UNIVERSIDADE LUSÓFONA

CENTRO UNIVERSITÁRIO DE LISBOA

FACULDADE DE MEDICINA VETERINÁRIA

MESTRADO INTEGRADO EM MEDICINA VETERINÁRIA

EVALUATION OF THE EFFECT OF PHOTOBIOMODULATION ON JOINT RANGE OF MOTION IN DOGS

Dissertação apresentada a provas públicas para a obtenção do grau de mestre em Medicina Veterinária, orientado por Professor Doutor João Carlos Alves.

Daniela Alexandra Almeida Duarte, nº 21903275

2025

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Versão Final

Dissertação defendida em provas públicas na Universidade Lusófona, Centro Universitário de Lisboa no dia 15/07/2025, perante o júri, nomeado pelo Despacho de Nomeação n.º: 380/2025, de 27 de Junho de 2025, com a seguinte composição:
Presidente: Professora Doutora Laurentina Maria Rilhas Pedroso
Arguente: Professora Doutora Ângela Paula Neves Rocha Martins (Universidade Lusófona)
Orientador: Professor Doutor João Carlos Agostinho Alves

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Resumo

A Fotobiomodulação é uma terapia que atua com luz vermelha e infravermelha para acelerar a cicatrização dos tecidos, aliviar a dor e reduzir a inflamação. Trata-se de uma opção de tratamento não invasiva e não dolorosa. Também designada por terapia com luz de baixa intensidade ou laserterapia, a fotobiomodulação terapêutica tem como alvo componentes celulares específicos que permitem a absorção da luz, iniciando assim processos biológicos.

Este estudo teve como objetivo avaliar o impacto da fotobiomodulação terapêutica na amplitude de movimento de articulações saudáveis, através da medição das alterações na amplitude de movimento das articulações imediatamente após a fotobiomodulação e após um intervalo de 5 minutos, avaliar as alterações induzidas pela terapia de fotobiomodulação na amplitude de movimento de articulações saudáveis, e na temperatura dos tecidos , e ainda se existem diferenças nas medições da amplitude de movimento de articulações entre um avaliador experiente e um inexperiente.

Para este estudo foram selecionados dezasseis cães de trabalho da Guarda Nacional Republicana (GNR). Os membros de um lado do corpo foram aleatoriamente atribuídos ao grupo de tratamento (TG), enquanto os membros contralaterais constituíram o grupo de controlo (CG). Foram avaliadas a flexão e a extensão das articulações do cotovelo, joelho e tarso, com medições efetuadas em triplicado pelos dois avaliadores.

Após as avaliações iniciais, as articulações do TG foram submetidas a fotobiomodulação. A segunda medição da amplitude do movimento de articulações foi realizada após 5 minutos. Adicionalmente, com a utilização de termografia digital, avaliaram-se as temperaturas superficiais das articulações antes do tratamento com fotobiomodulação, imediatamente após o tratamento e após os 5 minutos. A variabilidade nas medições médias da amplitude de movimento de articulações foi analisada utilizando testes t unilaterais e foram calculados os tamanhos de efeito.

Após o tratamento, foram registados aumentos na amplitude de movimento em todas as articulações ($p<0,01$), com um tamanho de efeito que variou entre 0,84 e 0,96. Após o período de 5 minutos, foi observada uma diferença significativa nas articulações do joelho e do tarso ($p<0,01$). Os resultados não indicaram diferenças significativas nas medições entre o avaliador experiente e o inexperiente. Além disso, as leituras de termografia digital indicaram aumentos nas temperaturas das articulações após a fotobiomodulação ($p<0,01$), com aumentos de temperatura de até 5ºC e tamanhos de efeito entre pequeno a médio (0,31-0,61).

Em conclusão, a fotobiomodulação aumentou significativamente a amplitude do movimento de articulações e a temperatura dos tecidos, sugerindo que a fotobiomodulação terapêutica pode melhorar os exercícios de mobilização articular, que devem ser efetuadas após o tratamento.

Palavras-chaves: Fotobiomodulação terapêutica; Cão; Articulação; Amplitude de movimento articular; Termografia digital.

Abstract

Photobiomodulation is a therapeutic approach that uses red and infrared light to promote tissue healing, alleviate pain, and reduce inflammation. This non-invasive and painless treatment, commonly referred to as low-level light therapy or laser therapy, targets specific cellular components that absorb light, thereby activating beneficial biological processes in the body.

This study aimed to evaluate the impact of photobiomodulation therapy (PBMT) on the range of motion (ROM) of healthy joints by measuring changes in joint ROM immediately after PBMT and after 5 minutes to evaluate changes in tissue temperature, and to determine whether there are differences in ROM measurements between an experienced and an inexperienced evaluator.

Sixteen police working dogs were selected for the study. The limbs on one side of the body were randomly assigned to the treatment group (TG), while the limbs on the contralateral side were assigned to the control group (CG). The flexion and extension of the elbow, stifle, and tarsal joints were assessed, with measurements taken in triplicate by the two evaluators. After the initial evaluations, the joints in the CG underwent PBMT. A 5-minute period was allowed before a second ROM measurement was taken. Joint temperatures were assessed with digital thermography before PBMT, immediately after treatment, and after 5 minutes. The variability in the mean measurements of joint ROM was analyzed using one-tailed t-tests, and effect sizes were calculated.

Post-PBMT, significant enhancements in ROM were noted across all joints ($p<0.01$), with an effect size ranging from 0.84 to 0.96. Moreover, digital thermography evaluation indicated increases in joint temperatures after PBMT ($p<0.01$), with temperature rises of up to 5ºC and effect sizes varying from small to medium (0.31-0.61). Significant differences were observed in the stifle and tarsus joints after the 5-minute period ($p<0.01$). Notably, there were no significant differences in measurements between the two evaluators.

In conclusion, PBMT increased joint ROM and tissue temperature, suggesting that PBMT may enhance joint mobilization exercises and that these should be performed following treatment.

Keywords: Photobiomodulation therapy; Dog; Joint; Joint Range of Motion; Digital Thermography.

List of Abbreviations

CG – Control group

CR - Computed radiography

CT - Computed tomography

Et al. - and others, latin for “*et all*”

GNR – Guarda Nacional Republicana

MIT – Medical infrared thermography

OA - Osteoarthritis

PBMT - Photobiomodulation therapy

PROM - Passive range of motion

ROM - Range of motion

TG – Treatment group

ΔT - Temperature difference

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Internship report

As part of the conclusion of the Integrated Master's Degree at the Faculty of Veterinary Medicine of Lusófona University, the author completed her curricular internship, starting on the 1st of September 2024 and ending on the 22nd of March 2025. It was conducted at the Hospital Veterinário of São Bento, located on the street of São Bento, Lisbon, under the supervision of Dr.Henrique Armés.

Throughout this period, the author completed a total of 1,278 hours of practical training distributed across various clinical areas: 368 hours in hospitalization, 308 hours in consultations, 296 hours in surgery and anesthesia, 96 hours on night shifts, and 210 hours during weekends and public holidays (Figure 1).

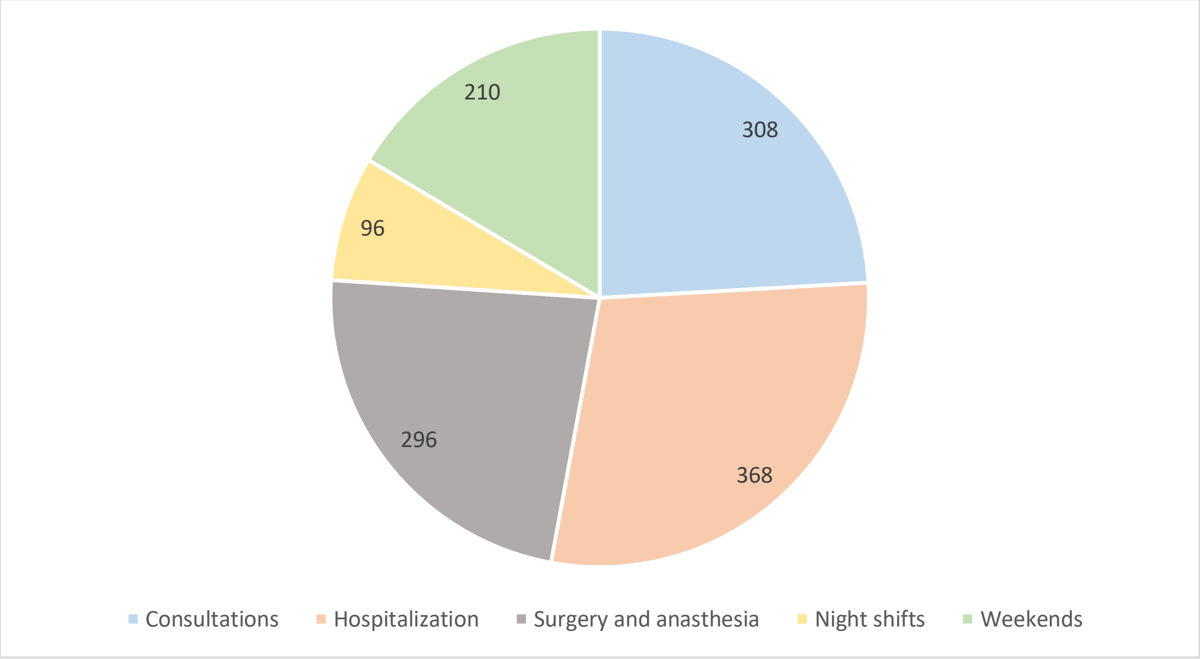

Figure 1. *Number of hours spent on the internship divided into categories.*

During the internship, the author followed companion animals, observing a total of 259 individuals: 127 during surgery and anesthesia and 132 during consultations. Among these, 122 were females, and 137 were males, which included 118 dogs and 141 cats (see Figure 2).

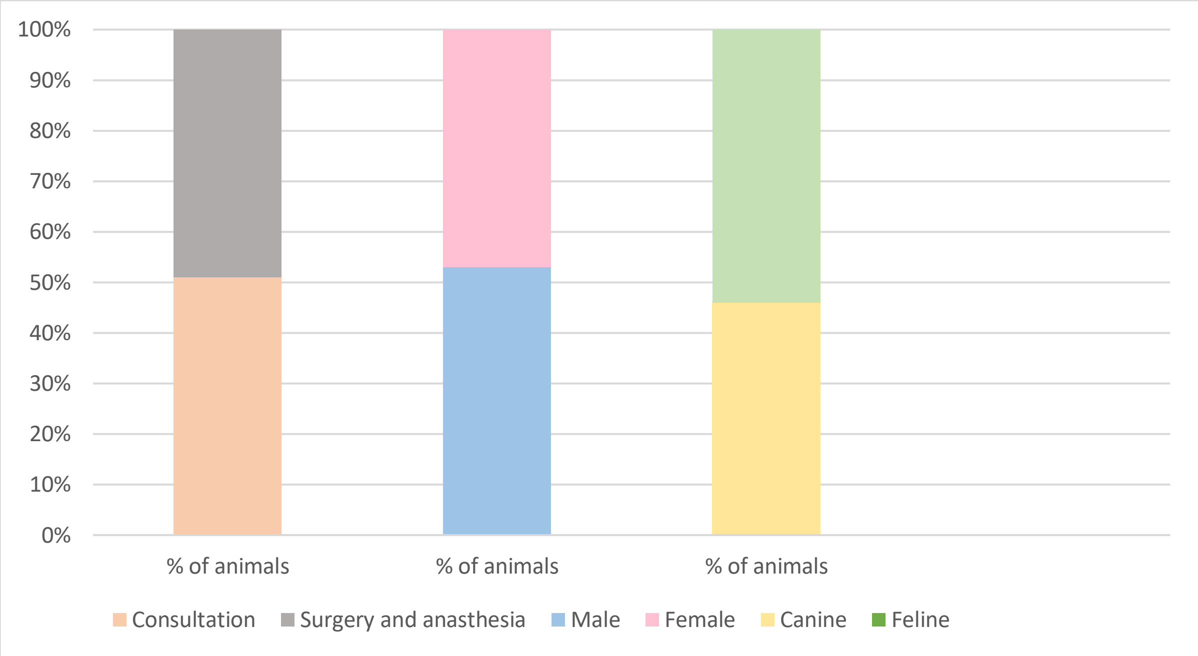

Figure 2. *Percentage of animals divided into three categories (consultation/surgery and anesthesia, male/female, canine/feline).*

Over six months, the author actively participated in a wide range of veterinary medical procedures, including the preparation and administration of pharmacological treatments, diagnostic imaging (radiography and ultrasonography), blood sampling and catheter placement, endotracheal intubation, clinical laboratory analyses and cytological evaluations, surgical assistance, animal restraint and cystocentesis.

Participation in night shifts, weekends, and public holidays further allowed the author to assist in emergency and intensive care situations, gaining valuable experience in critical care scenarios.

The author had the opportunity to observe a total of 127 surgical procedures, with the majority (28%) related to the field of neurology. Among the surgeries observed were 35 hemilaminectomies, minimal invasive surgery with 24 laparoscopic ovariectomies, 22 dental procedures (including cleanings, extractions, and radiographic evaluations), 12 tibial plateau leveling osteotomies (TPLO), elective surgeries which were 13 orchiectomies and 7 ovariohysterectomies, 4 arthroscopies, 3 nodular excisions, 3 foreign body removals via endoscopy, 1 ophthalmologic procedure for cataract resolution, 2 cystotomies and 1 case involving a prostatic cyst (Figure 3).

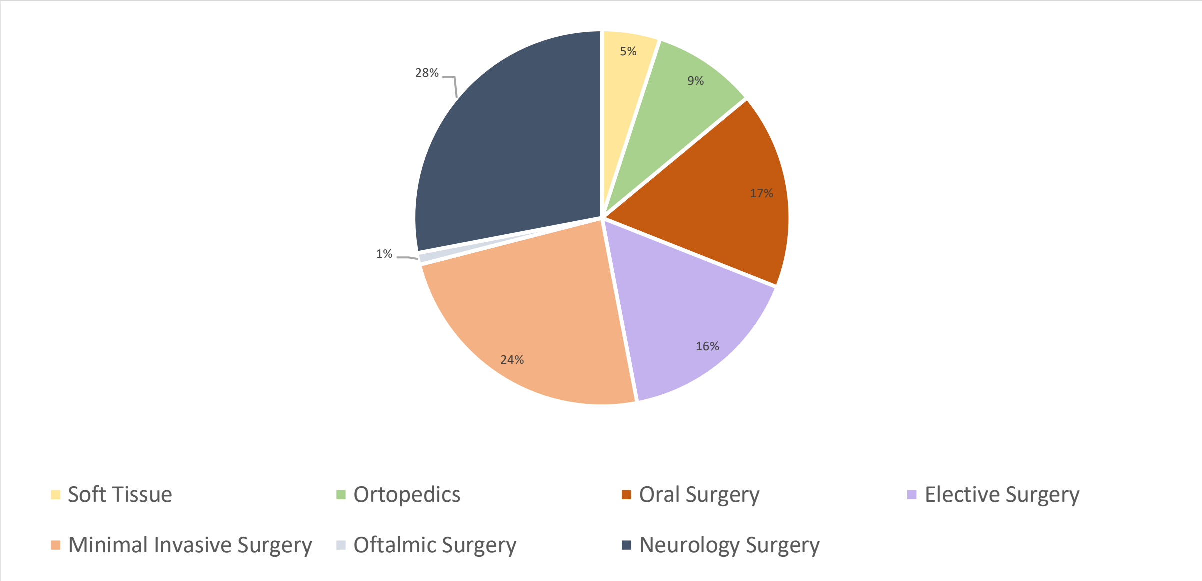

Figure 3. *Percentage of surgery types observed during the internship period.*

A total of 132 consultations across various veterinary specialties were attended by the author. These included 57 consultations in preventive medicine (vaccination, deworming, and/or microchipping), 25 imaging appointments (ultrasound, echocardiography, and computed tomography), 18 in gastroenterology, 10 in endocrinology, 7 in neurology, 4 in dermatology, 4 in oncology, 3 in urology and nephrology, 3 in ophthalmology and 2 in pulmonology (Figure 4).

