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REVIEW

Clinical usefulness of infrared thermography to detect sick animals: frequent and current cases

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Abstract

Infrared thermography (IRT) is a tool that has been studied extensively in the experimental medical field as a method for assessing surface thermal responses under various conditions. These may involve local inflammatory processes resulting from surgical procedures, wounds, neoplasms, pathologies, painful events, or stressful states in animals. IRT measures changes in blood flow in surface blood capillaries and the resulting heat radiation. In the clinical field, thermography has been used as a support method for detecting painful conditions. However, some guidelines indicate that it could be applied for assessing and monitoring animals in rehabilitation to quantify objectively possible improvements in their quality of life. Similarly, IRT makes it possible to assess the degree of circulation in dermal tissue, suggesting that it could be used to determine the degree of damage in traumatized tissue in cases of thromboembolic diseases and burns. This would be useful to distinguish between damaged and healthy tissue and thus determine the optimal therapy for burn patients. This review aims to analyze scientific evidence on the clinical applications of IRT for detecting diseases and assessing painful conditions. A literature search on different databases was performed to recover articles related to the application of IRT as a complementary diagnostic tool, and its potential for assisting in rehabilitation, monitoring wounds, and evaluating body temperature in domestic animals.

Keywords: domestic animals, pain, pathology, infrared thermography

Introduction

Infrared thermography (IRT) is a widely used tool in numerous fields, including architecture and mechanics, to assess the overheating of structures [1, 2]. Its medical applications are focused on detecting the energy radiated through the surface tissues that respond to changes in blood flow in the capillaries closest to the dermal tissue [3, 4], and those measures emit infrared radiation and display the information as a pictorial representation, called a thermogram, of the surface temperature of an object [5–7].

Applications in both human and veterinary medicine have focused on detecting and recognizing painful lesions associated with the presence of inflamed tissue that results in an increase in surface temperatures, as occurs, for example, in laminitis [8], mastitis, and pododermatitis [9, 10]. However, some authors have suggested broadening these applications by observing that changes in microcirculatory flows results from the autonomic nervous system (ANS) activity since an increase in sympathetic activity affects the activity of blood capillaries located in anatomical regions that present a high density of them. IRT could help to recognize pain

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and objectively quantify it in animals [10–12]. This kind of detection could ensure that animals in pain receive timely care and it could also expand and improve the care of patients in rehabilitation by continuously assessing joint pain post-therapy [13, 14]. Our literature search found no reports indicating whether this approach could be associated with improving quality of life and decreasing pain levels.

Another area of medical research is to determine whether the drop in temperature of surgical wounds can indicate the viability and potential success of skin grafts, a measure that has been verified experimentally [3, 15]. In this regard, reports in human medicine indicate that there are significant differences in temperature concerning the depth of these wounds, as the deepest lesions present a temperature of 2.3°C lower than surface wounds, which presented a decrease of only 0.1°C ($P < 0.001$) [16]. This concept could be transposed to the primary assessment of burns to indicate their depth and the possibility of differentiating healthy tissue from tissues that are no longer viable due to the loss of circulation. This issue has been proposed in various experimental studies [17, 18].

IRT could also help to determine if an animal is febrile during infectious processes by measuring the surface temperature at the level of the eye or ear [19, 20]. However, there are reports that environmental factors like wind and humidity can affect temperature readings in images taken to assess body temperature [21, 22]. Therefore, the question arises as to whether IRT can be useful for the timely detection and treatment of various pathologies in animals. For this reason, this article aims to analyze scientific evidence of the clinical applications of infrared thermography to detect diseases and assess painful conditions as a complementary tool for diagnosing various pathologies in domestic animals.

Review methodology

For this article, we searched such databases as CAB Abstracts, Scopus, Web of Sciences, and PubMed, for publications

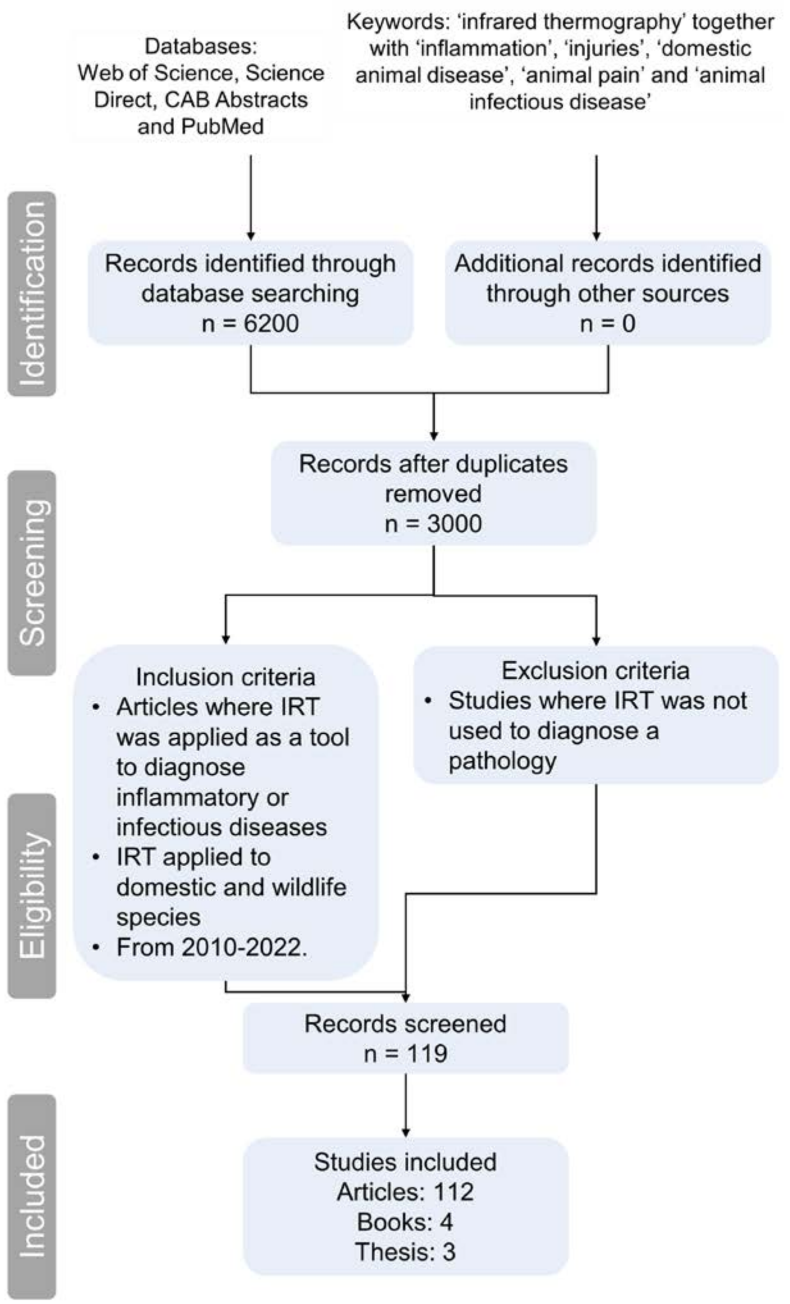

Fig. 1 Search methodology.

between 2010 and 2022, using the following keywords: "infrared thermography", "inflammation", "injuries", "animals", "pain", and "infection". The literature selection criteria are described in Fig. 1.

Assessment of painful conditions

IRT is used to assess body temperature in numerous species. One key advantage of this technique is that it is non-invasive [23–25]. It is used to assess the surface temperature at specific anatomical sites, a physiological characteristic dependent on changes in surface microcirculation that is, when the caliber of the surface blood capillaries decreases, the radiated heat also decreases, and vice versa [11]. The physiological bases that determine the operation of IRT permit its use in numerous conditions, such as recognizing inflammatory lesions and focused infectious diseases that cause local inflammation (Fig. 2) [7]. An observational study by Avni-Magen *et al.* [26], using the IRT technique to identify inflammatory lesions in 4 Asian elephants, three domestic cattle, and one buffalo, reported that IRT could identify changes of ±2°C associated with inflammatory lesions such as pododermatitis in limbs. Their work demonstrated IRT's usefulness for detecting these processes. Their findings were later reaffirmed in a review by Hilsber-Merz [27], who found that IRT effectively detects inflammatory lesions in limbs. This is critical in evaluating the disease status of wildlife species under human care since injuries in these body regions are common but recognizing them is challenging for veterinarians.

Results for domestic cattle are similar, as reported by Alsaaod and Büscher [28], who used IRT to evaluate the temperature of the coronary hoof band in 24 cows. They found that temperatures were significantly higher (31.8 ± 2.7°C) in sick compared to clinically healthy animals (29.8 ± 3.6°C, $P < 0.05$) and established a threshold value within 0.64°C and 1.09°C between injured and healthy hooves with a sensitivity of 85.7% and a specificity of 55.9%, where the temperature increase in the interdigital region was appreciable in cattle with a report of lameness for 2 months. These findings have been confirmed by dos Santos Sousa *et al.* [29], who examined 26 heifers using four diagnostic methods, including IRT, to detect hoof lesions induced by oligofructose overload. They observed that the temperature increased significantly by 5.7 ± 2.9°C in the left medial digit and 5.3 ± 1.4°C in the right medial digit ($P = 0.0001$). The IRT technique had a sensitivity of 96.2% and a specificity of 60.17%. According to Alsaaod *et al.* [30], IRT has provided similar results in giraffes, elephants, and horses to detect hoof lesions. These findings confirm that IRT can aid in veterinary diagnostic processes. This corpus of evidence indicates that vasodilation occurs locally during inflammatory processes and that an increase in radiation in the affected regions is observable, as Fig. 3 shows, in a study conducted by the authors where the thermal windows of a febrile domestic feline patient had a temperature increase between 0.7°C and 10.3°C, in comparison to a healthy patient.

At the physiological level, the changes observed when the tissular injury occurs include the release of pro-inflammatory substances such as interleukin 1 (IL-1), IL-6, prostaglandin F2α (PGF2α) [31], histamine, and serotonin, which cause dilation of the blood vessels closest to the dermal tissue [9, 10, 32, 33]. This fact suggests that IRT could be used to recognize inflammatory lesions in hard tissues like hooves and soft tissues such as muscle, as proposed by Cetínkaya and Demírutku [34]. Those authors conducted a

