and everyday contexts. This scale has two important points as reference: the freezing point of water, which is set at 0 degrees Celsius, and the boiling point of water, which is set at 100 degrees Celsius at sea level and under standard pressure conditions. This scale is based on the observation of these two water phenomena, which makes it intuitive for many daily applications, such as meteorology or cooking.

On the other hand, the Fahrenheit scale is mainly used in the United States and a few other countries. It was proposed by the German-Polish physicist Daniel Gabriel Fahrenheit in the 18th century. On this scale, the freezing point of water is set at 32 degrees Fahrenheit and the boiling point of water is set at 212 degrees Fahrenheit, under the same standard pressure conditions. The Fahrenheit scale divides the interval between freezing and boiling water into 180 parts, giving it finer resolution in certain contexts, although its use is more limited outside of the countries where it is used.

The Kelvin scale is the most used in the scientific field, especially in thermodynamics and physics. Unlike the other two scales, the Kelvin scale begins at absolute zero, which is the point at which the thermal energy of the particles completely ceases. This absolute zero corresponds to 0 K, and is the lowest possible temperature at which a system has no thermal energy. The Kelvin scale is directly related to the Celsius scale, but its values do not have negative temperatures. The freezing point of water on the Kelvin scale is 273.15 K and the boiling point of water is 373.15 K. This scale is used in scientific research as it provides an absolute measurement of temperature, which is fundamental in many physical and chemical processes.

Thermal equilibrium is a fundamental concept in thermodynamics that describes the state in which two or more systems or bodies that are in contact with each other have reached the same temperature, such that there is no further net transfer of heat between them. In other words, when objects are in thermal equilibrium, their temperatures are equal and thermal energy stops flowing from one to another.

This phenomenon can be understood through the zeroth law of thermodynamics, which states that if two systems are in thermal equilibrium with a third system, then those two systems are also in thermal equilibrium with each other. This principle is the basis for temperature measurement, as it allows thermometers, which are in thermal equilibrium with the object whose temperature is being measured, to indicate a consistent reading.

The process of reaching thermal equilibrium involves the transfer of heat between the systems in contact. Initially, if two objects are at different temperatures, heat will flow from the higher temperature object to the lower temperature object until they both reach the same value. Once this happens,

the heat flow stops and both systems remain at the same temperature, thus reaching thermal equilibrium.

In summary, thermal equilibrium is the point at which no net heat exchange occurs between objects in contact, and is a key principle for understanding how thermal energy is distributed in different systems.

In biological systems, such as warm-blooded animals, including mammals and birds, the body uses various mechanisms, such as metabolism, thermoregulation, and heat exchange with the environment, to maintain a constant internal temperature and achieve thermal equilibrium. These mechanisms collaborate to ensure that body temperature remains within a narrow range, despite variations in the external environment.

For example, in a colder environment, the body of warm-blooded animals can activate various mechanisms to conserve heat and keep their internal temperature constant. One of these mechanisms is vasoconstriction, which consists of the contraction of blood vessels close to the skin, which reduces heat loss to the outside. In addition, the metabolism accelerates, generating more heat to counteract the cold. An additional process that helps generate heat is shivering, in which muscles contract involuntarily, releasing thermal energy. On the other hand, in a hotter environment, the body can activate vasodilation, a mechanism that dilates blood vessels near the surface of the skin, facilitating the release of heat to the environment. Perspiration also increases, a process in which sweat glands release sweat onto the skin. As sweat evaporates, it absorbs heat from the body, cooling it. Additionally, the body reduces metabolic heat production, decreasing the activity of processes that generate internal heat. These mechanisms work together to maintain the body's internal temperature within an optimal range.

Thermal balance is essential for the proper physiological functioning of the body, since many biological processes, such as metabolic reactions and enzymatic activities, depend on specific temperatures. Variations in body temperature, both increasing and decreasing, can seriously alter cellular functions and enzymatic processes, affecting the organism's efficiency in maintaining homeostasis. For example, extremely high temperatures can denature proteins and enzymes, while excessively low temperatures can slow or even stop chemical reactions essential for life.

Therefore, maintaining a proper thermal balance is vital for the health and survival of living organisms. The body's ability to regulate its internal temperature is not only crucial for survival in different environmental conditions, but also for ensuring that all biological systems operate within optimal parameters. This thermoregulation process is essential both in natural environments and in situations of thermal stress, ensuring that the body can adapt and function efficiently in a variety of conditions.

2.2.2. Electromagnetic spectrum and infrared radiation

The electromagnetic spectrum encompasses all electromagnetic radiation, a continuous range of energy that includes various waves or particles propagating through space at the speed of light. This spectrum comprises a wide variety of wavelengths or frequencies and encompasses phenomena such as radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Electromagnetic radiation is distinguished by its wavelength, which measures the distance between consecutive peaks or troughs of a wave, or by its frequency, which indicates the number of cycles a wave completes in one

second. The electromagnetic spectrum is divided into different regions according to wavelength or frequency, and each one has its own characteristics, specific interactions with matter, and unique practical applications.

Figure 2.2.1 shows the different types of radiation in the electromagnetic spectrum, ordered from the shortest to the longest wavelengths:

- Gamma rays: It is the radiation with the shortest wavelength and the highest frequency of the electromagnetic spectrum. Due to their high energy, gamma rays are capable of breaking molecular bounds by extracting electrons out of atoms (ionize). This is why it is classified as “ionizing radiation” which has important and harmful biological effects. They are used in applications such as cancer treatment, sterilization of materials, and nuclear imaging.
- X-rays: The wavelengths are somewhat longer than gamma rays, but it is still ionizing radiation. Its primary use includes medical imaging, safety inspections, and industrial testing due to its ability to penetrate dense materials.
- Ultraviolet (UV) rays: With shorter wavelengths than visible light, not having enough energy to ionize atoms, and therefore classified as non-ionizing radiation, UV rays are known for their biological effects, such as sunburn and DNA damage. They are used in sterilization, disinfection processes and fluorescent lighting.
- Visible light: It is the region of the electromagnetic spectrum perceptible by the human eye. It includes colors ranging from violet to red and has applications in lighting, photography and visual displays.

- Infrared (IR) rays: They have longer wavelengths than visible light and are used in various applications, such as thermal imaging, remote sensing, and communication systems.
- Microwaves: With wavelengths longer than infrared rays, microwaves are widely used in communications, radar systems, and cooking food.
- Radio waves: They have the longest wavelengths and the lowest frequencies within the electromagnetic spectrum. They are essential for applications such as radio broadcasting, television, wireless communications and remote sensing.

THE ELECTROMAGNETIC SPECTRUM

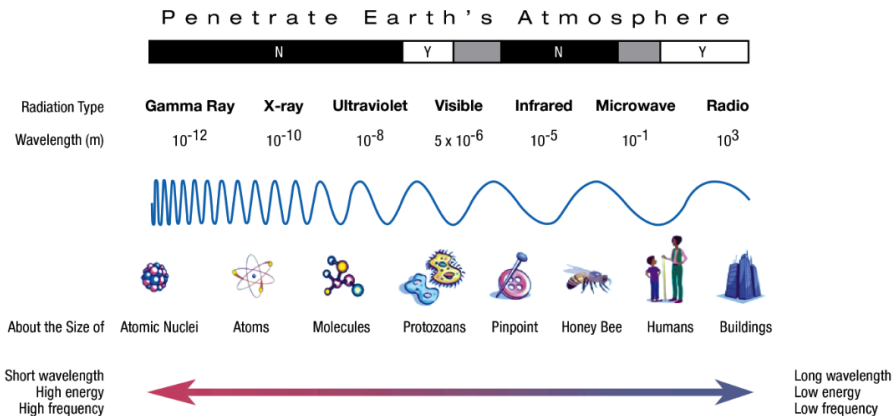


Figure 2.2.1. The electromagnetic spectrum. Image credit: NASA (<https://my.nasadata.larc.nasa.gov/basic-page/electromagnetic-spectrum-diagram>)

The focus of this thesis is on infrared radiation, a specific region of the

electromagnetic spectrum.

Infrared radiation is characterized by having wavelengths that are longer than those of visible light, but shorter than those of microwaves. This places it in the interval of the electromagnetic spectrum between visible light and radio waves. Thanks to its properties, infrared radiation is unique and is used in applications ranging from thermal imaging and remote sensing to communications and night vision technology.

Its relevance lies in its ability to interact with matter in specific ways, such as the emission of heat and the detection of thermal changes, which makes it a fundamental topic of study in various scientific and technological disciplines.

Infrared radiation is distinguished by its ability to generate heat when absorbed by matter. This type of radiation has a wide range of applications, including thermal imaging, remote sensing and communication systems.

All objects with a temperature above absolute zero emit infrared radiation, which allows it to be detected and measured with specialized equipment, such as infrared cameras or spectrometers. Its wavelength range spans from approximately 760 nanometers (nm) to 1 millimeter (mm), as illustrated in Figure 2.2.2.

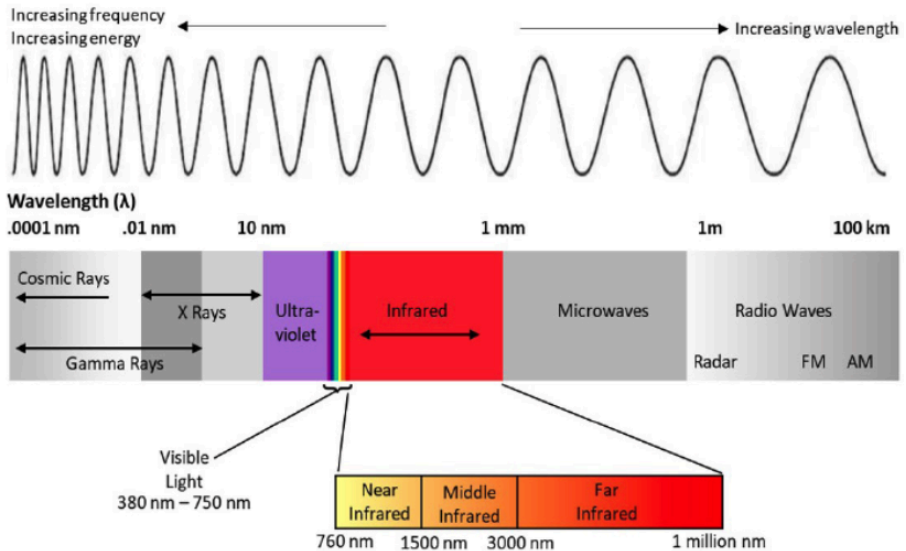


Figure 2.2.2. A depiction of the electromagnetic spectrum, highlighting the range of visible light for humans (approximately 380 to 750 nm) and the near-infrared region (approximately 700 to 3000 nm) [Butcher.G-2016].

2.2.3. Physical laws of infrared radiation

The theoretical foundations that explain infrared radiation and its relationship with temperature are based on the **black body theory**, proposed by Gustav Kirchhoff in 1860. A black body is an idealized concept that describes an object capable of absorbing all the electromagnetic radiation that hits it. on it and emit it at the same rate at which it absorbs it.

In this model, no incident radiation is reflected or transmitted through the blackbody. This ideal object has a uniform surface and temperature, becoming a perfect emitter of infrared radiation.

Various theoretical principles explain the behavior and properties of infrared radiation:

Theory of Electromagnetic Waves: Infrared radiation, like all electromagnetic radiation, follows the principles of the theory of electromagnetic waves. This theory describes how electromagnetic waves propagate in space through electric and magnetic fields that oscillate perpendicular to each other and to the direction of propagation. The energy of infrared radiation is determined by its wavelength and frequency: longer wavelengths correspond to lower frequencies and lower energy levels.

Wien's Displacement Law: This physical principle establishes the relationship between the temperature of a black body and the wavelength at which the most intense radiation emission occurs. According to this law, the wavelength of maximum intensity is inversely proportional to the temperature of the blackbody.

It was formulated by Wilhelm Wien in 1893. This law describes the relationship between the temperature of a black body and the wavelength at which it emits radiation most intensely. According to Wien's Law, the wavelength corresponding to the maximum radiation intensity decreases as the body temperature increases. Mathematically, it is expressed as:

$$\lambda_{\text{max}} \cdot T = b$$

In which:

- λ_{max} is the wavelength at which the maximum intensity of radiation occurs (in meters).

- T is the temperature of the object in kelvin (K).
- b is the Wien displacement constant,

This equation indicates that, as the temperature of an object increases, the wavelength at which it emits its most intense radiation shifts toward shorter values. That is, hotter objects emit more intense radiation at shorter wavelengths, such as the visible or ultraviolet spectrum, while cooler objects emit their maximum radiation at longer wavelengths, such as the infrared spectrum.

According to Wien's Law, the wavelength at which the maximum intensity of thermal radiation occurs is inversely proportional to the temperature of the emitting object. This means that as an object's temperature increases, the wavelength at which it emits its most intense radiation shifts toward shorter wavelengths.

In thermography, this principle is used to determine the temperature of objects or scenes based on the infrared radiation they emit. Infrared cameras detect and measure infrared radiation emitted by objects or scenes and subsequently convert this detected radiation into a visual image that represents the temperature distribution.

Using Wien's Law, thermography allows non-contact and non-destructive temperature measurements, since the infrared radiation emitted by objects or scenes can be detected without the need to physically touch them. This makes thermography a valuable tool in various applications where contact-based temperature measurements are not practical or feasible.

Planck's Law: Describes how the intensity or energy radiated by a black body varies depending on its temperature and wavelength. According to this law, as the temperature increases, the intensity of the emitted infrared radiation also increases and shifts to shorter wavelengths, which is related to Wien's displacement Law.

This is a fundamental law of physics that describes the distribution of the spectral intensity of electromagnetic radiation emitted by a blackbody at a given temperature. It was formulated by the German physicist Max Planck in 1900 and played a key role in the development of quantum mechanics.

It is expressed mathematically as follows:

$$B(\lambda, T) = \frac{2\pi hc^2}{\lambda^5 \left(e^{\frac{hc}{\lambda k_B T}} - 1 \right)}$$

Where:

- $B(\lambda, T)$ is the intensity or spectral radiance of a black body radiation at a given wavelength λ and temperature T
- h is Planck's constant (approximately $6.62607015 \times 10^{-34}$ J·s)
- c is the speed of light in vacuum (approximately 2.998×10^8 m/s)
- λ is the wavelength of the radiation
- k is the Boltzmann constant (approximately 1.380649×10^{-23} J/K)
- T is the temperature of the black body in kelvin (K), and

- e is the base of natural logarithm.

Planck's Law describes how the intensity of blackbody radiation changes with wavelength and temperature. It demonstrates that the intensity of radiation increases with increasing temperature and that the wavelength at which maximum intensity occurs shifts toward shorter wavelengths as temperature increases. Planck's Law is widely used in fields such as thermodynamics, astrophysics and quantum mechanics to describe the behavior of blackbody radiation and its relationship with temperature, and has important applications in various areas of science, technology and engineering.

Stefan-Boltzmann Law: states that the total energy radiated by a black body is proportional to the fourth power of its temperature. In practical terms, this means that as the temperature of the blackbody increases, the amount of infrared radiation it emits grows exponentially.

The emission of radiation from a hot body is determined by the Stefan-Boltzmann law.

The Stefan-Boltzmann law is a fundamental principle of thermodynamics that describes the relationship between the temperature of an object and the total amount of thermal radiation it emits. It is named after Austrian physicist Josef Stefan and Austrian physicist Ludwig Boltzmann, who derived this law independently in the late 19th century.

This law states that the total power radiated per unit area of a blackbody (a theoretical object that absorbs all incident radiation and emits radiation with the highest possible efficiency) is directly proportional to the fourth power of its absolute temperature. Mathematically, the Stefan-Boltzmann law can be

expressed as:

$$E = \sigma T^4$$

Where:

E is the total power radiated per unit area (also known as emissive power)

σ is the Stefan-Boltzmann constant (a fundamental constant of nature)

T is the absolute temperature of the black body in Kelvin.

It indicates that as the temperature of a blackbody increases, the amount of thermal radiation it emits per unit area also increases significantly. This means that hotter objects emit more energy compared to colder objects, and the rate of energy emission increases rapidly with higher temperatures. This facilitates non-contact temperature measurements and imaging, enabling tasks such as detecting energy losses, identifying anomalies in industrial processes, and detecting abnormal temperature patterns in the human body for medical diagnoses.

The law has important implications in various fields, such as astrophysics, engineering and energy management, as it helps describe the behavior of thermal radiation and energy exchange in different systems.

By rearranging the equation, we can solve for temperature (T):

$$T = (E / \sigma)^{(1/4)}$$

This equation allows us to calculate the temperature of an object by measuring the energy it emits, such as the thermal radiation captured by an infrared camera in thermography. Infrared cameras detect and measure the intensity of thermal radiation emitted or reflected by an object, and by applying the Stefan-Boltzmann law, they can calculate the temperature of the object based on the amount of energy it emits.

The exponential relationship between temperature and thermal radiation means that even small variations in temperature can be easily measured. This high sensitivity allows thermography to provide reliable and accurate temperature distributions on objects. For example, while the human hand can detect temperature differences of approximately 2°C in the skin [Waldsmith.JK-1992], thermography is ten times more sensitive, allowing even smaller temperature changes to be detected [Turner.TA-2001]. This increased sensitivity of thermography makes it a valuable tool in various applications where accurate temperature measurements and analysis are required, such as in medical diagnostics, industrial inspections, and building diagnostics.

Nevertheless, a blackbody is an ideal, non existing object. Real objects do not emit all the energy they receive, but slightly less, being this difference material dependent. To consider this variation respect the ideal blackbody, a term is introduced into the Boltzman law, which converts into the modified Boltzmann equation:

$$E = \epsilon \sigma T^4$$

Being ϵ the so-called **emissivity**, a real dimensionless number ranging between 0 and 1. $\epsilon=0$ means a perfect reflector with no emission, while $\epsilon=1$ represents the ideal perfect emitter with full emission. Emissivity is defined as

the ratio of the energy radiated by a material's surface to the energy radiated by a perfect emitter at the same temperature, wavelength, and viewing conditions.

Each material has a different emissivity. Materials which are very reflective, such as polished aluminium, have a very low emissivity (0,05 for this material), while most absorbers like human skin have an emissivity of about 0.98, which means they emit almost as much thermal radiation as a perfect blackbody.

The modified Stefan-Boltzmann equation is used by most infrared cameras and radiation thermometers to perform these calculations. As we will see, this technique is capable of evaluating physiological changes in the animal that alter vascularization and, therefore, its surface temperature.

Thermal emissivity in animals refers to their ability to emit thermal radiation or heat. Different animals have varied thermal emissivity characteristics, which can influence their thermoregulation and heat exchange with their environment.

Animals with higher thermal emissivity, such as those with thin coats or exposed skin, are more efficient at dissipating excess heat from their bodies. This allows them to cool effectively in hot environments, preventing overheating.

On the other hand, animals with lower thermal emissivity, such as those with thick fur or feathers, are better adapted to cold environments, as they can trap and retain more heat. These animals can regulate their body temperature and conserve heat more effectively, allowing them to stay warm in cold conditions.

The thermal emissivity of animals can also vary depending on factors such as their metabolic rate, size, and adaptations to the environment. For example, animals from arctic or polar regions may possess specialized adaptations, such as thicker fur or a layer of fat, to minimize heat loss and maintain their body temperature in extremely cold conditions.

Understanding the thermal emissivity characteristics of animals is crucial in fields such as ecology, physiology and wildlife management, as it can significantly influence their survival and well-being in different environments.

In animals, emissivity has not been sufficiently studied, but a value between 0.95 and 1 has been used [Autio.E-2007, Hovinen.M-2008, Lynch.M-2011, Westermann.S-2013]. Emissivity is necessary to obtain the absolute temperature of an object.

The main problem with this veterinary technique lies in the presence of hair on the animals, which varies the emissivity in an unknown way and makes it difficult to correctly determine the absolute or real temperature, despite the precision of the detectors.

However, the study of relative temperatures (such as changes in distributions, for example) is independent of the emissivity value, which allows us to use the proposed technique even without knowing said value.

Therefore, it will be more useful to use relative temperature variations rather than their absolute values in most cases. Absolute measurement will only be reliable in areas of known emissivity (usually shaved areas, in the case of humans or warm-blooded animals, where the emissivity of the skin is known).

The **Absorption and Emission Spectra**: Each material has characteristic absorption and emission spectra for infrared radiation. These spectra indicate the specific wavelengths that a material can absorb or emit, depending on the energy levels of its molecules or atoms. Absorption spectra are used in techniques such as spectroscopy to identify and analyze materials, while emission spectra are key in thermal radiation and energy transfer processes.

There are several characteristics of a body that can determine its behavior in the infrared spectrum. These features include:

- **Absorptivity (α):** Absorptivity refers to the ability of a body to absorb infrared radiation.
- **Emissivity (ϵ):** Emissivity is a measure of the efficiency with which a body emits and absorbs infrared radiation. Different materials have different emissivity values, which determine the amount of infrared radiation they emit or absorb. Materials with high emissivity, such as metals, ceramics, and most organic materials, tend to emit and absorb infrared radiation more effectively than materials with low emissivity, such as glass, plastics, and certain coatings.
- **Reflectivity (ρ):** Reflectivity is a measure of the amount of infrared radiation that a body reflects. Reflectivity can vary depending on the surface properties and materials of a body. Highly reflective materials, such as metals and shiny surfaces, tend to reflect infrared radiation, while darker, rougher surfaces tend to absorb more infrared radiation.
- **Transmissivity (τ):** Transmissivity is a measure of the amount of infrared radiation that a body allows to pass through it. Some materials, such as certain types of glass and plastics, are transparent

to infrared radiation and allow it to pass through, while others, such as metals and opaque materials, block or absorb infrared radiation.

- **Composition:** The composition of a body, including its molecular and atomic structure, can also influence its behavior in the infrared spectrum. Different materials have different molecular and atomic properties that determine their interaction with infrared radiation, including absorption, emission and transmission characteristics.
- **Thickness:** The thickness of a body can affect its behavior in the infrared spectrum, especially in terms of absorption and transmission. Thicker bodies may absorb more infrared radiation and have greater absorption characteristics, while thinner bodies may allow greater transmission or passage of infrared radiation.
- **Temperature:** The temperature of a body has a direct relationship with its behavior in the infrared spectrum. According to Wien's law and Planck's law, the temperature of a body affects the intensity and distribution of the infrared radiation it emits. Higher temperatures generally result in higher intensity infrared radiation and a shift toward shorter wavelengths in the spectrum, while lower temperatures result in lower intensity radiation and a shift toward longer wavelengths.

With these physical concepts in mind, we can better understand how Infrared Thermography (IRT) cameras detect infrared radiation to measure temperatures. These cameras capture the thermal radiation emitted by objects, which varies depending on their temperature and characteristics. The detected information is converted into thermal images that represent the temperature distribution on the surface of the object.

2.3. Physiology and thermal regulation of the body

It is known that the skin is the largest and most visible organ of the body, reaching an area of 1'5 - 2m² in adult humans and representing up to 15% of total body weight. In animals there is a lot of variability among species and breeds, but it has been studied that the skin accounts for 24% of the body weight of the puppy and 12% of the adult dog [Al-Bagdadi.F-1979, Pavletic.MM-1985]

The skin is composed of three parts that are overlaid: hypodermis, dermis and epidermis. The epidermis, the most superficial, is the one in contact with the air, being a protective barrier. The dermis It's where we can find the blood vessels, nerves, sweat glands, and hair follicles, consequently being very important for thermoregulation and sensation. The hypodermis has a function of isolation, is a reservoir of energy, mainly composed of lipid cells.

The thickness of the skin varies depending on anatomical areas, presenting less thickness on the abdomen compared to the back, and on the distal part of the extremities compared to the proximal part [Schumer.A-1981] ,

It has several functions, such as protection from physical, chemical and microbiological injuries [Henshaw.RE-1972, McCafferty.DJ-2007a, McCafferty.DJ-2007b] presenting a sensitive component capable of perceiving heat, cold, pain, itching, pressure and noise. touch, as well as serving as a support for the fur. This organ is related to other organs, presenting a mirror effect in which it reflects malfunction of these other organs [Vora.RV-2016].

The skin and fur changes according to species, breed and individuals, in addition to varying between different parts of the body. Hair is important in thermal insulation, sensory perception and as a barrier against chemical,

physical and microbiological injuries [Scott.DW-1990, Spearman.RIC-1973], in addition to being photoprotector.

Animal's ability to thermoregulate is directly linked to the type of coat (length, density and thickness), with long, fine coats being more adapted to cold weather, and with the capacity to increase the depth of the hair due to the piloerection function. Color also has some relevance, as well as its brightness and its ability to reflect light.

Skin regulates the animal's body hair by activating hair follicles, which causes the hair to stand and insulate air against the skin, increasing body temperature. It also has blood vessels dilating or constricting to regulate the conservation or loss of heat.

Dogs and cats do not sweat like humans, they mainly rely on panting to cool their body temperature.

Domestic animals that have fur (most breeds of dogs and cats) are already born with it and, when they reach maturity, do not shed it, but instead begin to form the final coat on top of the puppy coat.

In human medicine, infrared thermography measures directly the temperature emitted by the skin, as it does not present the protective layer of hair that animals present.

The hair coat is variable between breeds [McCafferty.DJ-2007a, McCafferty.DJ-2007B], so the interpretation of thermal patterns can be difficult with some hair types. In figure 2.3 there are four fur types as viewed with thermal imaging, being those: curly hair (Spanish water dog), long hair (Afghan hound), short hair (pug) and medium short hair (cat).

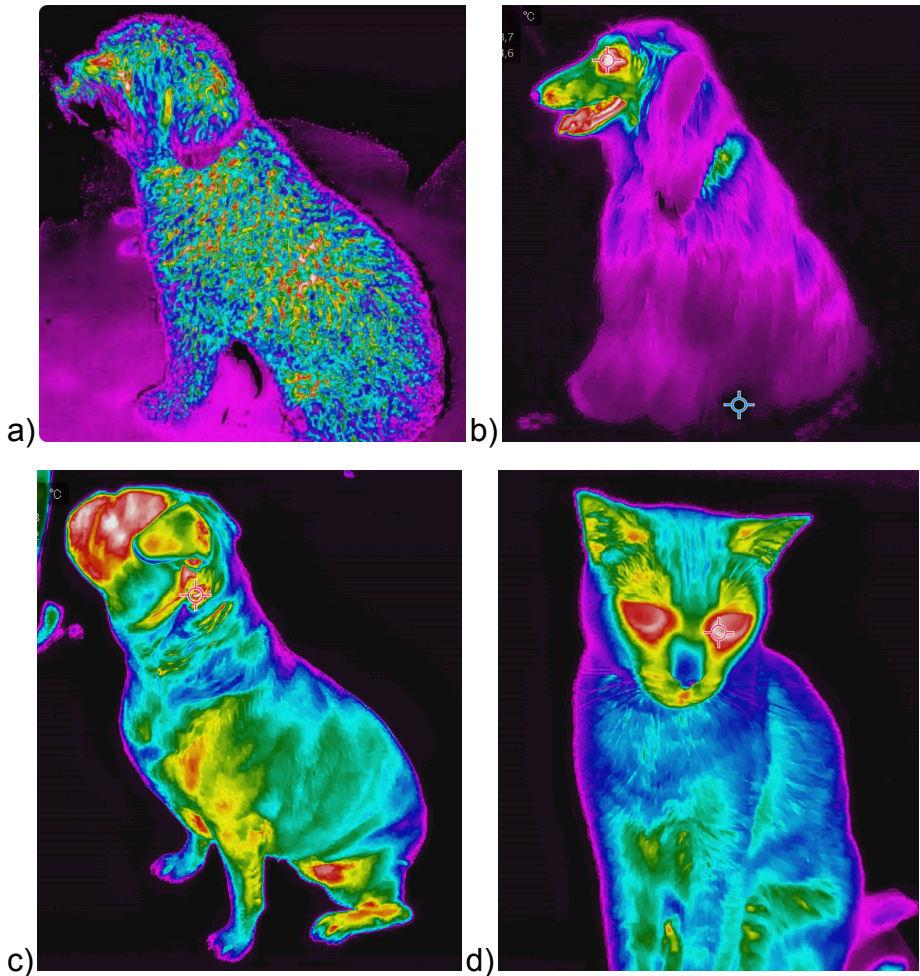


Figure 2.3: representation of different animals with various fur types a) Spanish water dog, b) Afghan greyhound, c) pug d) cat. We can see that the more fur, the more complicated it is to select the ROI and the less estimable the thermal alterations are. In the case of the spaniel, the technique is not very useful due to the asymmetrical pattern it presents due to its curly fur. **Source:** author.