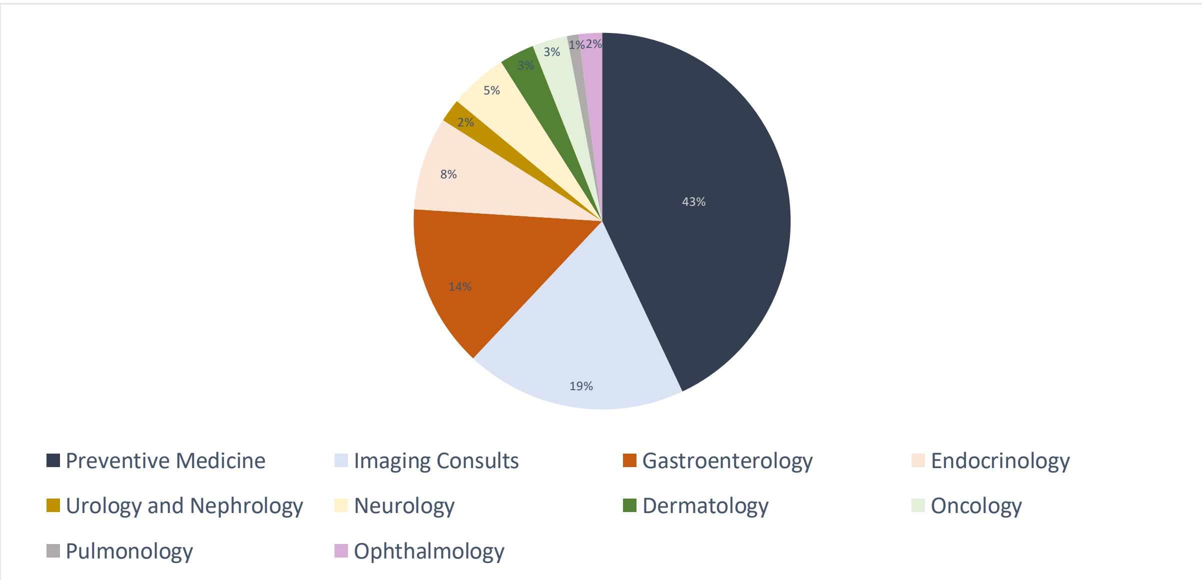

Figure 4. *Percentage of consultations by specialty.*

During the six-month internship, the author had the opportunity to acquire and further develop practical skills, while also reinforcing and consolidating the theoretical knowledge gained throughout the Integrated Master's in Veterinary Medicine. The author was also encouraged to research new diagnostic methods and therapeutic approaches for common pathologies encountered in daily veterinary practice, thereby fostering critical thinking and expanding scientific and technical knowledge.

Furthermore, the author significantly improved communication skills with both the clinical team and pet owners, recognizing the crucial role of emotional regulation and effective verbal interaction in the veterinary profession. The author had an active part in shift handovers and contributed to the discussion of complex clinical cases that required in-depth evaluation of the animal's symptomatology and clinical presentation.

In conclusion, the internship facilitated meaningful integration into the hospital's clinical team, allowing the author to consolidate and apply various areas of knowledge—including clinical, personal, and interpersonal skills—thus promoting a holistic professional development experience.

I. Introduction

1. Syndesmology

The canine musculoskeletal system incorporates a specialized tissue group, the joints, which define the body's overall structure and facilitate coordinated movement. The movement of the canine body is facilitated by muscles acting upon bones, which are connected through joints (Payne, 2013; Zink & Van Dyke, 2018). Articulations themselves are integral components, recognized as complex structures with distinct functional and morphological properties (J. C. Alves, 2021). Joints allow bones to move relative to one another, enabling animals to engage with their environment through movement, which is essential for locomotion. This movement is mainly produced by muscular contractions acting on bones connected by synovial joints, which facilitate a wide variety of biomechanical actions necessary for efficient locomotion and maintaining postural stability (Budras, 2010; Payne, 2013).

The primary movements at the joints include flexion, which reduces the angle between two bones—resulting in bending or retraction of the limb, digit, or vertebral column—and extension, which increases this angle, straightening the same anatomical structures (Budras, 2010; Payne, 2013). Joints are primarily responsible for withstanding mechanical forces during movement, reducing friction, enabling smooth movement of the articulation, and absorbing impact during ground contact. Consequently, their structural integrity must be comparable to the surrounding musculoskeletal components (J. C. Alves, 2021).

In the canine appendicular skeleton, joints are predominantly diarthrodial, also called synovial joints. Synovial joints are encased in a capsule lined by a synovial membrane, with articulating surfaces covered by hyaline cartilage. The joint cavity contains synovial fluid, which is crucial in lubrication and nourishment (Kirberger & McEvoy, 2016). Hyaline Cartilage facilitates efficient joint motion by providing a smooth, low-friction surface. This function is further supported by lubricin and hyaluronic acid, which are secreted by chondrocytes and synovial cells. These lubricants play an essential role in reducing friction and minimizing wear during repetitive movements, thereby maintaining the biomechanical integrity of the joints (Loeser et al., 2012).

1.1. Synovial Joints

Junctura synovialis, or synovial joint, is a unique type of diarthrosis—commonly referred to as a “true” joint—that stands out due to its role in facilitating mobility. All synovial joints are characterized by the presence of a joint cavity (*cavum articulare*), a joint capsule (*capsula articularis*) composed of an outer fibrous layer and an inner synovial membrane, synovial fluid (*synovia*), and articular cartilage (*cartilago articularis*) (Budras, 2010; Payne, 2013).

Synovial joints can be classified based on (1) the number of articulating surfaces, (2) the shape or form of the articular surfaces, or (3) the function of the joint (Cohen, 1961). Regarding the number of articulating surfaces, a joint may be simple (*articulatio simplex*)—involving two articular surfaces within a single capsule—or compound (*articulatio composita*), where more than two surfaces share the same capsule. Another standard system for classification is based on the shape of the articulating surfaces (Budras, 2010).

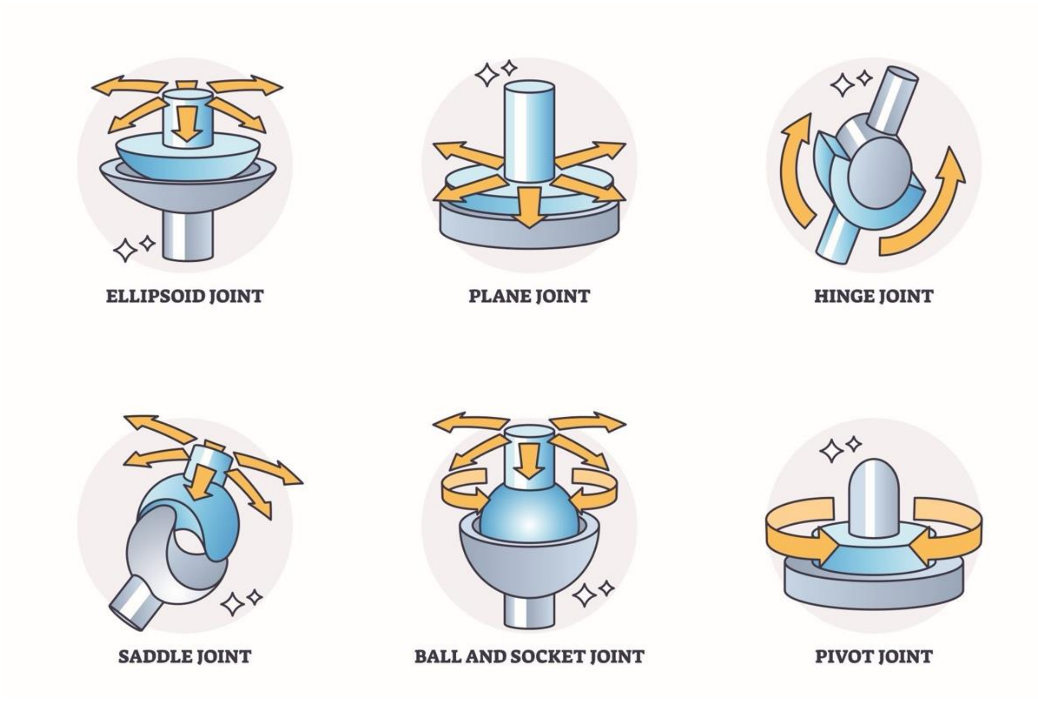

Figure 5. *Classification of the motion of synovial joints (Types of Synovial Joints. Brookbush Institute. Available at: https://brookbushinstitute.com/courses/definitions-naming-and-types-of-synovial-joints)*

Synovial joints facilitate a wide range of biomechanical movements that are essential for locomotion and posture. Flexion refers to the bending motion that decreases the angle between two bones to less than 180 degrees, while extension increases this angle back toward 180 degrees (Budras, 2010; Payne, 2013). These primary movements usually occur in the sagittal plane, with exceptions such as lateral flexion of the vertebral column, which occurs in the coronal plane (Budras, 2010).

Table 1. *The biomechanical movements of joints (Budras, 2010; Payne, 2013).*

Movement	Description	Plane
Flexion	Decreases the angle between two bones	Sagittal
Extension	Increases the angle between two bones	Sagittal
Abduction	Moves a limb away from the body's midline	Coronal
Adduction	Moves a limb toward the body’s midline	Coronal
Internal (medial) rotation	Rotates a limb toward the midline	Transverse
External (lateral) rotation	Rotates a limb away from the midline	Transverse
Circumduction	Combines flexion, extension, abduction, and adduction (e.g., shoulder circles)	Multiplanar

In addition to these primary movements, joints exhibit secondary or ancillary motions that are crucial for maintaining functional mobility. These include adduction and abduction within the coronal plane, internal and external rotation in the transverse plane, longitudinal traction (also known as distraction), and shear forces applied perpendicular to the limb's long axis. An example of this is the cranial drawer motion (Marcellin-Little & Levine, 2015; Payne, 2013). Although these ancillary movements have smaller amplitudes and are more complex to quantify, they are vital for normal gait. These movements are significant in athletic and working dogs, where optimal joint function is essential for performance (Marcellin-Little & Levine, 2015).

Overall, movement in the body is primarily generated by muscular contractions that act on bones interconnected by synovial joints, enabling a diverse range of biomechanical actions necessary for efficient locomotion and stability (Payne, 2013). They are particularly significant in athletic and working dogs, where optimal joint function is crucial for performance (Marcellin-Little & Levine, 2015).

The synovial joint contains an articular space bordered by the ends of two bones in simple joints (e.g., the shoulder) or three or more bones in compound joints (e.g., the stifle). This articular cavity, filled with synovial fluid, is enclosed by a joint capsule. The capsule is structurally supported by fibrous ligaments arranged in parallel fibers. The articulating bone ends are covered by hyaline cartilage, and the fibrous layer of the periosteum is continuous with the outer fibrous layer of the capsule. The inner synovial membrane lines the capsule and extends to the borders of the articular cartilage (Budras, 2010; Marcellin-Little & Levine, 2015; Payne, 2013).

Two types of synovial cells are found within this synovial membrane: (1) secretory cells, which regulate the composition of synovial fluid—formed as an ultrafiltrate of blood plasma that enters the joint cavity and serves a nutritive function for the avascular cartilage—and (2) phagocytic cells, which eliminate foreign substances such as blood cells following hemarthrosis or cartilage debris from degenerative conditions. The joint capsule typically forms folds and villi on its flexor aspect, particularly in highly mobile joints. It may also form outpouchings that enclose muscle tendons, such as the capsular sheath of the long digital extensor muscle at the stifle joint level (Budras, 2010; McLean, 2008).

Synovial joints should not be viewed as mechanical constructs composed of pulleys, levers, and lubricated surfaces. They should be understood as dynamic organs within the musculoskeletal system, constantly adapting and responding to the body's needs. Their function is heavily influenced by surrounding structures such as muscles, ligaments, and tendons (Ansulayotin C, 1960; Breit & Künzel, 2004; Payne, 2013).

1.2. The Elbow Joint

The elbow joint (*articulatio cubitii)*, is a composite synovial joint consisting of three main articulations: the humeroradial joint (*articulatio humeroradialis*), where the humeral condyle connects with the head of the radius; the humeroulnar joint (*articulatio humeroulnaris*), which is formed between the humeral condyle and the trochlear notch of the ulna; and the proximal radioulnar joint (*articulatio radioulnaris proximalis*). The proximal radioulnar joint freely communicates with both the humeroradial and humeroulnar components of the elbow joint (Budras, 2010). While flexion and extension are the primary movements of this joint, limited pronation and supination are also possible(Gemmill et al., 2006; Rycke et al., 2002).

Functionally, the humeroradial joint is responsible for carrying most of the axial load supported by the thoracic limb (Knox et al., 2003). In contrast, the humeroulnar joint provides stability and restricts joint motion primarily to the sagittal plane. Meanwhile, the proximal radioulnar joint facilitates the rotational movements of the forearm (Payne, 2013).

From a structural standpoint, the elbow joint is reinforced by collateral ligaments that branch out distally to attach to both the radius and ulna. Additionally, the annular ligament of the radius encircles the radial head, anchoring it between the medial coronoid process of the ulna and the lateral collateral ligament. The elbow functions as a ginglymus, or hinge joint, characterized by a guiding ridge that is perpendicular to the humeral condyle. This anatomical feature limits movement to flexion and extension, contributing to a distinctive "snapping" action during joint movement (Budras, 2010).

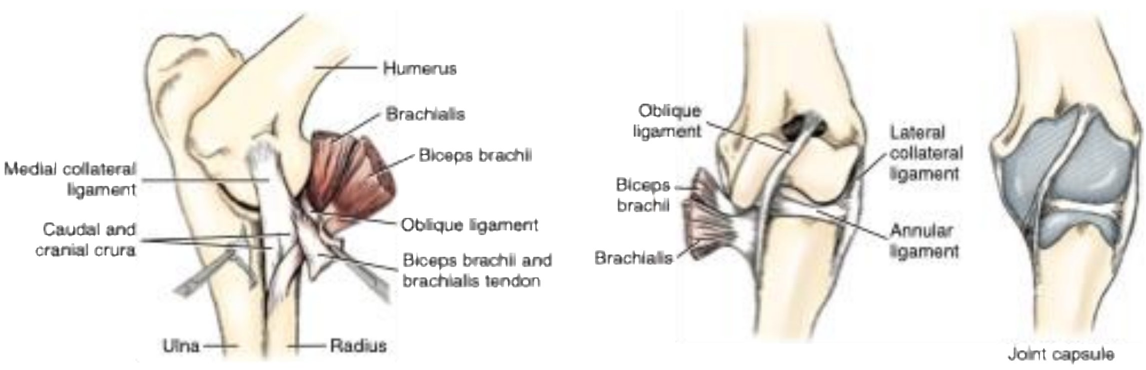

Figure 6. *Anatomy of the elbow joint (Payne, 2013)***.**

1.3. The Stifle Joint

The stifle joint *(articulatio genus)*, also known as the knee joint, is a complex synovial joint comprising seven bones and multiple ligaments. The femorotibial joint consists of two joint sacs that communicate openly with one another and with the femoropatellar and proximal tibiofibular joints. It also interacts with the sesamoid bones' articulations in the gastrocnemius muscle against the femoral condyles. Moreover, the joint capsule of the stifle surrounds the tendons of the popliteal and long digital extensor muscles, creating a capsular tendinous sheath that integrates these tendons into the joint (Budras, 2010).

Its functions include flexion, extension, and slight rotation, which occur as a result of the rolling and gliding action of the femoral condyles over the tibial plateau (Kirberger & McEvoy, 2016; Samii & Dyce, 2004; Schwarz & Saunders, 2011).

This joint features two incomplete menisci, facilitating free communication between all compartments of the joint cavity. Along with the temporomandibular joint, the stifle is one of the few synovial joints in dogs that contains menisci or articular discs. Due to its structural complexity—characterized by numerous ligaments and menisci—the stifle joint has the richest innervation of any joint in the canine body (Payne, 2013).

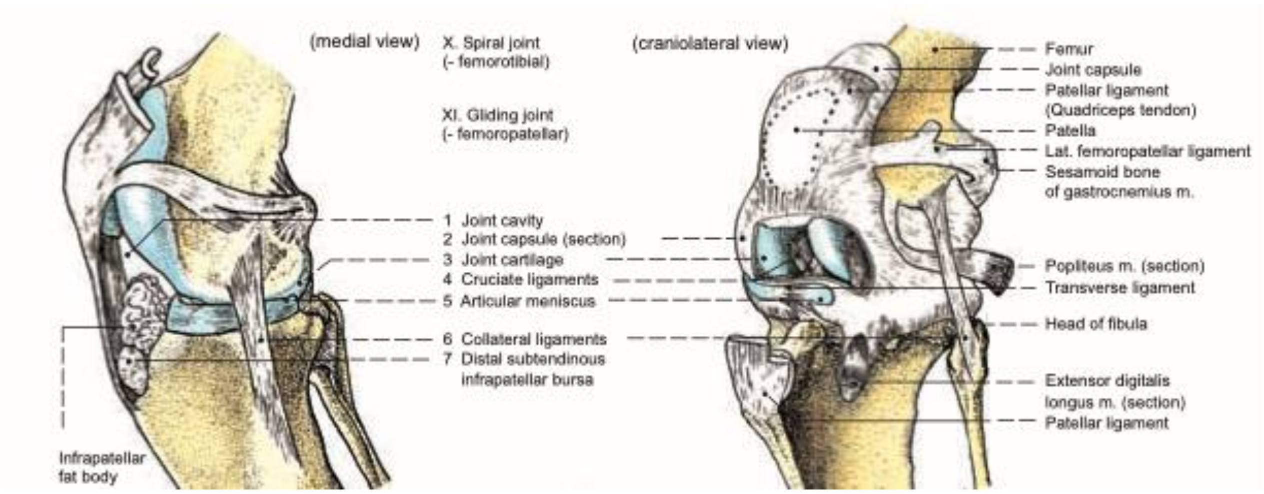

Figure 7. *Anatomy of the stifle joint (Budras, 2010).*

1.4. The Tarsus Joint

The tarsal joint (*articulationes tarsi*) is a complex joint like the carpal joints, forming joints such as the talocrural, intertarsal, and tarsometatarsal joints (Gielen et al., 2001; Kirberger & McEvoy, 2016; Schwarz & Saunders, 2011). The trochlea of the talus consists of two articular ridges that fit into complementary grooves on the cochlea of the tibia. It is important to note that these grooves and ridges are not perfectly aligned with the sagittal plane; they deviate laterally by about 25 degrees. This anatomical arrangement allows the hind limbs to extend laterally beyond the forelimbs during galloping, which enhances limb coordination and stride extension (Payne, 2013).