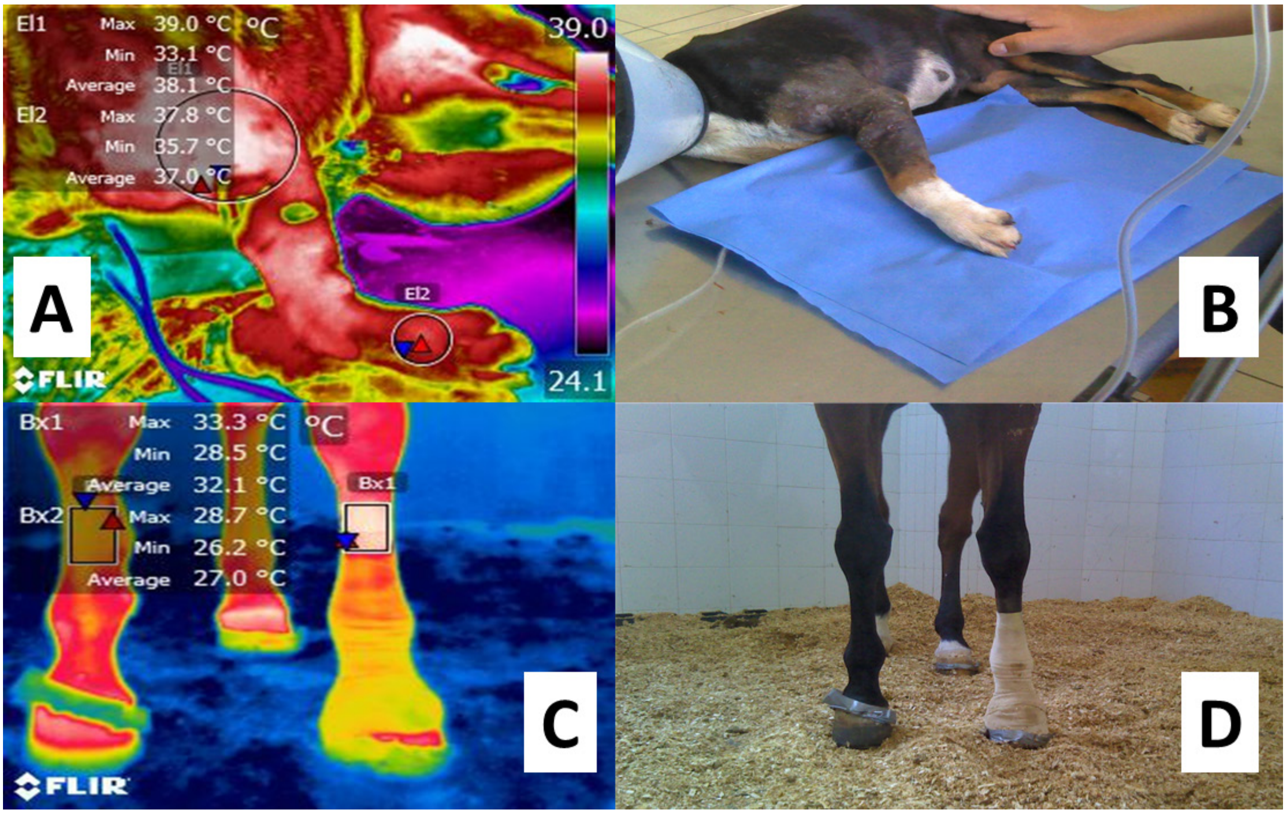

Fig. 2 Locations of joint inflammation in a dog (*Canis lupus familiaris*) and horse (*Equus caballus*). A. Elbow fracture in a dog. An intercondylar fracture of the left humeral-radio-ulnar joint (El1) of a 3-year-old Doberman Pinscher. A maximum temperature of 39°C (red triangle) with a minimum of 33.1°C were recorded (blue triangle) and compared to the temperature of the metacarpophalangeal joint (El2) (maximum temperature of 37.8°C (red triangle), with a minimum temperature of 35.7°C (blue triangle)). The former presented a significant increase in local temperature at the site of the inflammation that promoted the vasodilation of the blood capillaries that come from the radial artery. C. A horse with carpal injury after a race. This male quarter-miler presented second-degree claudication in the left thoracic member. IRT revealed that the facies dorsalis region of the carpus (Bx1) presented a maximum temperature of 33.3°C (red triangle) with a minimum of 28.5°C (blue triangle), 2.3°C higher than its healthy counterpart (Bx2). This phenomenon could be due to inflammation of the dorsal intercarpal ligaments. In both cases, local inflammatory processes caused the release of pro-inflammatory substances such as histamine, serotonin, and prostaglandins, that promote vasodilation, leading to greater heat radiation in the evaluated areas that was detected by IRT. B and D. Digital anatomical images.

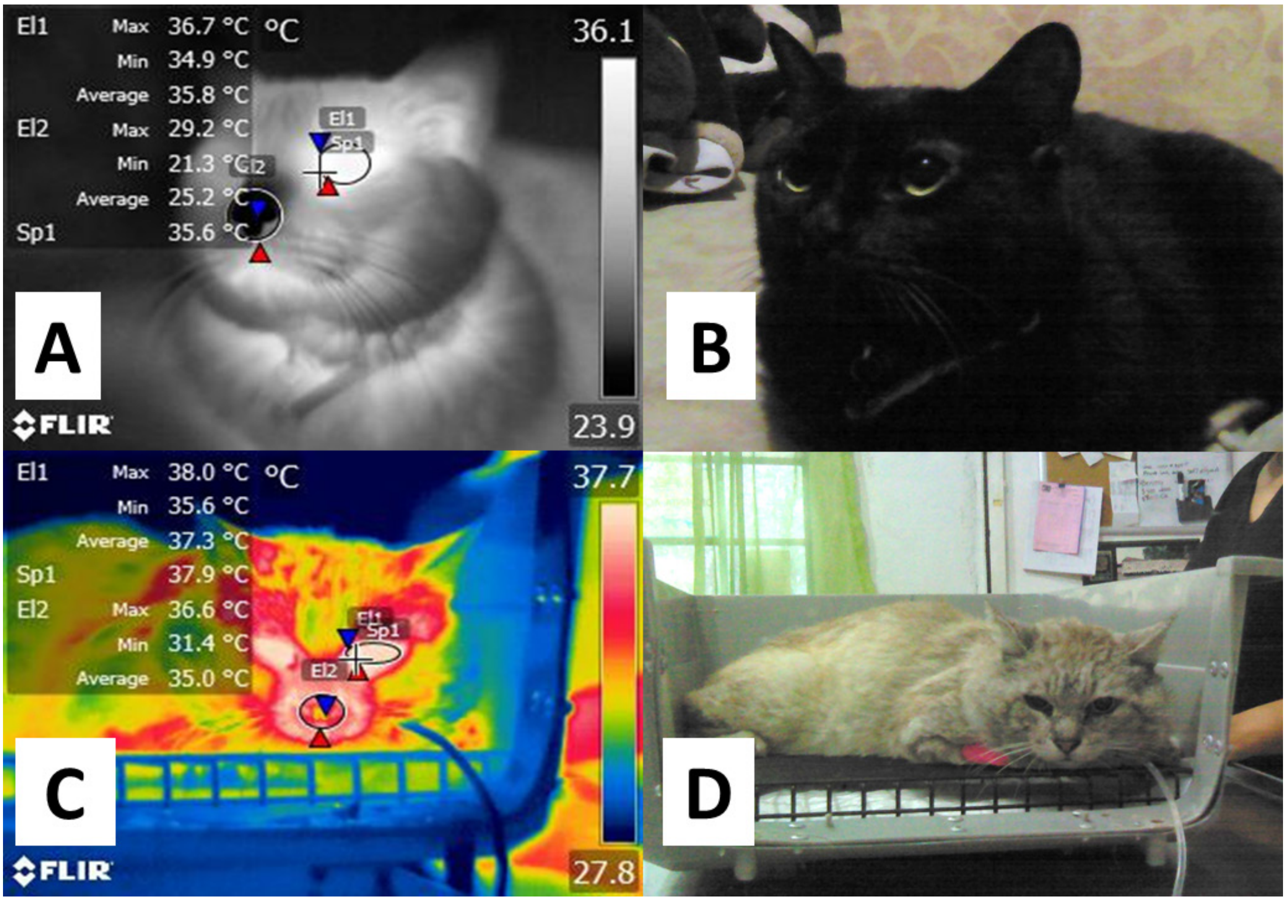

Fig. 3 Facial thermal pattern of healthy and sick feline (*Felis catus*) patients. A. Healthy cat. The ocular temperature (El1) of a 4-year-old male feline has a maximum temperature of 36.7°C (red triangle) and a minimum of 34.9°C (blue triangle). In the case of the lacrimal gland (Sp1), an average temperature of 35.6°C is observed, while the nostril (El2) presented a maximum temperature of 29.2°C (red triangle) and a minimum temperature of 21.3°C (blue triangle). B. Digital image of the healthy feline patient. C. Cat with acute diarrhea. 5-year-old cat with acute diarrhea, the ocular temperature (El1) increased by 1.3°C at its maximum (red triangle) and a minimum of 0.7°C (blue triangle), when compared to the healthy patient. In the case of the lacrimal gland (Sp1), the average temperature increased by 2.3°C, while the nostril's maximum temperature increased by 7.4°C (red triangle), and the minimum values differed by 10.1°C (blue triangle). D. Digital image of the sick feline patient. The temperature increase in the windows of the sick cat may be due to an acute response that causes the release of pro-inflammatory substances such as prostaglandins, causing vasodilation and increasing the radiation emitted into the environment.

study to evaluate the performance of IRT in detecting lameness by comparing it to diagnostic imaging by radiography and ultrasound. They evaluated 47 horses with clinical signs of some level of lameness after a previous physical examination. In the suspected painful areas (assessed by palpation), analysis with IRT showed increases of 0.5°C to 1.5°C between the affected and normal regions. This increase was observed only in horses with acute processes such as tendinitis, while IRT did not show significant differences in local temperature in chronic cases. Afterward, the problem in the same anatomical regions was evaluated and confirmed with radiography and ultrasound. Radiographic changes were observed in animals with lameness but no lumbago issues, while ultrasonographic imaging diagnosed joint effusion and tendonitis but no lumbago, tissue infection, or osteoarthritis cases. These findings show that IRT is a valuable complementary tool to routinely diagnosing methods and that the chronicity of the process must be considered when using IRT.

In the case of poultry, health problems affecting the leg include several pathologies that impact broiler chickens and laying hens. One of the main problems is bumblefoot, a pathology marked by chronic inflammation of the foot's plantar metatarsal or digital pads or both anatomical structures. This condition causes pain that discourages birds from perching or walking, reducing their ingestion of food and water. In addition to affecting the birds' health, bumblefoot also causes significant economic losses in the poultry industry due to the rejection of carcasses and stunted growth due to lameness [35]. In caged laying hens, the incidence of bumblefoot is associated with the perch's design when provided (e.g., plastic material does not improve foot condition) or the conditions of the cage [36]. Wilcox *et al.* [37] evaluated the efficacy of IRT for detecting subclinical bumblefoot in hens by taking thermal images of the dorsal side of the feet of 150 White Leghorn hens aged 60 weeks. Cases were classified as healthy, suspicious, or positive for bumblefoot according to whether they presented unusual thermal patterns (healthy if the difference between the maximum and minimum temperatures was ≤7.7°C; suspicious if the difference was 7.7°C–9.2°C; positive >9.2°C). Simultaneously, the presence or absence of abnormalities in the feet was evaluated using a visual scale to determine if there were signs of clinical or mildly-clinical bumblefoot or if they were healthy. It is important to mention that a percentage of the birds classified as lesion-free were inoculated subcutaneously with *Staphylococcus aureus* in each metatarsal footpad. Visual evaluations were made, and thermographic images were taken before and after inoculation. The first part of the study identified 43 hens with suspected bumblefoot, 36 of which received a "bumblefoot positive" visual score 14 days later. This demonstrated that the effectiveness of the IRT and the visual scale was 83%. Regarding the hens inoculated with *S. aureus*, a significantly higher average temperature difference was found compared to a control group (8.8 ± 2.1°C *vs*. 5.8 ± 1.9°C). The correlation between the thermographic images and the visual scale after 7 days post-inoculation in the hens previously classified as positive was 86.7%, while in the hens classified as suspicious, it was only 26.7%. This finding suggests that visual inspection is not sufficiently sensitive to detect subclinical stages of infection, unlike IRT which can also help monitor disease progress. The above findings confirm that IRT aid in detecting local inflammatory problems in animals, which could be early indicators of local conditions that would help clinicians provide better care. However, according to the findings by Oppermann *et al.* [38], it is important to consider that, at least in broiler chickens, footpad temperature can be altered by the effect of manual restraint, so it is necessary to include the duration of handling and immobilization of the birds in assessments, as well as the sampling order when using IRT to predict or detect subclinical footpad pathologies. Those authors encourage developing studies to explore such issues as to what extent the cooling of the foot produced by a stressful situation could mask an inflammatory process.