Animals with long, curly fur have a cooler surface (predominantly blue and purple) because these coat types act as thermal barriers, retaining body heat. Curly fur, in particular, creates a "pillow" effect that traps air in its curls, insulating the animal. Long fur creates an even layer that minimizes heat loss through the skin. In contrast, short and medium-short coats allow heat to dissipate more easily, resulting in images with areas of apparent higher body temperature (red and yellow areas on the head, back, and limbs). These warm areas are evident because short hair does not insulate as well, facilitating heat transfer from the body to the environment, thus allowing a more accurate thermal analysis when using IRT.

Clipping hair is proven to not modify the thermal distribution, but it can modify the absolute value of temperature. The main problem with hair clipping is that it can lead to an increase in stress levels [Yarnell.K-2013] and, with that, to a change of the peripheral blood by sympathetic influence of the nervous system [Travain.T-2015].

There is a study [Kwon.C-2019] that shows that short haired dogs have a more drastic increase in body surface temperature than other dogs, being this increase about 2°C.

In this study, patients with different coats and coat lengths were included, which is a factor to take into account when analysing thermographic images.

During the analysis of the images, it has been observed that the greater the density and length of the hair, the location of the anatomical markers to assess the ROI is more complicated, in addition to making it difficult to evaluate more subtle thermal variations.

The use of infrared thermography in patients with curly coats has also been

evaluated, but this technique is difficult to use and not very feasible, since the pattern of these animals is very irregular due to the curly distribution of the hair.

It has previously been studied that shaving the hair, both in dogs and horses, modifies the average temperature of the area without modifying the thermal pattern, so, if it is necessary to shave the area, we must take into account the complete ROI [Loughin.C-2007]. In addition, there are studies in giant pandas and dogs, which estimates the possibility of diagnosing a pregnancy by measuring abdominal temperature without shaving the hair [Durrant.BS-2006].

2.4. Symmetry of the body

In a healthy body of any animal (including humans), we can find thermal symmetry between contralateral parts of the body [Beaufort.NC-2002, Purohit.RC-1980, Loughin.CA-2007], including eye temperature [Klamann.MKJ-2012].

The body asymmetry described in humans varies depending on the body area, but there are several studies on the matter. Uematsu [Uematsu.S-1988a] et al. postulate a temperature difference between $0.17\pm0.14^{\circ}\text{C}$ in the abdomen, to $0.67\pm0.55^{\circ}\text{C}$ in the extremities. The most recent studies describe a thermal difference of $0.4^{\circ}\text{C}\pm0.3^{\circ}\text{C}$ in the most central parts of the body, and $0.4^{\circ}\text{C}\pm0.15^{\circ}\text{C}$ in the most regional parts [Vardasca.R-2012]. In short, in human medicine, a temperature difference greater than 0.5°C between contralateral parts of the body is suggestive of being pathological.

In dogs, as of the date of this report, only three relevant studies have been identified. One of them, by Loughin [Loughin-2007], concluded that there is no significant thermal difference between the forelimbs and hindlimbs, supporting the extrapolation of findings from human studies. Based on this, a temperature difference greater than 0.5°C between contralateral regions of the body can be considered pathological. Additionally, other studies have reported that a temperature asymmetry exceeding 1°C between contralateral body parts is abnormal and indicative of an underlying pathological process [Head.J-2001, Turner.TA-2001].

In horses, studies have also been carried out to assess the thermal pattern and reference values have been established. [Tunley.BV-2004].

2.5. Documented uses of infrared thermography in human and veterinary medicine

The temperature of the skin presents a thermal pattern that reflects its vascularization, so the presence of an increase or decrease in the temperature of this pattern or of a specific area is correlated with a change in its metabolic activity. Until now, these changes have been assessed subjectively by healthcare professionals through physical examination and individual experience, but thermography is proposed as a valid and viable technique that can objectively assess skin vascularization [Loughin.CA-2007].

This technique can be used to study pathologies that involve both an increase in temperature [Purohit.RC-1980, Cid.V-2021, Mota-Rojas.D-2022] (infection, inflammation, autoimmune diseases, among others), or a decrease in temperature (presence of ischaemia, surgery with cutaneous flap, neuropathies, among others).

By monitoring changes in the body's thermal pattern, we are able to assess those pathologies that involve thermal variation in our patient, whether it was with hyperthermia or hypothermia.

The use of this technique has been studied in both human and animal medicine.

In human medicine, the thermographic technique is not completely protocolised, as it is a method that is mainly used in research (with special interest in paediatrics, as patients cannot communicate) although there is already extensive experience in its use in different pathologies or situations, which is intended to be extrapolated to veterinary medicine.

In veterinary medicine, it has been used successfully for decades in the equine area [Díez.I-2018] and in livestock, although less so in small animals, with a considerable increase in publications in this respect in the last two years.

Up to date, the literature has focused mainly on livestock, wildlife and equine medicine, with a notable paucity of literature on domestic animals. This can be justified because livestock is a production element, necessary in today's social structure. In wildlife studies it is important to avoid contact with individuals so as not to alter their behaviour or their habitat.

2.5.1. Infection

Thermal alteration of infectious processes has been studied, as they involve an increase in both systemic and local temperature.

In human medicine there are articles on its use as a screening technique in large groups of humans as an effective and reliable method for fever arrest in the early stages of respiratory processes [Chiu.WT-2005, Wu.C-2025]. This technique has its limitations, e.g. if there is sweat on the subjects to be tested, it can result in false negatives [Chiang.MF-2008]. More recent studies show that the results of the IRT evaluation were mixed in terms of its efficacy in detecting infectious diseases. This suggests that it would be useful to consider more physiological parameters to improve the accuracy and reliability of non-invasive biosensors. [Khaksari.K-2021]

In veterinary medicine, this technique has also been used for the remote diagnosis of infectious diseases in animals [Mota-Rojas.D-2022], as well as being a promising tool as an early detection of disease [Sadeghi.M-2023]. It is still being a subject of study with positive results, as in the study by

Al-Naqshabendy et al, that compares the use of IRT and Histopathology in order to study the use of IRT in the detection of pneumonia [Al-Naqshabendy.A-2024] that indicates that pre-slaughter screening of animals in slaughterhouses using IRT is an effective strategy to detect possible infections.

Monitoring of the wound healing process using infrared thermography has been previously studied in animals, both for wounds without active infection and for the study of possible infections [Paterson.W-2011]

Studies have also been conducted in the use of infrared thermography for the diagnosis of mastitis in animals [Hovinen.M-2008, Gayathri.SL-2024] and viral diseases [Schaefer-2004].

2.5.2. Muscle Injuries

Skeletal muscles are the active components of the musculoskeletal system. Muscles are attached to bones and are contractile organs that, when contracted, provide the force that the skeleton needs to move. They also participate in supporting the body, either by fixing or stabilising joints. The muscles also participate in the movements of the thoracic and abdominal cavities, for example, being part of breathing. The muscles are widely irrigated by the vascular system, so an injury to this system will cause an alteration of the vasculature, and certain pathologies can be detected by infrared thermography, as we will see below.

In early studies, it was shown that there was an increase in temperature in the spots where there was pain in muscle insertion [Binder.A-1983]. In human sports medicine, the distribution of skin temperature during and after physical exercise has been studied[Ferreira.JJ-2008, Merla.A-2010].

In addition, it has been proven that performing an intense sport, such as running a marathon, causes damage to muscle fibers, which can generate an escape of muscle proteins into the bloodstream and its possible complications, such as muscle soreness, rhabdomyolysis or acute kidney disease [Halsen-SL-2014, Mujika.I-2017]

Muscle damage can be assessed analytically by analyzing some blood values such as Creatine Kinase (CK) and Lactate values [Ramos-Campo.DJ-2016, Rubio-Arias.JA-2019, Rojas-Valverde.D-2019]. The use of infrared thermography has been proposed in several studies as an alternative method to assess muscle damage, but the results are contradictory [Fernandes.A-2017, da Silva.W-2018, Priego-Quesada.JI-2019a, Pérez-Guarner.A-2019, Priego-Quesada.JI-2020].

In veterinary medicine, studies in sports have also been carried out with IRT, such as the evaluation of the musculoskeletal conditions after high intensity exercise [Soroko.M-2021].

Studies show a temperature difference following treatment involving various physiotherapeutic techniques [Grotto.D-2023, [Díez.I-2025]. It has also been observed that manual therapies, such as massage, induce changes in the surface temperature not only in the treated area but also in adjacent, non-manipulated regions, suggesting alterations in peripheral blood flow [Sefton.JM-2010], also being an useful technique to verify the decrease in thermal asymmetry between contralateral body regions [Rosales-Hernandez.A-2022]. However, it is important to highlight the evident lack of both quantitative and qualitative data regarding the long-term thermographic evaluation of these treatment effects.

In addition, its use in rehabilitation is being studied, proving to be an effective technique in assessing microcirculation [Hegedűs.B-2018].

Purohit and McCoy [Purohit.RC-1980] described in early studies the effective use of infrared thermography to assess inflammatory processes in horses both quantitatively and qualitatively. In dogs, this technique has also been proven useful to assess circulatory changes [Casas-Alvarado.A-2022].

In horses, there are thermographic studies on several conditions, identifying areas of inflammation or altered blood circulation [Kastberger.G-2003, Westermann.S-2013]. For example, on the influence of the saddle on the horse's back [Soroko.M-2019], the physiological response of horses to training [Masko.M-2019], as subclinical inflammation of the superficial digital flexor tendon in racehorses [Soroko.M-2013], early stages of laminitis [Smith.W-1964, Eddy.A-2001, Ciutacu.O-2006, Cetinkaya.M-2012, Okur.S-2023], as well as assisting in the diagnosis of various pathologies, such as tendinopathies [Turner.TA-2001, Rozendo da Silva.B-2024], knee inflammation and ligament tear [Purohit.RC-2006, Dogan.E-2023], carpal and tarsal joints [Turner.TA-2001, Orhun.ÖT-2021], dorsal metacarpal disease [Soroko.M-2011], back lesions [Masko.M-2021], like neuromuscular diseases [VonSchweinitz.DG-1999] and vertebral disease [Purohit.RC-1980a], among others.

Hoof abnormalities are a common condition that affects both their performance and overall well-being. This type of problem is not limited exclusively to horses but is also common in other livestock animals, which has prompted numerous thermographic studies of these abnormalities. [Bobić.T-2025]

In dogs we can find less studies related to muscular and tendinous lesions than in horses, but is also be an interesting tool to observe effects in the body produced by exercise [Soroko.M-2021, Pichová.K-2023], alterations in the cranial cruciate ligament [Igna.C-2017, Cain.AA-2023], and others. It has been shown to be a useful technique for assessing muscle pain in cats [Vainionpää.MH-2013].

There are several studies in the effect of rehabilitation modalities in dogs [Albuquerque.SPD-2021] and horses, like electric acupuncture [Dai.S-2025], magnetic field therapy [Jastrzebska.E-2021] and laser therapy [Zielinska.P-2023].

2.5.3. Joint Injuries

Joint injuries can have a variety of causes, including physical trauma, degenerative processes such as osteoarthritis, infections, immune-mediated disorders, or even the presence of tumors.

Osteoarthritis (OA) is a degenerative joint disease that can affect all joints and is associated with degeneration of the articular cartilage and meniscus, subchondral sclerosis and inflammation of the synovial membrane, with this inflammation being a central factor in the pathophysiology of this disease.

Given the presence of inflammation of the synovial membrane in OA, especially in the early stages of the disease, tissue edema and fibrin deposition occur, which can be observed clinically as joint swelling and the presence of pain [Lee.DM-2001, Scott.DL-2010, Smolen.JS-2016], therefore, changes in blood flow occur, so the structures of the subcutaneous tissue are altered, and it is reflected in the surface temperature [Salisbury.RS-1983, Kastberger.G-2003, Hildebrandt.C-2010, Hildebrandt.C-2012] . This can be

evaluated by using infrared thermography, this technique being useful both for the diagnosis and for monitoring the pathology and its response to medical treatment [Will.RK-1992, Ring.EFJ-2004, Brenner.M-2006, Frize.M-2009, Petrigna.L-2024].

In human medicine, it has been observed that in knees with osteoarthritis (OA), the presence of radiological alterations is associated with an increase in surface temperature, which positions thermography as a reliable method for evaluating joint inflammation [Denoble.AE-2010]. Furthermore, the temperature of knees affected by OA is influenced by both the degree of joint degeneration and the presence of symptoms. Symptomatic joints, especially those with predominant lateral pain, present higher temperatures and a different thermal pattern than asymptomatic knees, with the medial area showing the most marked temperature changes in the most severe cases of OA [De Marziani.L-2025].

In a study conducted by Varjú et al. [Varjú.G-2004], it was observed that the surface temperature of joints with osteoarthritis was higher at the onset of the disease and decreased as the pathology worsened radiologically, which is due to the inflammatory phase of the disease. Infrared thermography has been used to assess the efficacy of anti-inflammatory drugs in people with rheumatoid arthritis.

In Veterinary Medicine, OA is the most prevalent joint disease in dogs, with an estimated prevalence of 20% [Allan.GS-2007, Innes.JF-2012, Anderson.KL-2018, Bliss.S-2018]. Few studies have been conducted on the use of infrared thermography in OA in dogs, in a study by Alves et al 2023 [Alves.JC-2023] , they did not find a strong correlation between thermographic images and the presence of pathology in working dogs.

In livestock, its effectiveness has been studied for the diagnosis of septic arthritis in cows [Cockcroft.PD-2000].

2.5.4. Neurology

In human medicine, nerve injuries have been classified into three groups. The first is a total interruption of all nerve fibers, which can be seen as an increase in temperature surrounded by a hypothermic area. The second is a partial alteration of sympathetic function, in which a diffuse increase in temperature with surrounding hypothermia is noted in the injured area. Finally, an alteration that causes interruption of the surrounding nerves that maintains sympathetic function in the nerves that remain intact, a central hypothermic area surrounded by an area with an increase in temperature is observed [Uematsu.S-1985a].

Infrared thermography has been used to evaluate thermoregulation after an injury to the peripheral nervous system, in which images have been taken after cooling an area and monitoring how it returns to normal temperature, with areas with nerve injury taking longer to recover their physiological temperature [Ruijs.AC-2008]. This technique has also been used to study dysfunctions in peripheral nerves [Brelsford.KL-1985]. Studies have been conducted in human medicine in which infrared thermography is used as a complementary diagnostic method for the diagnosis of lumbosacral radicular pain [Liu.H-2024].

Infrared thermography has been proven as a sensitive and specific tool to assess the success or failure of locoregional blocks in human medicine [Zhang.S-2021, Ritt.MWJ-2023], while in dogs it's not a proven technique [Küls.N-2017].

Many nociceptive pathologies or those involving the presence of neuropathic pain are associated with changes in the thermal distribution of the body [Herry.CL-2004]. In addition, the use of this technique is also proposed in the study of diabetic neuropathies [Bagavathiappan.S-2010, FausCamarena.M-2023].

It has also been studied as an effective tool to assess the presence of intervertebral disc disease (IVDD) in dogs [Grossbard.BP-2014, Zaha.C-2025].

2.5.5. Oncology

Studies have been performed using infrared thermography in mice and humans indicating increases in temperature that could be useful in detecting some types of cancer, especially if they produce nitric oxide, which causes vasodilation and therefore increases temperature [Button.TM-2004]. In some regions, with necrotic tissue or depending on the type of tumor, like primary glial tumors or soft tissue lipomatous tumors, can appear hypothermic respect the surrounding tissue [Shimatani.A-2020]. This can be useful to monitor with IRT, that is becoming a promising tool in this area [Pokharel.A-2024].

In human medicine, even though this technique is not accepted as the only diagnostic technique, thermographic imaging can be used for risk assessment of developing breast cancer [Ravind.R-2023]. When used as an integrated technique, it's been studied that the accuracy to detect breast cancer is 80-95% with 100% sensitivity and 70% specificity, while on the other hand, the accuracy rate of clinical examination has an accuracy rate of 60-70% [Ng.EY-2008]. There are further studies using this technique as screening for breast cancer diagnosis [Kandlikar.SG-2017] and the localization of malignant

melanomas with thermography, after convection heating and cooling of the skin [Herman.C-2011].

In small animals, neoplasms exhibit great diversity in their composition and behaviour. Furthermore, the temperature of these tumours varies depending on the region of the body in which they are located. Due to this heterogeneity, further studies are needed to better understand how factors such as the histological type of the tumour and its clinical-pathological particularities (such as size, aggressiveness and stage) influence the observed thermal pattern [Gerardi.D-2024]. This will allow a more precise assessment of its behaviour and possible diagnostic or therapeutic implications [Holanda.AGA-2023].

There are also studies that evaluate the use of IRT in mammary gland tumors, finding temperature differences between tumors and healthy animals [Pavelski.M-2015].

2.5.6. Surgery

In human medicine, Infrared thermography has been used intraoperatively in order to monitor blood flow in different situations. Flap loss is one of the most feared complications after flap surgery. Traditionally, monitoring of these flaps is performed through a clinical evaluation that includes observation of tissue coloration, temperature, capillary refill, and turgor [Shen.AY-2021]. Thermography can provide information to the surgeon on the reperfusion of flaps [De Weerd-2006.L, Polidori.G-2017, Klama-Baryła.A-2020]. It has also been a useful technique monitoring skin perfusion in breast reconstruction [De Weerd.L-2009a, Verstockt.J-2020, Thiessen.FE-2020].

Studies have identified differences in the thermal pattern in response to a surgical injury, observed in the incision area between days 1 and 4 after

surgery, observing that non-infected surgical wounds showed an increase of approximately 1.5°C in the perilesional area during the first 48 hours after surgery [Childs.C-2019, Siah.CJR-2019]

Angiographic studies have shown that skin temperature is directly correlated with global tissue perfusion [Nagase.T-2011]. Therefore, it is not expected that patients with peripheral arterial disease present alterations in the distribution of skin temperature, especially in the plantar region [Ilo.A-2020].

In Veterinary medicine, thermography has been used to monitor tissue grafts in injuries caused by burns, malformations or oncological surgeries, where adequate blood perfusion is essential. In this area, thermography can quickly detect any vascular compromise in the use of flaps, as suggested by [Tenorio.X-2009], who studied 23 Wistar rats.

2.5.7. Fractures

When there is a fracture, at the site the body suffers a vascular interruption, followed by an inflammatory response [Reed.C-2021]. This acute inflammatory response increases the cytokines, which causes an increase of metabolism, resulting in a greater temperature of the tissue [Haluzan.D-2015]. After that, there is vascular ingrowth and neoangiogenesis, so there is growth of blood vessels, more cartilage production and osteoblastic cell action in order to start bone repair [Fazzalari.N-2011]. This process causes a change in the thermal pattern that we can study with infrared thermography [Corte.ACR-2016, Reed.C-2021].

The majority of studies have been performed on upper extremities [Haluzan.D-2015, Curković.S-2015, Reed.C-2020], being children the perfect population to implement the technique, in order to try and avoid X-ray radiation

and its negative effects. Sanchis-Sánchez et al. [Sanchis-Sánchez.E-2015] highlight that IRT is a promising technique for fracture detection, with a sensitivity of 91%, a specificity of 88% and a predictive value of 95%. They also emphasize that the size of the lesion is a key factor in the discriminatory capacity of the method [Sanchis-Sánchez.E-2015]. It has been proven effective in ruling out pediatric fractures in cases of acute trauma [Der Strasse.WA-2022].

It's been studied that closed fractures cause a temperature increase at the lesion site of the bone, this is due to the increased blood flow of the lesion [Haluzan-2015]. This temperatures can vary depending on the severity and decrease depending on the blood flow, if its being reduced or by an absence of regenerative progress [Haluzan.D-2015]

There are studies that show that bone repair and nonunion can be monitored by infrared thermography [Morasiewicz.L-2008, Díez.I-2018b, Auf der Strasse-2020].

2.5.8. Reproduction

Early detection of pregnancy improves reproductive efficiency, increasing productivity and optimizes agricultural economics, especially in dairy farms [Balhara.AK-2013, Barile.VL-2021]. In contrast, delay in identifying non-pregnant animals significantly increases management and financial costs, threatening the economic viability of dairy farming [Yadav.R-2019].

Fertility is not only studied in females, but also in males [Kastelic.JP-1995, Kastelic.JP-1996, Gabor.G-1998, Coulter.GH-1988]. The normal pattern of testes has been studied in bulls and stallions [Ramires-Neto.C-2013]. In sheep, with the use of thermal cameras, Caprano et al. [Capraro.GA-2008]

were able to detect significant cooling in testes and diagnose testicular torsion, as well as to evaluate fertility.

2.5.9. Stress and animal welfare

In veterinary medicine, one of the most promising applications of infrared thermography (IRT) is the evaluation of animal stress and welfare, as it enables non-invasive assessment, thereby minimizing the stress caused by handling. IRT has been more extensively studied under heat stress conditions compared to cold stress scenarios [Hernández-Sánchez.RC-2024].

Research has demonstrated the feasibility of real-time monitoring of heat stress responses in dairy cattle [Pereira.ALV-2024], as well as the detection of cold stress effects [Verkerk.G-2004]. Moreover, IRT has been used to evaluate the thermal properties of livestock resting surfaces, contributing to improved housing conditions [Lendelova.J-2005].

Additionally, infrared thermography has been employed to study cattle responses to both hot and cold branding [Schwartzkopf-Genswein.KS-1997]. In poultry farming, thermal comfort has been assessed using this technique [Bottcher.RW-1992; Hernández-Sánchez.RC-2024], and it has also been used to detect stress responses in laboratory animals, such as rats [Vianna.DML-2005].

In cats, IRT has been explored as a method for assessing stress, but its reliability remains questionable, and further studies are needed to validate its use in this species [Szenczi.P-2023].

3. Hypothesis

As previously stated, temperature has been studied in medicine and applied its relation to health or sickness. First being measured by feeling of the skin, then the development of thermometers and finally applying IRT.

IRT is based on the infrared emission of the skin, being symmetrical in a healthy body [Vardasca.R-2012], but this symmetry can be altered by several pathologies, like infection, inflammation... and these changes can be detected by thermal cameras.

There are many studies in human medicine and IRT application. As mentioned above, studies in veterinary medicine are mainly focused on cattle, horses and wildlife, because of their economic value as produce and the need to avoid contact with wildlife animals to preserve their behaviour and conditions. When it comes to small animal veterinary (cats and dogs), there is a lack of studies, noticing an absence in protocols of using this technique as a useful tool in the veterinary daily clinic.

IRT offers several advantages over other imaging diagnostic techniques, making it particularly valuable for potential use in small animal medicine.

The use of thermal cameras is fast and innocuous, also is objective as it provides a quantitative register of the thermal asymmetry, contrary to other methods, like palpation by a trained physician.

Unlike other clinical imaging techniques, such as radiography, the camera does not emit, it is a receiver of electromagnetic radiation in the thermal infrared range, which is naturally emitted by any object due to its temperature. Therefore, it is harmless for the patient, the guardians and the health staff of the centre.

It involves less stress as it does not require patient manipulation. Studies can

be carried out in a standing position without approaching the patient.

It is complicated to extrapolate the protocols and studies in human medicine, as it implies for the patient to remain still and that is not an option with most of the dogs and cats.

The **hypothesis** of this study is that IRT could be a useful technique for the daily practice of the small animal clinician in evaluating different pathologies. It could be used as:

- A diagnostic element of pathologies that include vascular alterations, such as inflammation or infection.
- A predictor element before clinical signs appeared, like low grade inflammation or early stages of infection.
- It could also be used as an adjuvant technique to other imaging diagnosis techniques.
- It could be applied to monitoring the evolution of pathologies or surgical interventions.

4. Objectives

The main **objective** of this thesis is to establish the use of IRT as a useful element in the daily clinic of small animal veterinary medicine.

To achieve this objective, there are several proposed **specific objectives**:

1. Establish an imaging protocol in which no standard patient positioning is considered, as animals, unlike humans, do not always maintain a single posture and most cannot avoid moving during the study.
2. Define the areas of interest (ROI) of the study to analyse the heat map of healthy subjects and those with pathology, in a reproducible manner.
3. Determine the study variables in the ROI analysed that are most appropriate for their characterisation.
4. Establish the thermographic pattern in the case of the healthy subject to assess the possible thermal symmetry between contralateral parts of the body.
5. To establish the thermographic pattern of the athletic dog, as a special case of the healthy dog, and the expected difference between contralateral parts of the body.
6. To study the thermal alterations in patients with various pathologies and compare them with the pattern of the healthy subject.

5. Material and methods.

5.1. Type of study

This study is a prospective study in animals from various centres in the Valencia area.

The thermographic imaging protocol is designed for dogs and cats. As it is a non-invasive and non-injurious procedure, the Conselleria de Agricultura, Medi Ambient, Emergències Climàtiques i Transició Ecològica (Regional Ministry of Agriculture, Environment, Climate Emergencies and Ecological Transition) authorised the study provided that informed consent was given by the animals' guardians. This consent is attached in annex 1.

All patients participating in this study received veterinary care and a complete clinical veterinary examination was carried out by the doctoral candidate, as well as the relevant complementary diagnostic tests for each case, and the diagnosed pathologies were treated.

The thermographic images were contrasted with other imaging tests, such as conventional photography, radiography, ultrasound and CT when available.

5.2. Inclusion and exclusion criteria.

All patients, both healthy and sick, that come to the consultation and complete the diagnostic protocol, as well as the protocol for check-ups, have been **included**. This criterion arose as a result of the problem of obtaining patients who complete the protocols correctly since, being private medicine, it is not always feasible to carry out all the necessary diagnostic tests in all pathologies, as there is a financial limitation or reluctance on the part of the guardians.

Moreover, in some cases, follow-up is not possible due to a lack of commitment on the part of some guardians. This is why the sample of patients, although large, is divided into different pathologies with a smaller caseload and not into a single pathology with a larger number of patients.

As for the **exclusion** criteria, patients who did not complete the diagnostic protocol or did not attend the scheduled check-ups were not included in the study, as well as those who were soiled by dirt or mud and it was not possible to clean them prior to the study, due to time or behaviour, and patients who came to the consultation wet and it was not possible to dry them prior to the study.

5.3. Case studies

The study sample included 148 dogs, ranging in age from 2 months to 11 years and weighing between 2.5 and 35 kilograms. Several breeds were studied and the patients were examined in veterinary clinics and canine sports centres in Valencia.

For these patients, different regions of interest (ROI) were analyzed according to their study group, which includes:

- 44 healthy dogs.
- 46 athlete dogs (Athlete dogs are considered healthy animals, without any pre-existing pathologies. However, they are classified in a separate group from the healthy dogs per se, as their high level of physical activity could result in specific characteristics.)
- 58 patients with various pathologies. Of these, 24 present acute pain after trauma, 22 with pathologies that produce chronic pain such as arthrosis, 5 with IVDD and 11 with neoplasms.

In all healthy and athlete dogs, the following common regions of interest (ROI) were measured: phalanges of the thoracic limb, carpus, forearm, elbow, shoulder, phalanges of the pelvic limb, tarsus, gastrocnemius, quadriceps, and biceps femoris.

For the healthy dogs, the shoulder region was included, while in the athlete group it was not measured due to the predominance of long-haired breeds, which made this area challenging to assess.