The cochlear joint *(articulatio talocruralis)*, functions as a hinge-like articulation, where the oblique alignment of the trochlear ridges restricts movement to flexion and extension, comparable to what is seen in the hock joint. As tendons pass over the hock, they are generally protected by synovial sheaths that reduce friction. A notable exception is the superficial digital flexor tendon, which is not associated with a synovial sheath but has a subtendinous bursa that provides similar protective and lubricating effects. The tendon sheaths of the digital joints in the pelvic limb are similar to those found in the thoracic limb. (Budras, 2010).

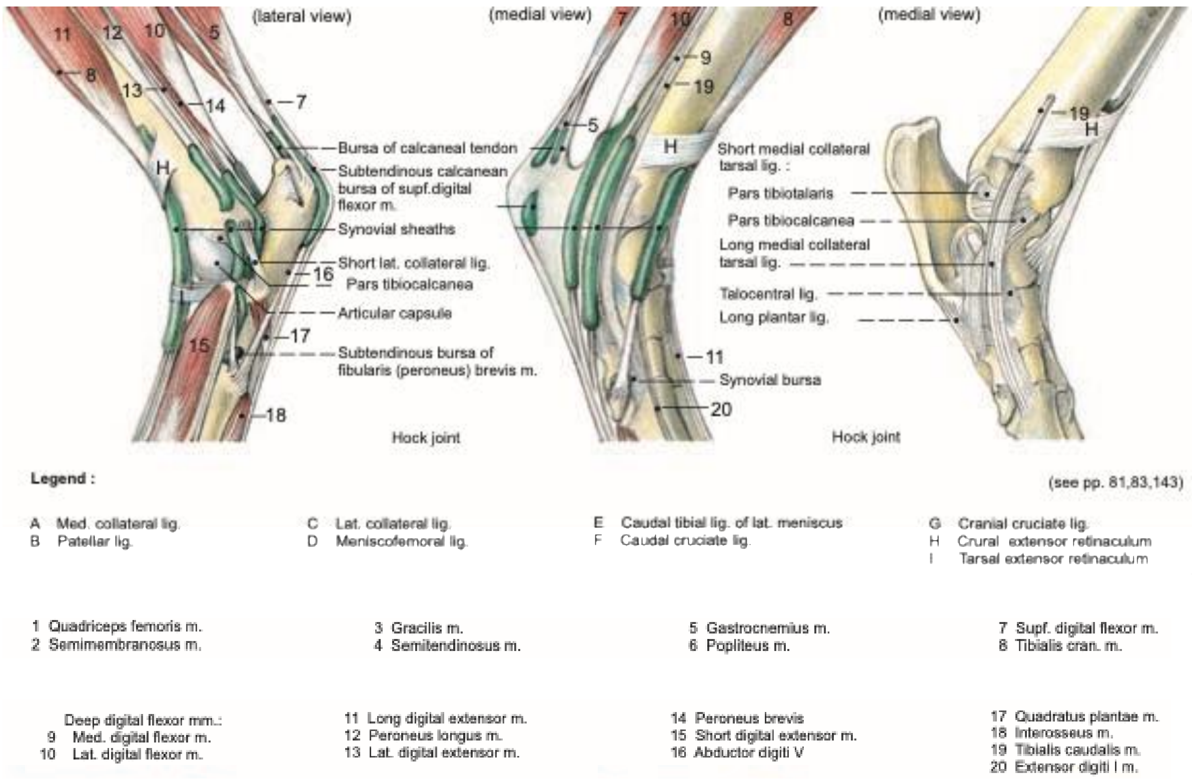

Figure 8. *Anatomy of the tarsus joint (Budras, 2010).*

2. Evaluation of Joints

2.1. X-Ray

The field of canine rehabilitation is experiencing significant growth, resulting in an increasing demand for objective, reliable, and user-friendly tools for outcome assessment. X-Ray, which is widely available in most veterinary practices, is often the first imaging technique used to detect and characterize lesions in bones and joints (Waldstein et al., 2012).

X-ray evaluations have inherent limitations, as they primarily detect specific structural changes such as new bone formation, bone loss, increased soft tissue mass, and mineralization within soft tissues (McLean, 2008; Thrall, 2012). Despite some drawbacks—such as the rigidity of flat-panel X-ray detectors and the reliance on wired or wireless data transmission, which can limit their use in certain anatomical regions like the nasal cavity—the benefits of digital radiography generally outweigh these issues (McLean, 2008).

For accurate X-ray assessments, proper positioning is essential and should be tailored to each joint, considering the anatomical diversity of the appendicular skeleton (Thrall, 2012).

While obtaining two orthogonal views is the basic requirement for X-ray evaluation, some joints, such as the carpus and tarsus, may require additional oblique projections. Additionally, imaging the contralateral limb can be a valuable reference for comparison, helping to identify bilateral pathologies even when clinical signs appear unilateral (McLean, 2008).

Table 2. *Radiographic positioning techniques and key considerations for evaluating the elbow, stifle, and tarsal joints in dogs (Thrall, 2012).*

Joint	Radiographic Positioning	Key Considerations
Elbow Joint	Lateral or sternal recumbency is the most common position used. Dorsal recumbency and horizontal beam techniques can be applied but are less routine.	The elbow is made up of three bones: the humerus, radius, and ulna. These bones overlap in a way that can make it difficult to see everything clearly on X-rays, so it may need several different images. It's important to tell apart normal variations, like the cranioproximal tubercles of the olecranon, from issues like bone spurs. In craniocaudal X-ray views, if the radial head appears to be pushed to the side, it should not be confused with a dislocation.
Stifle Joint	Two orthogonal views of both hind limbs are recommended.	It is advisable to obtain two distinct views of both hind limbs for optimal assessment. The use of sedation or general anesthesia is recommended to enhance the quality of the images obtained.
Tarsus Joint	Lateral and dorsoplantar projections are typically used.	The small size and anatomical complexity of the tarsus can limit radiographic clarity. Digital radiography enhances detail and contrast, facilitating the visualization of both osseous and soft tissue structures.

According to the principles of X-ray geometry, the examination of appendicular skeletal structures in dogs and cats should consist of at least two orthogonal projections: a lateral view and a craniocaudal (or dorsopalmar, dorsoplantar) view, to ensure a comprehensive assessment. If a bone lesion is suspected, the field of view must include the joint both proximal and distal to the bone of interest. When evaluating a joint, the primary X-ray beam should be centered on that joint. Although projection terminology may vary (for example, dorsoplantar versus plantarodorsal for hind limbs), these differences generally do not affect the X-ray appearance, as radiographs are two-dimensional representations of three-dimensional structures (Thrall, 2012).

In the following images, we observe the typical X-ray appearance of normal canine joints. These images illustrate the expected anatomical relationships and bone structures, serving as essential references for comparing joint health and identifying abnormalities.

Figure 9. *Cranio-caudal radiographic view of the elbow joint (Original by the author).*

Figure 10. *Lateral radiographic view of the stifle joint (Original by the author).*

Figure 11. *Medio-lateral radiographic view of the tarsus joint (Original by the author).*

2.2. Ultrasound

Ultrasonography has become a diagnostic tool for evaluating musculoskeletal conditions in veterinary medicine. It provides real-time imaging that enables a detailed assessment of soft tissue structures (McLean, 2008; Webster, 2017). While this technique has some applications, it can be complex, requiring a complete understanding of anatomical relationships and significant hands-on experience to ensure accurate diagnoses and build operator confidence (Webster, 2017; Zink & Van Dyke, 2018).

This imaging modality provides clear visualization of muscles, tendons, ligaments, joint capsules, synovial fluid, and parts of joint cartilage (McLean, 2008). Its key advantages include the absence of ionizing radiation, lower costs compared to advanced modalities like CT, shorter examination times, and the ability to perform assessments without sedation or general anesthesia—except in cases involving painful, aggressive, or otherwise difficult-to-restrain animals (McLean, 2008; Webster, 2017). Features are particularly beneficial for evaluating active or working dogs that require frequent monitoring for performance and rehabilitation (McLean, 2008).

On the other hand, ultrasonography has certain limitations, such as acoustic shadowing from mineralized tissues, but it remains a valuable tool for evaluating intra-articular soft tissues. This is especially relevant for joints containing intra-articular tendons, such as the biceps tendon in the shoulder, or for assessing visible ligaments like the patellar ligament or the Achilles tendon (Kirberger & McEvoy, 2016; Webster, 2017).

Ultrasound evaluation of joints typically involves systematic scanning around the joint in a proximodistal approach, allowing for the simultaneous visualization of both articular surfaces while also supplementing views with transverse imaging as needed (Kirberger & McEvoy, 2016; Webster, 2017). Optimal visualization can be achieved by manipulating the limb position—through flexion, extension, and rotation—to access different acoustic windows limited by bony anatomy (Kirberger & McEvoy, 2016).

In normal joints, cartilage appears as an anechoic layer parallel to the hyperechoic subchondral bone, with fine, linear hyperechoic surfaces marking the interface between the cartilage and the anechoic synovial lining. Small amounts of anechoic synovial fluid may be present as a normal finding. Although the joint capsule and collateral ligaments can be challenging to visualize due to their small size and limitations in equipment resolution, experienced operators can identify these structures (Kirberger & McEvoy, 2016; Webster, 2017).

For the elbow joint, while radiography, CT, and MRI remain standard imaging modalities, ultrasonography can provide valuable complementary information in assessing soft-tissue structures and identifying joint effusion or loose fragments (Knox et al., 2003; Lamb & Wong, 2005; Webster, 2017). This joint can usually be evaluated without sedation. The hair is clipped, and the dog is positioned in lateral recumbency with the elbow of interest elevated. After examining the lateral aspect, the dog is turned to allow for medial evaluation. A high-frequency linear transducer (>10 MHz) is preferred for assessing these small, superficial structures (Webster, 2017).

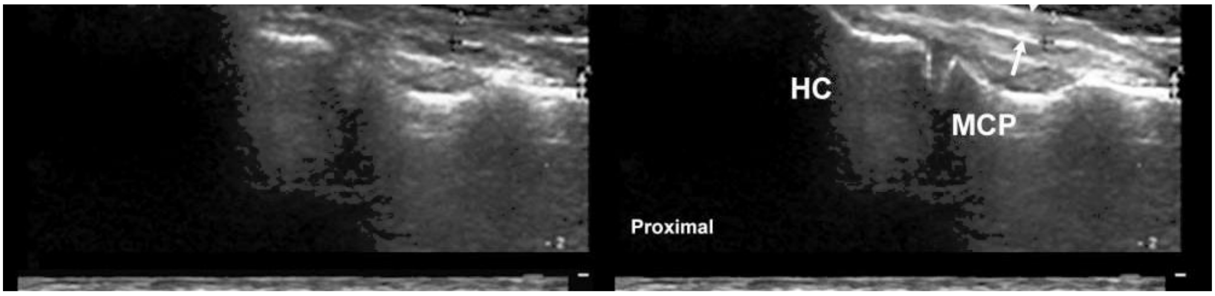

Figure 12. *The normal sonographic anatomy of the canine elbow is as follows: A: Longitudinal sonographic images and enhanced views of the craniomedial aspect of the elbow show a portion of the distal biceps brachii (BB) appearing as a hyperechoic, fusiform structure. This structure is characterized by dense hyperechoic lines that insert into the craniomedial proximal surface of the ulna (U). (Webster, 2017).*

In the stifle joint, a high-frequency linear transducer (>10 MHz) is also used, and the hair is clipped from the distal third of the femur to below the tibial tuberosity (Kramer et al., 1999; Webster, 2017). Initially, the patient is positioned in lateral recumbency with the affected limb uppermost. Dynamic assessment requires flexion and extension of the joint, as well as inward and outward rotation, to evaluate meniscal regions. The joint is systematically scanned in cranial, caudal, lateral, and medial regions (Webster, 2017).

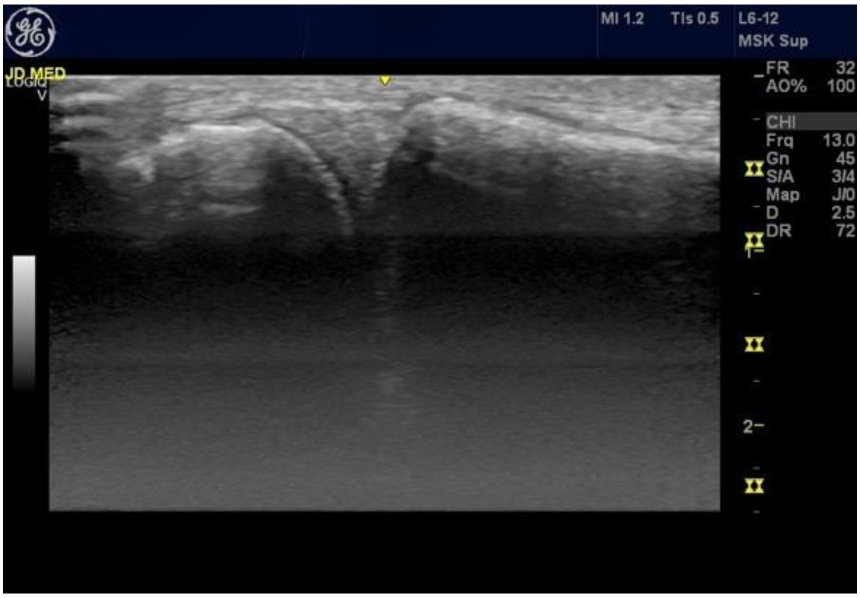

Figure 13. *Cross-section of the medial meniscus in the stifle. (Original by the author).*

Ultrasound imaging of the tarsal joint enables the evaluation of various soft-tissue structures, including the Achilles tendon, collateral ligaments, plantar ligaments, and associated musculature (Caine et al., 2009). A high-frequency linear transducer is positioned longitudinally over the calcaneal tuberosity to visualize the insertion point of the Achilles tendon. The transducer is then moved proximally to examine the entire tendon and its musculotendinous junctions (Kramer et al., 1999; Lamb & Duvernois, 2005; Webster, 2017). Transverse views are also obtained to assess the individual components of the tendon. Furthermore, a dynamic examination, which involves flexing and extending the hock, enhances diagnostic capabilities (Webster, 2017).

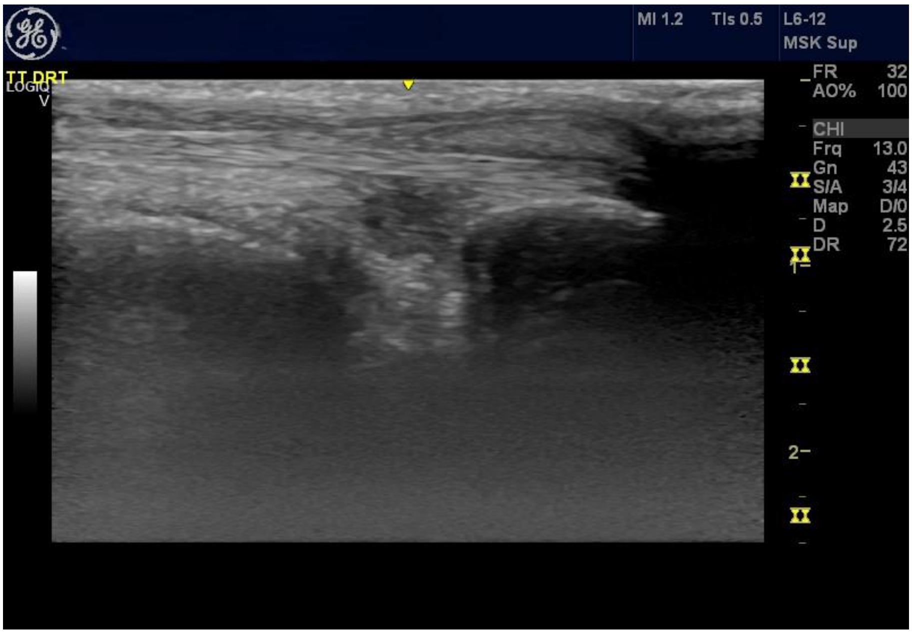

Figure 14. *The tarsal echo shows a longitudinal view of the Achilles tendon and its insertion into the calcaneus. (Original by the author).*

2.3. Computed Tomography

Computed tomography (CT) has become an essential diagnostic tool in veterinary medicine. It provides high-resolution cross-sectional images that offer detailed anatomical information, particularly for evaluating bone, joint, and neuromuscular pathologies. Unlike ultrasound, CT can penetrate mineralized tissues, enabling the assessment of deep or complex regions—such as the vertebral canal and joints—where conventional radiography may fall short (Kirberger & McEvoy, 2016; Schwarz & Saunders, 2011).

The CT unit consists of a gantry that houses the X-ray tube and detectors, through which the patient passes on a motorized table. As the X-ray source rotates, it captures data from multiple angles, creating thin slices in the transverse (X-Y) plane. These images can then be reconstructed into multiplanar (MPR) or three-dimensional (3D) renderings, providing enhanced visualization of intricate anatomical relationships (Schwarz & Saunders, 2011).