Similar results to those reported in horses have been observed in domestic cattle, but with a different pathology; mastitis, a disease that involves infections of the mammary tissue due to the proliferation of microorganisms or physical injuries that foster the development of a local inflammatory process of the udder parenchyma. Mastitis can cause structural changes in the mammary tissue and recruitment of neutrophils in the affected area, which subsequently increase the heat that radiates from the region. Clinicians must recognize mastitis, as it has been suggested that this anatomical region could be an effective thermal window in ruminants [39–41], as Fig. 4 illustrates. In bovines, an average temperature increase of 2°C in the mammary gland can indicate mastitis. In this regard, Hovinen *et al.* [42] used an experimental model of induced mastitis with six bovines. They determined that the mammary tissue increased heat radiation by 1.5°C, associated linearly with the increase in the number of somatic cells and rectal temperatures. This finding indicates that IRT could be a test with similar sensitivity to that of the California or cell count tests. This theory was posited by Polat *et al.* [43], who evaluated 62 Brown Swiss cows diagnosed with clinical mastitis, observing that IRT showed a positive correlation with California test scores (r2 = 0.86) and somatic cell counts (r2 = 0.73). That study found a sensitivity of 88.9% and a specificity of 98.9%.

In a study by Colak *et al.* [44] that compared the IRT technique to the California test for diagnoses of mastitis in dairy cows (Brown Swiss and Holstein), a correlation of r = 0.92 was found in the results related to the state of udder health. Zaninelli *et al.* [45] evaluated the health status of the udders of 155 Holstein Friesian cows. They found a significant relationship ($P < 0.05$) between changes in udder temperature and the total somatic cell count in the udder milk, with a sensitivity of 78.6% and a specificity of 77.9% in the characteristics observed according to the health status of the udder.

These results establish that IRT clinical application is valuable in dairy cattle and suggest its use for the continuous monitoring of temperatures in milking areas since data of this kind could be of great value. Likewise, its efficacy in propmtly detecting inflammatory and infectious diseases through changes in superficial temperature could make IRT a complementary diagnostic tool, as has been studied in dogs. The inflammatory response is characterized by increases in the permeability of the blood vessels, which results in increased blood flow that alters the heat pattern, and the measurement of these changes could help notice inflammatory processes [46].

For example, Infernuso *et al.* [47] evaluated 16 dogs with cruciate ligament ruptures *versus* healthy controls. IRT indicated that the joints with cranial cruciate ligament rupture were 1°C warmer than

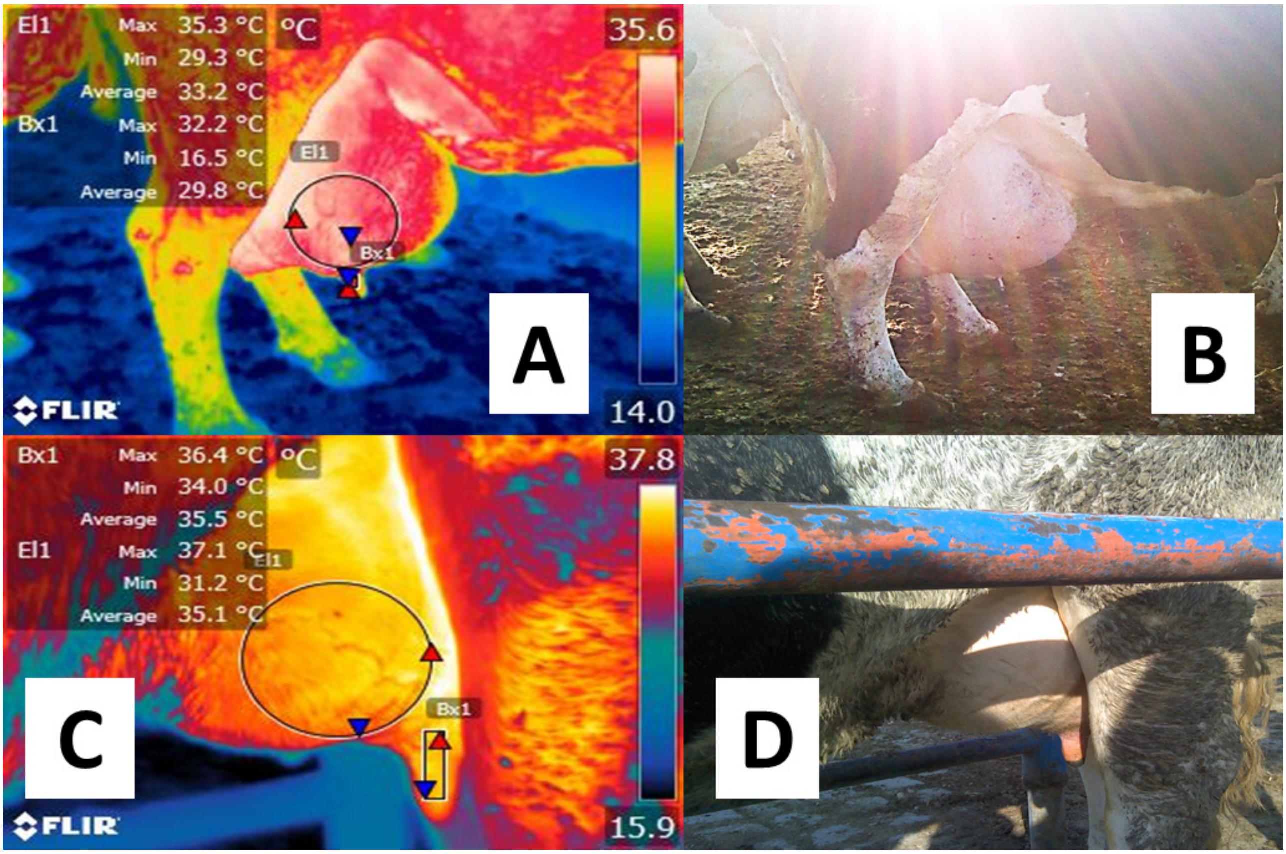

Fig. 4 Thermal pattern in the mammary gland of domestic cattle (*Bos taurus*) diagnosed with mastitis. A. Bovine with a healthy, productive mammary gland. This cow had an average temperature of 33.2°C with a maximum of 35.3°C (red triangle) and a minimum of 29.3°C (blue triangle) at the base of the breast (El1). The nipple (Bx1) presented an average temperature of 29.8 C, indicative of a healthy gland. B. Digital image of the healthy bovine. C. Bovine with mammary gland affected by mastitis. Compared to the previous specimen, the average temperature of the base of the gland (El1) presented an increase of 1.9°C, while the nipple (Bx1) presented an increase of 5.7°C above the average temperature. D. Digital image of the patient with mastitis. The results of this comparison may indicate clinical signs of an active inflammatory process in a bovine affected by subclinical mastitis.

the healthy joints (P < 0.05). The success rate for identifying cranial cruciate ligament rupture by IRT was 75%–85%. This sensitivity could be considered acceptable if it were not compared to more sophisticated diagnostic tools, such as radiography or magnetic resonance imaging (MRI). On this issue, Grossbard *et al.* [48] compared the effectiveness of IRT *versus* MRI in differentiating between healthy animals and those with Type I thoracolumbar disk disease (TLIVDD). When using IRT in 58 chondrodystrophic dogs with neurological conditions, the authors found a significant difference in the temperature of the affected region of TLIVDD dogs compared to control animals (24.95°C *vs.* 23.04°C, P = 0.022). IRT identified the healthy animals from the sick ones with an effectiveness of 88.5% and isolated the affected area at a rate of 89.7% compared to 90% and 97%, respectively, for MRI. Results suggest that IRT can only indicate inflammatory lesions so it cannot determine the precise lesion type, or which exact tissue was reacting. As long as these conditions persist, it will not be possible to cease using advanced diagnostic tools.

Another example of the clinical application of IRT was shown by Vainionpää *et al.* [49], who evaluated 103 cats at veterinary consultations for various motives by performing a general clinical review. They found that IRT assessment revealed painful limb or flank conditions that correlated moderately with clinical findings but poorly with the results of an owner-administered questionnaire on behavioral estimation. This is similar to the observations by Fukahori *et al.* [50], who evaluated the application of IRT to detect inflammation in the coxofemoral joint in 31 dogs. They found a significant difference in temperature between the healthy and swollen joints (P = 0.040) and observed that, in general, joint disease presented a temperature increase of 0.5°C compared to the healthy joints. Their work's sensitivity and specificity were 80% and 87.5%, respectively. This evidence is convincing regarding the increase in local temperature and its association with inflammatory-type lesions that IRT can reveal (Fig. 5). However, due to the limitations of IRT, it should be clear that it is still a complementary tool for clinical medicine that cannot replace specialized tools such as advanced imaging techniques.

Concerning IRT limitations, some studies have found that breed is a factor that can cause variations in readings of the radiation emitted from an animal's body. In this regard, one study of dogs evaluated the temperature of the coxofemoral joint, concluding that it was significantly lower in German Shepherds than in other large dogs, where higher temperatures were recorded. Also, that the temperature varied depending on the angle at which images were taken; that is, the lateral projection *versus* a dorsal view (28.4 ± 2.8°C *vs.* 25.3 ± 9.1°C) [51]. The explanation for this variation may involve the presence of hair or its thickness since this feature can cause a decrease in the amount of heat radiated [52]. A separate study of dogs explained that factors like hair and the type of coat could affect the amount of infrared radiation emitted into the environment such that negative correlations may be found ($r2 = -0.24$, P = 0.07) with body temperature assessed by IRT [53]. There are similar reports on equines where both the presence of hair and its length affect surface-level temperatures, which were