These ROI are illustrated in Figure 5.3.1:

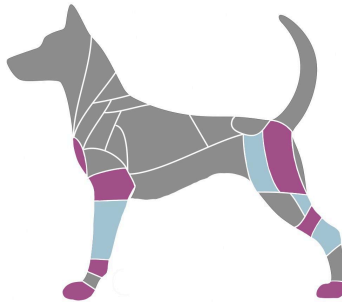


Figure 5.3.1: ROI studied in healthy dogs, in athletes the same ROI are studied except for the shoulder.

In patients presenting pathologies, the ROI is specifically selected and studied for each case, which are described in Table 5.3.1.

Table 5.3.1: ROI studied per patient in each group studied. Mean (Temp_mean), maximum(Temp_max), minimum temperatures (Temp_min) and standard deviation in degrees Celsius (°C) were recorded for each region of interest (ROI) from each patient.

Acute		Chronic		IVDD	
Nº cases	Location	Nº cases	Location	Nº cases	Location
7	Carpus	10	Espondilosis deformans	5	Spine
4	Tarsus	3	Tarsus	Oncology	
4	Phalanges	2	Hip	Nº cases	Location
3	Cuadriceps	2	Knee	4	Mammary gland
2	Shoulder	1	Shoulder	2	Linfoma
1	Chin	4	Hip	2	Tail
1	Longissimus Dorsi			1	Mastocitoma
1	Oblique			1	Eye
1	Gluteus			1	Phalange

For this study, the temperature comparison between homologous zones in each animal was analysed whenever possible, and when no homologous zone was available, a reference area was used.

As an example, the comparison between 2 homologous zones of the carpus is shown in figure 5.3.2. This figure shows the dog's carpus in visible and thermal photography. The thermal images show the temperature distribution in the mentioned area, in which we can see the warmest areas in red and yellow (where there is more vascularization), and the cooler areas appear blue and green (reflecting less vascularization). It is observed that the thermal pattern of both extremities is asymmetrical, indicating a difference in blood flow and temperature in both legs, in this case, due to inflammation post trauma.

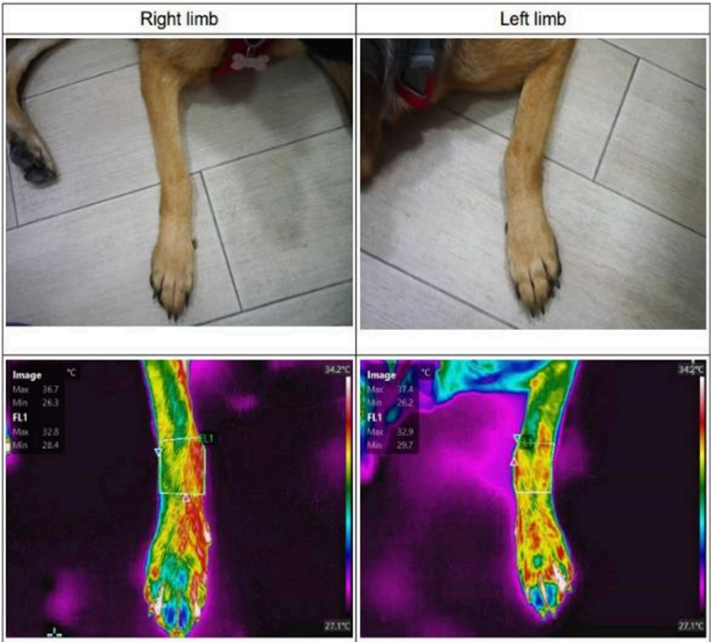


Figure 5.3.2: Example of the selected ROI. You can see the conventional photograph (top) and thermographic image (bottom) of a German Shepherd's carpus.

In addition to the population initially selected for the study, other patients have been identified who, due to their particular characteristics or the relevance of their cases, deserve a more detailed analysis. These patients, although they can be found both within and outside the previously studied group, present traits or conditions that make them particularly interesting for the research. For this reason, a detailed or individualised study of their clinical cases is considered appropriate.

The decision to conduct a more in-depth analysis in these specific cases is largely justified by the limited availability of the population in the study setting. With a limited number of patients, it is essential to maximise the value of each observation and to obtain as much information as possible. By analysing these particular cases in depth, patterns or details can be uncovered that might otherwise be missed in a more generalised analysis.

In addition, this approach allows exploring clinical variations that may not be adequately represented in the original sample. This not only enriches the understanding of the phenomenon under study, but also contributes to a more complete and accurate characterisation of the condition under investigation. Therefore, the individualised study of these cases not only complements the general findings, but also helps to build a more robust and detailed frame of reference, especially in settings where the available population is limited.

5.4. Material

Images are acquired with two different cameras from different manufacturers: Fluke Ti125 and FLIR I7.

Features Fluke Ti125 thermal imaging camera:

- Detector resolution: 160x120 Pixel.
- Temperature range -20 → +350°C.
- Thermal sensitivity ≤ 0.10 °C at a target temperature of 30 °C
- Spectral range 7.5 μm to 14 μm (longwave)
- Field of view: 22.5°H x 31°V. Minimum focusing distance 15cm.
- Spatial resolution 3.39 mRad
- Maximum temperature measurement accuracy $\pm 2\%$.
- IR-OptiFlex™ focusing system (free focus and manual focus)
- Capture or refresh rate 9Hz
- Display 3.5 inches diagonal (portrait format)
- Colour alarms High temperature, low temperature, isotherm
- Standard palettes Blue-red, greyscale, inverse greyscale, high contrast, hot metal, ironbow, amber, inverse amber
- Ultra contrast palettes Blue-red, greyscale, inverse greyscale, high contrast, hot metal, Ironbow, amber, inverse amber
- 2 megapixel visible camera
- Laser pointer
- Emissivity and transmittance correction
- Reflected background temperature compensation.
- Voice annotation (audio).
- Weight 726gr

Features FLIR I7 thermal imaging camera:

- Detector resolution: 140 x 140 pixel.
- Temperature range -20 → +250°C
- Thermal sensitivity 0.10 °C
- Spectral range 7.5 µm to 13 µm
- Field of view: 25° x 25° Minimum focusing distance 0.6 m.
- Spatial resolution 3.71 mRad
- Maximum temperature measurement accuracy ± 2%.
- Fixed focus
- Capture or Refresh Rate 9Hz
- 2.8' LCD colour display
- Iron, rainbow and black/white colour ranges
- Variable emissivity correction from 0.1 to 1.0
- Automatic reflected background temperature compensation, depending on reflected temperature input.
- Weight 365g

The images were processed with the Smart View 3.2 software for the Fluke camera and Quick Report for the FLIR i7. Images were processed, when needed, with ImageJ software (www.imagej.net). During the following sections, we will describe the image acquisition and processing protocol, as well as the statistical analysis.

5.5. Source of information

In order to carry out this work, a bibliographic search was previously carried out, reviewing the documentation related to veterinary medicine and human medicine.

This search was carried out using various databases, including the two main search fields (thermography in human medicine, thermography in veterinary medicine): Pubmed and Google Scholar.

The search was not limited to particular dates, but the most recent articles (last five years) were reviewed, given their greater impact on the current thermographic technique,

The keywords used were: Thermography, veterinary, pathology, dog, cat, horse, human.

5.6. Methodology of study

Patients that were classified as healthy or with specific pathologies were admitted to the veterinary center without any specific condition. They were asked if they were interested in joining the study, and upon agreeing, they began the process. All interested guardians joined the study with their pets. If pets did not meet the established criteria, they were not included in the final study. Appointments were scheduled in advance during the initial visit, and the diagnostic protocol was followed according to each patient's disease.

This protocol included a series of tests and evaluations designed to ensure an accurate diagnosis and proper monitoring of the pets' health status.

To study the athletes, the doctoral student contacted several Agility training centers, seeking to carry out the study with the participants of this discipline. The most representative centers were selected and coordinated with the coaches to plan the study sessions. All guardians were exhaustively informed about the objective of the thermographic study, as well as the methodology and the possible benefits of the results. The information provided included details on how the study would be conducted, the length of the sessions, and how the data collected would contribute to improving the understanding of the health and performance of canine athletes.

Additionally, we ensured that guardians understood the importance of their participation and how the study results could influence their pets' future training and care practices. They were guaranteed data confidentiality and offered access to the results of the study, allowing them to directly benefit from the findings. Collaboration between the training centers and the research team was key to carrying out the study efficiently and effectively, allowing for broad and representative data collection.

5.7. Data collection

The collection of patient data is always carried out in the same order, to optimize consultation time and carry out diagnostic studies more efficiently.

The visit begins by acquiring the patient's identification data and signing the informed consent form: patient's name, guardian's name and surname, age, sex, race, reproductive status.

After this, the anamnesis is carried out with a complete medical history and lifestyle (if the patient lives in a garden, flat, country, activity...).

Without manipulating the patient, the thermographic examination is carried out and thermographic and conventional images are taken.

Once the thermographic examination has been carried out, the patient can now be manipulated, so the conventional physical examination is carried out, measuring the following constants: Weight, intrarectal body temperature, cardiopulmonary auscultation, lymph node examination, pain, mobility, complementary examinations (traumatological and neurological), and symptomatology associated with their respective pathologies.

If necessary, the relevant complementary tests were carried out, such as imaging or analytical tests for the specific pathology. Then, a definitive or presumptive medical diagnosis is made.

We end the visit by prescribing the necessary medical treatment in each case: drug, start and end dates, dosage and associated nutritional or nutraceutical supplements.

5.8. Image acquisition protocol

An imaging protocol is established whenever possible. In exceptional cases, images were taken in different facilities, always trying to maintain the same conditions (temperature and handling). See Figure 5.8.1 below for an example of the positioning during thermographic study.

Protocol:

1. The thermal camera was turned on 10 minutes before the study began.
2. Patients are acclimatised in a room at 20-25°C for 15 minutes [Marins.JCB-2014], without restraints such as a harness or collar, and without being handled by their guardians or veterinary staff. The room had the air conditioner or heater off and no electronic devices connected to the area of the study. Also, the areas where the images were taken had no pipes or decorative elements.
3. Patients should come clean and brushed. It's been studied that brushing dirt from the hair coat as a standardized procedure, provides a more uniform image of its thermal pattern [Eddy.A-2001, Autio.E-2006, McCafferty.DJ-2007a].
4. The thermographic study is carried out prior to any physical examination or manipulation.
5. The coat is not handled. If shaving is necessary, the entire region of interest is shaved with a certain margin so as not to modify the thermal pattern [Loughin.CA-2007]. After this, the skin is acclimated for 15 minutes before imaging.

6. Patients are required not to have eaten a large portion of food and not to have exercised for at least two hours prior to the thermographic examination, as studies in human medicine have shown that some factors can modify blood circulation, such as smoking, alcohol or caffeine intake, heavy meals, exercise or physiotherapy techniques [Vardasca.R-2012].
7. Camera is positioned perpendicular to the region of interest (ROI), and all images were taken at the same distance and position within the same study (meaning that the position or distance could vary between patients but never within one patient).
The distance between the patient and the camera was approximately 1 meter in larger areas (like the back) and 0,5 meters in smaller areas (like the carpus).
8. After the thermographic study, the conventional physical examination is performed, as well as the taking of constants, including the basal temperature, which is measured in a standard intrarectal manner.

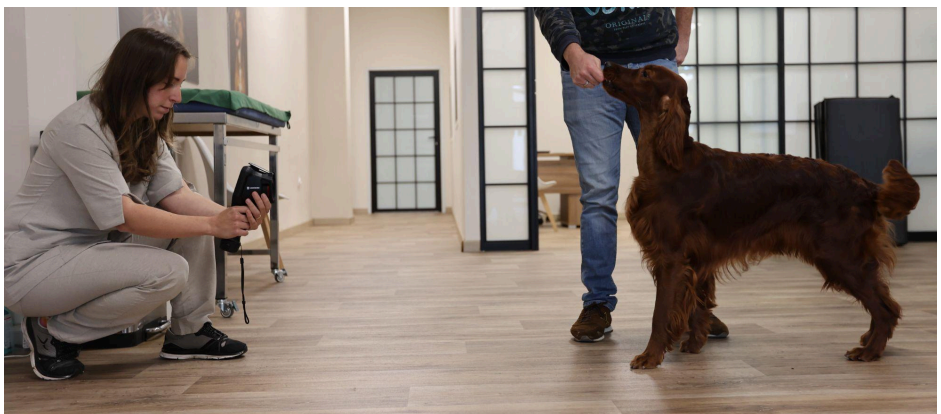


Figure 5.8.1: Positioning in order to take the thermographic images with the patient, the guardian and the doctoral student carrying out the study.

5.9. Image processing protocol and palette selection

The method of study of the images was to compare the contralateral parts of the body, so we are able to detect the thermal asymmetry secondary to different pathologies.

The general protocol mentioned above could vary depending on the patient and the study area, but the fixed criteria is that, within one patient, all images were taken under the same conditions (distance and position mainly).

ROI were defined and analysed by the author, to ensure consistency.

The ROI is selected and used essentially by comparing contralateral parts. The ROI selected was always the same for the same patient to ensure continuation of the measures.

In more specific cases, the ROI are selected at the discretion of the imaging veterinarian and according to the needs of the case, such as for example the assessment of a hypothermic area in the intervertebral spaces for the localisation of neuropathy.

From every patient, several measures were taken: Mean temperature, maximum and minimum from every region of interest (ROI), being measured in Celsius (°C).

In order to process the images, we would:

All thermographic images were analyzed in their respective formats: .IS2 and RJPJ (both proprietary formats from FLUKE and FLIR respectively that do not correspond to a photographic image and where each pixel represents a temperature value with decimals, rather than a grey or colour tone). Due to the

unique data structure in these formats, specialized software is required to interpret and process the images, as mentioned in 5.4.

When selecting a colour palette, the choice is not fixed, and various palettes can be applied to the images.

As seen in Figure 5.9.1, color palettes are graphical representations that assign different colors to the temperatures captured by the camera, facilitating the visual interpretation of the images.

High-contrast palettes use more pronounced color transitions, allowing us to spot subtle temperature differences, and are especially useful when seeking to quickly identify areas of heat or cold, such as lesions or inflammation in medicine. Low-contrast palettes, on the other hand, employ smoother gradients, helping to identify greater thermal differences, so they are more commonly used in other fields, like industry.

The choice between high and low contrast depends on the objectives of the study and the personnel analyzing the images. However, it is important to remember that these colors do not represent absolute data, as they are relative "false colors." For accurate quantitative analysis, the numerical data provided by the camera must be used.

For this study, a high contrast palette was chosen because it enhances the visual differentiation of temperature zones.

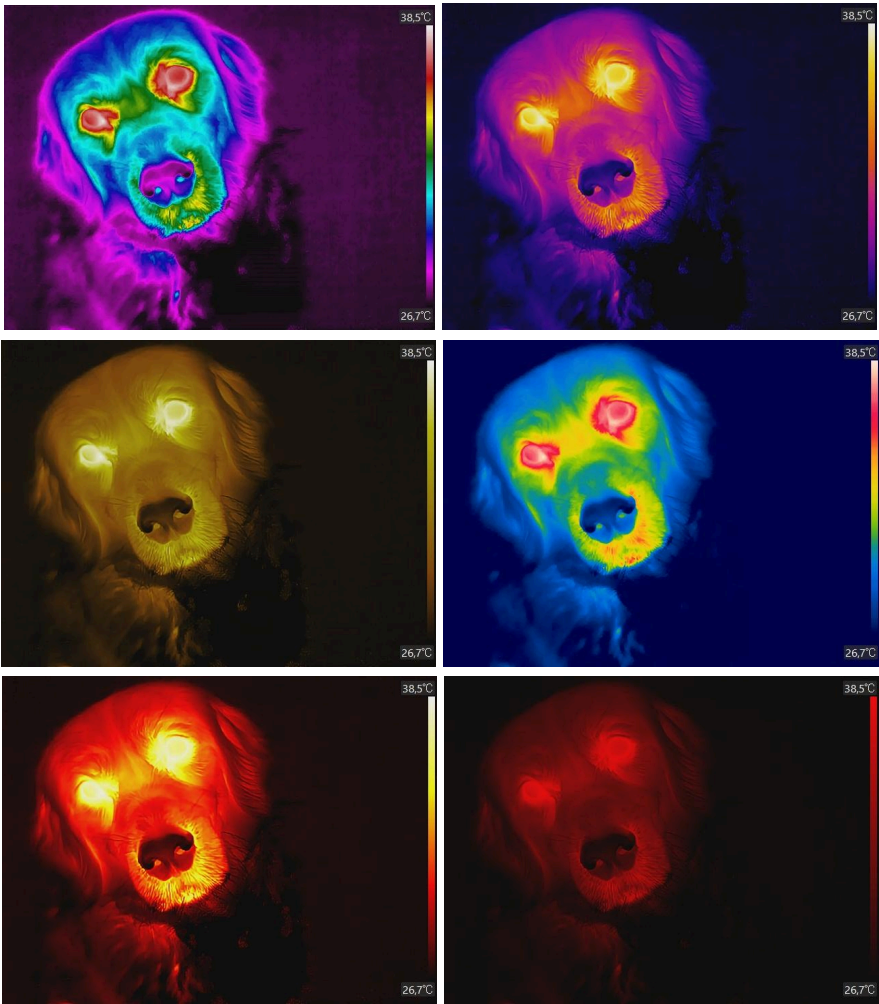


Figure 5.9.1: Comparison of the same thermographic image using different palettes The selected palette for this study, being that the “High Contrast” palette (top left of the image), is a high contrast palette that facilitates a more reliable visual inspection across images by increasing the contrast between areas of the image.

After capturing the images, they were downloaded to a computer and processed with the respective softwares. Within them, parameters such as background temperature and emissivity were adjusted to ensure accurate thermal readings.

A key step in processing was standardizing the maximum and minimum temperatures across all images, helping maintain consistent colour scales and facilitating better visual comparison.

Figure 5.9.2 shows how the way the temperature scale is adjusted in thermal images can affect data interpretation. In the image on the left, the camera automatically applied a scale adjustment based on the range of temperatures captured in that particular image (24,3°C - 38,8°C). This automatic adjustment can result in a visual representation with low contrast and fewer color differences, which can make comparison within the contralateral parts of the body difficult or even cause important temperature details to be missed.

In contrast, in the image on the right, a manual adjustment of the temperature scale was applied by the author (31,6°C - 36,7°C). The manual adjustment is performed to enhance image contrast, with the primary goal of eliminating unnecessary thermal information—such as the background—while preserving the patient's silhouette. This manual adjustment not only increases the contrast and facilitates the visual inspection of the image, but in a study with several thermal images, using the same temperature range for all compared images, ensures that the colors represent the same temperature values in each image. This uniform adjustment results in a clearer and more uniform contrast between cold and hot areas, making it easier to identify thermal patterns and compare structures.

Therefore manual adjustment is essential when you want to compare multiple images or identify specific patterns, as it increases contrast and ensures consistency.

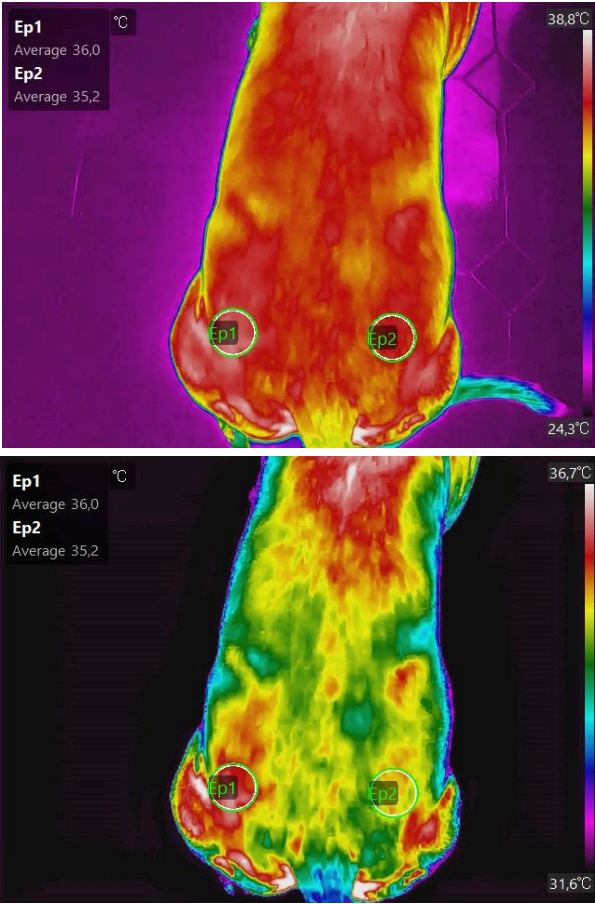


Figure 5.9.2: On the top, the image displays the automatic temperature adjustment by the camera, showing the highest and lowest temperatures captured at the time of image acquisition (24,3°C - 38,8°C). On the bottom, the temperature range has been manually adjusted and reduced (31,6°C - 36,7°C), allowing for a more precise visualization of potential thermal differences without losing the silhouette of the patient.

5.10. Statistical analysis

SPSS® software (SPSS Statistics 21.0, IBM, Armonk, New York, USA) was used for statistical analysis.

According to the central limit theorem, given the conditions of the sample and number of cases, parametric statistics can be considered throughout the study, so to characterise each group of interest (healthy, athlete or pathological) the mean, standard deviation and 95% confidence interval of the values of the thermographic variables in the ROI of each study group were determined.

For the comparison of means between two groups, Student's t-test was used, a specific statistical method for this case. In contrast, for the comparison between three or more groups, the analysis of variance (ANOVA) was used. For multiple comparisons, the Scheffé or Games-Howell procedure is used for independent groups provided that the variances of the Levene test are equal or different; or the Bonferroni test for paired measures. In all cases the test was considered significant for $p < 0.05$ [O'Rourke.N-2005].

The study of the existence or not of thermal symmetry in each study group was analysed by comparing the mean of the mean temperatures (°C) of the contralateral ROI by means of t-Student and regression lines. In the case of the regression lines, symmetry is accepted if the 95%CI of the slope and the ordinate at the origin include 1 and 0, respectively, so that the fit to the line $y=x$ can be accepted.

To establish criteria suggestive of injury, a Receiver Operating Characteristic (ROC) curve is used, which shows the relationship between the true positive rate and the false positive rate as the decision threshold of a binary classification model (e.g. healthy vs. diseased) is adjusted.

In addition, the Area Under the ROC Curve (AUC-ROC) is used as a summary metric of model performance. The AUC-ROC is a numerical value that quantifies the model's ability to distinguish between the two classes. An AUC-ROC of 1.0 represents perfect performance, while 0.5 indicates a performance equal to chance. To assess the discrimination ability of a binary classification model, we use the Youden Index, also known as the J Index, which is a statistical measure used to evaluate the effectiveness of a diagnostic test. It is calculated by adding the test's sensitivity and specificity, and subtracting one from the result. Its value ranges from 0 to 1, where 1 indicates a perfect test and 0 indicates that the test is unable to discriminate between diseased and healthy individuals. It is especially useful for determining the optimal cutoff point for diagnostic tests and for comparing the performance of different tests [Chang.PW-2024].

6. Statistical results.

Once the Regions of Interest (ROI) were established in the Materials and Methods section 5.3, we proceeded to the analysis of mean temperatures. Previously, in a pilot study, different temperature metrics, including maximum (Temp_max), mean (Temp_mean), minimum (Temp_min) and standard deviation (SD), were evaluated to determine which of them provided the most accurate representation of the ROI. The results indicated that the mean temperature was the most appropriate metric to characterise the ROI, as the relatively small size of the ROI caused the maximum and minimum temperature measurements to have spurious or outliers at certain points, compromising their reliability as overall representations of the ROI.

Figure 6.1 shows the histogram of the mean temperature difference between homologous zones (left minus right) of healthy dogs vs. athletes.

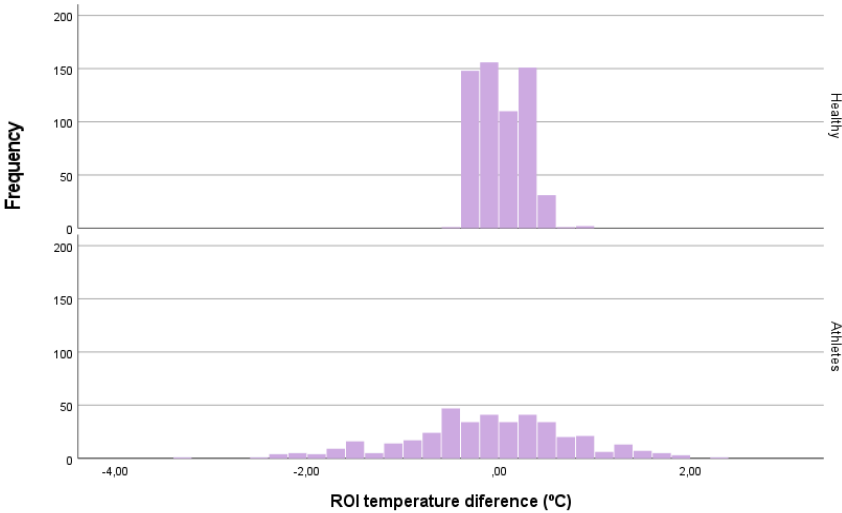


Figure 6.1: Histogram showing the frequency of occurrence of different Temperature Difference values in the ROI studied in healthy and athletic dogs.

Both healthy dogs and athlete dogs show symmetry as the data are evenly distributed on both sides of the central value, 0 , but with greater dispersion in the case of the athlete dogs, with one side having no overall higher temperature than the other.

Figure 6.2 presents two scatter plots illustrating the relationship between the mean temperatures of the contralateral regions of interest (ROI) of the body in two different groups of dogs: healthy dogs and athletic dogs. The comparison between the mean temperature of the left limb (Y-axis) and the mean temperature of the right limb (X-axis) was chosen as the criterion.

In Figure 6.2 a), which corresponds to healthy dogs, the points are clustered around the line of slope 1. This line represents a perfect equality relationship, where there is no difference in mean temperature between the contralateral limbs.

The proximity of the dots to this line suggests that there is a strong correlation between mean contralateral limb temperatures in healthy dogs, indicating that there is no distinction between comparative left vs. right or vice versa, being a random correlation.

On the other hand, in Figure 6.2 b), which represents athletic dogs, a strong correlation between contralateral limb temperatures is also observed. However, compared to healthy dogs, the points in this graph show a larger scatter around the slope line 1. This scatter indicates that, although contralateral limb temperatures in athletic dogs are strongly correlated, there are more marked differences between right and left limb temperatures in this group compared to healthy dogs.