CT is particularly effective in identifying intra-articular abnormalities, subtle bone lesions, neoplasms, and complex fractures. Its sensitivity for detecting early bone lysis and variations in subchondral bone density surpasses that of radiography, underscoring its value in musculoskeletal evaluations. Techniques such as arthro-CT, which utilizes intra-articular contrast, enable improved visualization of cartilage and soft tissue structures. While factors such as cost, scan duration, and operator expertise may influence its routine use, the diagnostic power of CT is indispensable in both general and specialized orthopedic investigations (Kirberger & McEvoy, 2016).

CT provides high-definition images that allow for detailed visualization of joint congruity, small bone fragments, and early degenerative changes. This imaging technique is beneficial for diagnosing conditions such as elbow dysplasia (Rycke et al., 2002; Schwarz & Saunders, 2011).

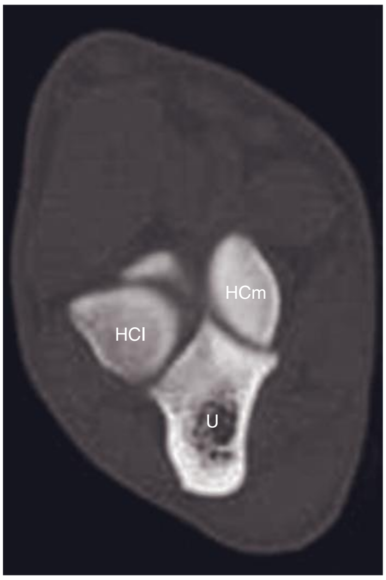

Figure 15. *Reference CT images of a normal right canine elbow. A transverse CT image at the joint space level shows the typical appearance and density of the medial part of the humeral condyle (HCm). The lateral part of the humeral condyle is labeled as HCl, and U represents the ulna (Schwarz & Saunders, 2011).*

CT is effective for assessing the integrity of the cruciate ligaments, evaluating patellar alignment, and detecting changes in the subchondral bone, especially when utilizing arthro-CT techniques (Kirberger & McEvoy, 2016; Samii & Dyce, 2004; Schwarz & Saunders, 2011).

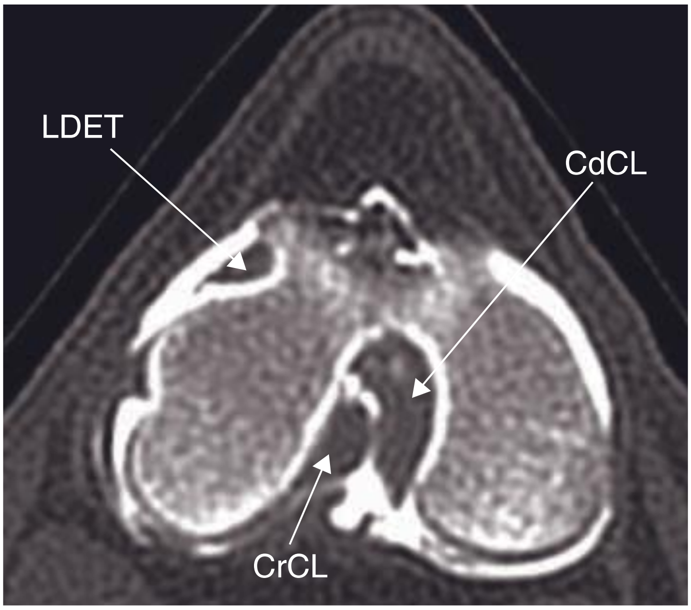

Figure 16. *Reference CT images of a normal right canine stifle. A transverse CT arthrogram (1 mm transverse) displays the cranial cruciate ligament (CrCL), the caudal cruciate ligament (CdCL), and the long digital extensor tendon (LDET) at the level of the intercondyloid fossa of the femur (Schwarz & Saunders, 2011).*

CT imaging can identify degenerative changes, fractures, and ligament injuries, particularly those involving the long plantar ligament, which is often implicated in lameness (Gielen et al., 2001; Kirberger & McEvoy, 2016; Schwarz & Saunders, 2011).

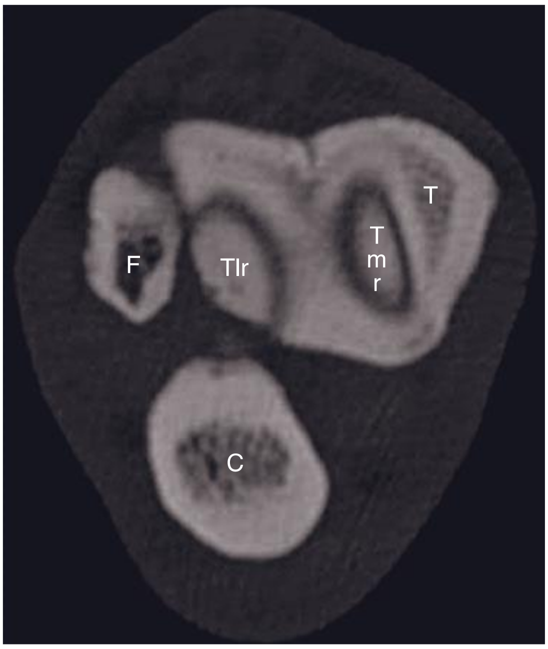

Figure 17. *Reference CT images of a normal right canine tarsus. Transverse CT image at the level of the proximal surface of the talar ridges shows the oval shape and homogeneous density of the ridges (Schwarz & Saunders, 2011).*

2.4. Goniometry

In veterinary medicine, ROM can be measured either actively through kinematic gait analysis or passively through goniometric assessment (Volz et al., 2024). Standard goniometric measurements are widely used in canine physiotherapy to detect limitations in joint mobility and also to evaluate the response to treatment. They are also applied as outcome parameters in orthopedic research (Reusing et al., 2020). Goniometry is not limited to dogs; it has also been reported in cats, horses, calves, and humans (Bergh et al., 2020; Reusing et al., 2020). Goniometry offers essential advantages over imaging techniques: it is fast, low-cost, non-invasive, easy to learn, and does not require sedation or radiation exposure (Jaegger et al., 2002a; Marcellin-Little & Levine, 2015; Reusing et al., 2020).

Passive range of motion (PROM) refers to the maximum movement possible between antagonistic joint functions, such as flexion and extension, without active muscle contraction. PROM is useful for identifying joint dysfunction, setting rehabilitation goals, tracking therapeutic progress, adapting treatment strategies, and designing interventions for osteoarthritis (Marcellin-Little & Levine, 2015).

The universal goniometer, consisting of a 180° or 360° protractor with two movable arms, remains the most used device due to its affordability and practicality (Bergh et al., 2020). Since the use of both hands during assessment is required, stabilization of the limb can be difficult. For proper technique, the dog should be positioned in lateral recumbency, with the proximal limb stabilized and the joint moved gently through its range of motion until the first signs of discomfort are noted (Marcellin-Little & Levine, 2015).

Figure 18. *An example of a goniometer measurement of the elbow joint (Original by the author).*

Several factors can significantly influence the results of PROM assessments, particularly in active and working dogs. One crucial element is the pre-assessment condition of the musculoskeletal tissues. Stretching and mobilization exercises are frequently utilized to promote joint health and flexibility in performance dogs engaged in activities such as racing, agility, tracking, and rehabilitation. Although optimal stretching techniques remain an area of ongoing research, existing evidence supports the integration of general warm-up and cool-down routines rather than overly prescriptive protocols. It is essential to recognize that the act of warming up does not directly decrease muscle stiffness or enhance muscle length; instead, it increases the tissues' tolerance to stretching. To enhance both the safety and efficacy of stretching and PROM evaluations, it is advisable to warm the target tissues prior to assessment. For example, applying localized heat for 5 to 10 minutes can raise tissue temperature by 3–4°C, a change associated with improved stretch tolerance and a reduced risk of discomfort or tissue injury during mobilization. These considerations are crucial when interpreting PROM data, as variations in preparation and tissue condition can significantly impact measurement reliability and inform clinical decision-making (Jaegger et al., 2002a; Marcellin-Little & Levine, 2015; Volz et al., 2024).

Joint conformation in healthy animals varies between breeds and can significantly affect ROM values (Reusing et al., 2020). For example, German Shepherds often show greater flexion and less extension in joints such as the elbow, shoulder, tarsus, stifle, and hip—excluding the carpus—compared to Labrador Retrievers (Marcellin-Little & Levine, 2015; Thomas et al., 2006). Despite these differences, the overall range of motion (ROM) remains similar between the two breeds. These variations may be linked to differences in posture and gait, with Labradors typically maintaining a more upright stance during standing and movement. At the same time, German Shepherds adopt a more crouched position. However, it remains unclear whether the altered joint motion in German Shepherds is a factor contributing to their unique gait or if their gait pattern influences joint mobility (Jaegger et al., 2002a; Marcellin-Little & Levine, 2015).

Furthermore, elements such as muscle mass and tone may impact ROM, as increased soft tissue around a joint can limit its ability to flex completely. The shape of the joints, the joint capsule, ligaments, tendons, and the surrounding muscles influence ROM in a dog's joints. Additionally, factors such as pain, stiffness, a higher body mass index, and being male can contribute to a reduced range of motion (Marcellin-Little & Levine, 2015). The influence of sedation on ROM measurements remains unclear. Some studies report differences between sedated and non-sedated values, while others find no significant effects (Bergh et al., 2020).

In the hind limb, measurements of the tarsus showed less variability than those of the stifle and hip joints in awake dogs. Also, measurements from several proximal joints, like the shoulder, hip, and stifle, were more variable than those from several distal joints, such as the elbow and tarsus. This may be due to higher amounts of soft tissue around the proximal joints, which can make it harder to feel the body landmarks. Dogs with muscular hind limbs typically exhibit less bending at the stifle joint compared to those with less muscular hinds, even if they have a similar degree of leg extension. Additionally, the larger muscle mass around these joints can complicate angle measurements, like when the triceps brachii bulges during shoulder flexion (Jaegger et al., 2002a). The discomfort experienced by the patient during joint manipulation may alter ROM values, although this factor is rarely documented in clinical settings, and a validated scoring system has not yet been established (Volz et al., 2024).

In awake dogs, goniometric measurements of the tarsus showed significantly lower variability compared to those of the stifle, indicating that measurements in distal joints tend to be more consistent and reliable. It is recommended that measurements be performed in triplicate and the median value recorded to ensure reliability. A previous study examining the accuracy and consistency of goniometric measurements found that they are not influenced by the clinician's level of experience (Jaegger et al., 2002a).

2.5. Medical Thermographic Imaging

A thermographic camera, commonly referred to as medical infrared thermography, is a non-invasive and contact-free imaging method that does not utilize radiation. It identifies physiological changes in skin surface temperature to evaluate the underlying functionality and potential pathology of the musculoskeletal system (Hildebrandt et al., n.d.-a). This modality is particularly advantageous in identifying thermal asymmetries linked to conditions such as inflammation, altered blood flow, or neuromuscular challenges (J. C. Alves et al., 2021; Riegel & Godbold, 2017).

Thermography is increasingly recognized as a valuable tool in veterinary medicine for screening and monitoring various musculoskeletal disorders, including muscle strains, tendinopathies, osteoarthritis (OA), intervertebral disc disease, and neoplasia (J. C. Alves et al., 2021; McLean, 2008). Recent research has illustrated its effectiveness in evaluating areas such as the hip, stifle, elbow, and others in canine patients (J. C. Alves et al., 2021; J. C. A. Alves et al., 2020; Riegel & Godbold, 2017).

The rationale behind the diagnostic capabilities of thermography is rooted in the understanding that injury and inflammation may lead to changes in local blood flow, thereby affecting the temperature of the skin's surface (Hildebrandt et al., n.d.-a; Loughin & Marino, 2007). Instances of vasodilation, commonly associated with inflammation, can elevate skin temperature in specific regions, while vasoconstriction may result in cooler temperatures in affected areas (Riegel & Godbold, 2017). The sympathetic nervous system modulates these physiological responses and the condition of dermal microcirculation (Hildebrandt et al., n.d.-b).

Thermographic cameras capture thermal radiation and convert it into color-coded images that effectively represent skin temperature distributions (J. C. Alves et al., 2021; Riegel & Godbold, 2017). A temperature difference (ΔT) greater than 1°C between symmetrical regions is generally viewed as clinically significant (Hildebrandt et al., n.d.-a). The integration of high-resolution focal plane array detectors and advanced digital imaging software facilitates objective temperature assessment with enhanced spatial and thermal sensitivity (Hildebrandt et al., n.d.-a; Loughin & Marino, 2007).

Digital thermography is particularly useful for working dogs, as it allows for assessment without the need for physical contact or sedation. This capability enables the early detection of musculoskeletal stress, potentially preventing the development of clinical lameness (J. C. Alves et al., 2021; Riegel & Godbold, 2017). Therefore, it is beneficial for performance monitoring, injury prevention, and rehabilitation efforts in both athletic and working dogs.

Furthermore, thermography can be used to monitor treatment responses, evaluate gait and performance abnormalities, and guide therapeutic interventions. Its role as a complementary tool alongside anatomical imaging techniques such as radiography, MRI, and ultrasound provides real-time physiological information, thereby enriching the overall approach to veterinary diagnostics and treatments (McLean, 2008).

Accurate interpretation of thermographic data requires diligent control of environmental factors, such as ambient temperature, lighting, drafts, and potential artifacts from wet coats, recent bathing, collars, harnesses, or topical products (McLean, 2008). Special attention should be given to coat characteristics, as studies suggest that breeds like German Shepherds may show lower thermographic values compared to others (J. C. Alves, Santos, Jorge, & Miguel Carreira, 2022).

It is also noteworthy that temperature patterns can vary along the limb, with distal regions, such as the tarsus, exhibiting greater variability due to their higher surface-area-to-mass ratio and increased exposure to environmental elements, notably when the insulating effect of the coat is reduced (Loughin & Marino, 2007).

3. Photobiomodulation Therapy (PBMT)

Photobiomodulation therapy, also referred to as low-level laser therapy, cold laser therapy, or low-intensity laser therapy, is a non-invasive treatment that employs red or near-infrared light to enhance cellular activity, accelerate healing, reduce inflammation, and manage pain (Laser Therapy in Veterinary Medicine, n.d.; Zink & Dyke, 2018). PBMT operates through the delivery of photochemical energy rather than heat, thereby promoting interaction with tissue chromophores and initiating a series of beneficial biochemical changes (Chavez et al., 2024).

The key photoreceptor PBMT acts upon is cytochrome C oxidase, an enzyme integral to the mitochondrial electron transport chain (Looney et al., 2018). The absorption of light at targeted wavelengths enhances electron transport, mitochondrial membrane potential, and ATP synthesis while also facilitating the displacement of inhibitory nitric oxide and encouraging the production of reactive oxygen species (Riegel & Godbold, 2017; Zink & Van Dyke, 2018). These cellular transformations lead to modifications in gene expression, including the upregulation of anti-inflammatory and anti-apoptotic proteins, as well as the stimulation of growth factor production (J. C. Alves, Santos, Jorge, & Miguel Carreira, 2022).

PBMT exerts its analgesic effects through various cellular and molecular mechanisms. It modulates pain perception by acting on ion channels such as TRPV1 (Transient Receptor Potential Vanilloid 1), enhancing peripheral opioid metabolism and inhibiting nociceptive signaling at both peripheral and spinal levels (Riegel & Godbold, 2017). These mechanisms contribute to its broader anti-inflammatory action, demonstrating efficacy in both clinical and preclinical settings. Importantly, stem cells and progenitor cells show notable responsiveness to PBMT, indicating its potential role in promoting tissue regeneration and repair (Looney et al., 2018). Although outcomes across studies exhibit some variability, likely linked to the use of different treatment parameters, PBMT has been investigated as a preconditioning strategy before surgery, aiming to mitigate inflammatory responses, improve vascularization, support tissue healing, and enhance perioperative pain management (Chavez et al., 2024).

When chromophores absorb light, it leads to increased levels of ATP, nitric oxide, and reactive oxygen species, which work to modulate inflammatory mediators and influence nerve signaling (Riegel & Godbold, 2017). PBMT reduces the production of pro-inflammatory cytokines, such as COX-2 (cyclooxygenase-2), TNF-α (Tumor Necrosis Factor alfa), IL-1 (Interleukin-1), and IL-6 (Interleukin-6), while promoting enhanced circulation to aid in the resolution of inflammation (Riegel & Godbold, 2017; Zink & Van Dyke, 2018).

Further mechanisms include the enhanced metabolism of endogenous opioids, inhibition of nociceptive nerve endings, and decreased latency in nerve conduction (Riegel & Godbold, 2017). Collectively, these effects help alleviate pain at the injury site and along associated neural pathways, making PBMT an invaluable tool for dogs recovering from musculoskeletal trauma or surgical procedures. On dogs, the capacity to relieve subclinical or early-stage pain through PBMT is particularly important, as these animals may not display overt signs of discomfort despite experiencing underlying pathology (J. C. Alves et al., 2024).

Laser devices employed in PBMT produce monochromatic, coherent, and collimated light capable of penetrating biological tissues. Light energy can be reflected, transmitted, or refracted, with the latter two pathways contributing positively to tissue-level changes. The recommended treatment parameters for PBMT may vary according to the manufacturer's guidelines, which consider factors such as the desired therapeutic outcome, skin tone, coat color, animal body condition, and the size of the treatment area. In addition, PBMT has been thoughtfully explored for its potential benefits in managing inflammatory processes and providing pain relief; however, the findings have shown a degree of variability, probably due to the use of different parameters. When the joints are the target issue, ensuring proper joint positioning, such as placing joints in an open or loose-packed position and applying gentle traction, can enhance the delivery of energy to the joint capsule and articular surfaces; this is particularly important when targeting structures such as the elbow, stifle, and tarsus in working dogs (Zink & Van Dyke, 2018).