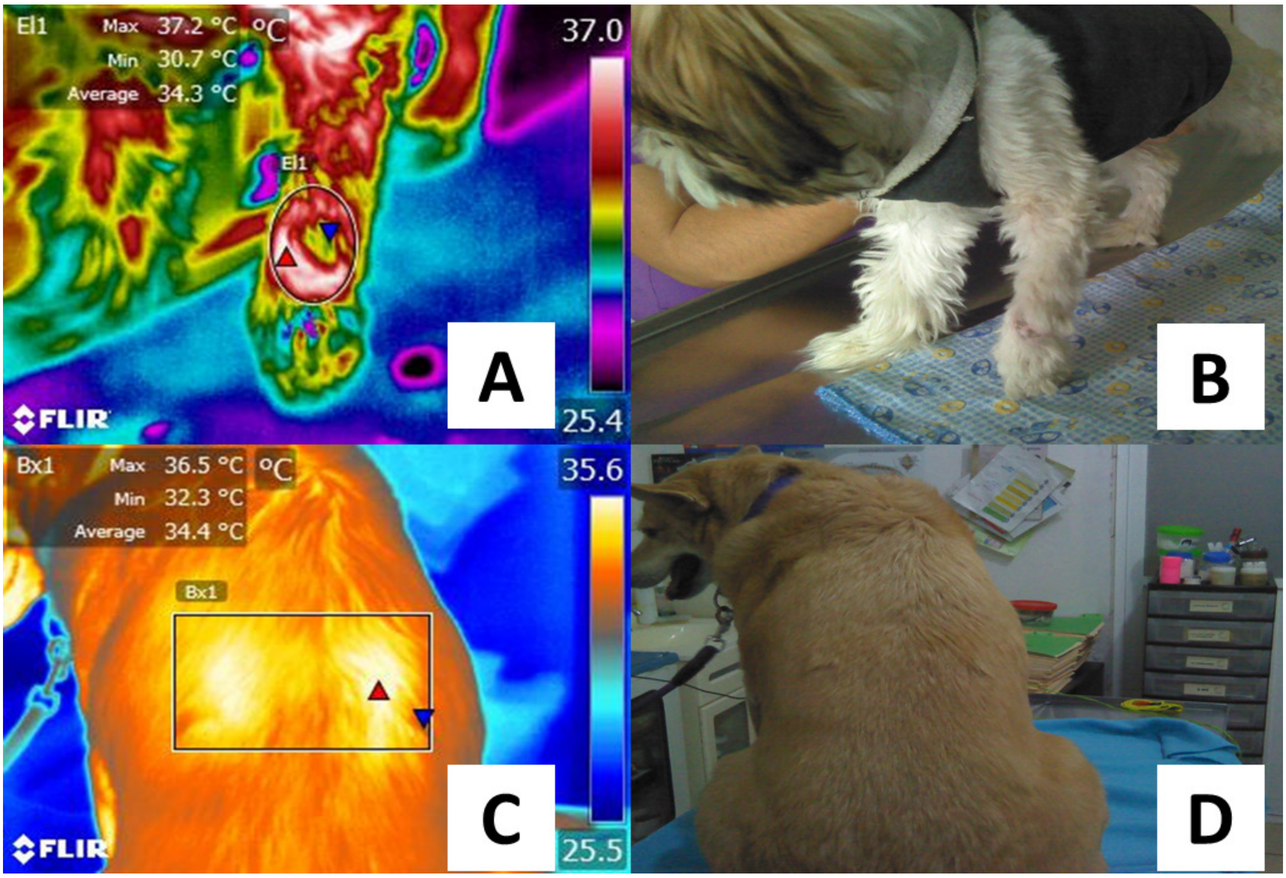

Fig. 5 Localization of lesions that cause pain in dogs (*Canis lupus familiaris*). A. Metacarpophalangeal joint injury. A 3-year-old male Lasha Apso with fourth-degree claudication in the left thoracic limb. IRT located a metacarpophalangeal area (El1) with a maximum temperature of 37.2°C (red triangle) and a minimum of 30.7°C (blue triangle), that reflects the increase in radiation emitted by inflammation of the *carpi radiatum* ligaments due to trauma. C. Thoraco-lumbar joint injury. A 12-year-old German shepherd with difficulty walking and acute pain sensitive to touch in the thoraco-lumbar region is shown. IRT was applied to the lumbar region (Bx1) which presented a maximum temperature of 36.5°C (red triangle) and a minimum of 32.3°C (blue triangle). These readings confirmed a reduction of the intervertebral space between thoracic vertebra 12 and lumbar vertebra 1 that produced a local inflammatory process. In both cases, the presence of an inflammatory process that triggered the release of substances such as histamine, serotonin, and prostaglandins which caused vasodilation of the blood capillaries. The areas with inflammation were identified despite the presence of hair. B and D. Digital images of the respective patients.

significantly lower (P < 0.001) [54]. Findings of this kind have led some authors to suggest that the IRT technique must be used with caution due to the possibility that a series of other factors could affect the heat emitted by tissues. It is important to note that some studies claim that environmental solar radiation and humidity also influence and alter IRT readings [55–57].

A series of studies have evaluated pain in regions with a large number of blood capillaries, and arteriovenous anastomoses called thermal windows [10, 12]. According to results demonstrated in farm animals during the perception of pain in such practices as castration or dehorning, the body responds to pain by activating the autonomic nervous system, triggering the neurosecretion of adrenaline and noradrenaline that cause vasoconstriction of blood vessels that decreases blood flow and the amount of radiation emitted (Fig. 6) [58–60].

Studies on companion animals, meanwhile, have suggested that the lacrimal caruncle may be a region where the pain response can be evaluated. This notion is supported by the research of Lush and Ijichi [61], who found that the temperature of the lacrimal caruncle decreased by 1.4 ± 0.5°C (P < 0.05) at 30 minutes post-surgery, and this response did not correlate with the Glasgow University Acute Pain Rating Scale (r = 0.12, *P* = 0.70) in dogs undergoing castration. However, in a study of 21 bitches undergoing ovariohysterectomy under three distinct analgesic regimens, the thermal response of the lacrimal gland was attenuated, and there were no significant differences between the use of lidocaine alone or combined with pure opioids, administered epidurally (P > 0.05). Those findings were corroborated by low scores on the Melbourne University pain assessment scale and the Visual Analogue and Interactive Dynamics scale (P > 0.05) [62].

IRT's assistance in recognizing painful conditions is valuable for veterinary clinicians. However, when used, it is essential to assess the potential effects of numerous factors that may alter readings to achieve early recognition of signs of pain that have a direct negative impact on the health of animals. Despite the above, IRT can provide effective pain management [11].

Assistance in rehabilitation

If assessing circulatory changes caused by painful inflammatory events is possible, then it may be feasible to monitor changes in surface temperature parameters over time that indicate whether an injury is in the process of repair or recovery (Fig. 7). This is one of the most widely-accepted theories in the field of veterinary rehabilitation [63]. Since most injuries that occur accompanied by an inflammatory event are chronic degenerative diseases – such as osteoarthritis or spinal diseases– that cause chronic pain, it is necessary to apply treatment to reduce both pain and the physiological effects that lead to its perception [64–66]. One strategy to counteract pain is rehabilitation, which provides effective pain treatment and improves the quality of life in animals suffering from chronic pain. It is even argued that IRT can help recognize joint stress and its dynamics during extreme exercise that could cause limb injuries in animals used in sports, such as horses [67].

The application of this tool was evaluated in a study carried out with 7 horses using a treadmill with three levels of water. The surface temperature of the animals' muscle masses was assessed as a direct measure of their activity. The study found that the semitendinosus muscle presented the most significant temperature increase and that when the water level was raised, the temperature of the pelvic limbs generally increased as well, compared to when the exercise was performed without water (P < 0.0001) [68]. These findings illustrate that IRT can provide information on circulatory and muscle dynamics and indicate the presence of deficiencies in muscle mass that require an ample blood supply during exercise. The assistance that IRT provides is extremely valuable since it could determine the effectiveness

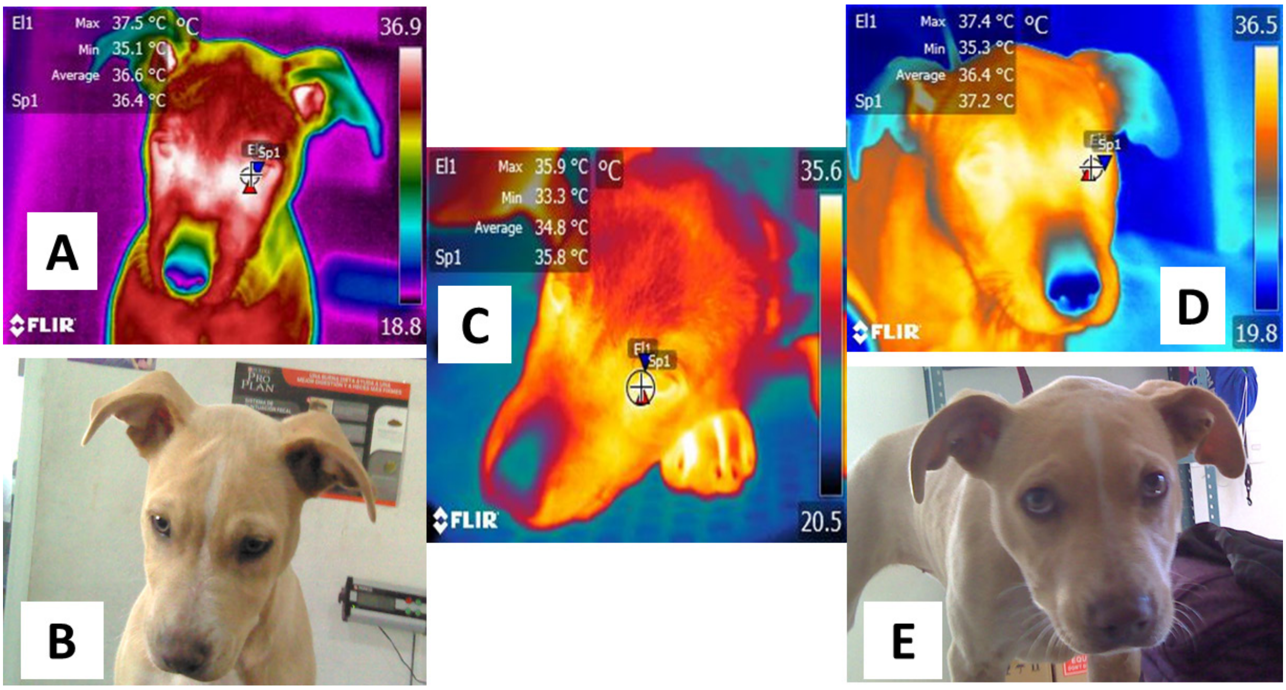

Fig. 6 Thermal response associated with acute pain in dogs (*Canis lupus familiaris*) undergoing surgery. A and B. Pre-surgery thermogram and digital image, respectively. A 1-year-old bitch is shown undergoing ovariohysterectomy surgery with intravenous application of meloxicam at 0.1 mg kg^{-1}. The response of the lacrimal caruncle presented a maximum temperature of 37.5°C (red triangle) with a minimum of 34.8°C (blue triangle). C. 1-hour post-surgery. There was a decrease in the temperature of the lacrimal caruncle to a maximum of 35.9°C (red triangle) and a minimum of 33.3°C (blue triangle) despite the use of analgesics prior to surgery. This change can be explained by the fact that during the perception of pain the sympathetic nervous system is activated through the neurosecretion of catecholamines that cause peripheral vasoconstriction, which decreases heat radiation. D and E. 2-hour post-surgery thermogram and digital image, respectively. The temperature of the lacrimal caruncle had a maximum of 37.4°C (red triangle) and a minimum of 35.3°C (blue triangle). These readings were equal to the temperature observed at baseline, possibly due to the effect of the rescue analgesic therapy applied with tramadol at a dose of 2 mg kg^{-1}. Applying analgesics reduces sympathetic nervous system activity as can be seen in the recovery of the temperature of the lacrimal caruncle.

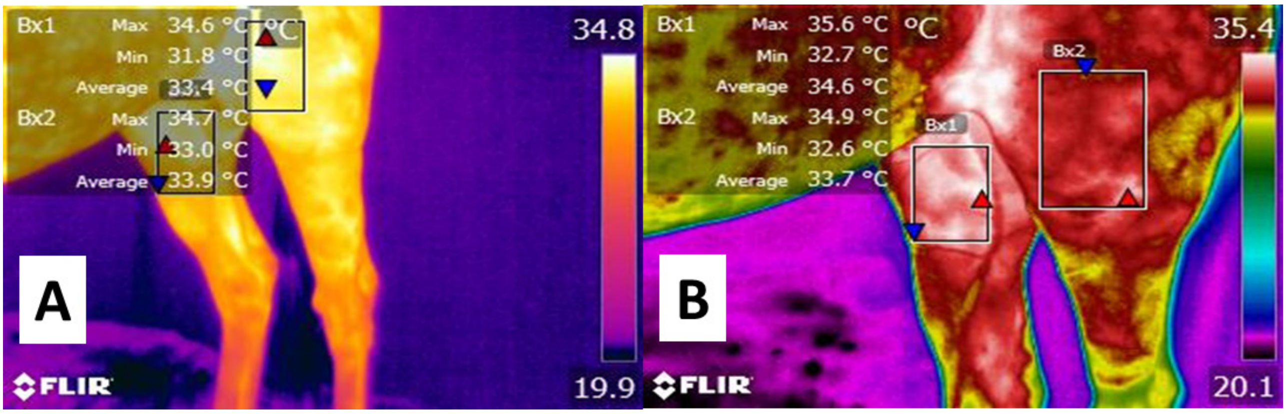

Fig. 7 Thermal response in horses (*Equus caballus*) under cold rehabilitation treatment due to muscle injury in the pelvic limb. A. Healthy equine. The thermal response in a female quarter horse where the temperatures in the region of the right (Bx1) and left (Bx2) femoral muscles averaged 33.4°C and 33.9°C, respectively, with no reports of signs of pain or claudication. B. Equine with claudication after a race. The average temperature in the medial femoral region of the right pelvic limb (Bx1) is 1.2°C higher than in a healthy animal, and 0.2°C higher in the left limb compared to its counterpart (Bx2) in a female quarter horse that reported signs of claudication and severe pain in the femoral region with a possible diagnosis of tearing. After three days of analgesic therapy with flunixin meglumine, and rehabilitation with cold water compresses, no improvement in the thermal pattern was seen. Together with the clinical signs, this demonstrates that IRT could aid in evaluating the course of recovery from muscle injury.

of rehabilitation therapy as a continuous, objective assessment tool. In a study by Rodrigues *et al.* [69], IRT was used to assess the temperature of the cervical, thoracic, dorsal, abdominal, and pelvic regions in 12 mixed-breed horses treated with dynamic mobilization exercise (longitudinal cervical flexion of the head between the hooves, between the carpus and to the chest) with or without acupuncture. They found that the temperature in the regions evaluated increased during the exercise session by 0.2°C ($P < 0.0001$). There was no temperature change when the animals' received treatment with or without acupuncture ($P = 0.58$).