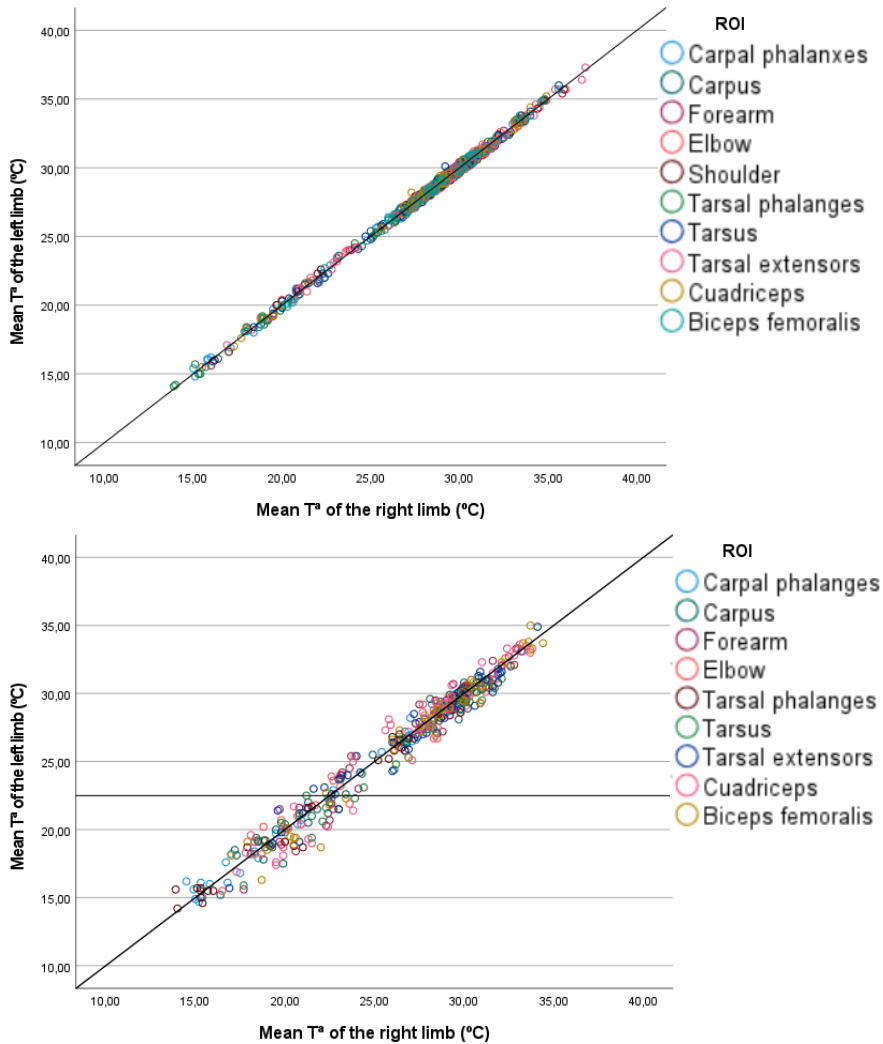


Figure 6.2: a) Comparison between the mean temperature values (°C) of the different ROI of the left limb compared to the right limb in healthy dogs. b) Comparison between the mean temperature values (°C) of the different ROI of the left limb with respect to the right limb in sporting dogs. Greater dispersion than in non-sporting animals

The data presented in the graphical form above are complemented by the numerical information detailed in table 6.1, which includes the confidence intervals (CI) for the ordinate to the origin and slope of the line that best fits the scatter plot data in figure 6.2. Specifically, we note that the confidence interval for the ordinate to the origin includes the value 0, and the confidence interval for the slope includes the value 1.

The fact that the confidence interval of the ordinate to the origin includes the value 0 suggests that, statistically, there is no significant difference in the mean temperature of the contralateral limbs when the effect of slope is not considered. In other words, any deviation from the ordinate could be attributable to natural variability rather than a systematic difference between limb temperatures.

The inclusion of the value 1 in the confidence interval of the slope indicates that the relationship between the mean temperatures of the contralateral limbs is very close to a relationship of perfect equality. A slope of 1 implies that for every unit increase in the temperature of one limb, there is an equivalent increase in the temperature of the contralateral limb. This relationship reaffirms the strong correlation observed in the scatter plots in figure 6.2.

This implies that, for healthy dogs, the inclusion of 0 in the ordinate CI and 1 in the slope CI confirms that the contralateral limb temperatures are nearly equal, supporting the visual observation of the strong correlation and low scatter in graph a) in figure 6.2.

For the athletic dogs, although a strong correlation is also observed, the higher scatter in graph b) of figure 6.2 may suggest a slight variability in contralateral temperatures. However, the inclusion of 1 in the CI of the slope

still indicates that this variability is not sufficient to significantly deviate the slope from a perfect equality relationship.

Table 6.1: It is observed that, in both healthy patients and athletes, the confidence interval (CI) of the ordinate at the origin includes 0 and the slope includes 1, indicating a very strong and proportional linear relationship between the two variables.

	Intercept			Slope			Standardization Coefficient
	Value	CI 95%		Value	CI 95%		
		LL	UL		LL	UL	
Healthy	0,09	-0,06	0,23	0,99	0,990	1,00	0,998
Athlete	-0,06	-0,51	0,39	1,00	0,98	1,01	0,985

CI: Confidence Interval (95%)
LL: Lower Limit of Confidence Interval
UL: Upper Limit of Confidence Interval

To address the extent to which a temperature discrepancy may indicate pathology, one of the aims of this thesis was to determine the distribution of the absolute value of the temperature difference between homologous zones in healthy and sporting dogs. The purpose of this methodology is to define a temperature difference value that is indicative of injury.

In the case of dogs with overt pathology, the temperature difference between the affected and healthy areas is considered with a sign, since both the increase and decrease of temperature in the affected area are equally relevant. On the other hand, oncological patients must be considered separately because the affected areas do not always correspond to specific areas studied in healthy patients, e.g. the breasts.

The histogram depicted in figure 6.3 illustrates the distribution of absolute value differences in temperature in healthy and sporting dogs. In this histogram it can be seen that athletic dogs have a larger scatter compared to healthy dogs, suggesting a wider variability in the temperatures of their contralateral limbs.

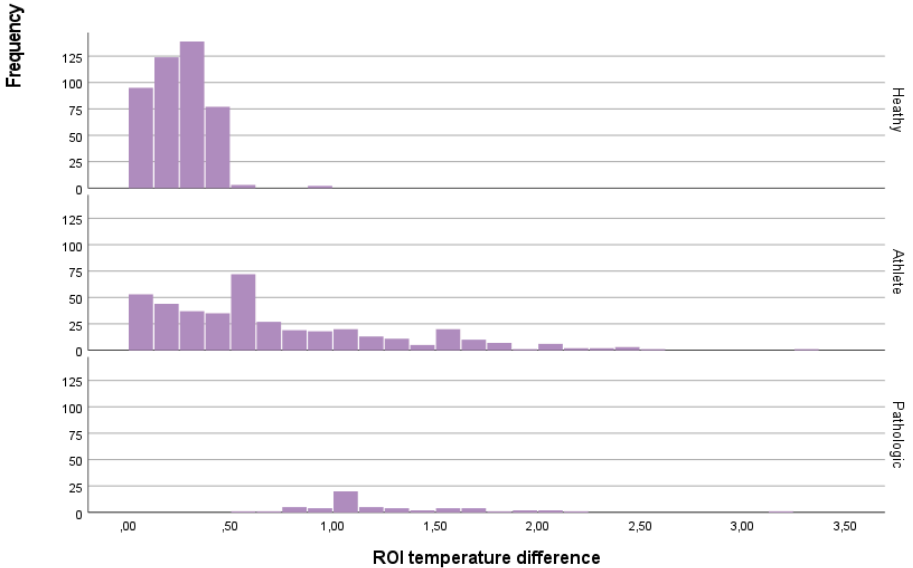


Figure 6.3. Three histograms are presented showing the frequency distribution of a data set for three groups: 'Healthy', 'Athletes' and 'Pathological'. The histogram for the 'Healthy' shows a clustered distribution, indicating a lower dispersion of the data. In contrast, the histogram of the 'Athletes' shows a higher dispersion. Finally, the histogram of the 'Pathological' shows a distribution with low and dispersed frequencies, indicating considerable variability in the data.

In the case of athletic dogs, the greater dispersion in temperature differences may be related to physical stress and micro-injuries that are common in dogs with high sporting activity. This variability requires an adjusted temperature

threshold to account for these normal fluctuations without overdiagnosing injury. These differences may be due in part to paw preference.

In humans, it is estimated that 90% of people are right-handed [Yamashita.H-2018], whereas in dogs there is no clear consensus. A recent meta-analysis found that paw preference is a widespread trait among dogs, with a clear bias toward either the left or right paw on an individual basis. However, when viewed across the population, there is no overall tendency toward one side, indicating the absence of a collective directional bias [Ocklenburg.S-2019].

The next objective of this thesis is to understand the thermal behaviour in the pathological patient group by studying the areas affected by lesions in comparison to the unaffected contralateral part.

This comparison is crucial to determine how lesions alter body temperature and to develop more accurate diagnostic methods based on thermography.

To this end, a scatter plot (Figure 6.4) has been produced showing a comparison between the mean temperatures of the regions of interest (ROI) in the patients in the group with pathologies. In this graph, the temperature of the affected area on the left limb (Y-axis) is associated with the temperature of the same area, but healthy on the right limb (X-axis). The points on the graph represent pairs of temperatures corresponding to these homologous zones.

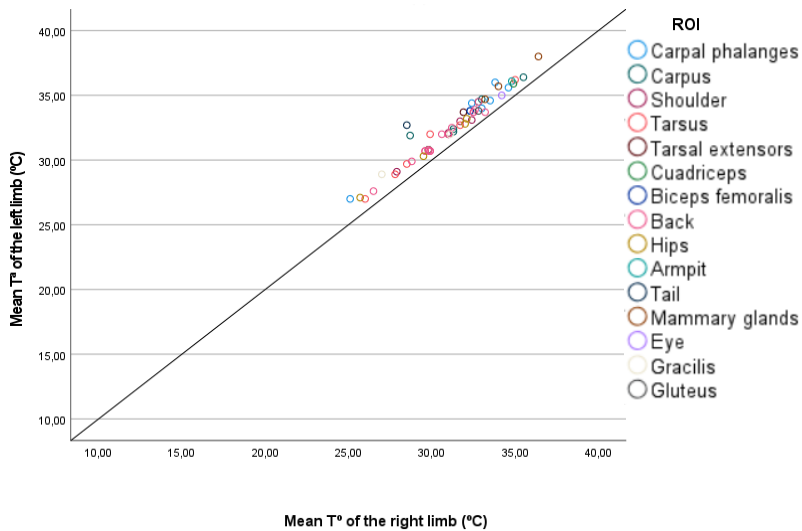


Figure 6.4: Comparison between the mean temperature values (°C) of the different affected ROI with respect to the contralateral healthy part in pathological dogs. The mean temperature of the affected area is higher than that of the healthy contralateral area.

Together with the experimental points, the line with slope 1 and ordinate at the origin has been plotted as a reference.

Looking at the graph, it can be seen that the values are above the line, suggesting that the affected region has a higher mean temperature than the healthy contralateral region.

This pattern indicates that injuries may cause an increase in local temperature, possibly due to inflammatory processes or tissue repair in the affected area.

Expressing the data in figure 6.4 numerically in table 6.2, it can be seen that the value of the ordinate at the origin is 2.4°C, suggesting that the affected ROI have a mean temperature difference of 2.4°C with respect to the healthy contralateral ROI, which is of particular interest, suggesting that a thermal variation of 2.4°C would be compatible with a pathological alteration.

Table 6.2: It is observed that, in pathological, the confidence interval (CI) of the ordinate at the origin does not include 0 while the slope does include 1.

	Intercept			Slope			Standardization Coefficient
	Value	CI 95%		Value	CI 95%		
		LL	UL		LL	UL	
Pathological	2,40 4	0,46 5	4,34 3	0,965	0,90 3	1,02 7	0,972

CI: Confidence Interval (95%)

LL: Lower Limit of Confidence Interval

UL: Upper Limit of Confidence Interval

Furthermore, it is observed that the confidence interval (CI) of the ordinate does not include the value 0, suggesting a significant difference in the temperature of the affected areas compared to the healthy ones. This supports the hypothesis that injuries raise the temperature in the affected region. In contrast, the confidence interval of the slope includes the value 1, indicating that, although there is an increase in temperature, the relationship between the temperatures of the contralateral extremities maintains a linear proportionality.

This is consistent with the initial pathology condition, where a thermal alteration is expected without a drastic distortion in the overall ratio of body temperatures between affected and healthy limbs.

To better understand the differences in mean temperature, a comparison of the regions of interest (ROI) studied in healthy, athletic, pathological and oncological dogs between contralateral body parts is made, and their numerical representation can be seen in table 6.3. The four well differentiated groups can be seen, in which mean temperature differences between contralateral body parts are statistically significant ($p>0.05$).

Table 6.3: Temperature difference between contralateral body parts (°C) in healthy, athletic and pathological dogs.

	N	Dif_Temp (°C)
Healthy	440	0,22 d
Athletes	407	0,70 c
Pathologic	51	1,23 b
Oncology	7	1,90 a

Number of ROI studied (N)

Temperature difference between contralateral body parts (Dif_temp)

Significance (Sig.)

$a>b>c>d$

A difference is considered statistically significant: Sig.= $p<0.05$.

In the above-mentioned table (6.3), a mean temperature difference between contralateral body parts of 0.22°C is observed in healthy dogs, indicating an almost perfect thermal symmetry, which is to be expected in individuals without pathologies.

In the case of athletes, the mean temperature difference increases to 0.7°C , which will be discussed further in the discussion.

Dogs with pathologies show an even greater mean temperature difference of 1.2°C , reflecting significant thermal alterations due to the presence of injuries or adverse health conditions.

The oncology group, as mentioned above, cannot be directly compared with the control group because the areas affected in these cases do not always correspond to the specific areas studied in the other groups. Cancer-affected areas may have unique thermal patterns and therefore require separate analysis for accurate assessment.

These differences in mean temperatures between contralateral parts of the body provide a clear picture of how different health conditions and activity levels affect the thermal symmetry of the body.

To sum up, healthy dogs show almost perfect thermal symmetry, athletes show greater variability, and pathological dogs exhibit significant thermal alterations, which underlines the usefulness of thermography to detect and evaluate different health states.

In the previous case, we have been able to group the dogs into four well-differentiated groups, although it is true that in the case of patients who present pathologies, not all of them behave the same.

Although we have already broken it down in table 6.3, it can be observed that the thermographic method efficiently discriminates between the different groups: healthy dogs, athletic dogs, pathological and oncological patients. In table 6.4 we can count on the novelty that the pathological patients are broken

down according to the pathology for which they came to the consultation, these being acute pain, chronic pain, hip dysplasia and disc disease.

Table 6.4: Classification of the study groups, in which a clear difference is observed between healthy, athletes and oncology, with the corresponding grading between the rest of the groups.

		N	Mean	Standard Deviation	CI 95%	
					LL	UL
Healthy		600	0,22 d	0,13	0,21	0,23
Athletes		407	0,69 c	1,10	0,88	2,91
Pathology	Acute pain	24	1,33 ab	0,57	0,63	0,74
	Chronic pain	18	1,16 b	0,55	1,09	1,56
	IVDD	5	1,16 abc	0,29	0,99	1,33
	Hip dysplasia	4	1,03 abc	0,345	0,57	1,48
Oncology		7	1,9 a	0,34	0,74	1,58

N: Number of patients

CI: Confidence Interval (95%)

LL: Lower Limit of Confidence Interval

UL: Upper Limit of Confidence Interval

a>b>c>d, statistically significant difference p>0,001.

Regarding the information acquired previously, we can now add that athletic dogs present a greater variability in temperature with respect to healthy non-athletic dogs, accompanied by a wider standard deviation, reflecting the

thermal fluctuations due to physical effort. The confidence interval for this group is also wider, indicating a greater dispersion of the data.

In dogs with pathologies (broken down in table 6.4 into the four subgroups: acute pain, chronic pain, hip dysplasia and intervertebral disc disease), a thermal gradient can be observed, showing that not all pathologies behave in the same way. This can be interesting when discerning between pathologies and their severity, as for example in the case of an acute trauma, where the inflammation is recent, it will behave more similarly to an oncology patient, denoting a greater difference in temperature.

Furthermore, oncologic patients, although not directly comparable to the other groups due to the specific nature of the affected areas, show thermal patterns that require separate analysis. This is because the cancer-affected regions may not match the areas assessed in the other study groups.

Next, we will establish the diagnostic criteria for the definitive classification into the different groups and establish the difference in behavior between healthy dogs and athletes, as well as assess from which thermal asymmetry we can consider a thermal alteration as pathological.

In order to establish the diagnostic criteria, a ROC curve is used, as described above, showing the relationship between the rate of true positives and false positives, adjusting the decision threshold to a binary classification model (in this case healthy/pathological).

The AUC-ROC will be used as a performance metric, in which 1 represents a perfect performance and 0.5 a performance similar to chance. To discriminate

between healthy and pathological patients, the Youden index or J index described before is used.

In the study of these curves, we have either positive study areas, which are those that really have the condition that the test is trying to detect, or negative areas, which are those that do not have the condition studied.

In this work, four ROC curves have been carried out, which are described below.

1. ROC1, a comparison between healthy and pathological patients, to determine which thermal difference between contralateral parts of the body is suggestive of pathology.
2. ROC2, in which healthy patients and athletes are managed together, comparing this group of groups with respect to the pathological ones. This is done in order to have a first idea of the importance of differentiating the athletic capacity of the patients.
3. ROC3, in which healthy patients are compared with athletes, to assess whether they present the same behavior in terms of thermal symmetry.
4. ROC4, comparing athlete patients with those who present pathology, to determine which thermal difference between contralateral parts of the body is a diagnosis of pathology in the case of dealing with specific characteristics, such as regular physical training.

A first curve (ROC1) is made (Figure 6.5) in which we compare healthy patients and those who present pathology, in order to discern from which thermal difference between contralateral parts of the body is a diagnosis of pathology.

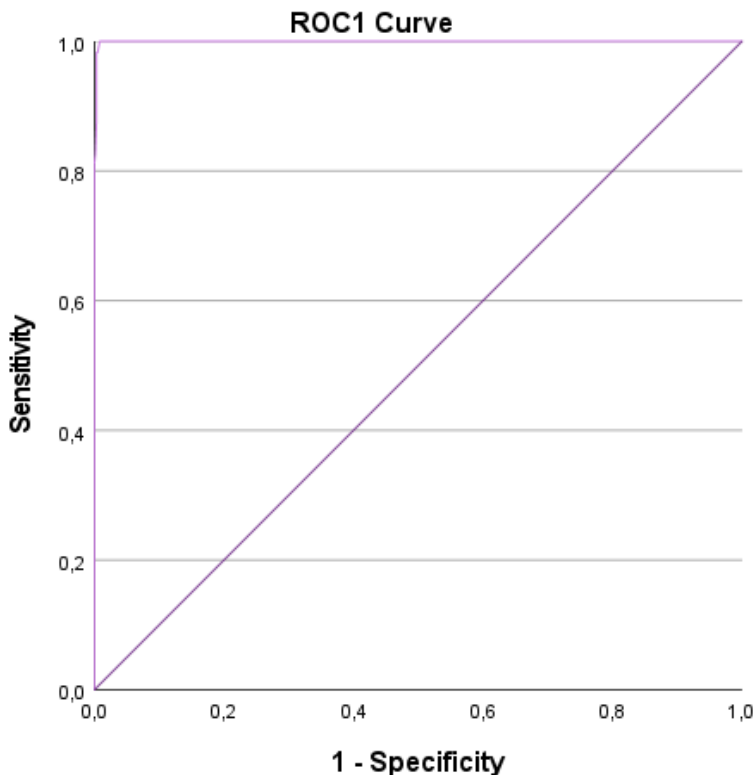


Figure 6.5: ROC curve of healthy vs. pathological patients.

The ROC1 curve, which relates healthy vs. pathological patients, indicates an almost perfect performance, with the AUC-ROC presenting a value of 0.999.

When studying the coordinates of the ROC1 Curve (Table 6.5) for healthy vs. pathological patients, we can observe that at coordinate 0.45, the model maintains a perfect Sensitivity and improves the Specificity compared to the previous threshold, which is where the Youden index is highest. This suggests exceptional performance in class discrimination.

Table 6.5: ROC1 Curve coordinates for healthy vs pathological patients for the temperature difference between contralateral body parts (Dif_Temp).

Dif_Temp (°C) Positive if greater than or equal to	Sensitivity	1 – Specificity	Youden’s Index
0,3000	1,000	0,165	0,835
0,3500	1,000	0,152	0,848
0,4000	1,000	0,048	0,952
0,4000	1,000	0,043	0,957
0,4000	1,000	0,010	0,990
0,4500	1,000	0,008	0,992
0,5500	0,983	0,005	0,978
0,6500	0,983	0,003	0,979
0,7500	0,966	0,003	0,962
0,8000	0,931	0,003	0,928
0,8500	0,879	0,003	0,876

With this, we can demonstrate that, with a variation of 0.45°C between contralateral parts of the body, a clear differentiation can be made with good sensitivity and specificity between healthy and pathological subjects.

A second curve (ROC2) is performed (Figure 6.6) in which we jointly compare healthy patients and athletes with those who present pathology. It is performed jointly considering that athletes are healthy patients but, as previously indicated, they present specific characteristics, so a first joint test is performed in order to discern from which thermal difference between contralateral parts of the body is a diagnosis of pathology.

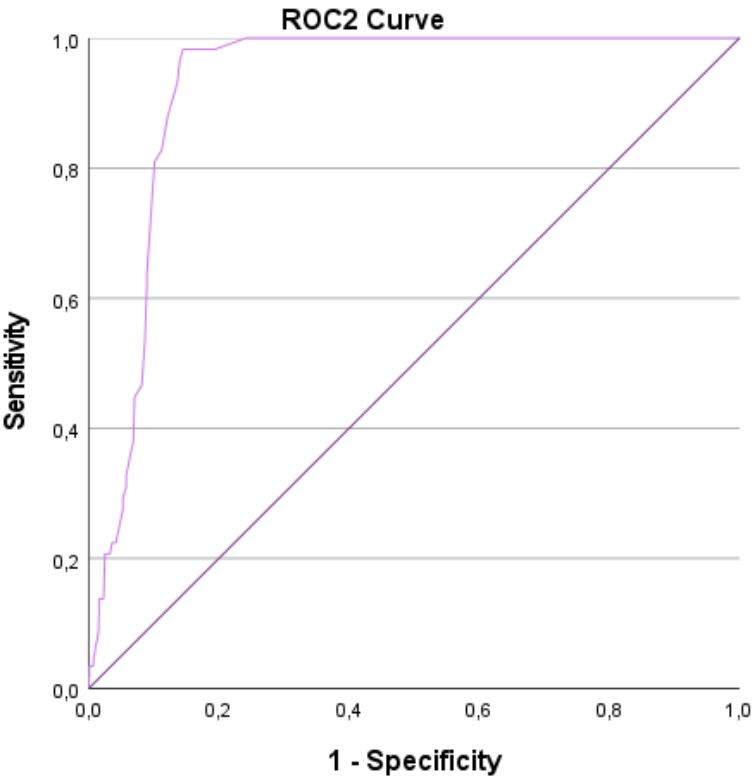


Figure 6.6: ROC curve of healthy and athletic patients vs. pathological patients.

The ROC2 curve of healthy vs. pathological patients indicates a very good performance, with the AUC-ROC presenting a value of 0.925

By studying the coordinates of the ROC2 Curve (Table 6.6) we can observe that the coordinate 0.7°C is where there is a better correlation between the highest possible sensitivity of the table and the lowest 1-specificity, which gives us a higher Youden's index.

Table 6.6: ROC2 Curve coordinates for healthy and athletic patients vs. pathological patients for the temperature difference between contralateral body parts (Dif_Temp).

Dif_Temp (°C) Positive if greater than or equal to	Sensitivity	1 – Specificity	Youden's Index
0,5500	0,983	0,194	0,789
0,6000	0,983	0,187	0,796
0,6000	0,983	0,185	0,798
0,6500	0,983	0,167	0,816
0,7000	0,983	0,165	0,818
0,7000	0,983	0,145	0,838
0,7500	0,966	0,140	0,825
0,8000	0,931	0,136	0,795
0,8500	0,879	0,121	0,758
0,9000	0,828	0,112	0,715
0,9500	0,810	0,101	0,709

Thus, we can demonstrate that, with a variation of 0.7°C between contralateral parts of the body, it is possible to differentiate with good sensitivity and specificity between healthy or athletic subjects and pathological subjects.

A third curve (ROC3) is performed (Figure 6.7) in which we compare healthy patients with athletes, in order to assess whether the athlete dog and the healthy dog have the same behavior in terms of thermal symmetry.

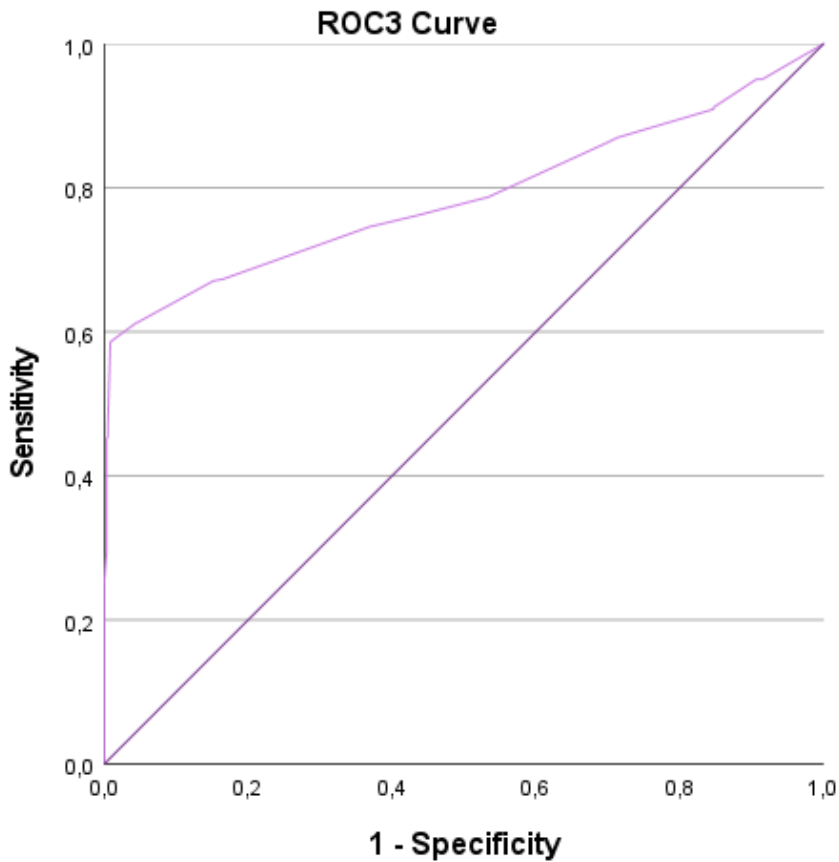


Figure 6.7: ROC curve of healthy patients vs. athletes.

The ROC3 curve of healthy patients vs. athletes indicates a reasonable performance, with the AUC-ROC presenting a value of 0.788.

When studying the coordinates of the ROC Curve, we can observe that the best correlation between the highest possible sensitivity with the lowest possible 1-specificity, correlated by the Youden index, is found at the coordinate 0.4°C (Table 6.7).

Table 6.7: ROC3 Curve coordinates for healthy patients vs athletes for the temperature difference between contralateral body parts (Dif_Temp).

Dif_Temp (°C) Positive if greater than or equal to	Sensitivity	1 – Specificity	Youden's Index
0,3000	0,747	0,372	0,375
0,3000	0,673	0,165	0,508
0,3500	0,671	0,152	0,519
0,4000	0,614	0,048	0,566
0,4000	0,612	0,043	0,568
0,4000	0,587	0,010	0,577
0,4500	0,585	0,008	0,576
0,5500	0,472	0,005	0,467
0,6000	0,455	0,005	0,450
0,6000	0,452	0,003	0,449
0,6500	0,408	0,003	0,405

With this, we can demonstrate that, with a variation of 0.4°C between contralateral parts of the body, a clear differentiation can be made with good sensitivity and specificity between healthy subjects and athletes.

A fourth curve (ROC4) (Figure 6.8) is performed in which we compare the sports patients with those who present pathology, in order to discern from what thermal difference between contralateral parts of the body is a diagnosis of pathology.