Several key parameters, including irradiance, wavelength, coherence, energy dose, application time, and treatment interval, significantly impact the clinical effectiveness of PBMT. Each of these factors plays a vital role in determining the therapeutic outcome, and it is advisable to tailor them to align with the treatment goals and the unique anatomical characteristics of each patient (J. C. Alves, Santos, Jorge, & Miguel Carreira, 2022).

PBMT demonstrates a biphasic dose response, which suggests that both insufficient and excessive doses may not yield optimal results. Once within the therapeutic window, increasing the dose does not improve clinical outcomes, underscoring the importance of adhering to established dosing guidelines. The generally recommended therapeutic window for PBMT lies between 600 and 1070 nm, with lower wavelengths (600–700 nm) being more suitable for treating superficial tissues, while higher wavelengths (780–950 nm) facilitate deeper tissue penetration (Zink & Van Dyke, 2018).

Moreover, the depth of penetration is affected not just by wavelength but also by power output and the specific characteristics of the tissues involved. Factors such as hair, skin pigmentation, or surface irregularities can attenuate photon energy, potentially diminishing penetration into deeper tissues and impacting therapeutic effectiveness. This consideration becomes particularly relevant when addressing deeper joints, such as the elbow or stifle, in working dogs, where optimal delivery to the joint capsule and surrounding structures is essential (Zink & Van Dyke, 2018).

To enhance treatment effectiveness and mitigate surface heat, applying a light water spray may be beneficial in dissipating excess energy and improving contact, particularly for animals with long or dense coats. It is also noteworthy that small details, including probe angle, pressure, and treatment area coverage, can significantly impact the therapeutic response. Thus, vigilant control of these factors is recommended to ensure that treatment is both effective and consistent (Zink & Van Dyke, 2018).

3.1. Therapeutic Applications

As mentioned, PBMT has demonstrated a wide range of therapeutic benefits, including pain relief, anti-inflammatory effects, and enhanced tissue repair through mechanisms such as angiogenesis, fibroblast proliferation, and collagen synthesis (Riegel & Godbold, 2017).

PBMT has been employed in veterinary medicine to address a wide range of conditions, including osteoarthritis, wound healing, gingivostomatitis, and neuropathic pain. It also plays a supportive role in recovery following orthopedic and neurological surgeries. Encouraging results have been reported in dogs recovering from intervertebral disc herniation and cranial cruciate ligament repair, with significant improvements in ambulation time and peak vertical force. Particularly noteworthy are its effects in cases of elbow and hip osteoarthritis, where PBMT has led to marked reductions in pain and lameness scores—even in highly active working dogs, whose stoic behavior often complicates clinical evaluation (Acevedo et al., 2019a; J. C. Alves, Santos, Jorge, & Miguel Carreira, 2022; Marcellin-Little & Levine, 2015).

PBMT has been shown to increase ROM in healthy joints by effectively reducing inflammation, alleviating discomfort, and promoting the relaxation of soft tissues. Research in both veterinary and human medicine suggests that combining PBMT with physical exercise yields significantly greater improvements in flexibility and mobility compared to exercise alone (Zink & Van Dyke, 2018).

A noteworthy 2016 study by Youssef and colleagues explored the effects of PBMT on human patients with knee osteoarthritis. The findings suggested that patients receiving PBMT experienced more substantial reductions in pain and improved ROM compared to those who engaged solely in exercise. Similar favorable outcomes in joint ROM have been documented in the treatment of osteoarthritis affecting canine hip joints in working dogs (J. C. Alves et al., 2021).

By facilitating collagen production and enhancing blood circulation, PBMT may contribute to the restoration of mechanical function in crucial joints such as the elbow, stifle, and tarsus, all of which play a vital role in the locomotor capabilities of working dogs (Zink & Van Dyke, 2018).

3.2. Precautions and Contraindications

While photobiomodulation therapy is widely recognized as a safe and non-invasive treatment approach, it is essential to observe certain precautions and contraindications to ensure its effective use and minimize potential adverse effects. The absolute contraindication pertains to any direct or reflected laser exposure to the eyes, particularly the retina. This concern highlights the importance of classifying laser devices according to regulatory standards and the need for strict adherence to proper eye protection for patients, operators, and bystanders during laser therapy (Riegel & Godbold, 2017).

Relative contraindications for PBMT include its use over photosensitive areas or in patients with epilepsy, as light exposure might trigger a response. Caution is also advised over sensitive regions like open growth plates, gonads, or the uterus during pregnancy. PBMT should be avoided in cases of active bleeding, endocrine glands, or areas with recent corticosteroid use due to unpredictable responses. For veterinary patients with thick or long fur, it may be beneficial to clip or part the hair to facilitate adequate energy delivery to the skin. The use of high-powered lasers further emphasizes the importance of minimizing superficial absorption, as energy loss due to pigmentation or fur can reduce therapeutic efficacy and increase the risk of thermal injury at the surface (Zink & Van Dyke, 2018).

In cases of neoplasia, PBMT is generally approached with caution due to the potential for photostimulation to accelerate tumor proliferation. However, when managed judiciously, it may serve as a palliative option for pain relief, provided that informed written consent is secured and that the objectives of care are clearly articulated (Zink & Van Dyke, 2018). By thoughtfully selecting treatment areas, adapting techniques as needed, and closely monitoring patient responses, clinicians can optimize the benefits of PBMT while minimizing safety risks (Riegel & Godbold, 2017).

4. Objectives of the study

The aim of this study was to evaluate changes in joint range of motion immediately following therapeutic PBMT and once the body returns to its normative temperature. The hypothesis was that PBMT could enhance joint range of motion and tissue temperature, as assessed through digital thermography. Additionally, we sought to explore whether any significant differences exist between the evaluations conducted by experienced and novice evaluators.

II. Materials and Methods

1. Sampling procedure and collection data

The study protocol was approved by the ethical review committee of the Faculty of Veterinary Medicine at Lusófona University (Comissão de Ética e Bem Estar Animal - CEBEA, approval number 07/2024). It complies with all relevant institutional and national guidelines regarding the care and use of animals and adheres to the ARRIVE guidelines for reporting. Written informed consent was obtained from the institution responsible for the animals.

Prior to the commencement of the study, a statistical power analysis was conducted, which determined a sample size of 16 dogs based on a type-1 error rate of 0.05 and a type-2 error rate of 0.8, ensuring an adequate number for statistical comparisons between study groups. The selected animals were drawn from the pool of police working dogs belonging to the Guarda Nacional Republicana, with written, informed consent obtained from the institution.

The inclusion criteria for participation in the study stipulated that dogs must be at least 18 months old, have no direct blood relationships with other dogs in the study, exhibit no lameness or history of orthopedic issues or trauma, pass a normal orthopedic examination, and show no radiographic evidence of joint disease in the relevant joints.

2. Methods

The thoracic and pelvic limbs from one side of each subject were designated as the TG, while the corresponding contralateral limbs served as the CG. The allocation of limbs to each group was determined randomly using statistical analysis software.

The ROM of the joints in the sagittal plane—flexion and extension—was assessed for the elbow, stifle, and tarsal joints. Two evaluators, one experienced and one novice, independently conducted goniometric measurements of each dog while they were awake. The investigators were blinded to whether the limbs were part of the treatment or control groups.

The evaluation of joint ROM has been described before (Jaegger et al., 2002b). Briefly, the arms of a transparent plastic goniometer were aligned with the relevant anatomical landmarks on the limbs. Prior to measuring the joint angles, each joint was moved through its full range of motion to establish the joint rotation axis. The center of the goniometer was then positioned over this axis. All measurements were collected in triplicate and meticulously recorded.

The joints were evaluated sequentially, adhering to the predetermined order. Following the initial assessment, the joint on the treated side underwent PBMT, the parameters of which are detailed in Table 3.

Table 3. *Photobiomodulation Therapy treatment parameters.*

	Light Parameters (Dose)		
	Elbow	Stifle	Tarsus
Wavelength (nm)	980nm	980nm	980nm
Radiant Power (W)	10.5	12	8
Irradiance (W/cm2) at skin surface	2.1	2.4	1.6
Fluence (J/cm^2)	15	15	15
Total Joules	3750	5250	1875
Treatment Protocol	Continuously moving grid pattern ON contact at a speed of 1-3 cm/s according to manufacturer recommendations	Continuously moving grid pattern ON contact at a speed of 2,5-7,5 cm/s according to manufacturer recommendations	Continuously moving grid pattern ON contact at a speed of 2,5-7,5 cm/s according to manufacturer recommendations
Treatment Area (cm^2)	250 (entire elbow area)	350 (entire stifle area)	125 (entire tarsus area)
Treatment Time	5 minutes, 57 seconds	7 minutes, 18 seconds	3 minutes, 54 seconds

An independent investigator administered the PBMT treatment. Subsequently, the dogs were allowed a 5-minute rest period without manipulation. After this interval, the range of motion (ROM) of the treated and control joints (ROM) was reassessed.

Digital thermography images were collected using a procedure consistent with prior methodologies (J. C. Alves et al., 2020a, 2021; J. C. A. Alves et al., 2020). The animals were positioned upright, ensuring symmetry to the greatest extent possible, while the region of interest was left undisturbed. Fur clipping was not performed prior to the image collection.

Each joint was imaged three times: before the PBMT treatment, immediately following the treatment, and after the 5-minute rest period. The imaging settings were calibrated to capture a temperature range of 15-40°C with an emissivity value of 0.98. An HT-19 Thermal Imager camera was utilized, and the thermographic images were subsequently analyzed using IR Image Tools. A Rainbow HC color palette was employed, with equal-sized temperature boxes placed over the anatomical area of each joint. Mean and maximum temperatures were recorded. Mild restraint was sufficient for the successful completion of all procedures.

3. Statistical analysis

To assess inter-tester variability, median measurements obtained from the two investigators were compared using paired t-tests for both joint extension and flexion. To assess goniometric measurements in each joint, the variability of mean measurements in flexion and extension between groups was compared with a 1-tail t-test.

The variability of mean measurements of digital thermography between groups of tarsus, stifle, and elbow joints was compared using 1-tail t-tests. Effect sizes were calculated and categorized as small ($r < 0.3$), medium ($0.3 < r < 0.5$), or large ($r > 0.5$). Statistical analyses were performed utilizing IBM SPSS Statistics version 27, with significance established at $p < 0.05$.

III. Results

The study involved a sample of 16 dogs, with a mean body weight of 25.3 ± 2.6 kg and a mean age of 10.6 ± 3.4 years. The sample included both sexes, consisting of 9 males and 6 females. Four breeds were represented: Belgian Malinois (n = 6), Labrador Retriever (n = 5), Dutch Shepherd (n = 3), and German Shepherd (n = 2).

There were no significant differences between the two groups at the initial evaluation. The results of measurements made by the 2 investigators did not differ significantly (ranging from 0.20-0.39). Therefore, the results presented are based on measurements performed by both investigators. Table 4 shows the range of motion (ROM) values for healthy elbows before the application of PBMT, as well as for the stifle and tarsal joints.

Table 4. *Joint range of motion (mean and standard deviation) of normal elbows, stifles, and tarsus (n indicates individual joints, i.e., each dog contributes with two joints each).*

	Elbow				**Stifle**				**Tarsus**			
	Flexion		**Extension**		**Flexion**		**Extension**		**Flexion**		**Extension**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Overall (n=32)	33.4	6.0	159.6	7.2	41.1	3.6	160.2	9.4	35.8	6.6	158.6	11.8
Belgian Malinois (n=12)	30.0	7.5	162.5	4.6	39.9	3.0	161.2	6.8	32.8	9.7	152.5	16.3
Labrador Retriever (n=10)	35.5	3.7	157.8	6.7	41.9	3.3	159.6	13.3	38.2	1.6	163.5	5.2
Dutch Shepherd (n=6)	37.6	2.6	155.1	10.2	43.0	2.7	158.7	4.0	35.9	2.7	161.8	2.2
German Shepherd (n=4)	32.4	2.6	162.2	2.4	40.3	0.5	161.0	1.5	39.0	1.2	160.0	5.1

Table 5 outlines the joint ROM values for both the CG and TG. Following PBMT, significant differences were observed in all joints, displaying a medium to large effect size. Additionally, the measurements recorded by the two investigators did not reveal any significant discrepancies.

Table 5. *Joint range of motion (mean, standard deviation, and variation - Δ°) of elbows, stifles, and tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy. * indicates significance.*

	Elbow															
	Flexion								**Extension**							
	Before PBMT		**p**	**After PBMT**		**Δ°**	**p**	**ES**	**Before PBMT**		**p**	**After PBMT**		**Δ°**	**p**	**ES**
Group	**Mean**	**SD**		**Mean**	**SD**				**Mean**	**SD**		**Mean**	**SD**			
CG	32.7	6.9	0.53	35.2	3.8	2.5	<0.01*	0.43	160.6	6.2	0.58	160.2	6.8	-0.4	<0.01*	0.86
PBMTG	34.2	5.2		30.6	8.1	-3.6			158.6	8.2		167.8	7.2	9.2		

	Stifle															
	Flexion								**Extension**							
	Before PBMT		**p**	**After PBMT**		**Δ°**	**p**	**ES**	**Before PBMT**		**p**	**After PBMT**		**Δ°**	**p**	**ES**
Group	**Mean**	**SD**		**Mean**	**SD**				**Mean**	**SD**		**Mean**	**SD**			
CG	41.4	3.1	0.19	39.2	6.2	-2.2	<0.01*	0.51	159.1	34.3	0.26	158.7	6.0	-0.4	<0.01*	0.96
PBMTG	40.9	4.2		34.3	6.6	-6.6			161.3	11.1		166.3	7.1	5.0		

	Tarsus															
	Flexion								**Extension**							
	Before PBMT		**p**	**After PBMT**		**Δ°**	**p**	**ES**	**Before PBMT**		**p**	**After PBMT**		**Δ°**	**p**	**ES**
Group	**Mean**	**SD**		**Mean**	**SD**				**Mean**	**SD**		**Mean**	**SD**			
CG	36.9	5.0	0.47	35.7	6.4	-1.2	<0.01*	0.66	156.5	12.4	0.32	155.5	13.6	-1.0	<0.01*	0.84
PBMTG	34.8	8.2		31.7	6.6	-3.1			160.8	11.1		165.8	11.1	5.0		

The digital thermography values for the elbows, stifles, and tarsus in the two groups are presented in Table 6, both prior to and following photobiomodulation therapy, as well as 5 minutes after the treatment.

Table 6. *Digital thermography values (mean, standard deviation, and variation - δt) of elbows, stifles, and tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy and after 5 minutes. * indicates significance.*

	Elbow												
	Before PBMT			After PBMT					After 5-minutes				
Group	Mean	SD	p	Mean	SD	ΔT	p	ES	Mean	SD	ΔT	p	ES
CG	32.9	1.3	0.11	33.1	1.6	0.2	<0.01*	0.61	32.6	1.5	-0.3	0.45	0.16
PBMTG	33.1	1.8		38.1	3.4	5.0			32.2	4.1	-0.9		

	Stifle												
	Before PBMT			After PBMT					After 5-minutes				
Group	Mean	SD	p	Mean	SD	ΔT	p	ES	Mean	SD	ΔT	p	ES
CG	32.4	1.7	0.26	32.8	2.3	0.4	<0.01*	0.55	32.1	1.3	-0.3	<0.01*	0.31
PBMTG	32.6	1.5		36.6	2.9	4.0			34.2	2.1	1.6		

	Tarsus												
	Before PBMT			After PBMT					After 5-minutes				
Group	Mean	SD	p	Mean	SD	ΔT	p	ES	Mean	SD	ΔT	p	ES
CG	33.0	2.3	0.25	32.7	2.1	-0.3	<0.01*	0.53	32.7	2.3	-0.3	<0.01*	0.12
PBMTG	32.8	2.6		38.1	3.0	5.3			33.6	1.8	0.8		

A significant difference was observed in all joints after PBMT, with a small to medium effect size. Notably, for both the stifle and tarsus, a significant difference was still evident even after the 5-minute period. Figures 19 to 21 illustrate lateral thermograms of an elbow, stifle, and tarsus, respectively, displaying the condition before PBMT (left), immediately after PBMT (center), and again after 5 minutes (right).