The possibility of evaluating the effectiveness of rehabilitation therapy has been reported in other species, as indicated in a study of 6 dogs with diagnoses of muscle contractures and 11 dogs with diagnoses of osteoarthritis. IRT was used before, at the end of, and then 60 seconds after therapy to assess the effect induced by diathermic capacitive-resistive therapy. The authors reported significant differences between basal temperature (32.42 ± 1.57°C) at the end of the therapy session (33.36 ± 1.17°C) ($P = 0.04$) and 60 seconds later (32.83 ± 1.31°C) ($P = 0.031$). This shows that the therapy had a positive effect by allowing greater blood circulation due to the transfer of capacitive and resistive energy that speeds up the healing process [14]. However, it does not determine whether this effect can benefit patient's quality of life undergoing rehabilitation.

Freeman *et al.* [13] evaluated thermal responses and degrees of pain in dogs with spinal osteoarthritis or intervertebral disk disease undergoing a series of photo modulation treatments. Those researchers found that the temperature of the thoracolumbar region decreased significantly 7 days after the photo modulation treatment (before treatment, 30.9°C; after treatment, 27°C). Results demonstrated a significant relationship when evaluated with the Colorado State University Canine Chronic Pain Scale (U value = 37.5, $P = 0.03$). The authors claimed that this clearly demonstrated the effectiveness of alternative treatments to pharmacological approaches and improved the quality of life of animals with chronic degenerative diseases.

Veterinary interest in the conventional physiotherapy techniques used in human medicine is focused on reducing pain, and improving mobility but the question is whether they can have similar effects in animals [70, 71]. A study that compared five thermotherapy techniques in healthy dogs (cryotherapy with an ice pack, massage with and without oil, heating with a thermal bag, and therapeutic ultrasound) observed that the hot bag and therapeutic ultrasound treatments generated a significant increase in surface temperatures of 3.76 ± 1.4°C ($P < 0.05$). In contrast, cryotherapy decreased temperatures by 12.4 ± 4°C ($P < 0.05$). The massage therapy, with or without oil, did not affect local temperatures [72]. This suggests that thermographic analysis makes it possible to assess which type of therapy can benefit the rehabilitation of companion animals.

The effectiveness of electroacupuncture therapy has also been evaluated with the help of IRT [73]. One such study found that applying a fine, electrically-charged needle mitigated chronic pain in animals with joint injuries, and may also be associated with a change in local thermal responses, as has been previously observed in human medicine where tactile stimulation alone reduced the KI3 point by up to 1.1°C ($P < 0.0001$), perhaps due to the decrease in local circulation [74]. In this regard, Um *et al*. [75] evaluated the efficacy of acupuncture to control pain by chronic arthritis in 8 dogs with joint pain caused by Freund's complement. One group of dogs subsequently received a regimen of electroacupuncture treatments using BL40, GB33, GB34, and LIV8 points. The authors observed an increase of 1.5°C in the elbow region in both the treatment and control groups, but the electroacupuncture treatment reduced the temperature by 0.5°C four weeks after treatment, compared to the control group ($P < 0.05$) until temperatures returned to basal levels.

The potential benefits of acupuncture were also evaluated by Collins [76] in 24 dogs with clinical signs of back pain. Those study animals were randomly allocated into a control group and a treated group with acupuncture using GV-14, BL-23, Bai-hui, and Shen-shu points for 15 minutes. IRT analysis showed a greater temperature change with a significant difference ($P = 0.000002$) in the acupuncture (2 ± 0.8°C) compared to the control group (0.8 ± 0.4°C). These results confirm that acupuncture modifies local blood flow, reflected in the modification of the surface temperature, which can have an analgesic effect in the region.

Scientific evidence indicates that IRT can help recognize and identify local injuries and monitor and facilitate clinical follow-up to evaluate traditional and alternative rehabilitation treatments applied to control pain in patients. In this way, it can also improve the quality of life of animals.

Evaluation of analgesic treatments

Modifications of local blood flow during active processes are one of the most widely studied areas involving IRT due to the changes that occur in cases of injury when the pathological processes triggered can be accompanied by variations in blood flow. This phenomenon was analyzed in the review by Casas-Alvarado *et al.* [3], who stated that the effects of administering medications like local analgesics could cause vasodilation at the surface level and increase heat radiation. Events of this kind can be helpful for veterinarians by providing information on the quality of the block or helping to determine if the goal of blocking the transduction of pain signals was accomplished [64].

The initial assumption is that this could help clinicians detect whether a regional or local block has been performed successfully. On this topic, a study by Van Hoogmoed and Snyder [77] evaluated surface temperatures in horses of different breeds that received local analgesics (bupivacaine 0.75% or lidocaine 2%) in the lumbar region, suspensory ligaments, and the tibial and palmar digitalis nerves. They observed that local injections decreased the temperature from 0.1°C to 0.01°C in the suspensory ligaments and tibial nerve but from 0.09°C to 0.18°C when administered at the lumbar level. This shows that local analgesics cause changes in thermal patterns at the local level, possibly reflecting the clinical efficacy of their application. Similar results were observed when IRT was used with rats that received local epidural analgesics in a study designed to validate blocks. The authors examined 10 C57BL/6 mice that received 0.25% bupivacaine epidurally and determined that the drug caused a progressive temperature increase in the pelvic limbs compared to the thoracic limbs ($P < 0.001$). Overall, the pelvic limbs presented a temperature of 1.56°C higher than the thoracic limbs ($P = 0.03$) [78]. This confirms that changes in local temperature due to drug administration are useful parameters for detecting correct blocks.

The aforementioned findings can be explained physiologically because local analgesics block the sympathetic postganglionic fibers that maintain vasomotor tone. This causes vasodilation and allows heat release at the local level [79]. Based on this theory, vasomotor changes are consistent and can be used as reliable indicators of local drug administration. Based on the effects of local analgesics, some authors have suggested that it may be possible to prevent intoxication using medications of this kind. For example, Carstens *et al.* [80] evaluated the predictive usefulness of local analgesics in Wistar rats that received an intraperitoneal injection of ropivacaine. The authors observed that before presenting clinical signs of intoxication, areas of hyper-radiation were visible in regions of the rats, such as the head and interscapular area ($P = 0.02$). This suggests that temperature changes due to the administration of local analgesics can modify systemic patterns.

Küls *et al.* [81] examined 29 dogs of different breeds with limb surgery. Some received epidural block bupivacaine, while others received a sciatic-femoral block with the same drug. Contrary to the authors' hypothesis, in only 12 of the dogs that received the sciatic-femoral nerve block and only 1 in the group given the epidural block, a 1°C temperature increases at the level of the plantar pads was observed. This finding shows that the dogs' footpads cannot serve as indicators of the epidural block. In contrast, the use of the coccygeal or anal region is suggested as a possible alternative since there is vascularization in that area from the ventral coccygeal arteries, and administration of local analgesics consisting of pure opioids—fentanyl and morphine—caused a temperature increase of 0.1°C to 0.2°C in this region in bitches that underwent ooforosalpingohysterectomy [62].

These results indicate sufficient evidence to show that IRT is a reliable indicator for the administration of drugs that can cause changes in local, even systemic, vasomotor tone. However, due to the discrepancies described, giving greater weight to these results will require accumulating data that validate the clinical usefulness of this tool during controlled surgical procedures and that provide information on the temperature range that can indicate the success of a regional block [82].

Monitoring of non-visible injuries

In general, the occurrence of an injury in any anatomical region produces a local inflammatory response that causes vasodilation and increases local temperature and, as a result, heat radiation [4, 10]. However, blood flow is altered to initiate healing phases when a wound destroys cells and capillaries [3]. In intensive care units, the continuous assessment of such wounds and this process is an essential step in preventive medicine.

A review by John *et al.* [83] reported that IRT can identify hyperthermic events and indicate the loss of local circulation (ischemia), so it can serve as an indicator in the field of reconstructive plastic surgery by distinguishing viable from non-viable tissues. For example, Czapla *et al*. [84], used 31 rats as models for skin tissue flaps. IRT analysis showed that the flaps' frequency of ischemia and partial necrosis showed significant differences ($P = 0.024$) that were attributed to changes in dermal circulatory patterns. Therefore, IRT allows the early detection of decreased tissue viability or tissue damage, reported as lower surface temperatures compared to surrounding tissue [15].

Another application related to injury repair involves monitoring wound healing in dogs and cats. In 41 animals, Gumpert Herlofson [85] used IRT to evaluate the inflammation and healing process of surgical wounds by comparing the skin temperature of the wound and control areas. At 14 days post-surgery, the injured zone's superficial temperature was significantly lower**.** This reaffirms the clinical usefulness of IRT for evaluating the progression of healing in wounds and the loss of local blood flow. This is shown in Fig. 8 in animals where ruptures of the surface blood capillaries can be recognized by decreased heat radiation.

In Fig. 8, Renkielska *et al*. [86] have used active dynamic IRT (represented as a thermal time constant) experimentally in domestic pigs with burns to assess their depth quantitatively. The authors observed that the mean value of this constant was higher in wounds that were expected to be healthy within three weeks (12.8 ± 1.94 s) than those where the healing time was expected to be beyond three weeks (9.07 ± 0.68 s) ($P < 0.05$). This application of thermography could aid in therapeutic decisions to continue with conservative treatments or opt for surgery. This has also been reported in human medicine, where IRT presented an accuracy (83%) greater than clinical classifications and similar to histopathology (84%) [87].

Regarding 3rd-degree burns, studies have determined that IRT makes it possible to identify the areas of injury that have no possibility of recovery at a 90% success rate, taking indocyanine green angiography as a reference. However, further assessments of the reliability of IRT found that the technique overestimated lesion areas by 1–2 cm [17]. This evidence indicates that IRT could help in the initial assessment and triage of trauma patients, key steps in determining the appropriate treatment. Similarly, Renkielska *et al.* [88] explored the relation of a static IRT thermal merit index to a basic burn classification for choosing the appropriate treatment in a porcine animal model. They observed that the thermal index accurately detected and classified 3rd-degree burns. Their results correlated with histopathological findings (true predictive value = 87.5%), at a sensitivity of 97.7% and specificity of 85.8%. Meanwhile, when IRT was applied in a series of studies of electrocution wounds in European birds, it showed that wounds with no thermal response were associated with the risk of death or amputation [89].

This evidence suggests that IRT can support decision-making related to limb amputation when lost active circulation. However, its applications are not limited to assessing only local thermal responses and therefore have also been used to monitor hyper- and hypothermic states, two conditions that threaten the survival of animals.