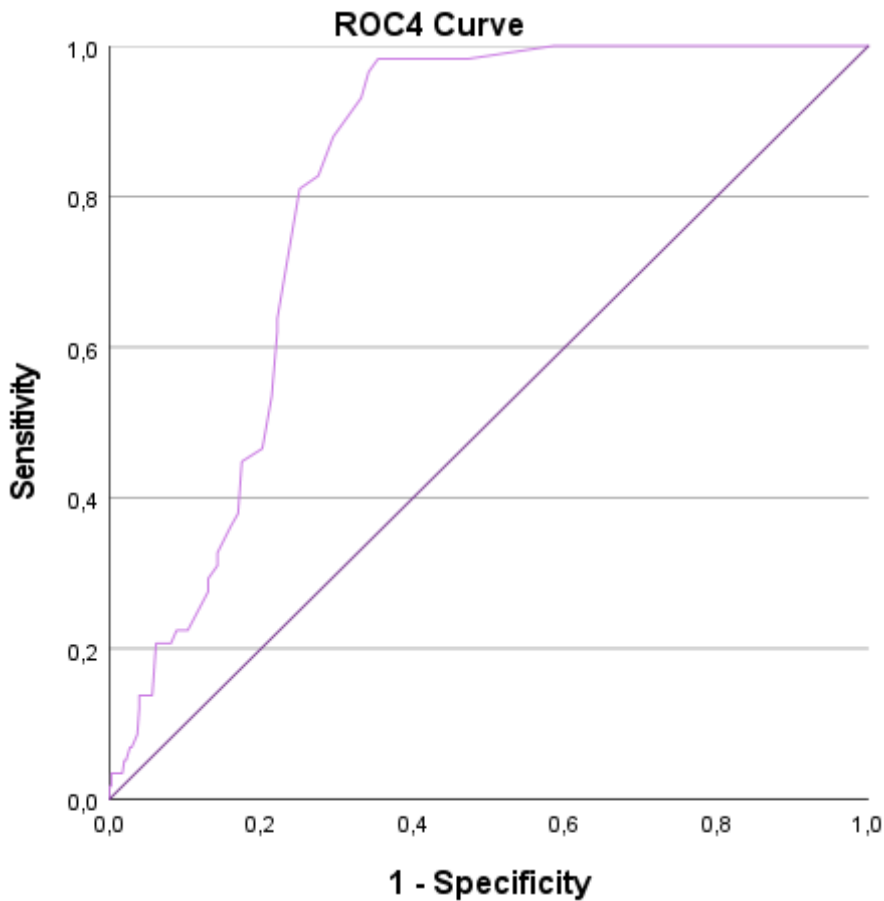


Figure 6.8: ROC curve of sports patients vs. pathological patients.

The ROC4 curve indicates good performance, with the AUC-ROC presenting a value of 0.815

When analyzing the coordinates of the ROC Curve, it is observed that the best relationship between the maximum sensitivity and the lowest 1-specificity, according to the Youden index, is found at the threshold of 0.7°C (Table 6.8).

Table 6.8: ROC4 Curve coordinates for sports vs. pathological patients for the temperature difference between contralateral body parts (Dif_Temp).

Dif_Temp (°C) Positive if greater than or equal to	Sensitivity	1 – Specificity	Youden's Index
0,5500	0,983	0,472	0,511
0,6000	0,983	0,455	0,528
0,6000	0,983	0,452	0,531
0,6500	0,983	0,408	0,575
0,7000	0,983	0,403	0,580
0,7000	0,983	0,354	0,629
0,7500	0,966	0,342	0,624
0,8000	0,931	0,332	0,599
0,8500	0,879	0,295	0,584
0,9000	0,828	0,275	0,552
0,9500	0,810	0,251	0,560

With this, we can demonstrate that, with a variation of 0.7°C between contralateral parts of the body, a clear differentiation can be made with good sensitivity and specificity between athletes and pathological patients.

7. Clinical case results.

This chapter focuses on the analysis of specific cases selected for their clinical relevance.

7.1. Thermal evaluation of a fracture development

A clinical case was presented of a female patient, 8 years old, mixed race, who suffered a displaced oblique fracture in the medial region of the tibia and fibula. This type of fracture, characterized by displacement of the fractured bone segments, requires a specific therapeutic approach. Standard treatment for displaced oblique fractures of the tibia and fibula generally involves immobilization of the affected area with the goal of promoting bone healing and preventing complications.

In this particular case, the fracture was stabilized by applying a splint, which was maintained for a period of three weeks, following the protocols established for this type of injury.

In addition to the x-ray studies, an evaluation using thermography to monitor the inflammatory process in the affected region was performed.

Figure 7.1.1 shows the three complementary views of a leg fracture. 7.1.1 a) is the X-ray taken the same day the injury occurred, showing a displaced oblique fracture of the tibia and fibula, b) shows the thermal image the same day of the x-ray study and c) it's the standard photography (visible image) of the injury that the thermal camera also captures. In this thermal image, there is a noticeable increase in temperature directly over the fracture site, signaling inflammation and increased blood flow, which are typical physiological responses to trauma. This finding is consistent with the body's physiological response to bone injury, suggesting the presence of an acute inflammatory process, characterized by vasodilation and increased blood flow in the affected area, typical of the initial phase of bone healing [Varjú.G-2004].

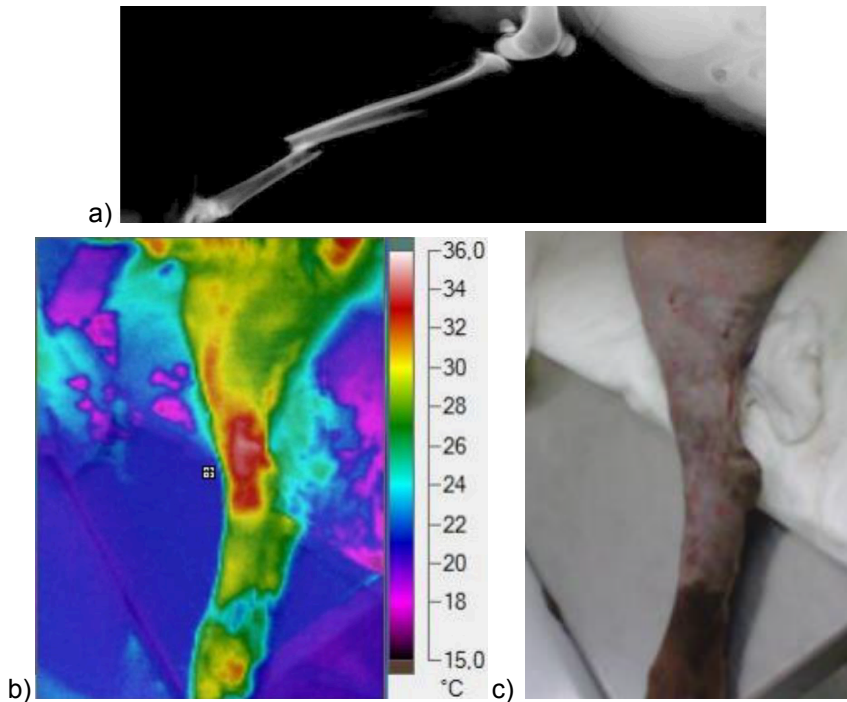


Figure 7.1.1: a) xray of the fracture the same day as the injury happened. b) thermal image of the lesion, in which we can observe the increase of temperature on the fracture area. c) visual image of the thermal image.

On the fifth day post-fracture, a follow-up radiological evaluation was performed with the objective of monitoring the progress of bone healing and verifying that the splint was in its proper position, ensuring that there were no displacements or movements that could compromise the fracture.

In Figure 7.1.2, we can see the follow-up X-ray, showing that the fracture remains present and still presents displacement of the bone fragments. Unlike what is expected in a normal bone healing process, no callus formation or signs of bone regeneration are seen around the fracture site. This indicates that there has been no significant progress in fracture repair.

However, it was not possible to perform a thermal study on this occasion due to the impossibility of removing the bandage, which limited the evaluation of the inflammatory process in a complementary manner to the radiological images.

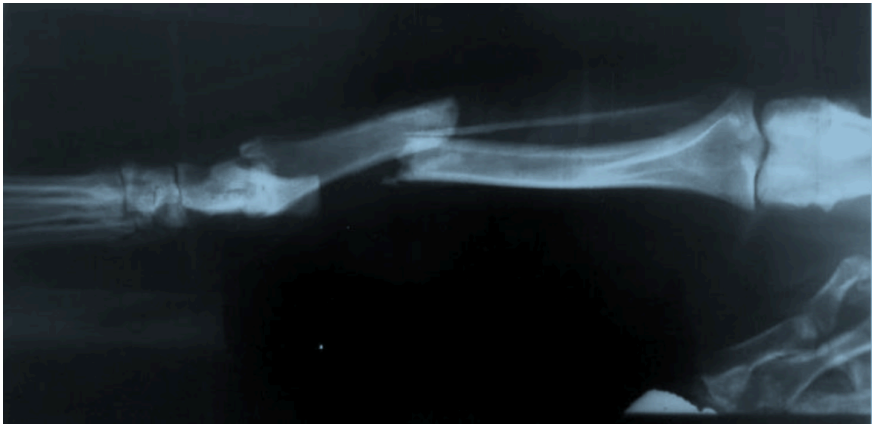


Figure 7.1.2: Radiography of the fracture 5 days post injury.

On day 15 post-fracture, ten days after the second radiological evaluation, the patient returned for a fracture check. In this consultation, the bandage was removed, which allowed new x-rays to be taken (Figure 7.1.3, where we can see that the fracture still remains displaced and there are no signs of bone regeneration.) and an evaluation using thermography (Figure 7.1.4).

When reviewing the radiographs obtained on day 15 post-fracture (Figure 7.1.3), it will be observed that the fracture had not yet shown signs of bone healing, since the formation of bone callus was not observed, which is a key indicator of the recovery phase. consolidation in the healing process of a fracture. Lack of callus formation may be indicative of delayed or

compromised bone healing.

Furthermore, when reviewing the thermal image obtained on day 15 post-fracture (Figure 7.1.4), it was observed that the thermal distribution of the injured leg was very similar to that of a healthy leg. This homogeneity in surface temperature suggests that there was no significant increase in vascularization of the fractured area, indicating a lack of inflammatory and regenerative response in the affected region. This finding is consistent with the absence of bone callus formation on the radiographs, which showed that the fracture had not healed adequately (Figure 7.1.3).



Figure 7.1.3: Radiography of the fracture 15 days post injury.

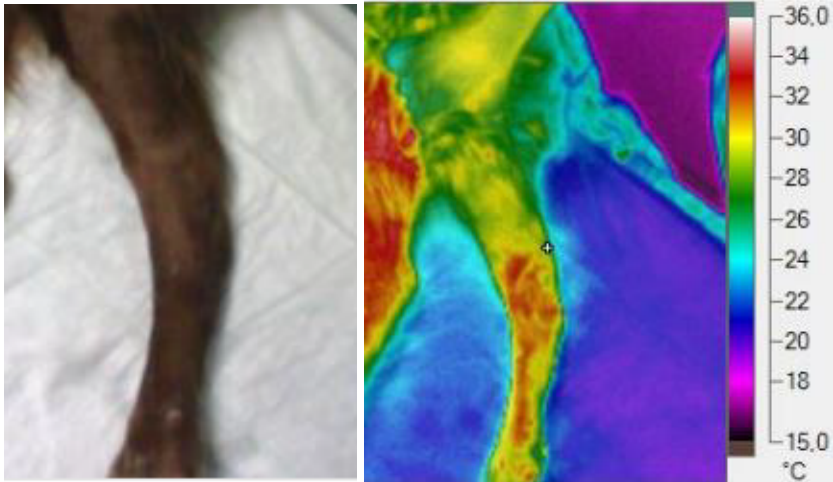


Figure 7.1.4: thermography of the fracture 15 days post injury.

This multidisciplinary approach, which integrates radiological and thermal imaging, provides a more accurate and complete assessment of the fracture status, allowing treatment to be adjusted if necessary to optimize the patient's recovery. Based on the previous stated findings, surgical intervention was considered the most appropriate option, as thermography revealed that the body was not responding effectively to the fracture and the physiological mechanisms necessary for healing were not occurring, requiring more precise stabilization and a more aggressive approach to ensure proper bone repair.

Seven days after the surgical intervention, a new evaluation was performed using thermography, and the results were presented in Figure 7.1.5. The thermal image shows an increase in the average temperature in the surgical area, which is common and expected in the context of post-surgical inflammation. This thermal increase was not located at a specific point, but rather covered a more generalized extension around the treated area. This

thermal pattern is indicative of a generalized inflammatory response, a normal physiological process necessary for postoperative healing. Post-surgical inflammation is the result of the intervention, in which the tissues are manipulated, incisions are made and the fracture is stabilized, which triggers a series of biological reactions.



Figure 7.1.5: After 7 days post surgery, xray of the site (left), visual image of the site (middle) and thermal image (right)

The increase in temperature in the surgical area reflects the increased metabolic activity and vasodilation, which are characteristics of the inflammatory phase of the healing process. Inflammation is a natural mechanism of the body that, in this case, aims to repair damaged tissues, promote the formation of new blood vessels (angiogenesis) and facilitate the elimination of dead or damaged tissues. The increase in temperature is due to increased blood flow, which carries immune cells and growth factors necessary for tissue regeneration and bone repair.

However, it is important to note that the increase in temperature in this phase is generalized and not localized to a specific area, suggesting that

inflammation is a global response to the surgical procedure and not necessarily a sign of complications such as infections or healing deficiencies. The lack of precise localization of the thermal increase in a specific area also indicates that there is no clear indication of focal infections, as might occur if an infection were developing in a specific area of the surgical wound. Instead, the thermal pattern observed is a reflection of general inflammation throughout the operated region, which is an expected behavior in the early stages of post-surgical recovery.

7.2. IRT as a predictive method of Feline aortic thromboembolism (FATE)

Feline aortic thromboembolism (FATE) is a serious and potentially fatal pathology in cats [Borgeat.K-2014], characterized by the sudden obstruction of one of the main arteries, usually the femoral artery, by a thrombus (blood clot) that originates in the heart, usually in the left atrium. This condition can occur as a complication of chronic heart diseases, such as feline hypertrophic cardiomyopathy (HCM), which predispose to clot formation.

The clinical manifestation of FATE is characterized by sudden paralysis of the cat's hind limbs, which can be unilateral or bilateral, depending on the location and extent of the thrombus. This paralysis is painful and may be accompanied by a number of clinical signs, such as the appearance of cyanotic (bluish in color due to lack of oxygen) or pale pads, indicating a reduction in blood flow to the affected extremities. Additionally, it is common to observe weakness or even the absence of a femoral pulse, suggesting that the blood supply to the extremities is severely compromised. In more advanced cases, the extremities may become cold due to decreased blood perfusion [Fuentes.LV-2012].

A differential diagnosis is essential to rule out other conditions that may present similar signs of paralysis, such as trauma, which can cause direct damage to the extremities, or spinal cord edema, which occurs when there is fluid buildup in the spinal cord due to injury or inflammation. These conditions can present similar symptoms, such as paralysis of the extremities and lack of pulse, so a thorough evaluation is essential.

The definitive diagnosis of FATE is achieved through direct visualization of the thrombus in the affected arteries, which can be done through imaging

techniques such as ultrasound or computed tomography (CT). Doppler ultrasound is particularly useful as it can assess blood flow in the arteries and detect the presence of blockages or thrombi. In some cases, CT can also be used to obtain detailed images of the arteries and confirm the exact location of the thrombus [Williams.TP-2017].

Management of feline aortic thromboembolism requires a rapid and effective approach, as blockage of the arteries can lead to necrosis of the affected tissues, resulting in irreversible loss of limb function or even death. Treatment includes the use of anticoagulants to prevent the formation of new thrombi and measures to improve blood flow, as well as in some cases surgery to remove the thrombus if it is accessible. Early identification and appropriate treatment are essential to improve the prognosis of cats affected by this condition.

The main objective of this study is to demonstrate that infrared thermography can play a crucial role in veterinary emergency situations, particularly in cases of sudden posterior third paralysis in felines. It is proposed that this tool be used as an initial diagnostic triage technique, allowing the status of the affected extremities to be quickly evaluated and to guide clinical decision making efficiently.

The present study included patients from several veterinary centers, which allowed us to obtain a representative sample of clinical cases from different environments. The design of this study was structured in two groups: the control group and the study group.

Control Group: The control group was made up of eleven clinically healthy felines that attended routine consultation for procedures such as vaccinations or annual check-ups. These animals did not present clinical signs or a history

of pathologies that affected their vascular, neurological or musculoskeletal system, which made them an appropriate reference to compare normal thermal patterns with those observed in patients with posterior third paralysis.

Study group: The study group included five feline patients who were admitted to the emergency department due to sudden paralysis of the posterior third, a critical clinical sign that warrants immediate attention. The etiology of this condition was determined through advanced diagnostic imaging studies, such as Doppler ultrasound and computed tomography (CT).

- Diagnosis of arterial thromboembolism (FATE): Two of the patients were diagnosed with arterial thromboembolism, identified through direct visualization of a thrombus in the distal aorta or femoral arteries using ultrasound and CT.
- Neurological diagnoses (trauma and spinal edema): The other three patients presented paralysis due to leptomenigeal dilation of traumatic origin and spinal edema, pathologies confirmed by CT. These differential diagnoses illustrate the complexity of triage in these cases.

In total, the study included 16 felines, of which 10 were males and 6 females, aged between 2 and 8 years. The breed of the animals was European Shorthair, an appropriate choice to ensure that the study findings can be extrapolated to a broad population of domestic cats.

A standardized protocol was applied to capture thermal images (in Figure 7.2.1 we can see an overlay of a conventional image and its corresponding thermographic image of the same animal, which helps to understand de

composition of the image taken), ensuring controlled environmental conditions and minimizing external factors that could alter the measurements, such as air currents, humidity or patient stress,. These measures are essential to guarantee the reproducibility and precision of the results obtained.

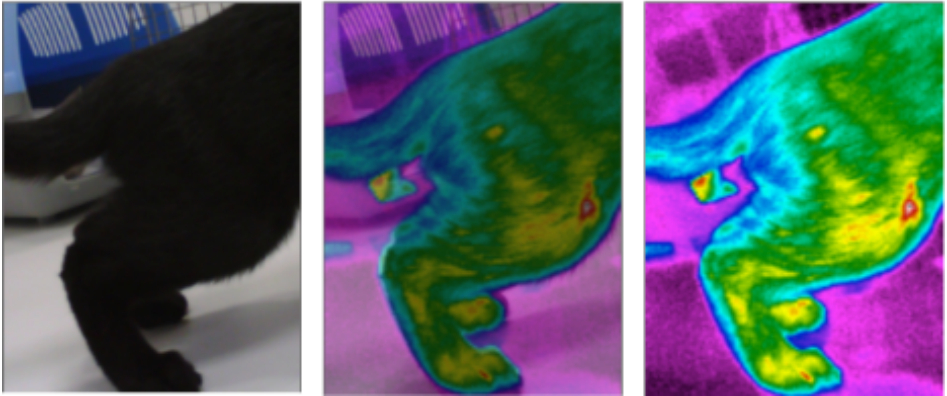


Figure 7.2.1: Overlay of a conventional image and its corresponding thermographic image of the same animal.

In figure 7.2.2 we can see the selected regions of interest (ROI) for this work, including from the elbow to the phalanxes in the forelimbs and from the knee to the most phalanxes on the hindlimbs. Maximum, average and minimum temperature are extracted from this ROI.

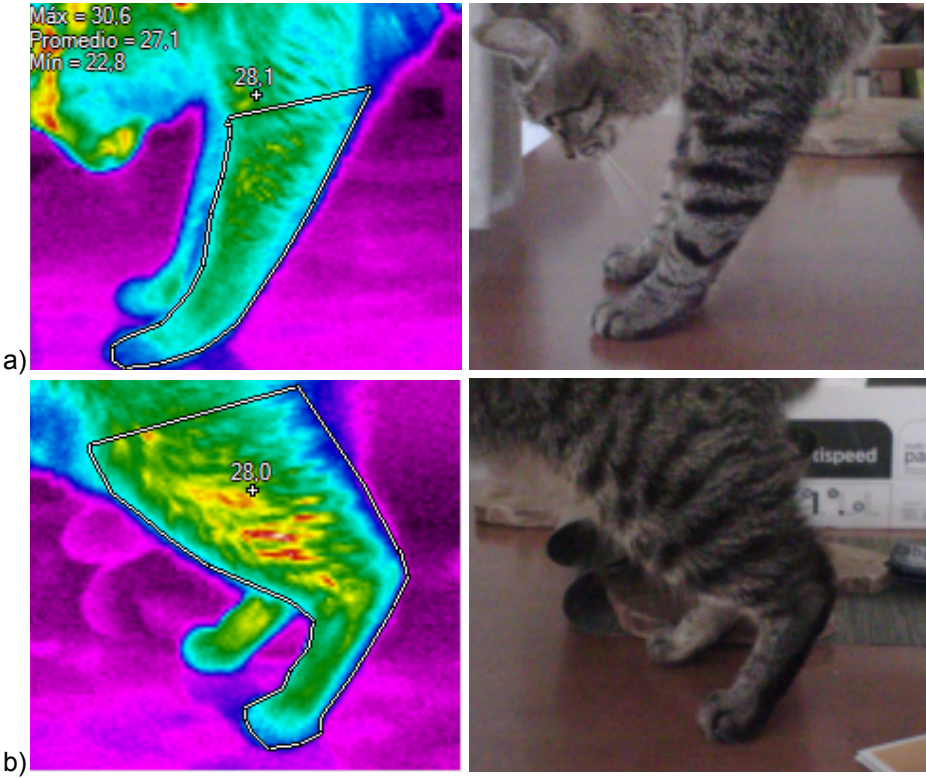


Figure 7.2.2: Regions of interest (ROI) selected for the study. In the forelimb (a), the image is taken from the elbow to the distal end, and in the hindlimb (b), from the knee to the distal end.

These data were entered into a spreadsheet for analysis.

When a patient is admitted with symptoms of sudden posterior third paralysis, immediate attention is focused on stabilizing and evaluating their general condition before moving forward with a specific diagnosis. The procedure is carried out as follows:

The first step is to measure the patient's vital signs to evaluate their general clinical status:

- Intrarectal temperature: Allows you to determine if there is hypothermia or hyperthermia, which may be associated with different underlying conditions.
- Cardiac and pulmonary auscultation: It is essential to detect abnormalities such as arrhythmias or heart murmurs, which may suggest underlying heart diseases, such as hypertrophic cardiomyopathy, a key risk factor for feline aortic thromboembolism (FATE).
- Capillary refill time (CRT): Evaluates peripheral perfusion and may reveal signs of ischemia or circulatory failure, which could correlate with subsequent thermographic observations.

After stabilizing the patient and performing the basic evaluation, thermal images of the extremities and the affected body region are obtained. These images are essential to identify thermal distribution patterns that may suggest ischemia, inflammation, or other abnormalities in the hind limbs. Thermography is performed following the standardized protocol defined in Chapter 5, subsections 5.8 and 5.9.

After thermal image acquisition, a detailed physical examination is performed to identify additional signs that may guide the diagnosis. This includes:

- Evaluation of mobility, reflexes and sensitivity in the extremities.

- Inspection of the pads for cyanosis, pallor, or other visual signs of ischemia.
- Palpation of femoral pulses to assess perfusion.

Based on the information collected during the initial assessment and the thermography findings, the owner is informed of the need for additional diagnostic testing to confirm the cause of the paralysis (CT scan, ultrasound, MRI...).

In this study, the data collected were analyzed using a statistical approach to evaluate significant differences between the groups of interest. Temperatures recorded in the different regions of interest (ROI) were summarized as average values and expressed along with their respective standard deviations, providing a measure of the variability of the data within each group.

Table 7.2.1 shows the average temperatures of the selected ROI in each limb. It is observed that the average temperature of the hind limbs of the group with vascular disease is lower than in the control and spinal disease groups.

Table 7.2.1: Average temperatures of forelimbs and hindlimbs (°C).

		Control n=11	Vascular n=2	Medular n=3
Forelimbs	Right	29,6 ± 1,2	27,8 ± 1,5	30,1 ± 1,8
	Left	29,4 ± 1,3	27,1 ± 1,2	30,2 ± 1,6
Hindlimbs	Right	29,3 ± 1,3	25,1 ± 0,9	29,5 ± 1,6
	Left	29,1 ± 1,2	24,5 ± 0,8	29,4 ± 1,5

To compare the study groups, the Student t test was used, a statistical tool commonly used to determine if there are significant differences between two

independent groups. This test assumes a normal distribution of the data and allows differences to be identified based on the means of the compared samples. In this analysis, a significance level of $p < 0.05$ was established, which indicates that any difference observed with this level of probability would be considered statistically significant, reinforcing the reliability of the results obtained.

This approach ensures a robust interpretation of the data and allows valid conclusions to be drawn about the relationship between the recorded temperatures and the conditions evaluated in the study.

When studying the average temperature difference between the ipsilateral extremities, it is higher in the group with thromboembolism than in the group of healthy animals or with spinal accidents (Table 7.2.2).

Table 7.2.2: Difference in mean temperatures in absolute value in healthy animals, with vascular accident and with spinal cord accident (°C).

Average Temp Difference	Healthy	Thrombi	Paralytic	P
Right	0,1 ± 0,5	2,8 ± 0,3	0,6 ± 0,5	0,01
Left	0,2 ± 0,5	2,7 ± 0,5	0,9 ± 0,1	0,01

7.3. Monitoring the evolution during rehabilitation of a patient with spondylosis deformans using infrared thermography

Spondylosis deformans is a non-inflammatory degenerative condition of the spine that affects both humans and animals, especially dogs. This disease is characterized by the formation of osteophytes (abnormal bony projections) that develop on the edges of the vertebrae. These bone formations can range from small spurs to complete bone bridges that span the intervertebral space, which can limit mobility.

Although the exact cause of spondylosis deformans, in both human and veterinary medicine, remains unknown, it is considered that factors such as aging, cumulative microtrauma, genetic predisposition and biomechanical changes in the spine could play a role in its development. Prevalence increases with age, being more common in dogs over nine years of age, with rates ranging between 25% and 70% in this age group [Morgan.JP-1967a].

In terms of genetic predisposition, Boxer dogs show a higher incidence of the disease [Langeland.M-1995, Carnier.P-2004, Kranenburg.HJ-2011], suggesting that some hereditary factors may play a role, being the most frequently affected regions L2-L3 and L7-S1 [Morgan.JP-1967a, Morgan.JP-1967b, Levine.GJ-2006].

Cats also show a significant prevalence of spondylosis deformans, with ranges varying between 34% and 68%, making it a common condition within this species, especially in older animals. In terms of anatomical location, the spinal segment that is most frequently affected is the one that includes the thoracic vertebrae T4 to T10. However, when the disease involves a larger

area, particularly from T10 to S1, the clinical signs are usually more severe [Kranenburg.HC-2012].

Although in many cases spondylosis deformans can be asymptomatic and detected incidentally during radiographic studies, affected patients can present various symptoms. Among them, rigidity in movements stands out, particularly when getting up after periods of inactivity. Localized pain in the lumbar or lumbosacral region is also common, along with a notable reduction in spinal flexibility. In more severe situations, although less frequent, compression of nerve roots could generate neurological manifestations.

The diagnosis is made mainly through x-rays, where osteophytes and possible bone bridges are evident. Sometimes it is complemented with magnetic resonance imaging (MRI) or computed tomography (CT) to evaluate adjacent structures and rule out other pathologies.

A 9-year-old, female, mixed-breed canine patient, weighing 35 kg, presents to the clinic. The patient's medical history includes a diagnosis of hip dysplasia at the age of 4 years, which caused joint discomfort, particularly in the dorsal and sacral regions of the spine. Hip dysplasia is an abnormality in the development of the hip joint, which can lead to chronic pain, inflammation and arthritis, often reflected in symptoms such as difficulty walking, lameness or stiffness. The patient has been dealing with these complaints since her diagnosis.

At 7 year old, a follow-up radiological review was performed. On the spinal x-rays, which we can see in figure 7.3.1, grade 3 spondylosis deformans according to the Norwegian scoring system was observed. This scoring system classifies the severity of spondylosis deformans in 3 grades, based on the size and number of osteophytes present, reflecting progression of spinal

degeneration. In the patient's case, grade 3 spondylosis deformans suggests a severe condition, which could be causing pain in the spine, particularly in the lumbar and sacral region, associated with hip dysplasia.