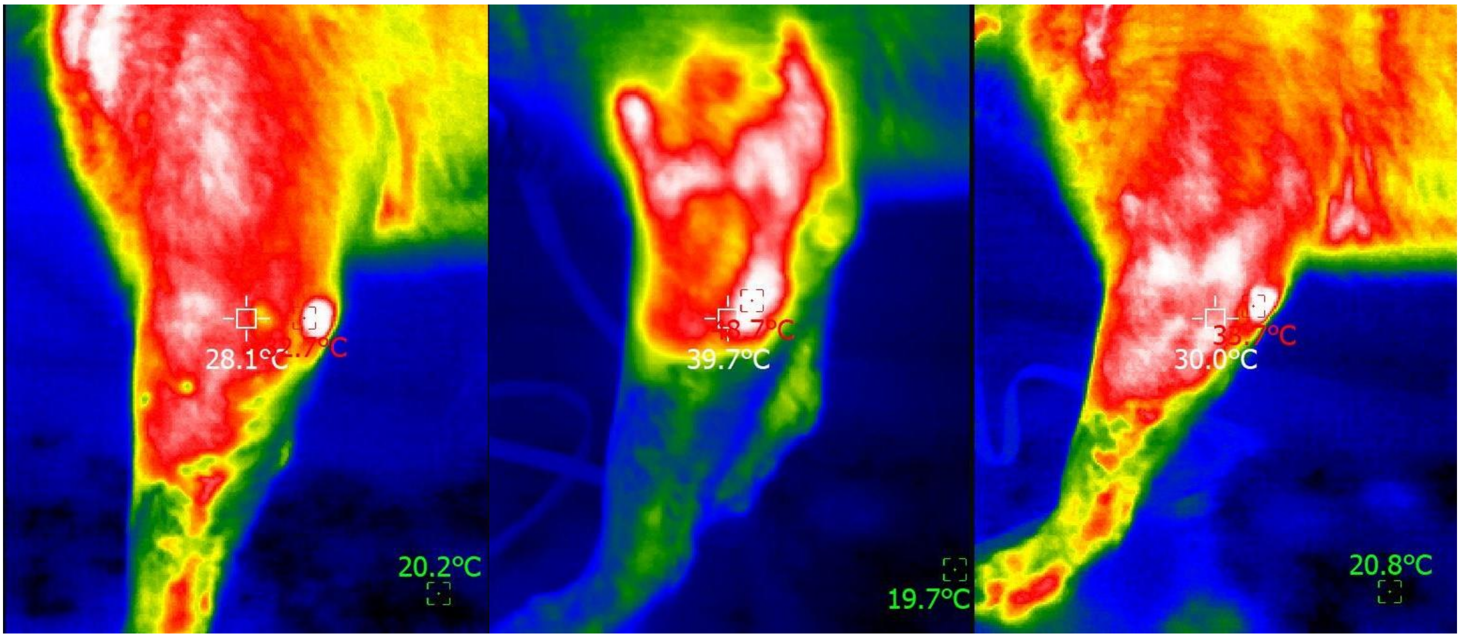

Figure 19. *Lateral thermogram of an elbow before (left), immediately after photobiomodulation therapy (center), and after 5 minutes (right). The head of the animal is to the left of the image. (Original by the author).*

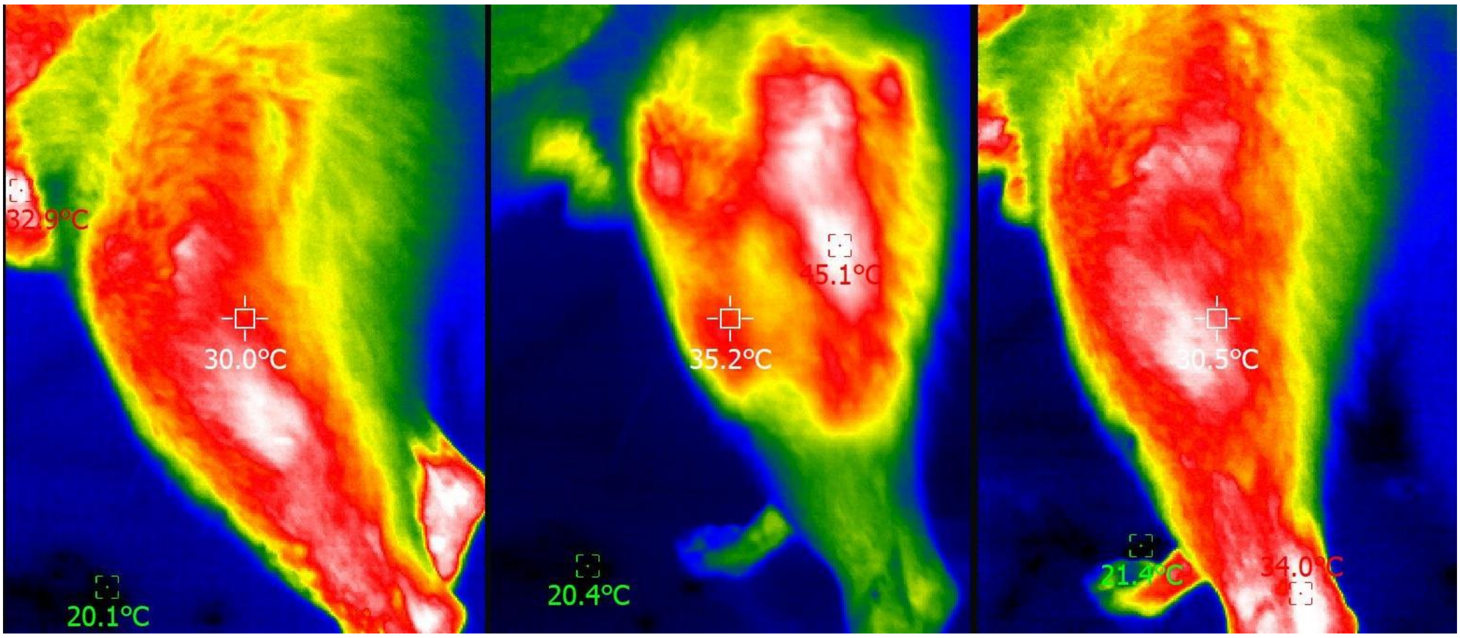

Figure 20. *Lateral thermogram of a stifle before (left), immediately after photobiomodulation therapy (center), and after 5 minutes (right). The head of the animal is to the left of the image. (Original by the author).*

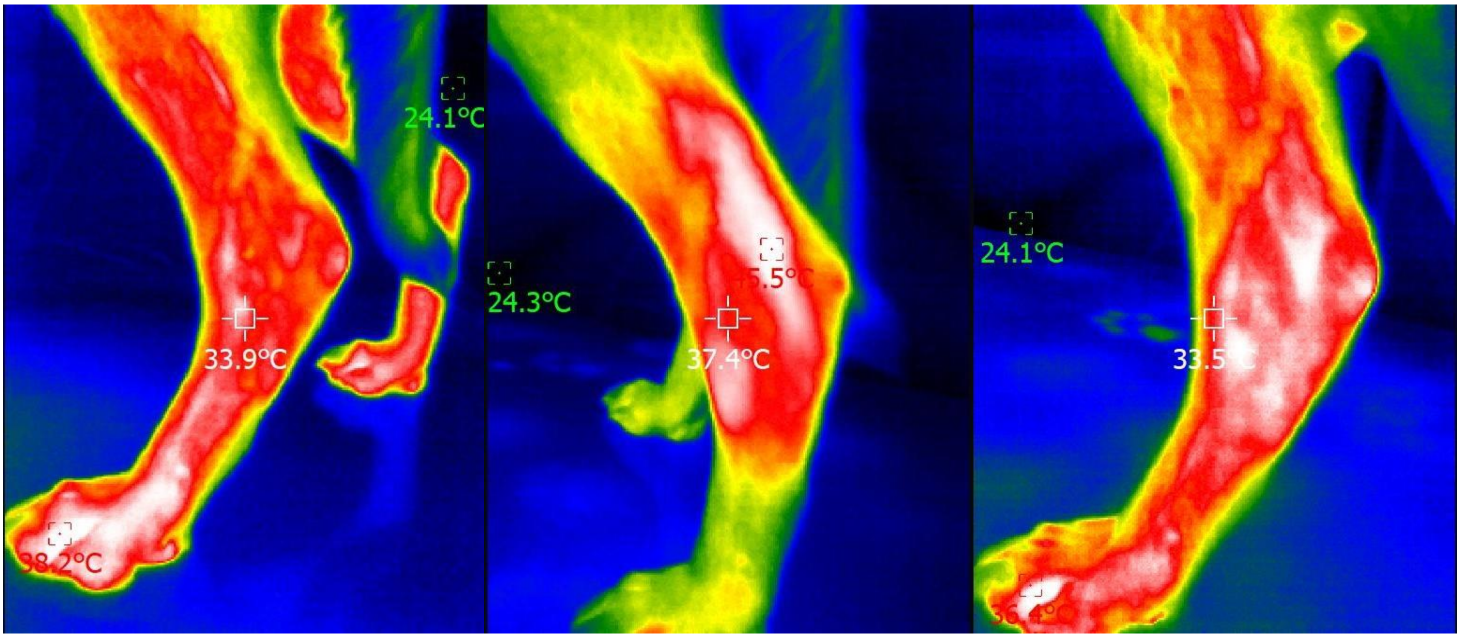

Figure 21. *Lateral thermogram of a tarsus before (left), immediately after photobiomodulation therapy (center), and after 5 minutes (right). The head of the animal is to the left of the image. (Original by the author).*

IV. Discussion

Our research shows that PBMT can increase the ROM of healthy joints and local tissue temperature. While no differences were observed between the two groups at the initial assessment, following PBMT, a significant increase in ROM was observed in all joints ($p<0.01$) of PBMTG, with a large effect size, ranging from 0.84 to 0.96 (as seen in Table 5). A previous report has shown that PBMT can improve joint ROM in dogs with hip OA, but these effects were only observed after 15 to 30 days of treatment, and within-session changes were not evaluated (J. C. Alves, Santos, Jorge, & Carreira, 2022). These changes in ROM can be attributed to the effects of PBMT on biological tissues, where light-based therapy stimulates cellular processes. PBMT increases mitochondrial ATP production, reduces oxidative stress, and enhances tissue repair (Hamblin, 2017). These mechanisms likely reduce inflammation in the synovial membranes and surrounding soft tissues, such as tendons and ligaments, resulting in increased flexibility and decreased stiffness within the joint capsule (Enwemeka et al., 2004). This explains the overall improvement in ROM after long-term treatment in joints where stiffness is often exacerbated by inflammation and structural degeneration, such as cartilage loss and osteophyte formation, which ultimately leads to restricted ROM (Enwemeka et al., 2004).

However, these are unlikely to be the cause in cases of healthy joints and within a single session. In diseased joints, putting a joint through its ROM can be painful and is also limited by sensory factors rather than just mechanical ones (Hamblin, 2017). In these cases, pain and inflammation become a central limiting factor, and the mechanical restriction, combined with pain, results in a more limited and variable ROM than healthy joints. The analgesic effect of PBMT can improve patient comfort and improve ROM within the session. Also, the thermal effect resulting from the PBMT session, while not responsible for the beneficial effects of PBMT, has resulted in a “beneficial side-effect”. An increase in temperature enhances the extensibility of collagen tissue, thereby improving tissue flexibility, which has clinical significance when therapeutic rehabilitation exercises and modalities are performed (Acevedo et al., 2019b). This may be one of the reasons why an increase in ROM was observed in this study.

Previous reports have shown that joints affected by osteoarthritis exhibit increased variability in ROM measurements (J. C. Alves et al., 2020b). There are several reasons for this finding. The pain and inflammation in joints affected by osteoarthritis often lead to reduced movement to avoid discomfort. It also can lead to muscle weakening and joint stiffness over time (Moreau et al., 2014). Additionally, when evaluating different joints, more soft tissue structures surround proximal joints, and the larger muscle mass surrounding proximal joints can make it harder to palpate bony landmarks, making adequate goniometric measurements more challenging (Jaegger et al., 2002b).

We found no differences between the two evaluators in any considered joints. Even though these were healthy joints, the animals were fully awake and energetic, which could have been more challenging. To overcome these possible limitations, adequate preparation was undertaken beforehand to ensure that the principles of proper evaluation were understood, particularly given that goniometry is recognized as having a relatively low learning curve (Jaegger et al., 2002b). Having a standardized protocol is crucial in minimizing operator variability. By following the established protocols and taking as much time as required to perform the evaluations, and adequately handle the dogs with care and attention to detail, goniometric measurements remained consistent across both researchers. This result is consistent with previously reported (Arabzadeh et al., 2023; Johnston, 1997).

Regarding the results obtained with digital thermography, significant temperature increases were observed in all joints immediately after PBMT ($p < 0.01$), with an increase of up to 5ºC (as seen in Table 6). This rise in temperature can be attributed to the thermal effect of PBMT, which leads to vasodilation, and increased blood flow to the skin and underlying tissues (Gunnar Wallin, 1990). Raising tissue temperature by more than 3ºC above baseline levels could notably enhance ROM, likely due to collagen's viscoelastic characteristics (Loughin & Marino, 2007). These findings imply that investigating the effects of PBMT on joint temperature could significantly improve patient care (Draper et al., 1998). The thermographic findings in the present study align with this observation, suggesting that the increase in temperature contributed to the improved ROM observed following PBMT. These further stresses the broad role of PBMT in rehabilitation. In addition to its healing and analgesic effects, which establish PBMT as a therapeutic modality, it can also serve as a preparatory modality for other therapeutic approaches, such as joint mobilization or therapeutic exercises.

After the 5 minutes, the increase in temperature was only observed in the stifle and tarsus ($p < 0.01$) (as seen in Table 6). The reason for this is unclear. The temperature rise was similar in the joints considered (4-5ºC). Surrounding muscle masses could have played a role, as the shoulder is surrounded by large muscle masses proximally, but also is the stifle. Future studies should consider measuring muscle girth to evaluate this effect. Coat characteristics could also play a role. A previous study highlighted that German Shepherd dogs exhibited lower values during thermographic evaluation compared to other considered breeds (J. C. Alves, Santos, Jorge, & Miguel Carreira, 2022; Marcellin-Little & Levine, 2015). This factor is balanced by having the same animal serving as a control and treatment. In addition, the remaining breeds included in the sample, particularly Belgian Malinois and Dutch Shepherd, have a similar coat with a thick undercoat.

Despite the recognized advantages, the homogeneity of the sample also has its limitations. The sample was composed exclusively of active police working dogs. These animals have musculoskeletal structures that endure significantly more stress and physical demands than companion dogs. They also exhibit greater muscle masses, joint strength, and overall physical conditioning (Arabzadeh et al., 2023). Although PBMT parameters were determined based on the patient's characteristics (as it should always be), future studies should include a more diverse sample of dogs, accounting for variations in size, breed, and physical activity levels. Additionally, future studies should include a longer post-PBMT follow-up to evaluate how long this increase in joint ROM is present.

Photobiomodulation therapy (PBMT) can improve joint movement and increase tissue temperature, which means using PBMT before joint exercises may make them more effective. These results show that photobiomodulation can help with muscle and joint recovery, especially for dogs needing better flexibility and comfort. This study provides important information in a field where research is still growing, particularly about PBMT's effects on healthy dog joints. By using a clear and repeatable method, this research supports PBMT as a helpful tool in veterinary physiotherapy and opens the door for more studies in the future. Measuring outcomes objectively is an important step towards evidence-based rehabilitation. As one of the first studies to look at these aspects in healthy canine joints, it can lay the groundwork for future research and clinical use in both preventive and treatment settings.

V. Conclusion

Our results show that PBMT can increase joint ROM in healthy joints. Including PBMT in treatment protocols, especially before joint mobilization exercises, can improve therapeutic outcomes by reducing stiffness and increasing joint flexibility and comfort. Importantly, no differences were found between goniometric measurements taken by experienced and novice evaluators, highlighting the reliability and reproducibility of this assessment tool in a clinical context. These findings support the potential role of PBMT as an adjunctive modality in veterinary rehabilitation and emphasize the need for further studies to explore its full therapeutic potential.

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Appendices

Appendix A - Record Sheet for measurements taken with the goniometer.

Nome ________________ Raça ________ Matrícula ________________
Articulação ________________

Termografia

Vista esquerda ☐ Vista direita ☐

ROM

Esquerda	Direita
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
ROM extensão __________ °	ROM extensão __________ °
ROM extensão __________ °	ROM extensão __________ °
ROM extensão __________ °	ROM extensão __________ °
ROM extensão __________ °	ROM extensão __________ °
ROM extensão __________ °	ROM extensão __________ °

Termografia

Vista esquerda ☐ Vista direita ☐

Termografia

Vista esquerda ☐ Vista direita ☐

ROM

Esquerda	Direita
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
ROM flexão __________ °	ROM flexão __________ °
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Appendix B – Abstract and poster presented in the XX Congresso Internacional Veterinário Montenegro, 11th-12th October 2024, Portugal.

EVALUATION OF THE EFFECT OF PHOTOBIOMODULATION THERAPY ON JOINT RANGE OF MOTION IN DOGS

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Photobiomodulation therapy (PBMT) is a non-invasive treatment commonly used in animal rehabilitation (Alves et al., 2022). PBMT induces tissue warming, and elevated temperature increases collagen tissue's flexibility, which is clinically important during therapeutic rehabilitation exercises and modalities (Acevedo et al., 2019; Marcellin-Little & Levine, 2015a). Goniometry is a cost-effective and non-invasive technique for measuring joint range of motion (ROM) (Marcellin-Little & Levine, 2015b). Digital thermography is a non-invasive tool for assessing soft tissue injuries. It detects variations in tissue heat due to structural and functional changes.

We aimed to evaluate changes in the ROM of healthy joints immediately after PBMT. We hypothesize that PBMT could increase joint ROM and that the goniometric measurements of experienced and novice evaluators do not differ.

Ethical approval was obtained for the study. A sample size of 16 dogs was determined. The thoracic and pelvic limbs from one side were used as the treatment group (PBMTG), and the contralateral limbs comprised the control group (CG). Experienced and novice evaluators used goniometric measurements to evaluate flexion and extension of the elbow, tarsal, and stifle joints. All measurements were made three times. After the initial assessment, the joints on the treated side underwent PBMT. Joint ROM was then reevaluated after a 5-minute rest period. Digital thermography was conducted before PBMT, immediately after PBMT, and after the 5 minutes.