Evaluation of body core temperature

Temperature is a key parameter that can help identify pathological conditions such as fever or hyperthermia in infectious states [90] or

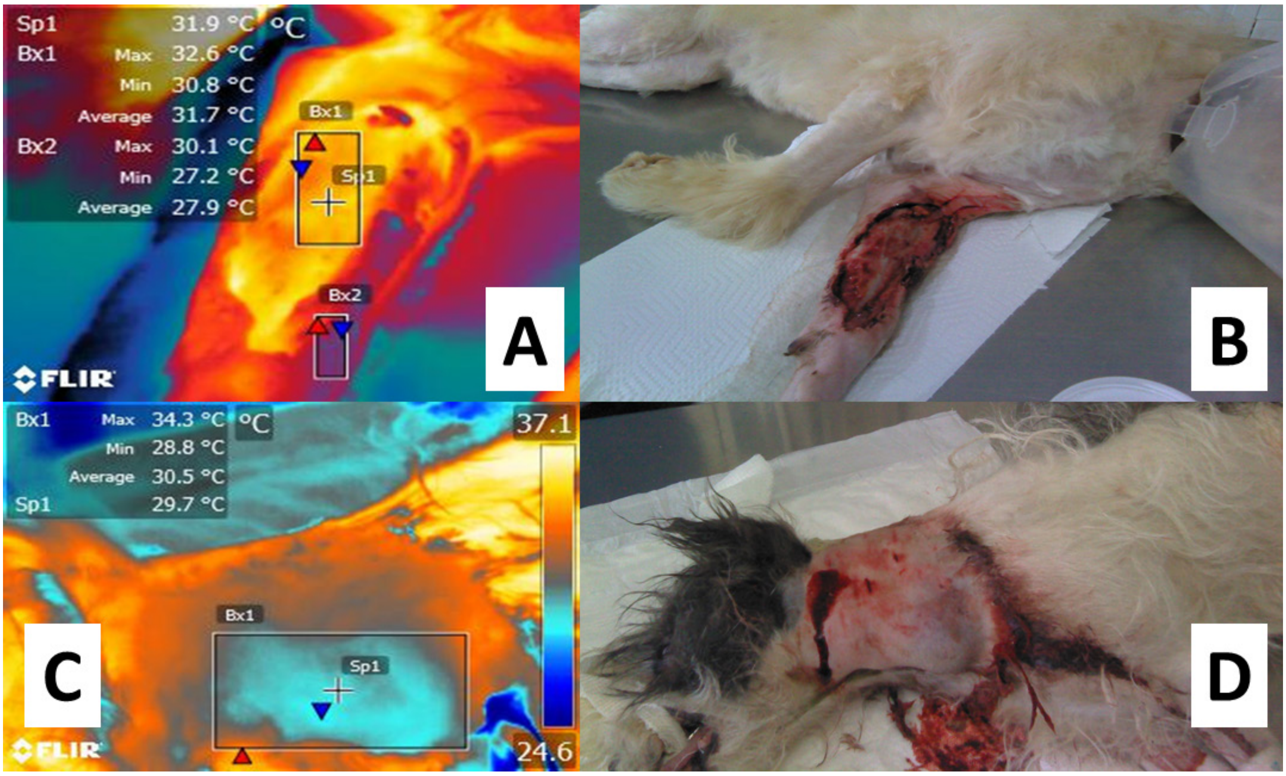

Fig. 8 Loss of peripheral circulation in two wounds caused by a dog (*Canis lupus familiaris*) attack. A. Wound to the forearm of a 3-year-old male mongrel. A temperature decreases in the tissue surrounding the injury (Bx2) is seen in the dorsal radial region of the right thoracic limb compared to the central region of the wound (Bx1), with a difference of 2.5°C in the maximum and 3.6°C in the minimum. This effect could be attributed to the destruction of the blood capillaries from the radial artery and the *carpeus dorsalis* branch that supplies blood to the tensor *fasciae antebrachii*, *extensor digiti I*, and *flexor digitorum brevi* muscles. B. Digital image of the forelimb wound. C. Injury to the lateral region of the neck in a 2-year-old mixed breed dog due to attack by a congener. The temperature decrease in this region can be seen with a maximum of 34.2°C and a minimum of 29°C. This reflects the rupture of blood capillaries from the intracarotid caudalis artery that nourishes the *splenius cervicis, brachiocephalicus*, and *cleidobrachialis* muscles. D. Digital picture of the injury at the cervical region. Both cases exemplify that the degree and depth of injury due to loss of blood circulation can be evaluated by IRT.

due to thermal stress [10, 91]. This thermal response to stressors of different natures can be observed in Figs. 9 and 10. In Fig. 9, the changes in superficial temperature in a domestic pig and water buffalo were registered. In the case of the domestic pig (A and B), high temperatures at the auricular level were recorded in an animal arriving at the slaughterhouse after a journey of eight hours. Similarly, in (B), the temperature in the frontoparietal window of a buffalo was evaluated in the vehicle after a short transport (30 min), reporting an increment of temperatures. Mobilization is one of the main stressors for animals due to environmental and management factors that can activate the central nervous system and promote hyperthermia. This effect activates peripheral mechanisms of vasodilatation to promote heat dissipation, thus, increasing the temperature in the auricular, periocular, and frontoparietal regions, as seen in the figure [92].

On the other hand, Fig. 10 represents the response of two wildlife species, an ostrich (A and B) and a bear (C and D). In (B) the behavioral response to heat stress of the ostrich can be observed when the enclosure does not have appropriate shaded areas for the animals. Spreading the wings, panting, tachypnea, and neck extension help to emit excess heat. In (D), pacing, a pathological behavior of animals in an enclosure that does not comply to their biological needs, is associated with an increase in core temperature and, consequently, in superficial temperature assessed at the parietal region.

IRT can detect thermal states in extreme conditions, such as heat exposure in species like pigs. Costa *et al.* [93] evaluated the temperature of 12 pigs during mobilization and found a linear relationship between the vehicle's internal temperature and the animals' skin surface temperature. ($R2 = 0.44$ and 0.77, respectively). In another study, the surface temperatures of 112,078 pigs of different breeds were recorded during transportation in winter and spring. The authors found that the surface temperature of the animals increased above 32°C in relation to the air temperature ($r2 = 0.82$, $P < 0.01$), but there was no interaction with the bedding level of transport [94]. This evidence indicates the potential use of IRT as a tool to monitor hyperthermia. However, some authors affirm that the bedding level, time of year, and duration of transport are other factors that can influence the appearance of hyperthermia [95]. Likewise, some technical features of the vehicle—type of window, humidity—can affect IRT images [10, 11]. Clearly, it is necessary to obtain full knowledge of all the parameters that can modify the accuracy and reliability of IRT images.

During infectious processes, the immune system cells secrete IL-1, IL-6, tumor necrosis factor-α (TNF-α), and PGE2, which can reach the brain through the blood-brain barrier and act directly on the anterior preoptic area of the hypothalamus to stimulate heat production and the subsequent increase in radiated energy [96, 97]. This chain of events has suggested that IRT could help identify infectious states in animals non-invasively, as shown in Fig. 11, where the temperature recorded in a healthy animal is compared to a sick one [98].

The possibility of non-invasive evaluations of body temperature using IRT has been analyzed in 16 Labrador Retrievers and 16 Beagles in a study by Zanghi [99]. These authors evaluated the animals after subjecting them to a physical test for 30 minutes to compare rectal temperatures with those detected in the eye and ear by IRT. Although all three methods detected increases in body temperature due to physical activity, a significant difference was observed between the ocular and auricular regions ($P < 0.00001$),

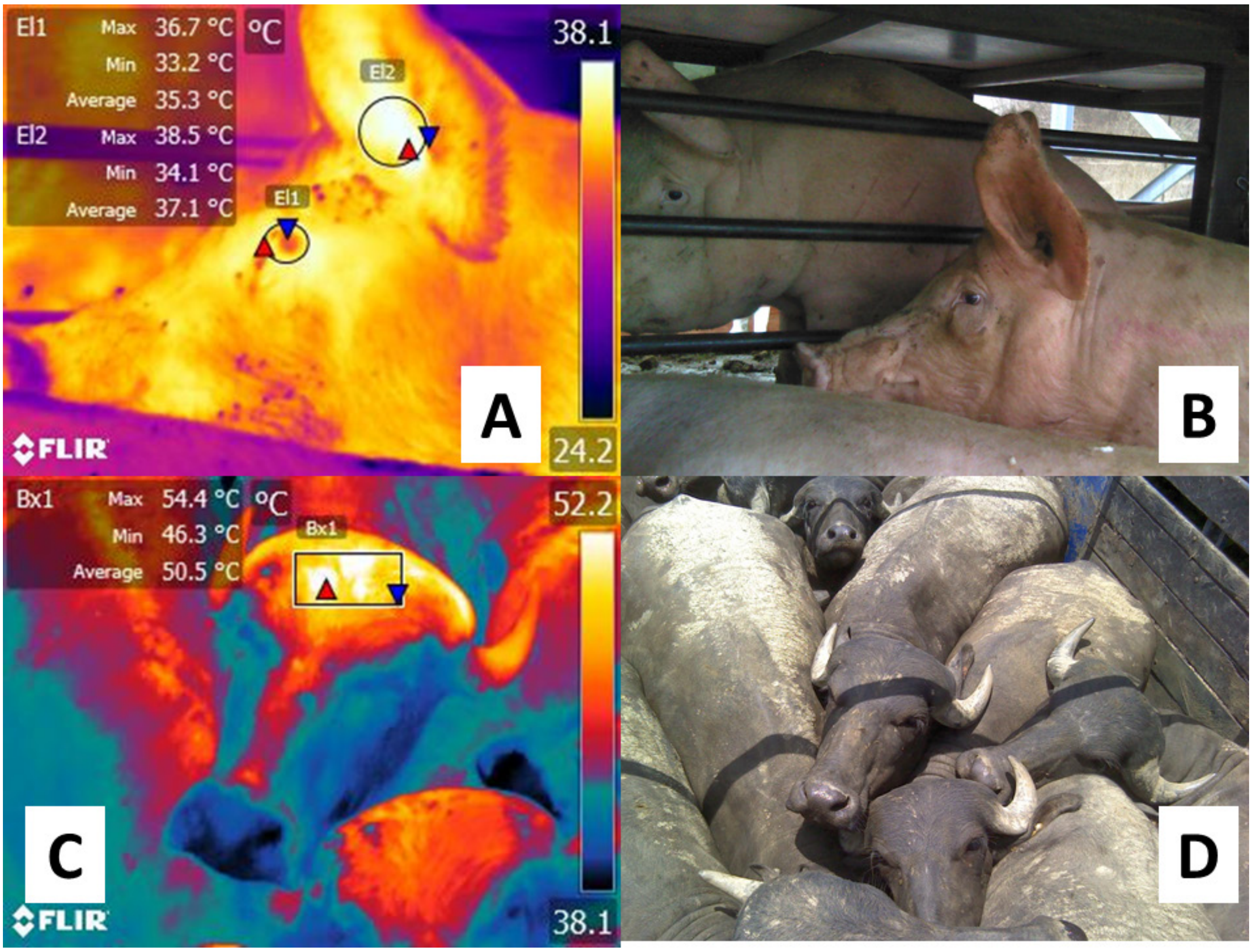

Fig. 9 Importance of IRT on the detection of stressors on farm animals. and wildlife species. A. Thermogram of a domestic pig (*Sus scrofa*) arriving at the slaughterhouse, after a journey of 8 hours. This process is considered stressful for the species and its influence on the thermal response can be evaluated through the ocular (El1) and auricular (El2) windows, where a maximum temperature of 36.7°C and 38.5°C was recorded, respectively. B. Digital image of the pig arriving to the slaughterhouse. C. Thermogram of a water buffalo (*Bubalus bubalis*) during a 30 minutes transport. In the frontoparietal region (Bx1), a maximum temperature of 54.4°C and a minimum of 46.3°C were recorded. In contrast, the masseter muscle region shows areas where the temperature could reach a minimum value of 38.1°C. D. Digital image of the water buffalo inside the truck. The response observed in both species could be attributed to the activation of the stress response and the secretion of catecholamines that increases the heat radiation at the respective thermal windows.

with temperatures in the former being directly correlated with rectal level temperatures (r = 0.615). Such differences between body regions are an essential factor in determining body temperature. Wang *et al.* [100] mention that using IRT, an anemometer, and a humiture meter can reduce the influence of humidity and wind speed on IRT accuracy. In this way, superficial temperatures of cattle differed by 0.04°C from rectal values, improving the measurements and association of both.