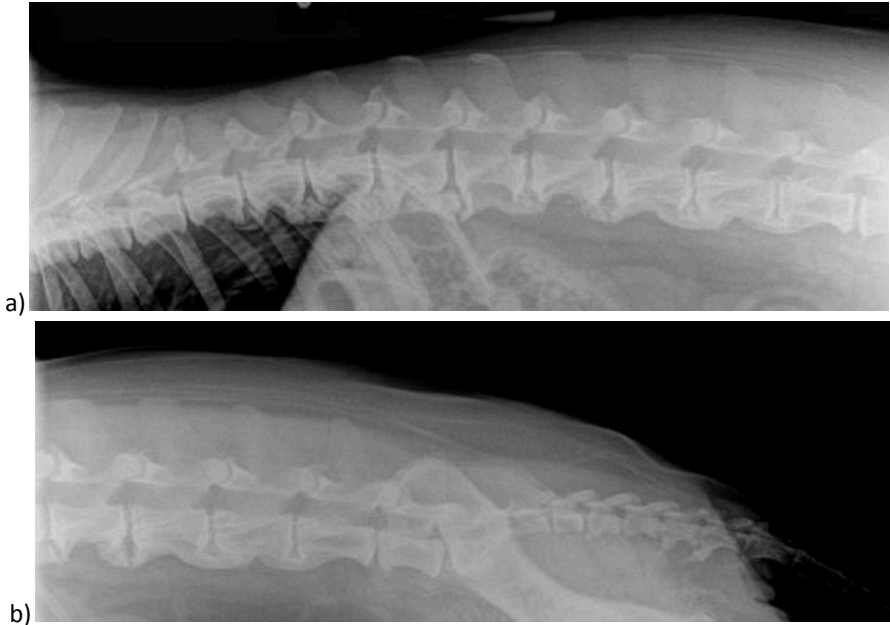


Figure 7.3.1: X-rays of the patient showing spondylosis deformans a) in the thoracolumbar area and b) the lumbar area.

In the presence of these conditions, he has been administered an anti-inflammatory treatment, specifically meloxicam, at a dose of 0.1 mg/kg/SID (once a day), in order to relieve the inflammation and pain associated with dysplasia. hip and spondylosis deformans. Meloxicam is a non-steroidal anti-inflammatory drug (NSAID) that helps reduce pain and inflammation in the joints, improving the quality of life for patients with degenerative musculoskeletal conditions. This treatment is adjusted according

to the discomfort that the patient manifests, with the aim of controlling symptoms and improving mobility.

When the canine patient goes to rehabilitation, her medication regimen in the last two years includes gabapentin at a dose of 10 mg/kg/12h, bedinvetmab at 20 mg monthly and a nutritional supplement that contains chondroitin sulfate, glucosamine hydrochloride, amino acids, vitamins, sodium hyaluronate, zinc, as well as natural extracts of turmeric, boswellia and devil's claw. This regimen is designed to manage pain and inflammation resulting from hip dysplasia and spondylosis deformans, supporting joint health and improving the patient's overall mobility. However, the guardian has noted a deterioration in the patient's mood in recent months, suggesting that the treatment, although helpful, may not be completely effective in controlling the pain or may need adjustments. Furthermore, the patient experiences a significant relapse in her condition if medication is delayed or withdrawn, indicating that pharmacological intervention plays a fundamental role in managing her symptoms.

Regarding mobility, the patient has shortened stride and ambling, which suggests that pain or discomfort may be limiting her ability to walk normally. In addition, he shows difficulty remaining in a still quadruped position, which causes him to sit up quickly after stopping, seeking relief in a more comfortable position. This may be indicative of discomfort or stiffness in the spine and hip joints, probably related to spondylosis deformans and hip dysplasia.

Before manipulation during rehabilitation, a thermographic study of the dorsal muscles is performed to evaluate possible circulatory alterations or inflammation in the soft tissues. This analysis is complemented by the physical

examination, where severe pain is detected in the dorsal muscles, suggesting the presence of contractures or muscle tension. When manipulating the skin on the back, the patient shows shuddering, which could be related to increased sensitivity or pain in that area. In addition, tightness is observed in the skin, which is not able to separate from the underlying muscles, a characteristic sign of deep muscle tension and fibrosis. There are also tight bands on both triceps, indicating possible muscle overload or response to chronic pain, and a trigger point in the right glute, which could be generating referred pain to other areas of your body, such as the hip or spine.

The presence of these muscle contractures and trigger points highlights the need for a therapeutic approach that not only addresses joint and bone inflammation, but also the management of muscle tension and fibrosis. In this case, rehabilitation may include manual therapy techniques, such as therapeutic massage, muscle stretching, and physical therapy aimed at improving flexibility and reducing pain associated with trigger points and muscle contractures. Likewise, the use of heat therapy or cryotherapy could help improve circulation and relieve muscle discomfort. It is essential to adjust treatment comprehensively to improve the patient's quality of life, reducing both muscle and joint pain, and addressing possible long-term side effects of medications.

The following therapeutic plan is proposed with the objective of improving the patient's condition and relieving the symptoms associated with hip dysplasia, spondylosis deformans and generalized muscle tension. The approach will be comprehensive, combining manual, osteopathic and electrostimulation techniques, in addition to including recommendations for home care.

Frequency and Duration of Treatment:

It is recommended to hold weekly sessions for a minimum of two weeks, with the possibility of spacing the sessions depending on the patient's progress. This approach will allow evaluating the animal's response to treatment and adjusting the frequency according to the degree of improvement or persistence of symptoms.

Treatment during the physiotherapy sessions:

- Manual therapy: Manual therapy will focus on a variety of techniques to address muscle tensions and improve circulation in the dorsal musculature. The following modalities will be included:
 - o Stroking: Gentle, long movements that help relax muscles and improve blood circulation.
 - o Petrissage (kneading): Technique used to release deep tension and mobilize deeper tissues, such as muscles and muscle knots.
 - o Friction: Rubbing movements with the fingers, ideal for releasing adhesions or contractures in the muscles.
 - o Effleurage (gliding): Long, gentle movements over the skin to promote muscle relaxation and reduction of inflammation.
 - o Stroking: Repetition of stroking movements to relieve muscle pain and improve circulation.

- Osteopathic techniques: Osteopathic techniques will be incorporated to mobilize the joints and improve spinal alignment. These techniques will help relieve stiffness, improve range of motion, and reduce pressure on affected areas, such as the lumbosacral area. The goal is to restore balance between the bone structure, muscles and soft tissues to improve the overall function of the spine.
- Electroacupuncture: it will be used along the dorsal muscles, a technique that combines traditional acupuncture with electrical stimulation. Electroacupuncture has been shown to be effective in relieving chronic pain, reducing inflammation, and improving blood circulation. In this case, it will focus on areas with greater muscle tension and painful areas, seeking an analgesic and relaxing effect.

Home Care:

- Gentle massage of the dorsal muscles: It is recommended that the guardian perform a gentle massage on the patient's dorsal muscles 48 hours after each session. This massage should be of light intensity to avoid any additional irritation or inflammation in the muscles worked during the session. The goal is to maintain muscle relaxation and reduce post-treatment stiffness.
- Spinal mobilization: The guardian should perform slow circles to gently mobilize the patient's spine, also 48 hours after the session. These movements will help maintain spinal flexibility and reduce joint stiffness. Slow, controlled movement is essential to avoid straining the joints affected by spondylosis deformans.

A first therapeutic session (day 0) is performed for the canine patient, 15 days after receiving the last dose of bedinvetmab, a biological treatment used to control pain associated with osteoarthritis.

Figure 7.3.2 shows the thermographic image captured before the session. In this image, we can initially observe an increase in warm colors (red, yellow, and white) in the right side of the body compared to the contralateral area, where green tones predominate. After this visual inspection, a measurement is taken to numerically quantify the observed thermal asymmetry, displaying a temperature difference of 1°C between the contralateral sides of the dorsal muscles with hyperthermia on the right side of the back.

According to previous studies, a temperature difference greater than 0.5°C between the contralateral parts of the body is considered pathological [Loughin.CA-2007, Vardasca.R-2012] which indicates that the patient has areas with inflammation or circulatory alteration in the dorsal muscles, probably related to muscle tension and pain. chronic in the spine due to spondylosis deformans and hip dysplasia. This thermal difference may reflect an activation of the inflammatory process in one of the muscle areas, which justifies the need for therapeutic treatment.

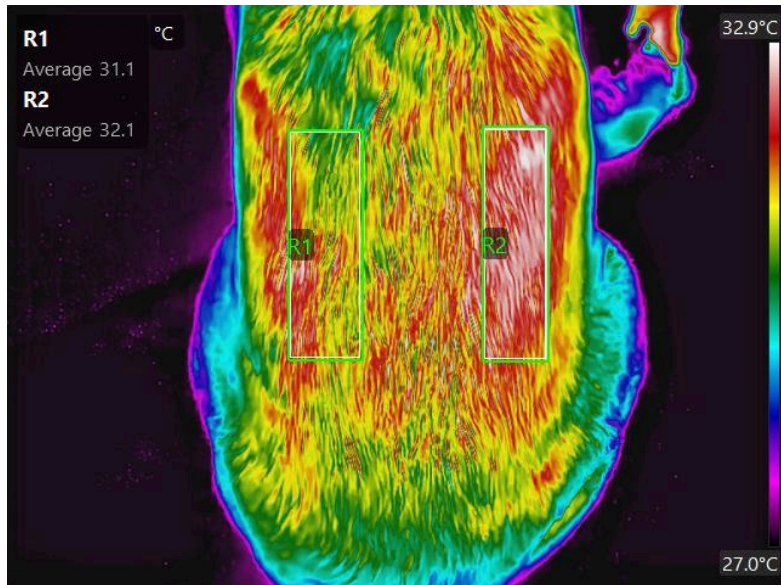


Figure 7.3.2: Thermal images of the dorsal muscles at the first visit, with a difference of 1°C between contralateral parts of the body, compatible with inflammation.

Seven days after the first session (day 7), the guardian describes a significant improvement in the patient's condition. The dog appears more energetic, eager to climb onto the couch on her own, indicating an increase in mobility and a reduction in pain and stiffness that previously made it difficult for her to make these movements. He also shows greater agility and more endurance during walks, suggesting an improvement in his ability to walk and maintain moderate physical activity without the immediate onset of fatigue or pain. These positive changes in behavior and energy reflect a beneficial impact of the therapy on the patient's quality of life.

During the physical examination, it is observed that the patient has greater mobility when turning on herself, which indicates an improvement in flexibility and the ability to make larger movements, which previously could have caused discomfort or pain. In addition, a greater separation of the skin from the underlying muscles is noted, which suggests that muscle tightness has decreased, allowing better elasticity of the soft tissues and greater relaxation in the dorsal area. In terms of trigger points, the trigger point in the right gluteus is noted to have disappeared, indicating a resolution of the localized pain and associated contractures in that area. However, a tense band of lower intensity persists in the left triceps, indicating that although improvement is evident, there are still areas that require attention to completely relieve muscle tension.

Figure 7.3.3 is the thermographic image taken in the follow-up session that shows a generally symmetrical temperature distribution. We can initially observe very similar color patterns on both sides of the body, with only subtle variations. After this visual inspection, a measurement is taken to numerically quantify the thermal asymmetry. In this case, a small temperature difference of 0.3°C is found between the contralateral sides of the dorsal muscles, which is compatible with normality.

This decrease in thermal difference suggests that inflammation or circulatory disturbances have significantly decreased, confirming the effectiveness of the treatment in terms of controlling muscle inflammation and improving blood circulation.

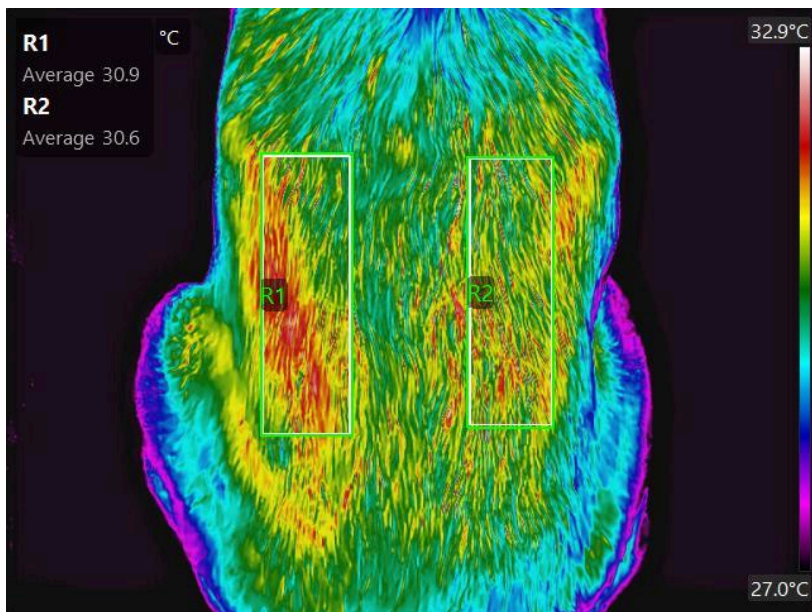


Figure 7.3.3: Thermal images of the dorsal muscles at the second visit, with a difference of 0.3°C between contralateral parts of the body, compatible with normality.

The third therapeutic session is scheduled for the canine patient 15 days after the second session (day 22). When she came to the consultation, the patient seemed very cheerful, with a notable improvement in her energy and general condition. The canine walks with agility, without showing the shortening of her stride that previously limited her ability to move normally. This indicates that the treatment is having a positive impact on his mobility, reducing the stiffness and pain he experienced in his extremities, and that his agility in movement reflects a better ability to move without discomfort.

On a physical level, the patient presents a greater separation of the skin from the underlying muscles, which suggests that the muscle tightness that

previously limited flexibility has decreased considerably. This is a clear indication that manual therapy techniques, especially those aimed at muscle relaxation, are being effective in reducing muscle tension and improving tissue elasticity. Furthermore, the presence of trigger points or tense bands is not observed in the previously affected areas, which indicates a significant resolution of the contractures and muscle pain in specific areas such as the glutes and triceps.

However, in the physical evaluation an overload of the triceps is detected, which may be indicative of additional effort in this area due to the general improvement in mobility and the reduction of discomfort in other areas of the body. This overload could be related to the adaptation of the muscles to the greater physical activity that the patient can now perform, after having benefited from the reduction of pain in the joints and muscles.

Figure 7.3.4 presents the thermographic images taken on day 22, showing a generally symmetrical temperature distribution in the dorsal muscles. Visually, there is no apparent difference in the thermal pattern, when checking the difference numerically, a small temperature difference of 0.2°C is observed between the contralateral sides, which is considered compatible with normality.

This minimal thermal difference falls within acceptable ranges, indicating that muscle inflammation has decreased significantly and that blood circulation in the area has become more balanced, with fewer signs of alteration or pathology.

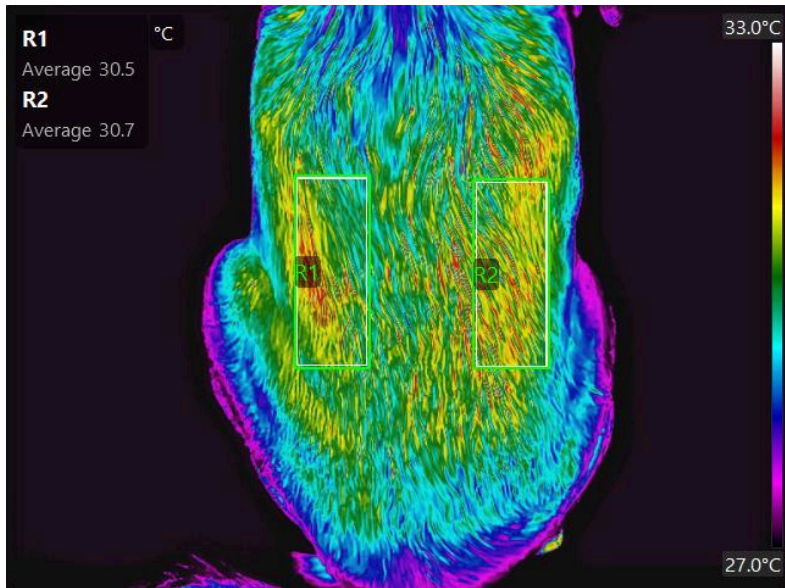


Figure 7.3.4: Thermal images of the dorsal muscles at the third visit, with a difference of 0.2°C between contralateral parts of the body, compatible with normality.

Figure 7.3.5 compares the images from the three visits, being able to compare the evolution of the inflammation of the back muscles.

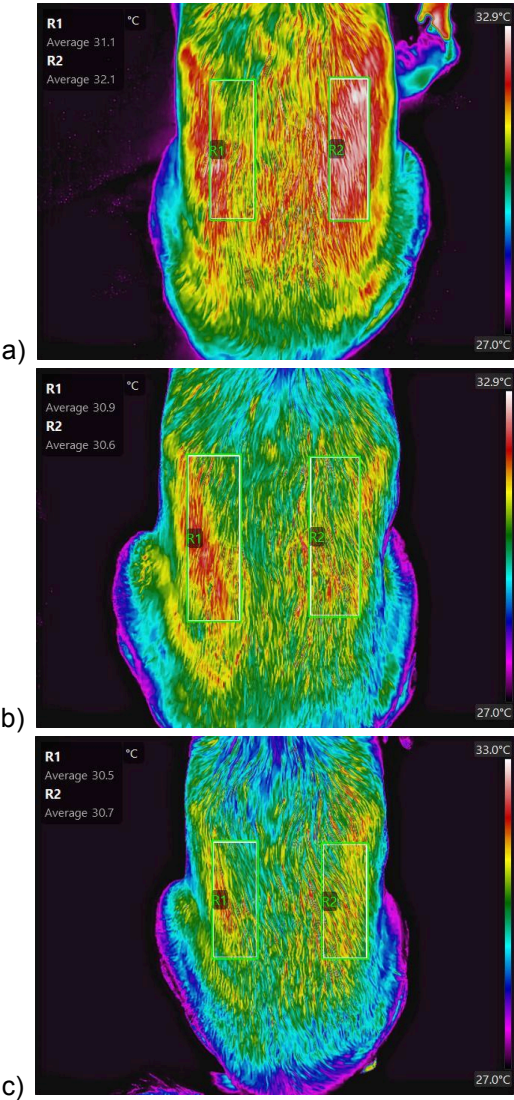


Figure 7.3.5: Thermal images of the dorsal muscles at the first visit a), the second visit b), and the third visit c), allowing us a clearer visual inspection.

Given the progress observed, it was decided to maintain the rehabilitation sessions every 15 days. This interval will allow treatment to continue, monitoring the patient's progress and adjusting the therapeutic approach as necessary. At the same time, the decision is made not to administer bedinvetmab again, as the patient shows a substantial improvement in her mobility and mood, indicating that no additional treatments of this type are required for pain management at that time.

In addition, the patient's mobility and mood will continue to be monitored, observing her response to the rehabilitation sessions and ensuring that progress is maintained. To do this, a constant assessment of the temperature difference between the contralateral parts of the body will be maintained using infrared thermography, which will allow the evolution of inflammation to be closely monitored and any early signs of relapse or imbalance in muscle circulation to be detected.

7.4. Evaluation of tissue damage with IRT after laparoscopic ovariectomy vs. laparotomy

Laparoscopic surgery is a minimally invasive surgical technique that has gained popularity in various specialties due to its many advantages over conventional surgery. In this type of surgery, the abdominal cavity is accessed through small incisions through which a rigid optic (laparoscope) is inserted to allow visualization of the internal organs [Lhermette.P-2020]. To facilitate visibility, CO₂ is insufflated into the abdominal cavity, which distends the area and provides adequate space to perform interventions without the need for large incisions. Among the most notable advantages of laparoscopic surgery are less tissue trauma, both in the skin and muscles, which significantly reduces the systemic inflammatory response and postoperative pain [Tweet.D-2006]. This, in turn, decreases cardiovascular stress and immunosuppression, which is a crucial factor in rapid patient recovery [Hancock.RB-2005]. In addition, laparoscopy has been shown to be effective in accelerating the return to daily activity [Culp.WT-2009], allowing patients to recover in a much shorter time than with conventional surgery, which reduces both hospital stay and the rate of complications associated with laparoscopy. surgical incision [Austin.B-2003].

In terms of postoperative assessment, the temperature of the dermis plays a fundamental role, since it is directly related to the vascularization of the skin. An increase or decrease in skin temperature may be a reflection of alterations in the metabolic activity of the skin. Traditionally, these changes have been evaluated through the veterinarian's subjective assessment, which could generate variability in the results. However, infrared thermography has established itself as a reliable and objective tool to evaluate skin vascularization [Loughin.CA-2007]. IRT is useful to detect an increase in

temperature, which could be indicative of inflammation or infection, and also to identify areas of decreased temperature, which could suggest ischemia, compromised skin flaps, or neuropathies [Purohit.RC-1980].

The main objective of this study is to compare the vascularization of the postsurgical incision in patients who have undergone ovariectomy, using conventional surgery and laparoscopic surgery. To do this, infrared thermography will be used to objectively evaluate the differences in skin temperature in the incision area, which will serve to identify how both surgical techniques affect the blood circulation of the skin in the operated area. Through this comparison, it will be possible to determine whether laparoscopic surgery, being less invasive, induces a more efficient vascular response in the incision area, thus reducing the risk of complications and promoting a faster recovery compared to conventional surgery.

45 females, 30 cats and 15 dogs, between 6 months and 4 years of age, have been studied. Of these, 21 were operated by conventional surgery and 24 by laparoscopy.

The surgery was performed with Ligasure® Valleylab LS10 vascular sealant, LS Series Single Channel Vessel Sealing Generator COVIDIEN and the AMNOFLOW 30 CO2 insufflator.

Three thermograms are performed on each patient to evaluate in detail the changes in the vascularization of the skin before, during and after surgery.

For the analysis of thermographic images, we begin with a preliminary visual inspection of the abdomen of each patient. During this initial inspection, we seek to identify any significant thermal alterations that could indicate an

abnormal condition, such as inflammation, infection, or alterations in blood circulation. This quick visual check allows you to rule out potential areas of concern before performing a more detailed measurement.

Once possible significant visual alterations have been ruled out, a ROI of approximately 1 cm² is selected to perform temperature measurements, located between the third and fourth breast of the left mammary chain. This area was chosen because it is located in an anatomical area not manipulated during surgery, which ensures that measurements are as consistent and standardized as possible, without being affected by surgical manipulations or the shaving process. Selecting a region that is not influenced by surgical procedures ensures that observed temperature differences are primarily due to the effects of surgical techniques and not external factors.

This control area remains constant in all patients in the study, allowing a direct comparison of measurement results between different cases and conditions. Since the region of interest is systematically selected and is the same in all patients, standardization in temperature measurement is achieved, which increases the reliability and precision of thermographic analysis.

Once the control zone has been identified, a comparison of the maximum and minimum temperatures is made between the healthy areas (not operated on surgically) and the areas corresponding to the surgical incisions made through laparoscopic surgery and conventional surgery. This analysis allows us to evaluate how each surgical technique affects the surface temperature of the skin, reflecting possible alterations in vascularization and blood flow.

Differences in temperatures between healthy areas and operated areas provide key information about the impact of surgical interventions on peripheral circulation and post-surgical recovery.

To perform thermographic images, it is essential that the patients' body temperature be maintained within a physiological range, since any alteration in general body temperature could affect the precision and reliability of thermographic measurements. With that, we make sure that the observed thermal variations are representative of local changes in the area of interest and not external factors or patient conditions that could influence the measurement.

The first image (Figure 7.4.1) is taken prior to surgery and shaving the area where the intervention will be performed. In figure 7.4.1, we can observe the patient's thermal pattern. However, because the hair is not very short, some information about the true thermal pattern may be lost due to the insulating effect of the fur.

This image serves as a basis for evaluating the patient's initial skin temperature and allows establishing a reference point for subsequent comparisons. In this patient, no alterations were observed, and the thermal pattern of the abdomen appears symmetrical and consistent with normal findings.

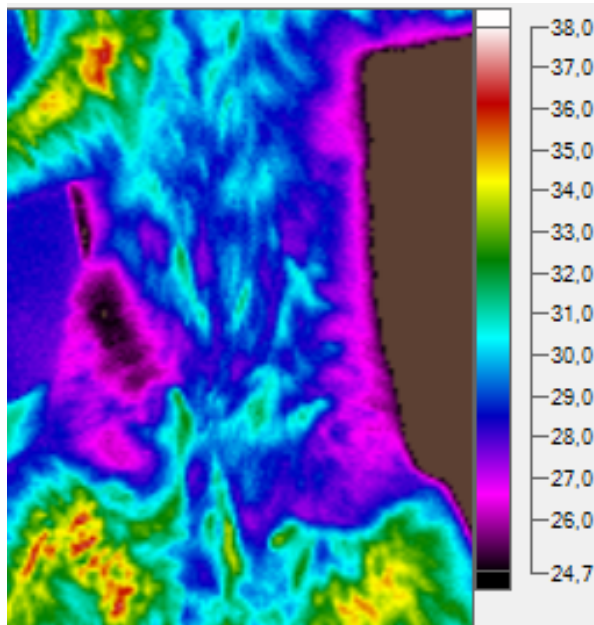


Figure 7.4.1: Thermal image of the patient's abdomen before shaving.

The second image (Figure 7.4.2) is captured after the surgical area has been shaved and an acclimatization period of 15 minutes, which is part of the pre-surgery process to increase sterilization, facilitate access and visibility of the operated area. After shaving and completing the acclimatization period, we obtain a more accurate depiction of the patient's thermal pattern, without the insulating effect of the fur, allowing us to observe any immediate changes in the surface temperature, providing additional information about blood flow in the affected area. In this case, in figure 7.4.2, we can appreciate that the thermal pattern remains symmetrical and within normality.

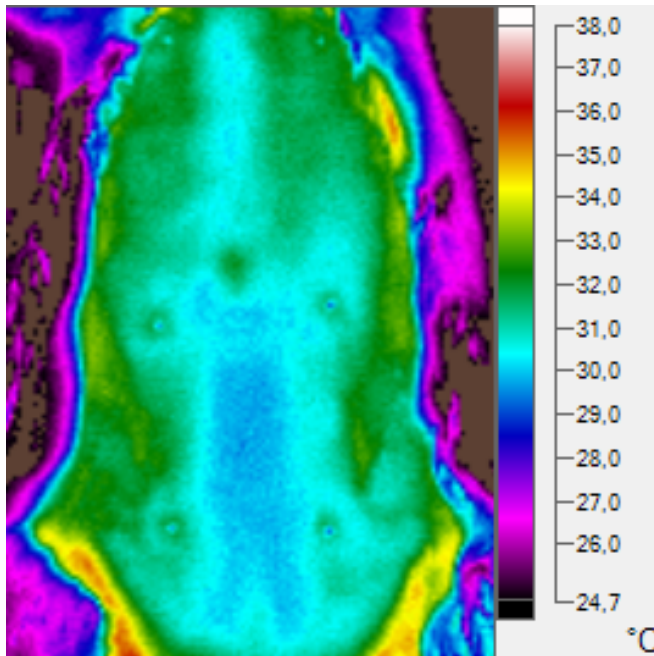


Figure 7.4.2: Thermal image of the patient's abdomen after shaving.

Finally, the third post-surgical image is taken (Figure 7.4.3), after the intervention has been completed. This image is crucial for evaluating how the surgery has affected the skin temperature in the incision area, which can reflect both the body's response to the surgical wound and the healing process and circulation in that area. Variations in post-surgical temperature could indicate signs of inflammation, infection, or poor blood circulation (ischemia), providing a useful tool for monitoring the recovery process.

In a normal thermal pattern, without surgical intervention, temperature distribution is expected to be symmetrical, with gentle temperature gradients that follow normal tissue blood flow and metabolic activity. The temperature

difference between contralateral areas (e.g., left and right abdomen) is minimal and less than 0.5°C , indicating circulatory balance and the absence of significant inflammatory or pathological processes.

In order to compare both surgeries, we can see in Figure 7.4.3 two patients after laparoscopic intervention (left) and conventional surgery (right), with both conventional (top) and thermal (bottom) images. The laparoscopic images (left) show a more marked thermal heterogeneity that breaks with this normal pattern, presenting two cold areas (blue and green), where the incision for surgery was made. The numeric difference will be analyze further down.

On the other hand, conventional surgical images (right) show higher temperatures distributed more homogeneously along the abdomen (with a predominance of red and white), losing the normal thermal pattern of a healthy abdomen and reflecting the effect of surgical manipulation on the tissue surface. There is a generalized increase in temperature and a lower thermal gradient.