For inter-tester variability, the two investigators' median measurements for joint extension and flexion were compared using paired t-tests. A one-tailed t-test was conducted to assess the variability of median flexion and extension measurements for each joint's goniometric measurements. The variability of median measurements of the tarsus, stifle, and elbow joints was compared using 1-tail t-tests. The effect size was determined.

The dogs weighed 25.3 ± 2.6kg and were 10.6 ± 3.4 years old. Nine males and 6 females were included, representing four different breeds: Belgian Malinois Shepherd Dogs (n=6), Labrador Retrievers (n=5), Dutch Shepherd Dogs (n=3), and German Shepherd Dogs (n = 2).

Joint ROM in flexion and extension was 33.4º±6.0 and 159.6º±7.2 for elbows, 41.1º±3.6 and 160.2º±9.4 for stifles, and 35.8º±6.6 and 158.6º±11.8 for tarsus. There were no differences between the two groups at the initial assessment. PBMTG showed increased ROM in all joints ($p<0.01$), with a large effect size (0.84 to 0.96). There were no differences in the measurements conducted by the 2 investigators.

Digital thermography values were significantly different in all joints after PBMT ($p<0.01$), corresponding to an increase of up to 5ºC, with a small to medium effect size (0.31-0.61). A significant difference was observed for the stifle and tarsus after the 5 minutes ($p<0.01$).

PBMT increased joint ROM in the joints evaluated. This suggests that joint mobilization exercises can be improved by and should be conducted after PBMT. All clinicians can easily perform goniometry, with no significant difference between experienced and novice evaluators' measurements.

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Evaluation of the effect of photobiomodulation on joint range of motion in dogs

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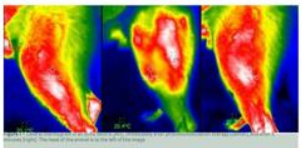
Introduction

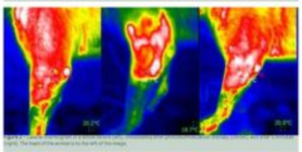
Photobiomodulation therapy (PBMT) is a noninvasive animal rehabilitation treatment known for its lack of adverse effects[1]. PBMT works by inducing tissue warming, which triggers thermal effects. The extent of tissue warming is directly related to the magnitude of these effects. Elevated temperature enhances the flexibility of collagen tissue, which is crucial in therapeutic rehabilitation exercises and modalities[2]. Goniometry is a cost-effective and noninvasive technique for measuring joint range of motion (ROM). It is influenced by joint morphology, the joint capsule, ligaments, and periarticular tendons and muscles[3]. This technique offers excellent precision and repeatability with a straightforward learning curve. Ultimately, digital thermography is a noninvasive tool for assessing soft tissue injuries. It detects variations in tissue heat caused by structural and functional changes.

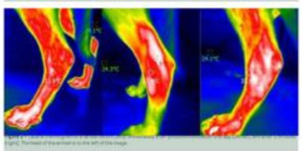
Materials and Methods

Ethical approval was obtained for the study. A statistical analysis determined a sample size of 16 dogs (type-1 error 0.05, type-2 error 0.8) from the police working dogs of the Guarda Nacional Republicana. Inclusion criteria included dogs aged ≥ 18 months with no lameness, orthopedic issues, or direct blood relations with other study dogs. The thoracic and pelvic limbs on the left side were the treatment group (PBMTG), and the contralateral limbs were the control group (CG), with side allocation randomized. Using a goniometer, two blinded evaluators assessed the joint range of motion (ROM) for the elbow, stifle, and tarsal joints. Measurements were taken before and after PBMT and after a 5-minute rest period. After that, a digital thermography was conducted before PBMT, immediately after, and post-rest. An HT-19 Thermal Imager camera was used, and an analysis was performed using IR Image Tools software. Intertester variability and goniometric measurements were analyzed using paired and 1-tail t-tests, with effect sizes classified as small ($r<0.3$), medium ($0.3<r<0.5$), or large ($r>0.5$).
Statistical analysis was performed using IBM SPSS Statistics version 20, with significance at $p<0.05$.

Results







Elbow

Group	Flexion: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES	Extension: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES
CG	32.7	6.9	35.2	3.8	2.5	<0.01*	0.43	160.6	6.2	160.2	6.9	-0.4	<0.01*	0.86
PBMTG	34.2	5.2	30.6	6.1	-3.6			159.6	6.2	167.8	7.2	8.2		

Stifle

Group	Flexion: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES	Extension: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES
CG	41.4	3.1	39.2	6.2	-2.2	<0.01*	0.51	159.1	34.3	158.7	6.0	-0.4	<0.01*	0.86
PBMTG	40.9	4.2	34.3	6.6	-6.6			161.3	11.1	166.5	7.1	5.2		

Tarsus

Group	Flexion: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES	Extension: Before PBMT Mean	SD	After PBMT Mean	SD	Δ	p	ES
CG	36.9	5.0	35.7	6.4	-1.2	<0.01*	0.88	156.5	12.4	155.5	13.6	-1.0	<0.01*	0.84
PBMTG	34.8	8.2	31.7	6.6	-3.1			160.8	11.1	165.6	11.1	5.0		

Table 1 – Joint range of motion (mean, standard deviation, and variation – Δ) of elbows, stifles, and tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy. * indicates significance.

Elbow

Group	Before PBMT Mean	SD	After PBMT Mean	SD	ΔT	p	ES	After 5-minutes Mean	SD	ΔT	p	ES
CG	32.9	1.3	33.1	1.6	0.2	<0.01*	0.61	32.6	1.5	-0.3	0.45	0.16
PBMTG	33.1	1.8	38.1	3.4	5.0			32.2	4.1	-0.9		

Stifle

Group	Before PBMT Mean	SD	After PBMT Mean	SD	ΔT	p	ES	After 5-minutes Mean	SD	ΔT	p	ES
CG	32.4	1.7	32.8	2.3	0.4	<0.01*	0.55	32.1	1.3	-0.3	<0.01*	0.31
PBMTG	32.6	1.5	36.6	2.9	4.0			34.2	2.1	1.6		

Tarsus

Group	Before PBMT Mean	SD	After PBMT Mean	SD	ΔT	p	ES	After 5-minutes Mean	SD	ΔT	p	ES
CG	33.0	2.3	32.7	2.1	-0.3	<0.01*	0.53	32.7	2.3	-0.3	<0.01*	0.12
PBMTG	32.8	2.6	38.1	3.0	5.3			33.6	1.8	0.8		

Table 2 – Digital thermography values (mean, standard deviation, and variation – Δ) of elbows, stifles and tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy and after 5 minutes. * indicates significance.

The results in Table 1 indicate that there were significant improvements in the range of motion (ROM) in both the CG and PBMTG. After PBMT, all joints showed significant improvement with a moderate to large impact.
In Table 2, the digital thermography values for all joints in the two groups before and after PBMT and the following 5 minutes are presented. The results show a considerable improvement in all joints after PBMT, with a small to moderate effect. Additionally, there was a significant improvement in the stifle and tarsus after 5 minutes.

Conclusion

PBMT, or photobiomodulation therapy, has been found to have a positive effect on joint mobility in the joints that were examined in the study. It is noteworthy that there was no significant variance between the measurements taken by experienced and novice evaluators, indicating the reliability and accessibility of this therapy. This finding suggests that PBMT can be widely adopted as a non-invasive, cost-effective, and low-risk method for preserving the health and functionality of canine joints.

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Appendix C - Article Published in Lasers in Medical Science.

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RESEARCH

Evaluation of the effect of photobiomodulation on joint range of motion in dogs

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Abstract

To evaluate the effect of photobiomodulation therapy on healthy joint's range of motion (ROM). Sixteen police working dogs were selected. The limbs of one side of the body were randomly assigned to the treatment group, while the limbs of the other side formed the control group. Elbow, stifle, and tarsal flexion and extension were evaluated, and measurements were made in triplicate by two evaluators, one experienced and one novice. After the initial evaluation, the treated side's joints underwent PBMT. The dogs had a 5-minute rest before the joint ROM was again measured. Digital thermography was also used to assess the joints before and immediately after PBMT, and after the 5-minute rest period. The variability of the joint median measurements was compared using 1-tail t-tests, and the effect size was determined. Following PBMT, significant differences in ROM were observed in all joints ($p < 0.01$) with a large effect size (0.84 to 0.96). Additionally, digital thermography values showed significant differences in all joints after PBMT ($p < 0.01$), with an increase of up to 5ºC, with a small to medium effect size (0.31–0.61). A significant difference was found for the stifle and tarsus after the 5 min ($p <$ 0.01). There were no differences in the measurements by the two investigators. PBMT increased ROM and tis- sue temperature. This suggests that joint mobilization exercises can be improved by and should be conducted after PBMT. There was no significant difference between the measurements of experienced and novice evaluators.

Keywords Photobiomodulation therapy · Dog · Joint · Joint range of motion · Digital thermography

Introduction

Photobiomodulation therapy (PBMT) is frequently used in animal rehabilitation due to its noninvasive nature and lack of adverse effects [1, 2]. This therapy involves lasers that emit monochromatic, coherent, and collimated electromagnetic radiation, which allows the laser light to penetrate tissues and stimulate non-harmful and non-thermal cell reactions, resulting in positive therapeutic effects, including pain and inflammation alleviation, immunomodulation, and the promotion of wound healing and tissue regeneration [3–5]. PBMT also produces tissue warming and, consequently, thermal effects, which are correlated to the magnitude of tissue warming. An increase in temperature increases collagen tissue extensibility, thus improving the flexibility of the tissues, which has clinical significance when therapeutic rehabilitation exercises and modalities are performed [6].

To maintain optimal movement and daily activities, adequate joint motion is essential. In veterinary rehabilitation, passive ROM exercises are commonly utilized to promote cartilage nutrition, reduce tissue adhesion, decrease

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swelling, and relieve pain [7, 8]. The ROM is influenced by a combination of factors, including the joint shape, joint capsule, ligaments, and surrounding tendons and muscles. Normal ROM values vary according to the dog's size, breed, and body type [9, 10]. ROM is closely linked to flexibility and is susceptible to the effects of physical activity, over- all physical condition, and joint health. Specific exercises can be designed to target and improve joint flexibility. An example is passive joint manipulation, which caregivers can conduct [10]. This form of manipulation also improves joint movement and has the potential to contribute positively to tissue healing [7]. Goniometry is a simple, affordable, and noninvasive method, to measure joint angles and quantifies range of motion with excellent precision and repeatability [7].

Digital thermography is a non-contact, noninvasive tool for assessing soft tissue injuries in humans and animals based on heat resulting from physiological functions related to skin temperature regulation [11, 12]. This technology works by detecting variations in tissue heat caused by modi- fications in structure and function. The thermal patterns are displayed on a color map, with the warmest regions shown in white or red and the cooler regions in blue or black [13]. It can be used as diagnostic screening, enhancing interpreta- tion of physical examinations, guiding therapeutic manage- ment, and assessing long-term response to treatment [14]. In human and equine medicine, thermography has proven beneficial, particularly as it does not require anesthesia and does not expose the patient to radiation [13]. It has been extensively reported in canine medicine, from the initial and follow-up evaluation of osteoarthritis patients, includ- ing different joints, to tendinopaties [15, 16].

This study aimed to measure the changes in joint range of motion immediately after therapeutic PBMT and once the body returns to its normal temperature. We hypothesized that PBMT could increase joint range of motion and tissue temperature, as measured by digital thermography. Additionally, we aimed to determine if there is any significant difference between the measurements taken by experienced and novice evaluators.

Materials and methods

The study protocol was approved by the ethical review committee of the Faculty of Veterinary Medicine, Lusófona University (Comissão de Ética e Bem Estar Animal - CEBEA, approval nº 07/2024) and complied with the relevant institutional and national guidelines for the care and use of animals. The ARRIVE guidelines for reporting were followed. Written, informed consent was obtained from the Institution responsible for the animals.

A sample size of 16 dogs was determined before the onset of the study by conducting a statistical power analy- sis (type-1 error, 0.05; type-2 error, 0.8) to determine the minimal number of dogs necessary to perform statistical comparisons between study groups. Animals were selected from the population of police working dogs of the Guarda Nacional Republicana. Written and informed consent was obtained from the Institution. The inclusion criteria were that dogs were ≥ 18 months of age, with no direct blood relationship with other dogs in the study, no lameness or history of orthopedic disease or trauma, normal orthopedic examination, and no radiographic evidence of joint disease in the considered joints.

The thoracic and pelvic limbs from one side were used as the treatment group (PBMTG), and the contralateral limbs comprised the control group (CG). The side allocated to each group was randomly determined using statistical analysis software. The joint range of motion over the sagit- tal plain (in flexion and extension) for the elbow, stifle, and tarsal joints were evaluated. Two experienced and novice evaluators independently made goniometric measurements of each dog awake. Investigators were blinded to treatment and control groups. The evaluation of joint ROM has been described before [17]. Briefly, the arms of a transparent plastic goniometer were aligned with anatomic landmarks on the limbs. Before joint angle measurement, each joint was moved through a complete range of motion to determine the joint rotation axis. The center of the goniometer was placed over that axis. All measurements were made in triplicate and recorded. Joints were evaluated one at a time in the order outlined above. After the first evaluation, the joint from the treated side was submitted to PBMT. PBMT parameters are summarized in Table 1. An independent investigator performed PBMT treatment. After PBMT, dogs were allowed a 5-minute rest period, during which they were not manipulated. After the 5 min, joint ROM was again measured in both the treated and control joints.

For the collection of the digital thermography images, the same procedure as described before was used [18–20]. The animals were positioned standing in an upright position, as symmetrically as possible. The region of interest was not touched. No fur clipping was performed before image collection. Three images were collected from each joint: before PBMT, immediately after PBMT, and after the 5-minute period. Image settings were adjusted to include a range of 15–40 °C and an emissivity of 0.98. An HT-19 Thermal Imager camera (HTI) was used, and thermographic images were analyzed with IR Image Tools (HTI). A Rainbow HC color pallet was selected, and equal-sized temperature boxes were placed on the joint's anatomical area. Mean and maximal temperatures were determined. Only mild restraint was required to perform all the procedures.

Table 1 Photobiomodulation therapy treatment parameters

	Light Parameters (Dose)		
	Elbow	Stifle	Tarsus
Wavelength (nm)	980 nm	980 nm	980 nm
Radiant Power (W)	10.5	12	8
Irradiance (W/cm2) at skin surface	2.1	2.4	1.6
Fluence (J/cm^2)	15	15	15
Total Joules	3750	5250	1875
Treatment Protocol	Continuously moving grid pattern ON contact at a speed of 1–3 inches/second according to manufacturer recommendations	Continuously moving grid pattern ON contact at a speed of 2,5–7,5 cm/s according to manufacturer recommendations	Continuously mov- ing grid pattern ON contact at a speed of 2,5–7,5 cm/s accord- ing to manufacturer recommendations
Treatment Area (cm^2)	250 (entire elbow area)	350 (entire stifle area)	125 (entire tarsus area)
Treatment Time	5 min, 57 s	7 min, 18 s	3 min, 54 s

To evaluate intertester variability, the median measurements for the 2 investigators were compared using paired t-tests for joint extension and flexion. To assess goniomet- ric measurements of each joint, the variability of mean measurements in flexion and extension between groups was compared with a 1-tail t-test. The variability of mean measurements of digital thermography between groups tarsus, stifle, and elbow joints was compared using 1-tail t-tests. The effect size was determined and considered to be small if $r < 0.3$, medium if $0.3 < r < 0.5$, and large if $r > 0.5$. Results were analyzed with IBM SPSS Statistics version 20, $p < 0.05$.

Results

The sample included 16 dogs, with a mean body weight of 25.3 ± 2.6 kg and a mean age of 10.6 ± 3.4 years. Both sexes were represented, with 9 males and 6 females, and four breeds were represented: Belgian Malinois Shepherd Dogs ($n = 6$), Labrador Retriever ($n = 5$), Dutch Shepherd Dogs ($n = 3$), and German Shepherd Dogs ($n = 2$).

There were no significant differences between the two groups at the initial evaluation. The results of measurements made by the 2 investigators did not differ significantly (ranging from 0.20 to 0.39). For that reason, the results presented are the result of the measurements performed by both investigators. Table 2 presents values for joint ROM in healthy elbows (before PBMT was performed), stifle, and tarsus. Table 3 presents values for joint ROM in CG and PBMTG. A significant difference was observed in all joints after PBMT, with a medium to large effect size.

Digital thermography values of elbows, stifles, and tar- sus in the two groups, before and after photobiomodulation therapy and after 5 min, are presented in Table 4. A significant difference was observed in all joints after PBMT, with a small to medium effect size. For the stifle and tarsus, a significant difference was still observed after the 5-minute period. Figures 1, 2 and 3 show a lateral thermogram of an elbow, stifle, and tarsus (respectively) before (left), immediately after photobiomodulation therapy (center), and after 5 min (right).