In a similar work, Pérez de Diego *et al.* [101] evaluated sheep infected experimentally with bluetongue virus. Temperatures were measured with a rectal thermometer and by IRT at the ocular level. Results showed that the rectal and ocular temperatures were positively correlated ($r2 = 0.54$, $P < 0.05$) and could differentiate between febrile and non-febrile animals with a sensitivity of 85% and a specificity of 97%. Similar findings were reported by Schaefer *et al.* [102] in 133 heads of weaned cattle that exhibited clinical signs of bovine respiratory disease. In that study, IRT showed higher positive and negative predictive values compared to clinical signs, with an efficiency of 71%–80% *vs*. 45%–70%.

In relation to this, Rainwater-Lovett *et al.* [103] studied Holstein steers aged 6–8 months, exposed directly or indirectly (by inoculation) to the foot-and-mouth disease virus. In those animals, IRT was able to detect the disease even in preclinical stages by recording a mean increase in the forelimbs' maximum temperature of 4.7°C from the initial to the preclinical stage, and of 7.2°C in the clinical and preclinical stages in the inoculated animals ($P < 0.001$). There were no significant differences in the animals exposed directly in any stage of infection (preclinical, $P = 0.95$; clinical, $P = 0.81$, post-clinical, $P = 0.21$). Similarly, Menzel *et al.* [104] conducted a study of pigs with pleuropneumonia produced by *Actinobacillus pleuropneumoniae.* A difference of 2°C was found between the thoracic and abdominal regions on the fourth day after infection, compared to the control group, revealing a specificity of 100% (95% confidence interval 69%–100%) and a sensitivity of 66%. Likewise, Jorquera-Chavez *et al*. [105] found that IRT can early detect respiratory disease in pigs exposed to *A. pleuropneumoniae* challenge. In these animals, the temperature in the eye and the base of the ear increased an average of 8.1°C and 0.8°C–1.8°C, respectively, in the sick pigs, who also presented clinical signs such as tachycardia and bradycardia.

Bovine respiratory disease is another pathology that has significant economic repercussions for cattle production units since animals with advanced lung lesions have lower weight gain and poor carcass quality. Martin *et al.* [106] carried out a study to compare and evaluate physiological and behavioral parameters such as rectal temperature, facial thermography (on the medial canthus of the left eye), average activity levels, computerized stethoscope lung scores, blood metabolite levels (cortisol, substance P, prostaglandin E2 metabolite), and lung lesion scores (based on lung consolidation

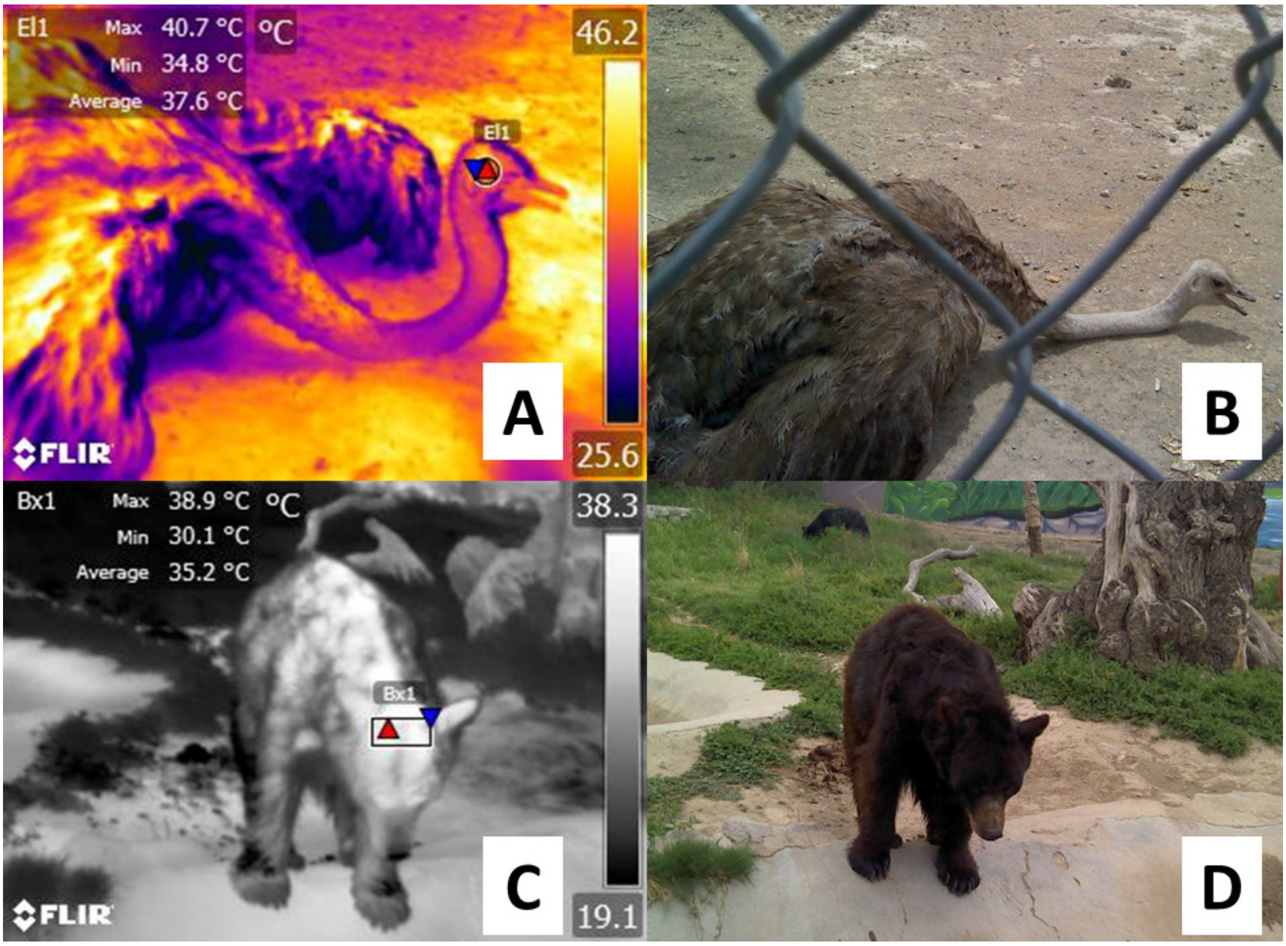

Fig. 10 Importance of IRT on the detection of stressors on wildlife species. A. Thermal image of the response of an ostrich (*Struthio camelus*) to heat stress when not provided an enclosure with shaded areas. In the ocular window (El1), a maximum temperature of 40.7°C and a minimum of 37.6°C can be observed. B. Digital image of the ostrich. In this picture, thermoregulatory behaviors when exposed to high temperatures are present. The spreading of the wings, opening of the beak to pant, and elongation of the neck are mechanism that help to dissipate heat by exposing body regions to the environment, and by evaporative losses. C. A bear (*Ursus americanus*) performing stereotypical pacing. In the parietal region (Bx1), a maximum and minimum value of 38.9°C and 30.1°C, respectively were registered. D. Digital image of the bear performing pacing. This thermal response is elicited by the constant movement of the animal, but also by the activation of the sympathetic nervous system after perceiving astressor in this case, the enclosure design.

assessed at autopsy) as predictors of lung lesions. They used 26 calves aged 6–7 months (average weight 185 ± 4 kg), 18 inoculated by bronchoalveolar lavage with a strain of *Mannheimia haemolytica* that is the etiological agent of fibrinous pleuropneumonia and also associated with the bovine respiratory complex [107]. After analyzing the information obtained from 48 hours before disease onset up to 192 hours post-onset, they found that 16 of the 18 calves inoculated with *M. haemolytica* presented lung injury scores above 10%. Regarding the results of the biomarkers and clinical signs related to the detection of bovine respiratory disease, there were variations in the specificity, objectivity, and association with pain. For example, in the first 72 hours after disease onset, average activity level, gait velocity, step count, and rectal temperature were the most accurate biomarkers for predicting calves with significant lung lesions (greater than 10% consolidation). In contrast, after 72 hours, IRT, gait distance, step count, cortisol, average activity, prostaglandin E2 metabolite, and serum amyloid A levels were the most accurate biomarkers for predicting the severity of lung lesions. However, it is important to keep in mind that environmental factors and the distance between the IRT camera and the animals can affect thermographic images [108]. For this reason, Martin *et al.* [106] recommend continuing research on biomarkers that predict lung injuries and are specific to pain to improve diagnoses of bovine respiratory disease.

The evidence shows that IRT can be implemented as a technique that eliminates the need for stressful handling associated with standard rectal temperature measurements, for example [109]. However, it is necessary to consider various factors that may alter the sensitivity and specificity of this tool. In the case of cats, studies have determined that the ocular region may be the most suitable area for determining body temperature [20].

Study trends

According to the available literature, IRT is a clinical support tool that can aid in the primary approach to traumatized or rehabilitated patients but may have applications in other fields. For example, in veterinary cardiology, IRT has shown that a drop in temperature of 2.4°C at the level of the pelvic limbs suggests a loss of peripheral circulation caused by occlusion due to aortic thromboembolism. IRT has identified this alteration with a sensitivity of 90% and a specificity of 100% [110]. This represents an area of opportunity and development to generate a tool that can provide more accurate data for the care of patients with cardiovascular problems [111].

Research in oncology has shown that IRT can serve in initial assessments of the presence of tumors based on temperature increases in the lesion region [112]. Figs. 12 and 13 describe this