After the initial visual inspection, in order to determine the exact thermal difference, a statistical analysis was carried out.

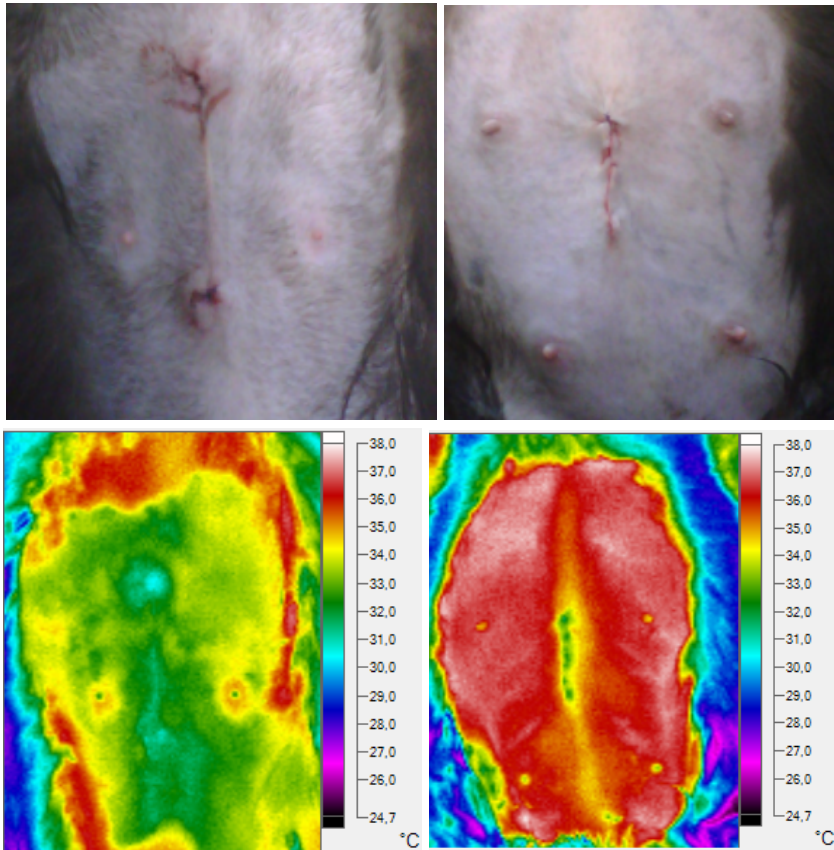


Figure 7.4.3: Conventional image (top) and thermal image (bottom) of two patients after surgery, being the laparoscopic surgery on the left and the conventional surgery on the right.

To compare the thermal differences between the study groups (laparoscopic surgery and conventional surgery), a statistical T-Test is used, which is appropriate to compare the means of two independent groups. In this case, the p value obtained in the test is used to determine if the differences observed between the temperatures of the surgical incision and the control area are statistically significant. It is considered that a p value < 0.05 indicates

that the differences found are large enough to be considered not due to chance, which suggests that the surgical technique used has a measurable impact on the skin temperature and the vascularization of the area. intervened.

In the context of this study, patients presented, prior to surgery, both before and after shaving, a difference in surface temperature in the control area of $0.4^{\circ}\text{C} \pm 0.0312^{\circ}\text{C}$, which is within the normal range according to the aforementioned study. This data reflects that, in an optimal state of health before surgery, there are no significant thermal differences in the control area, which suggests that there are no circulatory or metabolic alterations in the skin before surgery. The constant measurement of this control zone allows us to compare temperatures in the surgically operated areas and evaluate the effects of surgical techniques on superficial vascularization.

As for patients operated by laparotomy (conventional surgery), the study found a temperature difference of $3.7^{\circ}\text{C} \pm 1.3^{\circ}\text{C}$ between the control area and the surgical incision, with a p value < 0.05 , which indicates that The thermal difference between the areas is statistically significant. This large difference in temperature can be attributed to an increase in inflammation or altered blood circulation in the incision area, which is characteristic of conventional surgery due to its invasive nature. Laparotomy involves a larger incision and more extensive tissue damage, which leads to a greater inflammatory response and alterations in local blood flow, reflected in a greater temperature difference.

On the other hand, patients operated by laparoscopy, a minimally invasive technique, have a temperature difference of $1.2^{\circ}\text{C} \pm 0.03^{\circ}\text{C}$ between the control area and the surgical incision. Although a temperature difference still exists, the value is considerably lower than that observed in patients

undergoing laparotomy. This suggests that laparoscopic surgery, being less invasive, generates a lower inflammatory response and less alteration of blood circulation, which translates into a faster recovery of the vascularization of the operated area.

The significant difference between the two techniques is highlighted by the p value < 0.05 , which confirms that the results obtained are not the result of chance and that laparoscopy has a smaller impact on skin temperature, which could be related to a lower tissue injury and faster recovery of blood flow compared to conventional surgery.

8. Discussion and conclusions

8.1. Introduction

As mentioned in the introduction, infrared thermography (IRT) is useful in various fields, both in industry and in human and animal medicine, being a growing object of study. This is mainly due to the advantages of the technique, such as its speed and safety, as well as its diagnostic potential by qualitatively assessing the thermal distribution of the body.

In current veterinary medicine, IRT relies on the body's thermal symmetry to assess animal health. This technique covers various species, from pets to livestock, as well as wildlife. It has acquired great relevance, especially in recent years, as it is a non-invasive monitoring and diagnosis tool, allowing changes in body temperature to be detected and, therefore, assessing the presence of various pathologies.

IRT is especially useful in patients who are difficult to manage or who cannot be easily manipulated, allowing medical decisions to be made before the full development of the disease. For example, in companion animals such as dogs and cats, IRT can identify orthopaedic problems and early musculoskeletal injuries, while in livestock, it can detect diseases such as mastitis in dairy cows, thereby improving animal productivity and well-being. In wildlife, its application allows health monitoring without the need to capture the animals, reducing the stress and risk associated with handling.

In the studies carried out for this work, the existence of thermal symmetry in the bodies of dogs has been corroborated and the value from which the asymmetry is considered pathological has been established. These studies

have also differentiated between dogs with normal physical activity and athletes, something that had not been considered until now. This differentiation is crucial, since athletic dogs can present different thermal patterns due to their high physical activity, which requires a specific interpretation to avoid erroneous diagnoses.

In summary, infrared thermography has become an essential tool in modern veterinary medicine, facilitating more accurate diagnoses and more effective monitoring of various health conditions in animals. Its ability to detect thermal abnormalities early allows veterinarians to intervene in a timely manner, thus improving the quality of life of animals and optimizing treatments.

Establish an imaging protocol

In Chapter 5, subsections 5.8 and 5.9, we establish a detailed protocol covering everything from image acquisition to processing and the appropriate selection of color palettes, thus achieving the **first objective** of this work.

It should be noted that a fixed patient position is not considered, since, when working with animals, maintaining a rigid or standardized posture is not always feasible. This flexibility allows the protocol to be adapted to the actual conditions of veterinary practice, ensuring the acquisition of reliable thermographic data without compromising the animal's well-being or comfort.

Define the areas of interest (ROI)

The **second objective** of this study was accomplished by defining the areas of interest (ROI) for reproducible analysis of the thermal map of healthy and diseased subjects.

As established in chapter 5, subsection 5.3, in all healthy and athletic dogs, following anatomical regions were consistently identified and measured as common ROI: phalanges of the thoracic limb, carpus, forearm, elbow, shoulder (only in healthy dogs), phalanges of the pelvic limb, tarsus, gastrocnemius, quadriceps, and biceps femoris.

In the group of athletic dogs, the shoulder region was excluded due to the difficulty of evaluation in long-haired breeds. In patients with diseased subjects, ROI selection was performed on a case-specific basis, as detailed in Table 5.1, always with the criterion of comparing contralateral regions to detect thermal asymmetries suggestive of disease.

Although the general protocol may vary slightly depending on the patient and the anatomical region being studied, fixed criteria were maintained to ensure reproducibility, such as consistency in distance and position within each patient. The ROI were defined and analyzed by the author, ensuring consistency in the assessment. In all cases, the same regions were measured repeatedly in the same patient to allow for continuity and objective comparison of the obtained values.

In specific situations, the ROI were determined by the veterinarian responsible for the imaging, based on clinical requirements, such as the evaluation of hypothermic areas in intervertebral spaces for the localization of neuropathies. Multiple thermal parameters were extracted from each region of interest: mean, maximum, and minimum temperatures, all expressed in degrees Celsius (°C).

Comparison of studied ROI.

The **third** objective of this study was to determine the study variables in the ROI analysed that are most appropriate for their characterisation. The relevance of the different regions of interest (ROI) in relation to the observed mean temperature differences is assessed considering that not all ROI manifest thermal changes in a similar manner.

For example, an alteration in the shoulder typically does not generate large thermal variations in the initial stages, while an injury to the tarsal extensor muscles tends to present more marked temperature differences from an early stage. This is due to the nature of the pathologies involved; a tendinopathy does not induce the same level of immediate inflammation as a muscle injury, which explains the discrepancies in the initial thermal responses observed.

So far, the analysis has been carried out without discriminating between the different Regions of Interest (ROI). In the following section, specific comparisons are made by ROI (Table 8.4.1), in order to assess whether there are areas of the body that are more indicative of the patient's condition. This disaggregation by ROI allows us to identify areas of the body that may be more sensitive to thermal changes associated with different health conditions.

This detailed approach makes it possible to determine whether certain areas of the body, such as the limbs, torso or head, show more significant thermal variations than others in relation to the patient's health. Identifying these areas can improve diagnostic accuracy and allow for more effective monitoring of the evolution of pathologies.

In the case of oncology patients, since there are no ROI studies in healthy patients to make a direct comparison, they will be analyzed independently. This is because the nature of cancer itself does not always fit into a standard anatomical area. Cancerous lesions can appear in various parts of the body that do not match the areas commonly studied in the other groups. Despite this limitation, cancer-affected ROI will be included in the tables and figures to allow for a visual comparison and to contextualize the thermal data in the general framework of animal health.

The graphical representation of the means and their confidence intervals can be seen in Figure 8.4.1, which shows the estimated marginal means of temperature and standard deviation across different regions of interest (ROI) for healthy (green), athletic (blue), and pathological (red) groups. In the healthy (green) and athlete (blue) groups, the standard deviations across all ROI are consistently very small, indicating low variability in temperature measurements. Suggesting thermal stability and uniform physiological regulation in these populations.

In contrast, the pathological group (red) shows notably larger standard deviations across several ROI. The most prominent variability appears in the tail, axilla, and mammary gland, where the error bars are substantially wider. This elevated variability implies inconsistent or abnormal thermal patterns, likely due to inflammatory or pathological processes affecting these regions unevenly.

Oncologic ROI display the greatest thermal variability, suggesting an heterogeneous thermal expression in these regions, likely due to tumor-associated metabolic or vascular changes.

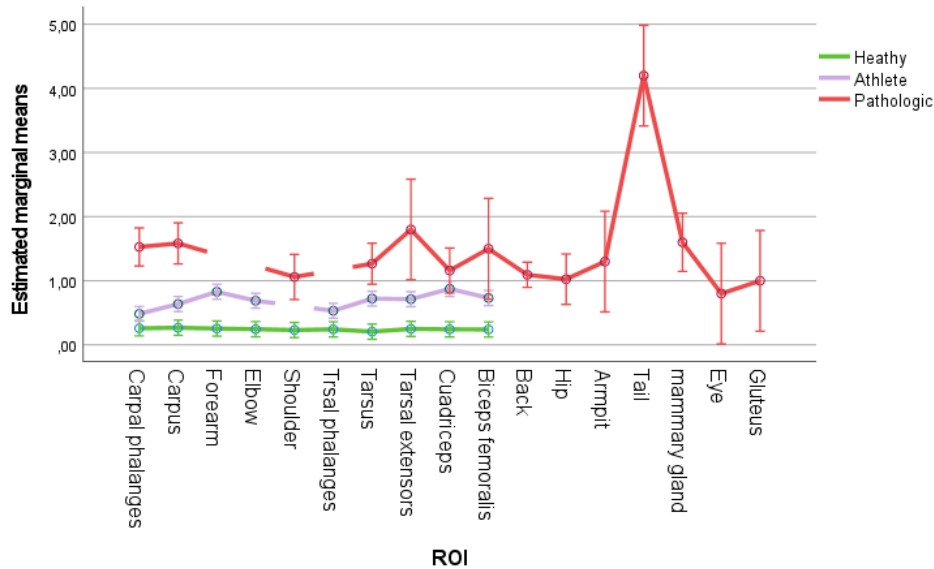


Figure 8.4.1: Graph representing the temperature means and standard deviation in the ROI studied for the different groups (healthy, athletes and pathological). In the pathological cases, it was decided to separate the oncological patients so as not to distort the values.

The numerical data can be seen in Table 8.4.1, we can identify areas that exhibit the greatest thermal differences in each group, suggesting that alterations in these zones may be detected earlier using thermography, are the elbow in the healthy group the tarsal extensor in the athletes group, the hip in the pathological group, and the tail in the oncology group, with the latter showing the highest overall thermal deviation.

Table 8.4.1: Mean temperature difference (TM_Dif), standard deviation and confidence interval (95%CI) for the healthy, athletic and pathology groups of the ROI studied.

	ROI	TM_Dif (°C)	Standard Deviation	95% CI	
				LL	UL
Healthy	Carpal phalanges	0.23	0.12	0.13	0.32
	Carpus	0.25	0.14	0.14	0.33
	Forearm	0.23	0.11	0.14	0.32
	Elbow	0.26	0.13	0.15	0.34
	Shoulder	0.24	0.12	0.14	0.33
	Tarsal phalanges	0.21	0.10	0.12	0.29
	Tarsus	0.20	0.13	0.10	0.30
	Tarsal extensor	0.24	0.11	0.14	0.31
	Quadriceps	0.23	0.13	0.12	0.33
	Femoral biceps	0.28	0.14	0.17	0.39
Athletes	Carpal phalanges	0.63	0.09	0.55	0.72
	Carpus	0.83	0.10	0.74	0.93
	Forearm	0.64	0.07	0.56	0.71
	Elbow	0.65	0.11	0.54	0.76
	Tarsal phalanges	0.55	0.09	0.46	0.64
	Tarsus	0.60	0.10	0.50	0.69
	Tarsal extensor	0.71	0.13	0.58	0.83
	Quadriceps	0.73	0.12	0.61	0.85
Pathologic	Femoral biceps	0.73	0.65	0.61	0.85
	Carpal phalanges	1.67	1.11	1.13	2.20
	Carpus	1.80	0.77	1.28	2.32
	Shoulder	1.56	0.64	1.11	2.01
	Tarsus	1.27	0.42	1.01	1.53
	Tarsal extensor	1.29	0.51	0.96	1.63
	Quadriceps	1.13	0.65	0.65	1.61
Oncology	Femoral biceps	1.10	1.31	0.29	1.91
	Back	1.09	0.33	0.59	1.59
	Hip	1.93	0.35	1.38	2.87
	Armpit	1.30	0.42	0.74	2.87
	Tail	4.20	2.34	2.42	5.98
	Mammary gland	1.60	1.15	0.23	3.28
	Eye	1.80	0.39	1.02	2.59
	Gluteus	1.00	0.22	0.78	2.59

CI: Confidence Interval (95%)

LL: Lower Limit of Confidence Interval

UL: Upper Limit of Confidence Interval

The comparative analysis of different Regions of Interest (ROI) highlights that thermal variations are not uniform across anatomical sites and depend significantly on the underlying physiological or pathological condition. While healthy and athletic groups show thermal stability with minimal variability across ROI, pathological groups exhibit greater temperature fluctuations, particularly in areas like the hip, tail, axilla, and mammary gland. These differences reflect localized inflammatory or disease processes. Notably, oncologic ROI display the highest thermal variability, consistent with the heterogeneous metabolic and vascular characteristics of tumors. Identifying specific ROI with the greatest thermal deviations—such as the elbow in healthy subjects, tarsal extensor in athletes, hip in pathological cases, and tail in oncologic patients—enables earlier detection and more targeted monitoring of health alterations via thermography. This ROI-specific approach enhances diagnostic precision by focusing on body areas most sensitive to thermal changes related to distinct health states.

Thermographic pattern in healthy subjects.

The **fourth** objective of this thesis was to establish the thermographic pattern in the case of a healthy subject to assess the possible thermal symmetry between contralateral parts of the body. In order to do so, after the statistical analysis conducted, we can interpret the following results.

The histogram shown in Figure 6.1 reveals that the mean temperature differences between the contralateral limbs cluster around the zero value. This indicates that there is no significant bias towards a specific limb, reflecting a balanced distribution of temperatures between opposite parts of the body. Centralizing the data around zero reinforces the idea of thermal symmetry inherent in healthy individuals.

Likewise, the scatter diagram in Figure 6.2 confirms this thermal symmetry by showing a strong positive correlation between the average temperatures of the contralateral limbs. The points align closely with the line of perfect equality ($x = y$), reinforcing the consistency of thermal measurements and their correspondence between opposite sides. This homogeneous behavior allows us to identify a characteristic thermographic pattern in healthy subjects, where the observed differences are considered insignificant and attributable only to natural variations.

The underlying statistical analysis supports these findings, demonstrating that the discrepancies detected between contralateral temperatures are minimal and not clinically significant. This thermal symmetry pattern provides a reliable frame of reference to evaluate possible deviations in cases of pathologies or physiological imbalances.

Furthermore, the results derived from the ROC1 (Figure 6.5) curve highlight that a thermal difference threshold of 0.45 °C is optimal to discriminate between healthy and pathological individuals. This threshold offers high sensitivity and specificity, becoming an effective tool for the detection of thermal anomalies. The implementation of this cut-off value not only facilitates early identification of pathologies, but also improves diagnostic accuracy and optimizes follow-up in clinical and animal health contexts.

In conclusion, this study establishes a solid foundation for the use of thermography as a diagnostic tool. The clear thermal symmetry between the contralateral limbs in healthy individuals and the threshold of 0.45 °C as an indicator of pathology constitute significant advances that enhance the effectiveness of thermal monitoring and its application in clinical practice.

Thermographic pattern in athletes.

The **fifth** objective was to establish the thermographic pattern in athlete dogs, as they are healthy patients but with a specific condition, that is high level training.

In athlete dogs, the results obtained are similar to those observed in healthy dogs, which indicates that they also present a notable thermal symmetry between the contralateral limbs. However, a greater dispersion is seen in the graphs. This suggests that, although they maintain a pattern of correlation between the average temperatures of the extremities, the variability of the measurements is higher compared to healthy dogs.

A possible explanation is the increased metabolic activity generated by intense exercise, which may influence the distribution of body heat. Physical exercise is also related to an increase in blood flow, which could result in greater thermal variability in the tissues due to the intense blood supply.

Another plausible explanation is that regular practice of intense physical activities can lead to chronic muscle decompensation. Although these decompensations are not necessarily pathological, they can be detected through thermography. For example, a dog that predominantly uses one side of its body during training might show thermal differences compared to the other side, thus reflecting an asymmetrical use of its muscles.

Additionally, athlete dogs are subject to greater physical wear and tear and constant recovery from micro-injuries that could influence their thermal profile. These microlesions, although not always visible or detectable using conventional methods, can manifest as areas of greater heat due to the

inflammatory and tissue repair process, thus increasing thermal dispersion.

The second part of the study will focus on establishing specific reference values for athletic dogs and dogs with normal activity, which will improve diagnostic accuracy when using infrared thermography in different veterinary contexts.

With the results obtained through the ROC4 (Figure 6.8) curve, we can demonstrate that a variation of 0.7 °C between the contralateral parts of the body allows us to clearly and accurately differentiate between athletes and pathological subjects.

This differentiated approach is crucial to avoid misinterpretations and to adapt therapeutic and training recommendations to the particular needs of each group, thus optimizing the well-being and performance of the animals.

Alteration of the thermal pattern in several conditions.

The **sixth** objective of this thesis is to analyze the thermal alterations in patients with various pathologies and compare them with the thermal pattern of healthy subjects.

Statistical analysis of patients with pathologies, supported by graphical representations and tables, provides key information on thermal variations associated with different medical conditions. The scatter plot visually reveals a thermal increase in the affected ROI (Region of Interest), manifested as hyperthermia compared to healthy contralateral regions. This phenomenon is quantified in Table 6.2, which records an average difference of 2.4 °C between

the pathological areas and their healthy counterparts, as indicated by the value of the ordinate at the origin. This data stands out as a potential diagnostic marker, suggesting that a thermal increase of this magnitude can be a reliable indicator of pathological alterations.

Characterization of pathologies and thermal gradient

Table 6.4 presents a detailed breakdown of the four pathological subgroups studied: acute pain, chronic pain, hip dysplasia and IVDD. Each of these groups exhibits a particular thermal gradient, which allows us to infer differences both in the physiological behavior of the pathologies and in the intensity of the associated inflammatory or pain processes. This finding is crucial not only to identify pathologies, but also to evaluate their relative severity.

The data show a clear thermal differentiation between healthy subjects and those with pathologies, since the thermal patterns of the latter are different and do not overlap with those of healthy individuals. Furthermore, among the pathological groups, the pathologies that generate pain are grouped according to their severity. Conditions that produce less pain present thermal patterns closer to those observed in healthy active animals (such as athletes), while more intense pathologies, such as acute trauma, show a thermal profile more similar to that of patients with severe conditions such as cancer. This thermal gradient allows a more precise categorization of pathologies based on their physiological impact.

Specific thermal patterns in Oncology patients

Oncology patients represent a special case within thermal analysis. The areas affected by this condition do not necessarily coincide with the regions of interest evaluated in the other subgroups. This is due to the heterogeneous nature of cancer lesions and systemic processes that can influence thermal measurements. Therefore, thermal patterns associated with cancer require a specific analytical approach that considers the particularities of this disease. This uniqueness limits direct comparisons with other subgroups, but underscores the need to develop differentiated thermal models for cancer diagnosis and monitoring.

To sum up, the study of thermal gradients and their associations with different pathologies not only improves the ability to differentiate between physiological and pathological states, but also provides tools to evaluate the progression of a disease or the response to treatment. The ability to classify pathologies according to their thermal severity has significant clinical applications, such as the design of personalized intervention strategies and non-invasive monitoring of the evolution of medical conditions.

8.2. Comparison between healthy patients, athletes and dogs with pathologies

The results have shown that thermography is an effective tool to discriminate between healthy dogs, athletes and those with various pathologies, showing a clear difference in the thermal symmetry of the contralateral limbs between the groups, with healthy dogs showing the greatest symmetry and pathological dogs the greatest temperature differences.

For athletic dogs, although there is a greater difference in mean temperature compared to healthy dogs, the 95%CI limits are still relatively narrow. This suggests that, despite the thermal fluctuations discussed above, possibly caused by exercise and the microlesions it causes, thermal variability is not extremely high. Athlete dogs show a greater difference in mean temperature due to their intense physical activity, but this difference remains within a predictable range. One of the possible developments of this work is to elaborate in a future project whether dogs have a tendency to use a particular limb.

On the other hand, dogs with pathologies show a greater variability in temperature differences between the affected and the healthy contralateral parts. The 95%CI limits in this group are much wider, reflecting a greater dispersion in the thermal data. This variability may be due to the nature and severity of the injuries, since different pathologies can influence body temperature differently. For example, inflammatory or infectious conditions can significantly elevate local temperature, while other types of injuries could have more moderate thermal effects.

To represent this in a visual way, it can be observed that in Figure 8.8.1 the lower and upper limits of the 95% confidence interval (95%CI) are graphically shown for the different groups studied: healthy dogs, athletes and those with pathologies.

This visual representation facilitates the comparison of thermal variability between the groups. In healthy dogs, the 95%CI limits are narrow, reflecting a smaller temperature difference between the contralateral parts of the body. This narrow band indicates high thermal consistency and symmetry, which is expected in healthy individuals.

This figure clearly illustrates how thermal variability increases with the presence of pathology. In healthy and athletic dogs, the temperature difference between the contralateral parts is relatively constant and predictable. However, in pathological dogs, this difference becomes more erratic, reflecting the diversity of thermal responses to different health conditions.

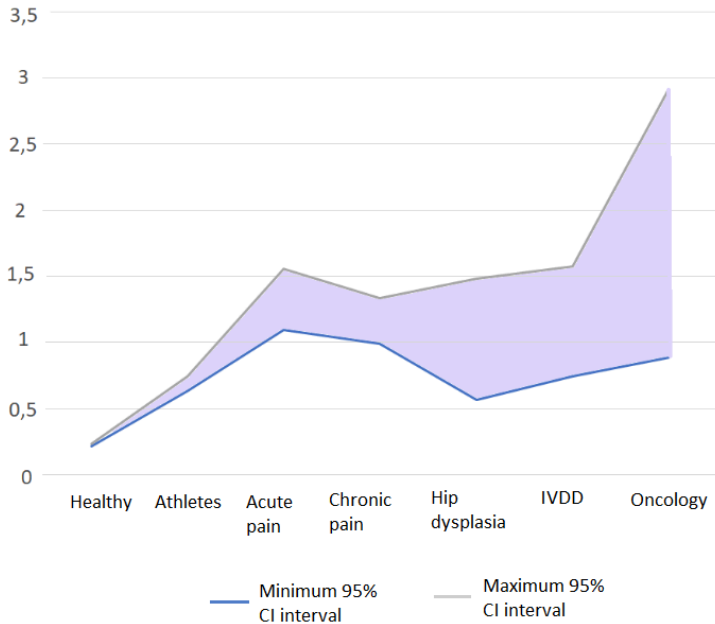


Figure 8.8.1: This graph shows the 95% confidence intervals (95%CI) for the maximum and minimum values of the temperature difference between contralateral body parts (°C). The maximum and minimum values of the temperature difference between contralateral body parts (°C) are represented on the ordinate axis (Y axis), while the study patient groups are represented on the abscissa axis (X axis).

This visual analysis of the 95%CI limits provides a deeper understanding of how body temperature can vary between different health states. It allows the identification of thermal patterns associated with physical activity and the presence of pathologies, which can be crucial for the diagnosis and monitoring of animal health. The greater variability observed in dogs with pathologies highlights the importance of a personalized approach in the interpretation of thermographic data, taking into account the specificity of each pathological condition.

8.3. Absolute or signed temperature difference values?

A comparison is carried out between the groups studied and a statistically significant difference is observed between the three study groups, these being the healthy ones, the athletes and those who present pathologies. Within the pathological ones, there are subgroups that we will comment on later.

The assessment of thermal symmetry in healthy dogs and athletes is performed in absolute values for several key reasons. First, it allows us to standardize the results and obtain consistent comparisons between different studies, since the left Region of Interest (ROI) is always compared with the right ROI. This methodology ensures that the results are uniform and comparable, regardless of the individual variations of each study or patient.

Additionally, using absolute values provides greater diagnostic clarity, removing ambiguity from the signs and allowing focus on the magnitude of the thermal difference. This is crucial to detect anomalies objectively, as any significant variation in temperature between the two compared areas can be easily identified.

In the case of patients who present a pathology, the sign of the temperature difference becomes more relevant. The technique is standardized by comparing the affected ROI with its healthy contralateral part. Thus, the temperature difference sign may indicate increases (which may be indicative of inflammation) or decreases (which may suggest necrosis) in temperature.

This information is vital for an accurate diagnosis, since it allows us to identify not only the presence of a pathology, but also its nature.

In summary, assessment in absolute values not only facilitates standardization and comparison between studies, but also provides a clear and objective diagnostic tool, especially useful in the detection and characterization of pathologies.

8.4. When do we consider a dog an athlete?

In order to classify as an athlete for this study, the dogs had to be in a federation and have training sessions at least twice a week. The debate lies in whether we can consider dogs that do not train in a regulated sport on a regular basis.

A dog can be considered an athlete when it has a high level of physical activity, outstanding performance in tasks or sports, and/or follows a consistent training regimen.

This includes challenging activities such as running, jumping, swimming, or participating in dog sports such as agility, racing, mushing, frisbee, or field work.