Discussion

Our research shows that PBMT can increase joint ROM of healthy joints and local tissue temperature. While no differences were observed between the two groups at the initial assessment, following PBMT, a significant increase in ROM was observed in all joints ($p < 0.01$) of PBMTG, with a large effect size, ranging from 0.84 to 0.96. A previous report has shown that PBMT can improve joint ROM in dogs with hip OA, but these effects were only observed after 15 to 30 days of treatment, and within session changes were not evaluated [21]. These changes in ROM can be attrib- uted to the effects of PBMT on biological tissues, where light-based therapy stimulates cellular processes. PBMT increases mitochondrial ATP production, reduces oxidative stress, and enhances tissue repair [22]. These mechanisms likely reduce inflammation in the synovial membranes and surrounding soft tissues, such as tendons and ligaments, leading to increased flexibility and decreased stiffness in the joint capsule [23]. This explains the overall improvement in ROM after long-term treatment, in joints where stiffness is often exacerbated by inflammation and structural degenera- tion, such as cartilage loss and osteophyte formation, which ultimately leads to restricted ROM [23].

However, these are unlikely to be the cause in case for healthy joints and within a session. In disease joints, put- ting a joint through its ROM can be painfull, and is also limited by sensory factors rather than just mechanical ones

Table 2 Joint range of motion (mean and standard deviation) of normal elbows, stifles, and Tarsus (n indicates individual joints, i.e., each dog contributes with two joints each)

	Elbow				Stifle				Tarsus			
	Flexion		Extension		Flexion		Extension		Flexion		Extension	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Overall ($n = 32$)	33.4	6.0	159.6	7.2	41.1	3.6	160.2	9.4	35.8	6.6	158.6	11.8
Belgian Malinois ($n = 12$)	30.0	7.5	162.5	4.6	39.9	3.0	161.2	6.8	32.8	9.7	152.5	16.3
Labrador Retriever ($n = 10$)	35.5	3.7	157.8	6.7	41.9	3.3	159.6	13.3	38.2	1.6	163.5	5.2
Dutch Shepherd ($n = 6$)	37.6	2.6	155.1	10.2	43.0	2.7	158.7	4.0	35.9	2.7	161.8	2.2
German Shepherd ($n = 4$)	32.4	2.6	162.2	2.4	40.3	0.5	161.0	1.5	39.0	1.2	160.0	5.1

[22]. In these cases, pain and inflammation become a central limiting factors, and the mechanical restriction, combined with pain, results in a more limited and variable ROM than healthy joints. The analgesic effect of PBMT can improve patient comfort and improve ROM within the session. Also, the thermal effect resulting from the PBMT session, while not responsible for the beneficial effects of PBMT, has resulted in a “beneficial side-effect”. An increase in temperature increases collagen tissue extensibility, thus improving the flexibility of the tissues, which has clinical significance when therapeutic rehabilitation exercises and modalities are performed [6]. This may be one of the reasons why an increase in ROM was observed in this study.

Previous reports have shown that joints affected by osteoarthritis exhibit increased variability in ROM measurements [24]. There are several reasons for this finding. The pain and inflammation in joints affected by osteoarthritis often lead to reduced movement to avoid discomfort. It also can lead to muscle weakening and joint stiffness over time [25]. Addi- tionally, when evaluating different joints, proximal joints are surrounded by more soft tissue structures, and the larger muscle mass around proximal joints can make it harder to palpate bony landmarks, making adequate goniometric mea- surements harder [17]. We found no differences between the two evaluators in any considered joints. Even though these were healthy joints, the animals were fully awake and were energetic, which could have been more challenging. To overcome these possible limitations, an adequate prepara- tion was followed beforehand, to make sure that the prin- ciples of proper evaluations were understood, particularly given that goniometry is recognized as having a relatively low learning curve [17]. Having a standardized protocol is crucial in minimizing operator variability. By following the established protocols and taking as much time as required to perform the evaluations, and adequately handle the dogs with care and attention to detail, goniometric measurements remained consistent across both researchers. This result is consistent with previously reported [26, 27].

Regarding the results obtained with digital thermogra-
phy, significant temperature increases were observed in all joints immediately after PBMT ($p < 0.01$), with an increase of up to 5ºC. This rise in temperature can be attributed to the thermal effect of PBMT, which leads to vasodilation, and increased blood flow to the skin and underlying tissues [28]. Raising tissue temperature by more than 3ºC above baseline levels could notably enhance ROM, likely due to collagen’s viscoelastic characteristics [14]. These findings imply that investigating the effects of PBMT on joint temperature could significantly improve patient care [29]. The thermographic findings in the present study align with this observation, suggesting that the increase in temperature contributed to the improved ROM observed following PBMT. This

Table 3 Joint range of motion (mean, standard deviation, and variation - Δ°) of elbows, stifles, and Tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy. * indicates significance

Group	Elbow															
	Flexion								Extesion							
	Before PBMT		p	After PBMT		Δ°	p	ES	Before PBMT		p	After PBMT		Δ°	p	ES
	Mean	SD		Mean	SD				Mean	SD		Mean	SD			
CG	32.7	6.9	0.53	35.2	3.8	2.5	< 0.01*	0.43	160.6	6.2	0.58	160.2	6.8	-0.4	< 0.01*	0.86
PBMTG	34.2	5.2		30.6	8.1	-3.6			158.6	8.2		167.8	7.2	9.2		
	Stifle															
CG	41.4	3.1	0.19	39.2	6.2	-2.2	< 0.01*	0.51	159.1	34.3	0.26	158.7	6.0	-0.4	< 0.01*	0.96
PBMTG	40.9	4.2		34.3	6.6	-6.6			161.3	11.1		166.3	7.1	5.0		
	Stifle															
CG	36.9	5.0	0.47	35.7	6.4	-1.2	< 0.01*	0.66	156.5	12.4	0.32	155.5	13.6	-1.0	< 0.01*	0.84
PBMTG	34.8	8.2		31.7	6.6	-3.1			160.8	11.1		165.8	11.1	5.0		

further stresses the broad role of PBMT in rehabilitation. In addition to healing and analgesic effects, which establish PBMT as a therapeutic modality on its own, it can also serve as a preparatory modality for other therapeutic approaches, as joint mobilization or therapeutic exercises.

After the 5 min, the increase in temperature was only observed in the stifle and tarsus ($p < 0.01$). The reason for this is unclear. The temperature rise was similar in the joints considered (4–5ºC). Surrounding muscle masses could have played a role, as the shoulder is surrounded by large muscle masses proximally, but also is the stifle. Future stud- ies should consider measuring muscle girth to evaluate this effect. Coat characteristics could also play a role. A previous study highlighted that German Shepherd dogs exhibited lower values during thermographic evaluation compared to other considered breeds [21]. This factor is balanced by having the same animal serving as a control and treatment. In addition, the remaining breeds included in the sample, particularly Belgian Malinois and Dutch Shepherd, have a similar coat with a thick undercoat.

Despite the recognized advantages, the homogeneity of the sample also has its limitations. The sample was com- posed exclusively of active police working dogs. These animals have musculoskeletal structures that endure sig- nificantly more stress and physical demands than compan- ion dogs. They also exhibit greater muscle masses, joint strength, and overall physical conditioning [27]. Although PBMT parameters were determined based on the patients individual characteristics (as it should always be), future studies should include a more diverse sample of dogs, accounting for variations in size, breed, and physical activ- ity levels. Additionally, future studies should include a lon- ger post-PBMT follow-up to evaluate how long this increase in joint ROM is present.

Conclusions

Our results show that PBMT can increase joint range of motion in healthy joints. Including PBMT in treatment protocols, especially before joint mobilization exercises, can improve therapeutic outcomes by reducing stiffness and increasing joint flexibility and comfort. No differences were found between goniometric measurements taken by experienced and novice evaluators.

Table 4 Digital thermography values (mean, standard deviation, and variation - ΔT) of elbows, stifles, and Tarsus in the control (CG) and treatment (PBMTG) groups before and after photobiomodulation therapy and after 5 min. * indicates significance

Group	Elbow												
	Before PBMT			After PBMT					After 5-minutes				
	Mean	SD	p	Mean	SD	ΔT	p	ES	Mean	SD	ΔT	p	ES
CG	32.9	1.3	0.11	33.1	1.6	0.2	< 0.01*	0.61	32.6	1.5	-0.3	0.45	0.16
PBMTG	33.1	1.8		38.1	3.4	5.0			32.2	4.1	-0.9		
Group	**Stifle**												
Before PBMT				**After PBMT**					**After 5-minutes**				
	Mean	**SD**	**p**	**Mean**	**SD**	**ΔT**	**p**	**ES**	**Mean**	**SD**	**ΔT**	**p**	**ES**
CG	32.4	1.7	0.26	32.8	2.3	0.4	< 0.01*	0.55	32.1	1.3	-0.3	< 0.01*	0.31
PBMTG	32.6	1.5		36.6	2.9	4.0			34.2	2.1	1.6		
Group	**Tarsus**												
Before PBMT				**After PBMT**					**After 5-minutes**				
	Mean	**SD**	**p**	**Mean**	**SD**	**ΔT**	**p**	**ES**	**Mean**	**SD**	**ΔT**	**p**	**ES**
CG	33.0	2.3	0.25	32.7	2.1	-0.3	< 0.01*	0.53	32.7	2.3	-0.3	< 0.01*	0.12
PBMTG	32.8	2.6		38.1	3.0	5.3			33.6	1.8	0.8		

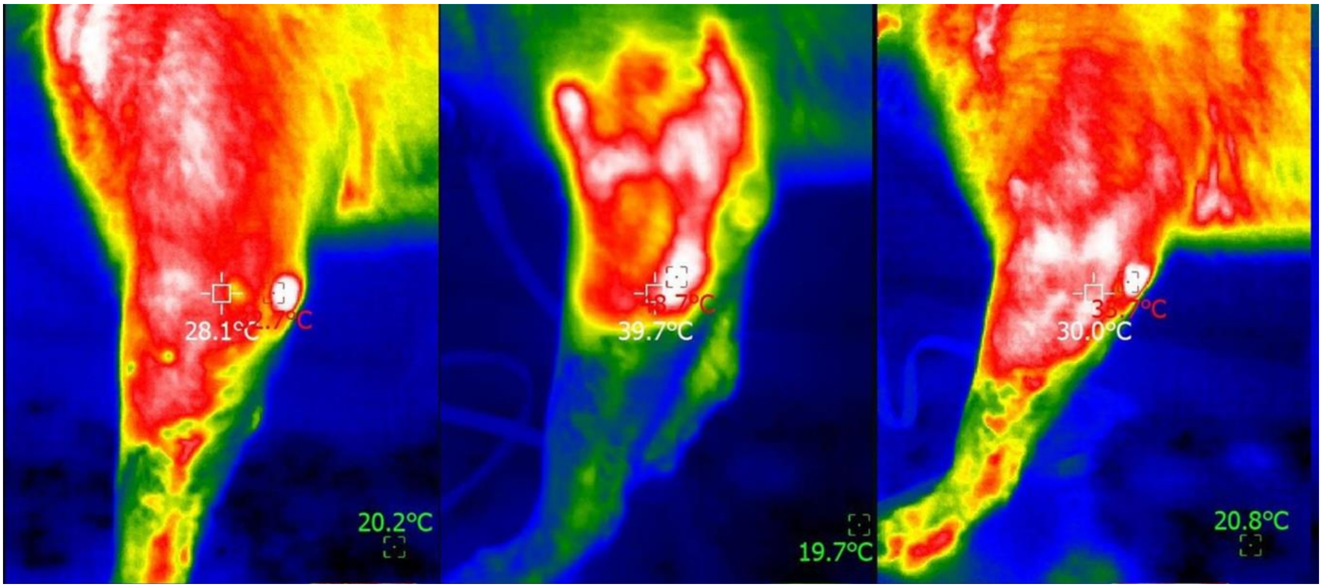

Fig. 1 Lateral thermogram of an elbow before (left), immediately after photobiomodulation therapy (center), and after 5 min (right). The head of the animal is to the left of the image

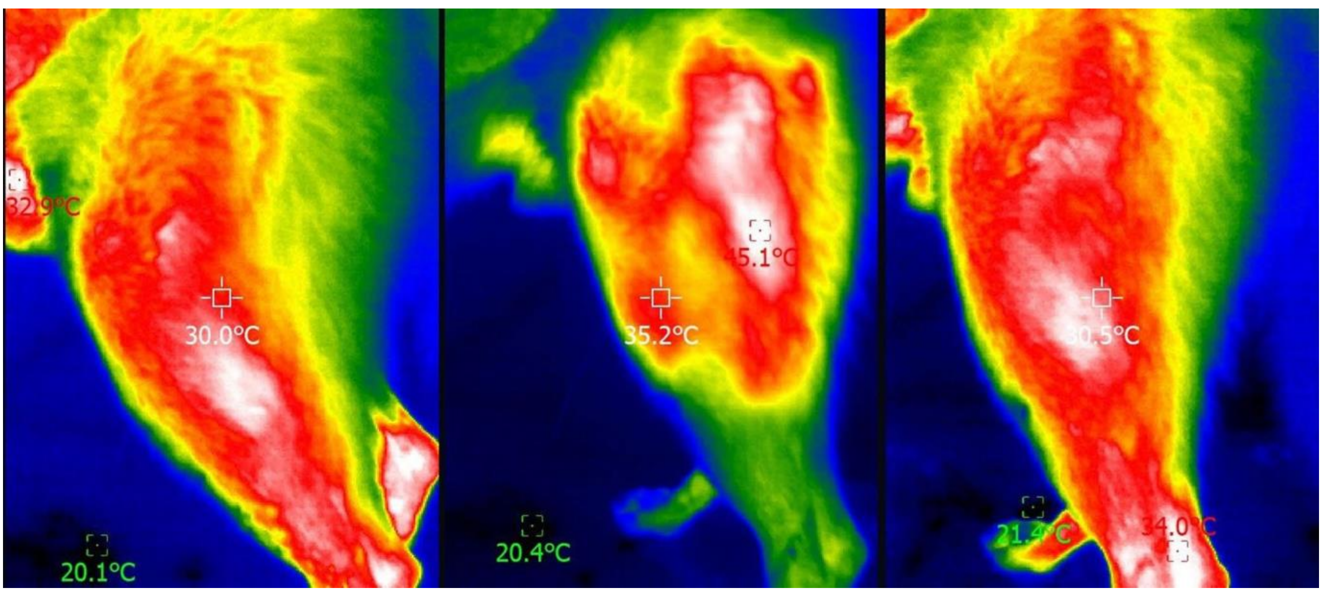

Fig. 2 Lateral thermogram of a stifle before (left), immediately after photobiomodulation therapy (center), and after 5 min (right). The head of the animal is to the left of the image

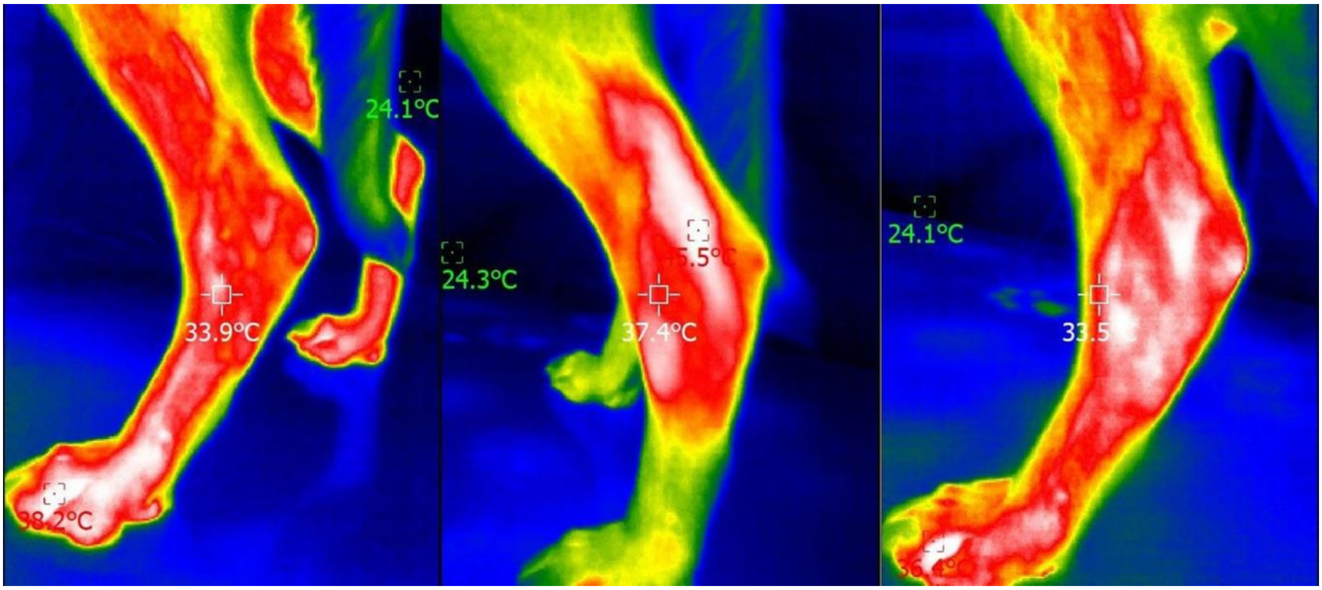

Fig. 3 Lateral thermogram of a tarsus before (left), immediately after photobiomodulation therapy (center), and after 5 min (right). The head of the animal is to the left of the image

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Data availability No datasets were generated or analysed during the current study.

Declarations

Consent to participate Not applicable.

Competing interests The authors declare no competing interests.

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