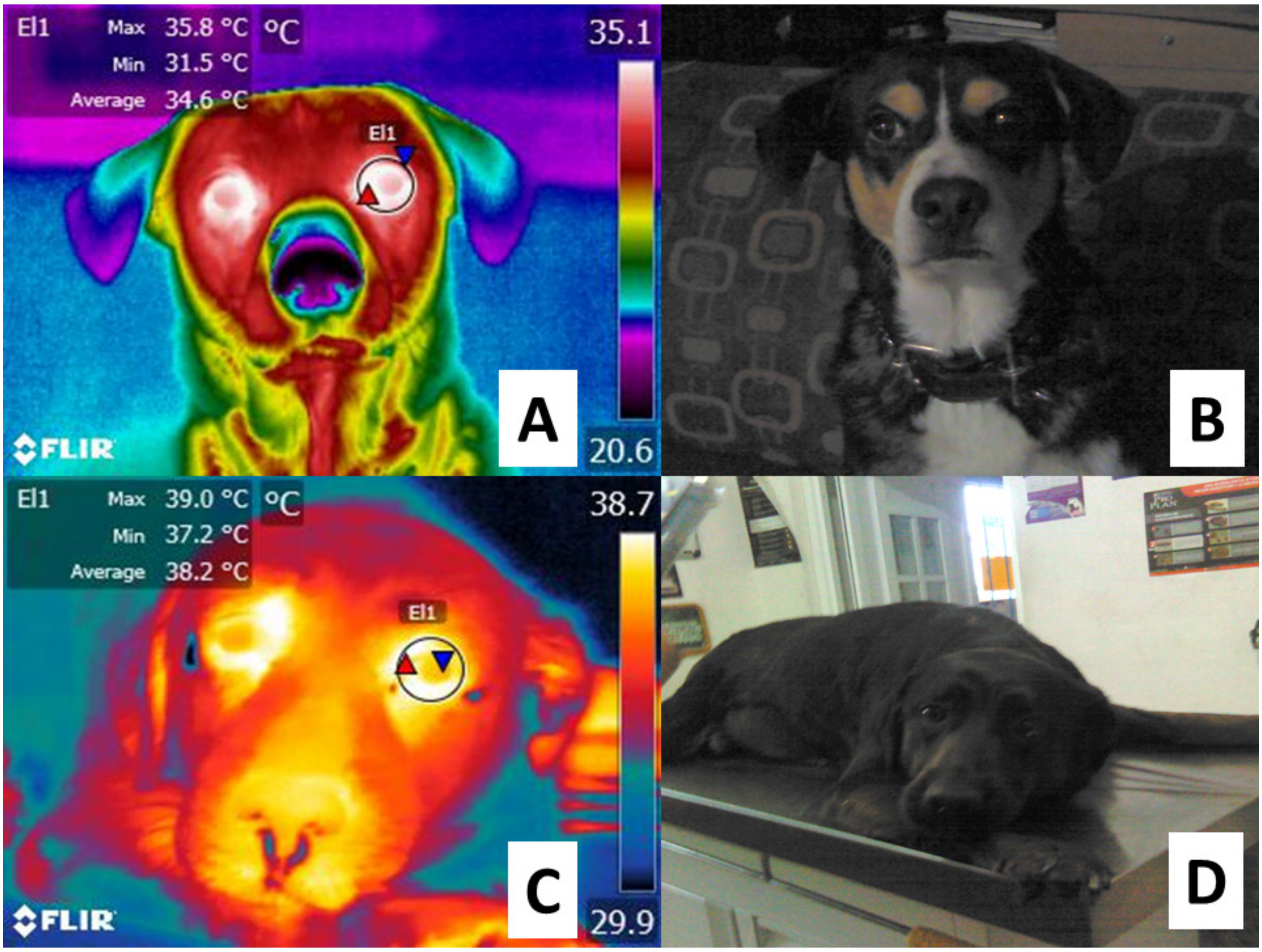

Fig. 11 Evaluation of thermal status in a canine (*Canis lupus familiaris*) with fever. A. Dog in thermal equilibrium at rest. A 4-year-old male domestic canine. In the ocular region (El1), a maximum temperature of 35.8°C (red triangle) and a minimum of 32.1°C (blue triangle) were recorded, that represent a euthermic state. C. Dog in a febrile state. A 9-year-old female diagnosed with pyometra with a progression period of three weeks. The ocular thermal window (El1) had a maximum temperature of 39°C (red triangle) and a minimum of 37.2°C (blue triangle). Compared to the euthermic dog, the temperature increases in the second thermogram is due to dilation of the peripheral blood vessels that allowed more heat radiation to the environment, which was detectable by IRT.
B and D. Digital version of both thermograms.

application in two patients with tumor growth to distinguish between malignant and benign tumors.

Reports on dogs and cats have shown that malignant tumors can generate a surface temperature of 2°C higher than in healthy regions [113, 114]. This suggests a potential application in the care of cancer patients [115]. Fig. 11 compares benign *versus* malignant neoplasia in a feline patient. The malignant tumors show an average increase of 2°C.

Finally, IRT applications in medicine are not exempt from factors that can alter evaluations. These factors have been described in studies of diverse species, where wind, humidity, and the presence and type of hair can affect the measurement of the infrared radiation emitted by a specific anatomical region [21, 53, 116, 117]. In light of this, further studies are necessary to determine the sensitivity and specificity of specific pathologies to establish IRT's reliability as an instrument in medical care.

Conclusions

IRT has the potential to be applied in various clinical fields of veterinary medicine. Detecting temperature increases or decreases in a specific region allows these changes to be associated with painful conditions, such as a wound or joint or muscle injury that involve inflammatory processes and the secretion of substances that dilate the dermal capillaries. Similarly, there is the possibility that temperature assessments of specific anatomical regions, such as the lacrimal caruncle, may provide indirect indices of autonomic nervous system activity related to local vascular responses.

The physiological basis of IRT means that it can be implemented not only to detect inflammatory processes but also infectious events with the consequent fever, or to assess tissue viability in wounds with hypothermic tissue that could indicate a compromised blood supply. Likewise, IRT's ability to detect increases in peripheral circulation, which can be attributed to an angiogenesis event present in the development of neoplasms, is a potential field of application that requires additional studies to determine its usefulness.

Since a series of external and environmental factors can alter thermographic images, it is essential to consider these elements when interpreting readings. It is preferable, therefore, to consider IRT a complementary diagnostic tool that requires evaluation when used in conjunction with other techniques utilized to diagnose diseases in farm and domestic animals.

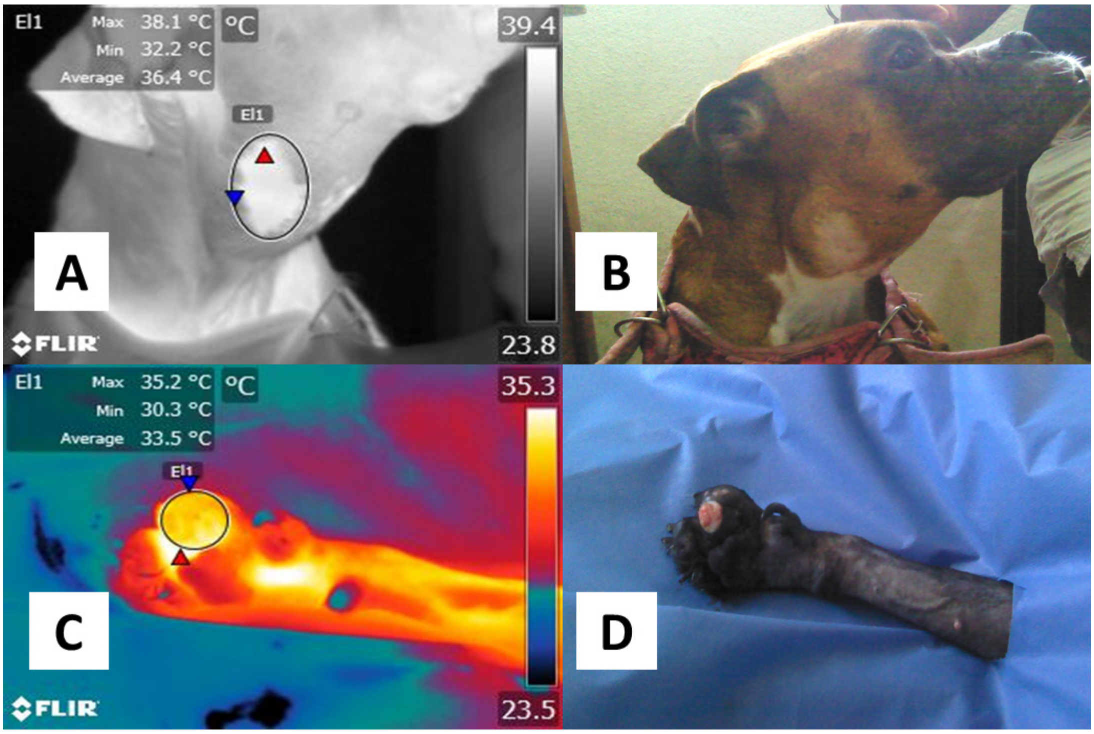

Fig. 12 Identification of malignant tumors by infrared thermography. A. Canine (*Canis lupus familiaris*) lymphoma. Male Boxer aged 9 years. A neoplasm 4 cm in diameter is visible in the right mandibular arch. It had a maximum temperature of 38.1°C (red triangle) and a minimum of 32.2°C (blue triangle). This reflects a temperature increase due to the growth of cancer cells in the submandibular lymph node. B. Digital image of the Male boxer dog. C. Squamous cell carcinoma in a 4-year-old male cat (*Felis catus)* of the Mexican domestic breed. The patient presents a neoplastic growth in the second phalanx of the right thoracic limb. The tumor presented a maximum temperature of 35.2°C (red triangle) and a minimum of 30.3°C (blue triangle). D. Photograph of the forelimb lesion. In both cases, the growth of cancer cells is associated with the secretion of pro-inflammatory substances such as serotonin, histamine, IL-6, IL-10, and TNF-α, that cause the growth of new capillaries at the local level and their vasodilation.

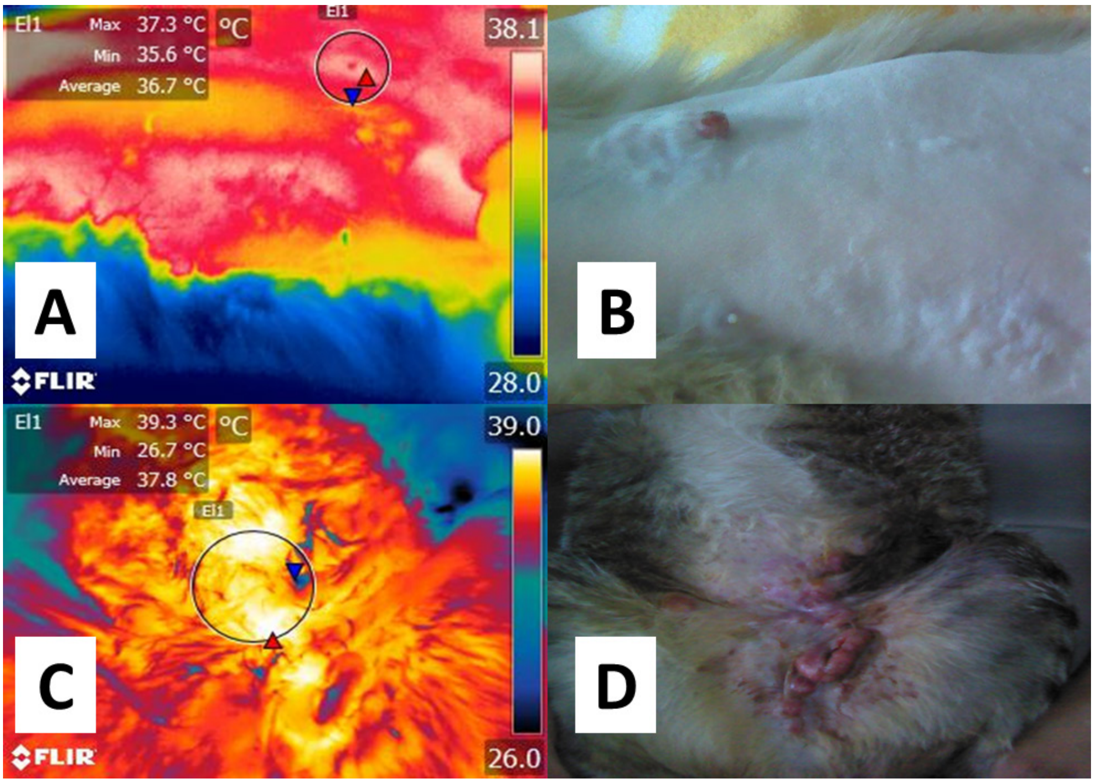

Fig. 13 Comparison of surface temperatures in felines with neoplasia. A. Benign tumor. A 4-year-old female with a tumor (El1) in the right thoracic mammary gland presented an average temperature of 36.7°C, a maximum of 37.3°C (red triangle), and a minimum of 35.6°C (blue triangle). C. Malignant tumor (El1) in the inguinal region of a 9-year-old female cat (*Felis catus*) diagnosed with a poorly differentiated squamous cell tumor. The average temperature was 1.1°C higher than in the benign tumor. This difference may be due to the secretion of prostaglandin F2α and interleukins that cause vasodilation of local blood capillaries. B and D. Digital images of the patients with neoplasia.

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