An athlete dog is characterized by having optimal physical condition, with good muscle tone, adequate weight and robust general health, which allows it to perform above average dogs, recovering quickly from intense physical efforts.

When speaking of high-energy dogs that regularly play sports with their owners, such as cycling, running, swimming or hiking, it is important to consider the possibility of classifying them as athletes when performing a thermographic study.

This decision should ultimately be made by the trained clinician conducting the study, who will evaluate the dog's physical activity level and its ability to meet the criteria of an athlete.

8.5. Limitations and Strengths

Sample number and diversity of pathologies

One of the main limitations identified in this study is the difficulty in obtaining a sufficient sample of individuals with a single pathology to allow a more focused analysis of thermographic images. This is because the study was conducted in a daily veterinary clinical practice setting, where consultations typically involve a wide variety of cases and medical conditions. The diverse nature of the patients treated and the limitations of continuity in the follow-up of specific cases complicated the accumulation of a homogeneous and representative sample for a single pathology.

Challenges in data collection

In the context of daily clinical practice, standardized data collection faces multiple obstacles:

- Variability in the cases treated: The cases that present in a veterinary clinic are usually heterogeneous, reflecting a diversity of conditions and levels of severity that make it difficult to isolate a single pathology with sufficient recurrence for robust statistical analysis.
- Continuity of follow-up: Not all patients return for subsequent follow-ups or are available for ongoing monitoring, reducing the potential sample size for longitudinal studies.
- Inclusion requirements: The need to meet strict criteria to ensure the validity of thermographic measurements and the quality of the data

further limits the number of cases that can be included in the study.

- The differences between dog breeds represent a particular challenge not seen in humans, and also contribute to a more heterogeneous population than that observed in conventional studies.
- Veterinary centers are typically smaller than human hospitals, limiting access to a broad population.

Introduction of Various Pathologies

Given these limitations, it was decided to include various pathologies in the analysis. Although this could be perceived as a source of variability that complicates direct comparisons between specific pathologies, this decision also provides certain benefits:

- Expansion of the reference framework: By including multiple pathologies, the study generates a broader comparative framework that allows identifying general patterns and differentiating between physiological and pathological states.
- Clinical relevance: More closely reflects the reality of veterinary practice, where case diversity is the norm and diagnosis requires tools that can be applied to a spectrum of conditions.
- Initial exploration: This strategy is particularly useful in exploratory studies, where the goal is to generate hypotheses and detect general trends that can be further investigated in future studies with a more specific focus.

Impact on results and future research.

The inclusion of various pathologies, although it limits the possibility of performing detailed analyzes for a single disease, allows the development of an initial vision of the capabilities of thermography to differentiate between pathologies and evaluate their severity. However, this approach also highlights the need for future studies designed to address this limitation:

- Expanding the sample size: It is recommended to increase collaboration between veterinary clinics or resort to specialized centers to accumulate a broader and more specific database for each pathology.
- Specific studies: Once general trends have been identified, more focused studies can be carried out on individual pathologies, with stricter inclusion and follow-up criteria.
- Implementation of multicenter databases: Collaboration between clinics and research centers could facilitate the collection of standardized data on a broader spectrum of pathologies and in greater volumes.

In conclusion, although the inclusion of various diseases in this study emerges as a practical solution to the difficulty of collecting homogeneous data, it also underlines the importance of continuing to develop methodologies that allow overcoming this limitation in the future. The combination of general studies with focused analyzes will ensure a greater understanding of the clinical applications of thermography in the veterinary field.

Impact of hair variability on infrared thermography

Variability in patient hair characteristics represents a significant limitation in the application of infrared thermography, especially in the context of selecting Regions of Interest (ROI). The physical properties of hair, such as length, texture and density, directly influence the ability to obtain accurate and consistent thermal measurements, complicating thermographic analysis in certain cases.

Extremely long hair

In patients with extremely long hair, the hair acts as a barrier between the skin surface and the infrared sensor, making it difficult to obtain accurate measurements of the underlying skin temperature. This complicates the identification and selection of ROI, since the hair layer generates thermal insulation that can mask relevant temperature differences between areas. Additionally, irregularities in hair distribution can introduce variability in measurements, affecting the reliability of the results.

To mitigate this problem, it is common to resort to auxiliary methods, such as trimming or separating the hair in the areas of interest. However, these solutions are invasive, increase the time needed for the procedure, and may not be feasible in some contexts, especially if the patient is under stress or if the medical condition prevents manipulation of certain areas.

Curly hair or dreadlocks

In the case of patients with curly hair or dreadlocks, complications are even greater. These hair textures generate an extremely irregular surface, creating areas of thermal shadowing and variability that make accurate interpretation of the images difficult. Additionally, hair density in these conditions may be more

pronounced, precluding direct evaluation of the underlying skin.

In these situations, the infrared thermography method may become inapplicable or highly limited, since the measurements obtained would not be representative of the real temperature of the ROI. Additionally, processing thermographic images may require advanced correction techniques or specific algorithms to attempt to compensate for irregularities, adding complexity and cost to the analysis.

Practical considerations and recommendations

- Patient selection: Before performing thermographic analysis, it is essential to evaluate the characteristics of the patient's hair to determine if the technique is appropriate. In cases where the hair is excessively long, curly or has dreadlocks, IR is not, at present, appropriate and it will be necessary to opt for alternative evaluation methods.
- Patient preparation: When feasible, hair trimming in areas of concern may be a practical solution to reduce thermal barriers. However, this should be done with caution to minimize stress on the patient and ensure their comfort.
- Complementary studies: In patients where infrared thermography is not applicable due to the characteristics of the hair, it is suggested to combine this method with other diagnostic techniques that do not depend on direct visibility of the skin, such as ultrasound or clinical analysis.

Hair variability represents a major challenge in the application of infrared thermography in the veterinary field. Although there are strategies to mitigate

some of these problems, it is essential to recognize the limitations of the method in patients with long, curly hair or dreadlocks. Adaptation of preparation techniques, along with the development of new technologies, will be key to expanding the applicability of infrared thermography and ensuring accurate and useful results in a greater diversity of patients.

Strengths of the use of infrared thermography in the daily veterinary clinic

The use of infrared thermography in daily veterinary clinical practice has numerous strengths that make it a valuable tool, especially in contexts where the aim is to minimize stress in patients and maximize diagnostic security. Among its main advantages are:

- Total safety: infrared thermography is a completely non-invasive technique that does not use ionizing radiation. This guarantees absolute safety for both the patient, the owner and the veterinary staff, eliminating risks associated with cumulative radiation exposure and costs related to radiation protection measures and their maintenance. This aspect positions it as an ideal alternative to other diagnostic methods that require additional precautions to protect the health of those involved.
- "Stress-Free" strategy: measurements can be made remotely, without the need for direct contact with the animal. This approach significantly reduces stress, especially in patients who may be sensitive to handling, such as nervous, aggressive or pain-prone animals. By avoiding direct physical interaction, the technique is particularly useful

for exotic species, hospitalized animals, or in situations where handling could aggravate a medical condition.

- No physical manipulation: thermography allows accurate data to be obtained without the need to restrain, immobilize or sedate the patient. This not only contributes to the well-being of the animal, but also reduces the risk of accidental injury to both the patient and veterinary staff. In addition, it avoids complications derived from physical management, such as alterations in physiological patterns that could bias diagnostic results.
- Speed and ease of implementation: infrared thermography allows obtaining images in real time, with quick and easy-to-execute procedures. This makes it ideal for integration into the daily clinical routine, allowing multiple patients to be evaluated in a short time without compromising the quality of the results.
- Diagnostic versatility: thermography is capable of identifying thermal abnormalities associated with a wide range of conditions, such as inflammations, infections, musculoskeletal or circulatory problems, and pathologies associated with pain. This versatility makes it a highly effective initial screening tool, which can complement other more specific diagnostic methods.
- Continuous monitoring and follow-up: thanks to its non-invasive and safe nature, thermography can be used repeatedly to monitor the evolution of a medical condition or the response to treatment without causing discomfort to the patient. This facilitates long-term monitoring of chronic pathologies or recovering injuries.

8.6. About fracture monitoring

In Chapter 7.1, focused on the thermal evaluation of a fracture development, it has been analyzed how infrared thermography can detect physiological changes associated with the onset and progression of bone injury.

The process of bone callus formation, which is essential for fracture healing, largely depends on the presence and functionality of the vasculature in the affected area. The formation of new blood vessels, a phenomenon known as angiogenesis, is crucial in the early stages of the healing process as it allows for adequate delivery of nutrients and oxygen necessary for bone repair. If there is a deficiency in the vascularization of the fractured area, as may occur in injuries with significant displacement or in difficult-to-locate fractures, bone healing may be delayed or even at risk of not occurring adequately, leading to the possibility of complications such as non-union.

During the healing process of a fracture, it is expected to observe an increase in vascularization in the affected area, as part of the process of regeneration and repair of bone tissue. This increase in blood circulation is essential for the supply of nutrients and oxygen, facilitating the formation of bone callus and promoting healing. This phenomenon generally manifests as an increase in temperature in the injured region, reflecting the increased metabolic activity and inflammatory response associated with fracture healing.

The integration of the information provided by thermal images, radiographs and the patient's clinical picture allowed us to conclude that the fracture healing process was absent or significantly delayed. This reinforces the need to consider an alternative or additional therapeutic approach to promote

healing, such as stimulation of vascularization or surgical intervention if necessary. The combination of these diagnostic methods, including thermography and radiography, allowed a more accurate assessment of the fracture status and provided crucial data for clinical decision making in patient management.

Thermography played a fundamental role in making clinical decisions for the management of this fracture. Although conventional treatments, such as manual reduction and the use of bandages, had been applied twice, the lack of bone callus formation and the absence of an adequate thermal response indicated that the healing process was not occurring as expected. Thermography, by detecting differences in surface temperature, offered valuable information about metabolic activity and vascularization in the fractured area. Inflammation is a key component of the body's response to a fracture, as it involves the activation of cells responsible for bone regeneration thus the formation of bone callus. When there is no thermal reaction accompanying the inflammation, this indicates that the area is not making progress in healing, necessitating an immediate adjustment in treatment. However, in this case, the absence of thermal changes suggested that there was no significant inflammatory response in the fracture region, indicating that the body was not making the necessary adjustments to heal the injury effectively.

Using thermal imaging, we were able to observe the lack of physiological changes necessary for the fracture to heal, allowing for a more accurate prognosis and a change in treatment approach. Ultimately, the fracture was resolved through surgery, as seen in X-ray (Figure 7.1.5) with the use of an osteosynthesis plate.

Despite receiving traditional treatments such as manual reduction and taping on two occasions, the fracture showed no signs of healing. The lack of visible inflammation or a thermal response in the fractured area suggests that the bone healing process was stalled.

Surgery in this context would not only provide more effective stabilization of the fracture, but could also facilitate better alignment of the bone fragments and allow direct access to optimize healing through techniques such as bone grafting or stimulation of local vascularization. , essential factors when spontaneous healing is compromised. The combination of thermal evaluation, radiographs and clinical follow-up allowed a more precise and personalized approach to fracture treatment, evidencing the importance of using complementary tools to guide the treatment decision.

8.7. About Feline Aortic Thromboembolism (FATE)

In Chapter 7.2, this work explores IRT as a predictive method of Feline Aortic Thromboembolism (FATE).

The temperature difference in healthy animals or with paralysis of the posterior third of spinal origin tends to zero, as expected, while in animals with aortic thromboembolism a temperature difference between ipsilateral limbs of more than 2.2°C, highlighting the hypothesis of the detectability of a vascular accident that produces a lack of blood supply, which causes a decrease in temperature.

Pouzot-Nevoret et al (12) suggest that a difference of 2.4°C in temperature between ipsilateral extremities is suggestive of Aortic Thromboembolism. In this case, even with a low number of cases, these results have been validated.

The decrease in temperature of the hind limbs is a very relevant clinical sign in aortic thromboembolism, but human touch is subjective, and thermography allows the results to be objectified, being also 10 times more sensitive than human touch (6), facilitating the diagnosis.

The technique has been especially useful in emergency settings, where time is critical for diagnosis and treatment. In cases of FATE, for example, thermography can identify cooling patterns in the affected extremities, associated with a lack of blood flow distal to the thrombus. These findings can preliminarily differentiate between FATE and other possible causes of paralysis, such as traumatic injuries or spinal edema, which could present different thermal patterns.

The use of infrared thermography in initial triage offers several advantages. Firstly, it allows us to quickly identify if there is a significant decrease in extremity temperature, which suggests ischemia and points towards a probable diagnosis of thromboembolism. This finding may be sufficient to prioritize more specific confirmatory tests, such as Doppler ultrasound or computed tomography, avoiding unnecessary delays. Furthermore, in cases where thermography does not show significant temperature differences, attention can be directed towards other potential etiologies, such as trauma or neurological disorders, adjusting the diagnostic protocol appropriately.

Establishing infrared thermography as an initial triage tool in cases of posterior third palsy could transform the way diagnosis is approached in emergency situations. Its speed and ability to offer relevant physiological information in real time not only optimizes the use of more advanced diagnostic resources, but also reduces stress and pain for the patient, minimizing unnecessary manipulations in a critical condition.

Finally, by integrating this technique into the triage protocol, the veterinary team's ability to establish an early and accurate differential diagnosis is improved, which has a direct impact on patient survival and recovery.

This study seeks to provide evidence to support the routine use of infrared thermography as part of a systematic, efficient and animal welfare-focused approach in cases of posterior third paralysis.

Other causes of cooling of the hind limbs must be taken into account, such as hypothermia or hypovolemia, so a physical examination and a thermographic study of the entire patient must be performed.

More studies should be carried out on the use of thermography in arterial thromboembolism, since more statistics are needed to obtain a firmer conclusion.

8.8. About spondylosis deformans

In Chapter 7.3, in which a patient with deforming spondylosis was studied, the way in which the body's adaptive mechanisms respond to chronic mechanical stress and spinal instability is analyzed. Osteophyte formation is an adaptive response to chronic mechanical stress and spinal instability. Over time, intervertebral discs lose height and flexibility due to aging and other degenerative factors, causing increased stress on adjacent bone surfaces. In response, the body generates osteophytes to stabilize the spine, but this can lead to stiffness and even bone fusion in severe cases.

Skeletal muscles, essential for movement and stability of the body, receive a wide and complex network of blood supply through arteries and capillaries. This abundant blood circulation is crucial for the proper functioning of muscles, as it provides the oxygen and nutrients necessary for their contraction and regeneration, in addition to eliminating waste products generated during muscular activity. However, any injury or alteration to the musculoskeletal system, such as those caused by degenerative conditions as spondylosis deformans, can affect blood flow and cause alterations in local circulation. These alterations can manifest themselves in the form of changes in tissue temperature, since compromised blood circulation can lead to less oxygenation and an accumulation of heat in the affected areas, which could make it easier to identify circulatory or inflammatory problems.

The patient's symptoms are compatible with myofascial pain, a type of pain that originates in the muscles and connective tissues, and which can be exacerbated by the presence of osteoarthritis, trigger points or muscle contractures. This type of pain does not always respond well to conventional

pharmacological treatments, [Desai.MJ-2013] which can generate alterations in the patient's mood, such as anxiety, irritability or depression, and also frustration in guardians who do not see improvements with traditional medical treatments. In this context, it is crucial to adopt a global assessment of the symptoms, which considers not only the physical aspects, but also the emotional ones, to apply complementary and individualized therapies according to the needs of each case.

In the case of this patient, although the original problem was hip dysplasia and spondylosis deformans, the persistent symptoms that were not completely relieved by pharmacological treatment were, in large part, a consequence of myofascial pain. This type of pain is common in animals with chronic joint conditions, since tension and disruption in the normal functioning of muscles and joints can trigger trigger points, which in turn generate pain and limitation in movement. For this reason, the combination of physiotherapy therapies, which include manual techniques and electroacupuncture, has allowed significant progress in the patient's improvement, reducing the need for medication and eliminating the use of bedinvetmab without causing a relapse in symptoms. The positive response to these therapies has resulted in an evident improvement in both the patient's physical and emotional state, which translates into a better quality of life for her, reflecting the importance of a comprehensive and personalized therapeutic approach.

Furthermore, the patient's improvement has been evaluated objectively through infrared thermography. Thermography has proven to be a useful tool to assess the response to treatment, since it has been observed that during manual therapies, such as massages, changes occur in the surface temperature both in the treated area and in adjacent areas. These thermal changes suggest that manual therapies directly influence peripheral blood

flow, which improves circulation in the treated areas, such as the dorsal muscles in this case. The improvement in blood flow may be key to relieving muscle tension and facilitating joint mobility, which in turn contributes to the improvement of the clinical signs observed in the patient, such as greater agility, less pain and reduction of tension bands and trigger points. Thermographic images, therefore, act as an objective indicator of the effectiveness of therapies, allowing detailed monitoring and precise evaluation of the patient's evolution.

However, regarding spondylosis deformans, although its prevalence and clinical consequences of the condition have been demonstrated in various species, there are still no studies that explore its diagnosis or monitoring using infrared thermography. This represents an area of pending research, given that the technique could provide valuable information on the presence of local inflammation, alterations in circulation and the evolution of the disease, thus allowing a more detailed approach in monitoring the progression of spondylosis deformans. and other musculoskeletal disorders in animals and humans.

To sum up, this case shows that a multidisciplinary therapeutic approach that combines pharmacological treatments with personalized physical therapies, such as physiotherapy and electroacupuncture, can be much more effective in treating myofascial pain and other complications associated with chronic conditions, such as dysplasia. hip and spondylosis deformans. Additionally, the use of infrared thermography as a diagnostic and monitoring tool allows for objective and accurate evaluation of treatment progress, facilitating adjustment of therapies and optimizing patient recovery.

8.9. About conventional vs. Laparoscopy surgery

Chapter 7.4 presents a comparative study of the thermal pattern after surgery, analyzing the differences between the conventional and laparoscopic techniques. When trauma to the skin occurs, whether accidentally or as part of a scheduled surgical procedure, immediate changes occur in the skin's vascularity. This occurs due to the alteration in local blood flow, which responds to both inflammation and tissue regeneration. These changes are fundamental for the healing and recovery process, and are reflected in thermal variations on the skin surface, which can be detected using infrared thermography techniques.

This work confirms the results obtained by Verdasca et al. [Vardasca.R-2012] regarding the surface temperature in the most central areas of the body. The previous study established a normal thermal difference range in unmanipulated areas of approximately $0.4^{\circ}\text{C} \pm 0.3^{\circ}\text{C}$. By comparing these values with the thermal differences observed in the surgically operated areas, the impact of the different surgical techniques on the superficial vascularization and, therefore, on the general physiological state of the patient can be evaluated.

These thermographic results provide objective evidence of the physiological and vascular effects of the surgical techniques used, showing how laparoscopy can offer benefits in terms of fewer complications related to superficial vascularization and faster recovery.

In this study, the difference in temperature measured in patients subjected to the two surgical techniques, laparotomy and laparoscopy, indicates that the

laparoscopic technique generates less alteration in the patient's physiological state compared to laparotomy. Laparoscopy, being a minimally invasive technique, causes less incisional trauma, which is reflected in a lower temperature difference between the incision area and the control area. This finding highlights the ability of laparoscopy to maintain better vascularization and less inflammatory response in the skin, which implies a faster recovery and fewer adverse effects on superficial circulation.

The thermographic technique offers an objective assessment of these changes in superficial vascularization. By measuring skin temperature in different areas of the surgical incision, it can be seen how each type of surgery affects local blood circulation. The results obtained show that laparoscopic surgery presents a lower alteration in skin temperature, indicating that the technique is less traumatic for superficial tissues compared to laparotomy, which involves a larger incision and, therefore, greater tissue damage and a more pronounced inflammatory response.

The advantage of thermography is that it offers an objective method to evaluate the physiological effects of surgical interventions, which alleviates the subjectivity inherent in traditional methods, such as visual analysis of two-dimensional thermal distributions. While visual inspection can be influenced by the observer's interpretation and external factors, infrared thermography provides quantitative and reproducible data on thermal variations, making the analysis more precise and reliable. This approach provides crucial information on the effectiveness of surgical techniques in terms of vascularization recovery and tissue response to surgery, helping to improve postoperative management and optimize patient outcomes.

8.10. Summary Key points

- **Infrared thermography (IT)** is a non-invasive, safe and fast technique, very useful in veterinary medicine. With great capacity to detect thermal anomalies, allowing the diagnosis and monitoring of various pathologies in domestic, farm and wildlife animals, reducing stress by avoiding direct manipulations.
- In **healthy dogs**, studies show thermal symmetry between contralateral limbs. The average temperature difference is $\leq 0.45^{\circ}\text{C}$, establishing a reliable reference standard for identifying disease-related deviations.
- **Athlete dogs**, although healthy, have greater thermal variability. A threshold of 0.7°C was determined to adequately differentiate between athletic dogs and those with pathologies.
- In animals with **various pathologies**, thermal gradients help to classify diseases based on their severity and thus evaluate their severity.
- In **fractures**, the lack of thermal response in the affected area indicated problems in healing, guiding decisions towards surgical interventions.
- In cases of **feline aortic thromboembolism**, temperature differences greater than 2.2°C were observed between the affected extremities, supporting the use of infrared thermography as an effective triage tool for patients presenting to the emergency room with sudden paralysis of the hindlimbs.

- For **spondylosis deformans**, IT allowed identifying thermal alterations associated with circulatory and muscular problems.
- Among the **strengths** of IT is its ability to reduce animal stress, its versatility to identify pathologies of various kinds and its usefulness as a continuous and personalized monitoring tool.
- **Limitations** of the study include the difficulty in obtaining homogeneous samples due to the variety of pathologies and the influence of coat characteristics on thermal measurements.

Infrared thermography (IT) is positioned as an essential tool in modern veterinary medicine. Its ability to non-invasively detect thermal changes related to various pathologies offers a safe, rapid and efficient approach in the diagnosis and monitoring of animal health.

IT not only allows problems to be identified before they manifest clinically, but also optimizes therapeutic decision making, helping veterinarians to offer more personalized and effective treatments. In addition, its non-invasive nature reduces stress in animals, improves their well-being and avoids complications derived from unnecessary manipulations.

In the future, the potential of thermography will be expanded with the integration of advanced technologies such as artificial intelligence, which promises to automate analysis and democratize its access in veterinary clinics around the world. Its application is not limited to diagnosis, but also contributes to the continuous monitoring of treatments, improves post-surgical recovery and offers new perspectives in fields such as oncology and rehabilitation.

Ultimately, infrared thermography not only improves the quality of life of animals by facilitating early and more precise interventions, but also drives the evolution of veterinary medicine towards more modern, sustainable practices focused on animal welfare.

8.11. Clinical Applications and Future Research

With this work it has been proven that Infrared thermography is a tool with enormous potential for research and development of applications in veterinary medicine, with a view to improving both diagnosis and animal welfare. Future lines of study can explore several key areas that expand its scope and effectiveness.

Integration with Other Diagnostic Techniques

One of the most promising areas is the combination of thermography with other advanced diagnostic technologies, such as magnetic resonance imaging (MRI), ultrasound, or even computed tomography (CT), through the use of image registration techniques specifically adapted to the thermographic modality. This integration allows for more precise correlation between surface temperature patterns and internal anatomical or pathological findings, enhancing diagnostic accuracy and clinical decision-making [Hawkes-DJ-1998, Jian.BL-2019, Goswami.S-2022]. This would allow the superficial thermal changes detected by thermography to be correlated with internal structural or functional alterations. For example, it could be used to more precisely locate internal injuries that might go undetected with traditional methods. This comprehensive approach would offer veterinarians a clearer and more holistic view of pathologies, improving both diagnosis and treatment planning.

Chronic Disease Monitoring

Monitoring chronic diseases using thermography represents another crucial field of research. Conditions such as arthritis, chronic kidney problems or periodontal disease are often associated with persistent inflammation or metabolic alterations that can be visualized by changes in thermal patterns. With detailed studies, a database of thermal images associated with different phases of these diseases could be established, allowing not only more precise monitoring, but also early intervention before symptoms worsen.

Optimization of Treatments through Physiological Monitoring

An application of great interest for thermography is the optimization of treatments through objective physiological monitoring. Thermography makes it possible to evaluate in real time the response of animals to different therapies, such as analgesics, anti-inflammatory treatments or surgical interventions. This facilitates more precise and personalized adjustments, reducing the likelihood of side effects and promoting faster recovery. For example, in patients with musculoskeletal injuries, thermography can monitor reduction in inflammation throughout treatment, providing quantifiable data to determine whether the therapeutic approach is effective or needs to be modified.

Improving Animal Welfare in Production

In the field of zootechnics, thermography could play a fundamental role in monitoring animal welfare. Future research could focus on developing protocols to identify early signs of heat stress, dehydration or infectious diseases in farm animals, such as cows, pigs or birds. These advances would

allow preventive and corrective strategies to be implemented in a timely manner, promoting not only animal health, but also the sustainability of agricultural practices by reducing losses and improving the quality of derived products.

Applications in Oncology

Thermography could also be used in the early detection of tumors. Additional studies could investigate how changes in surface temperature may correlate with malignant processes that alter blood flow or tissue metabolic activity. This would be particularly useful in companion animals, where early detection of cancer can significantly improve prognosis and quality of life.

Automation and Advanced Image Analysis

The development of advanced analytics technologies, such as artificial intelligence (AI) and machine learning, promises to revolutionize the use of thermography in veterinary medicine. These tools could automate the interpretation of thermal images, removing much of the subjectivity of manual analysis and detecting subtle patterns that might go unnoticed by the human eye.

By using algorithms trained with robust databases, AI systems could identify thermal correlations associated with different pathologies, generate preliminary diagnoses in a matter of seconds and prioritize critical cases. For example, in animals with inflammatory lesions, an automated system could quantify the extent and intensity of inflammation, facilitating rapid and objective decisions.

Additionally, these technologies could be integrated with real-time monitoring systems, especially in animal production environments. Thermal sensors connected to AI tools would make it possible to identify thermal changes associated with stress, infections or metabolic diseases, alerting caregivers immediately.

In the future, combining AI with wearable devices or mobile apps could democratize the use of thermography, making it more accessible in small clinics or rural areas. This approach will not only save time and costs, but also improve diagnostic accuracy, optimizing clinical management and animal welfare.

To sum up, the future of thermography in veterinary medicine is full of possibilities. As the technology is refined and more research is conducted, this tool can be applied more broadly and effectively in a variety of areas, from disease diagnosis and monitoring to treatment optimization and welfare monitoring in farm and livestock animals. company. These innovations will not only directly benefit animals by improving their quality of life, but will also contribute to the advancement of the veterinary profession through the use of modern and sustainable technologies.

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Annex I: Informed consent

INFORMED CONSENT FORM FOR THE USE OF INFRARED THERMOGRAPHY IN DOGS

Veterinary Clinic: [Clinic Name]

Address: [Clinic Address]

Phone: [Contact Number]

Email: [Clinic Email]

OWNER INFORMATION

Name:

Phone Number:

Email:

ANIMAL INFORMATION

Name:

Species:

Breed:

Chip number:

Age:

Weight:

Sex: M / F / N

PURPOSE OF THIS CONSENT

By signing this document, I authorize the use of **infrared thermography** as a **complementary diagnostic technique** in the clinical evaluation of my dog. Infrared thermography is a **non-invasive and safe imaging technique** that detects superficial temperature patterns on the surface of the animal's body by capturing its naturally emitted infrared radiation. It **does not emit ionizing radiation**, making it **harmless** to both animals and operators. It requires **no sedation** and

no physical contact. It causes no pain or side effects. It is a complementary tool, and does not replace clinical examinations or other diagnostic tests.

FINAL CONSENT

I declare that I have been clearly and fully informed about the nature, benefits, limitations, and conditions of infrared thermography, as well as about the processing of my personal data.

I hereby give my consent to carry out the procedure and to the data processing under the terms described above.

Owner's Signature: _____

Date: ____ / ____ / _____

Veterinarian's Signature: _____

Name and License Number: _____