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Use of Thermography in Clinical and Sports Evaluations of Equine Animals: A review

Uso da Termografia em Avaliações Clínicas e Esportivas de Equinos: Uma Revisão

Uso de Termografía en Evaluaciones Clínicas y Deportivas de Equino: Una Revisión

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Abstract
Thermography in equine medicine is applied in the prevention, diagnosis and prognosis of diseases, as it can detect changes in peripheral blood flow. It can also act in the treatment by monitoring the instituted therapy. Skin infrared imaging thermometry is a method that detects, records, and produces images reflecting the microcirculatory dynamics of the skin surface in real time. The technique emerged from the studies of Hippocrates and has since gone through several advances, reaching significant milestones in the period of World War II, when it was effectively used in the tank's night vision system. In the 1970s, there was a big leap when it was possible to generate an image in five minutes. Several scientific studies point out its functionality both in human medicine and veterinary medicine with precision and practicality. It has been applied in equine sports medicine to clinical practice to assess musculoskeletal injuries, as an indicator of physiological stress, assess resistance, be part of the anti-doping program of the International Equestrian Federation. It is an easy to apply, safe, and affordable method It proves to be an excellent non-invasive diagnostic method for athlete horses.
Keywords: Athlete horses; Diagnosis; Musculoskeletal injuries; Teaching.

Resumo
A termografia na medicina equina é aplicada na prevenção, diagnóstico e prognóstico de afecções, por ser capaz de detectar alterações no fluxo sanguíneo periférico, podendo também auxiliar no tratamento de desordens musculoesqueléticas por meio do monitoramento da terapia instituída. A termometria cutânea por imagem infravermelha é um método que detecta, grava e produz imagens refletindo a dinâmica micro circulatória da superfície da pele em tempo real. A técnica tem como base os princípios de detecção de alterações orgânicas por variações de temperatura no corpo, difundidos por Hipócrates ainda na antiguidade, e passou por vários avanços associados ao desenvolvimento de tecnologias, tendo marcos significativos no período da Segunda Guerra Mundial, momento em que foi utilizada efetivamente no sistema de visão noturna dos tanques. Na década de 1970 teve um grande salto, quando se tornou possível gerar uma imagem com gradiente de temperatura em apenas 5 minutos. Vários estudos científicos apontam sua funcionalidade tanto na medicina humana quanto na medicina veterinária, com precisão e praticidade. Na medicina esportiva equina é empregada em algumas rotinas clínicas a fim de avaliar injúrias musculoesqueléticas, sendo considerada também uma valiosa técnica para análise de estresse fisiológico e para avaliação de resistência física, além de fazer parte do programa antidoping da Federação Equestre Internacional. Por ser um método de fácil aplicabilidade, seguro e de custo acessível, demonstra ser uma excelente ferramenta de diagnóstico não invasiva para cavalos atletas.
Palavras-chave: Cavalos atletas; Diagnóstico; Lesões musculoesqueléticas; Ensino.

Resumen
La termografía en medicina equina se aplica en la prevención, diagnóstico y pronóstico de afecciones, ya que es capaz de detectar cambios en el flujo sanguíneo periférico, y también puede ayudar en el tratamiento de trastornos musculoesqueléticos mediante el seguimiento de la terapia instituida. La termometría cutánea por imágenes infrarrojas es un método que detecta, registra y produce imágenes que reflejan la dinámica microcirculatoria de la superficie de la piel en tiempo real. La técnica surgió de los estudios de Hipócrates y desde entonces ha

experimentado varios avances, teniendo hitos significativos en el período de la Segunda Guerra Mundial, cuando se utilizó de manera efectiva en el sistema de visión nocturna de los tanques. En la década de 1970 hubo un gran salto cuando fue posible generar una imagen en 5 minutos. Varios estudios científicos señalan su funcionalidad tanto en medicina humana como veterinaria con precisión y practicidad. Ha sido aplicado en medicina deportiva equina para la práctica clínica con el fin de evaluar lesiones musculoesqueléticas, como indicador de estrés fisiológico y evaluación de resistencia, además de ser parte del programa antidopaje de la Federación Ecuestre Internacional. Como es un método fácil de aplicar, seguro y asequible, demuestra ser una excelente herramienta de diagnóstico no invasivo para caballos atléticos.
Palabras clave: Caballos atléticos; Diagnóstico; Lesiones musculoesqueléticas; Enseñanza.

1. Introduction

Equines are animals domesticated by man long ago, and Brazil has a herd of more than five million animals of the most diverse breeds for various purposes (Lima & Cintra, 2015). Equine athletes who compete in high performance are subject to various injuries due to the physical effort required during sports practice (Resende, 2005; Sala *et al*., 2012). The market linked to equine sport and leisure was approximately US$5.84 billion/year in 2016, which justifies investments in keeping these animals in good clinical condition to compete with high athletic performance (Gerardi *et al*., 2019).

Thermography in equine sports medicine has been applied to increase clinical practice because it is useful in preventing, diagnosing, and prognosis of diseases (Holmes *et al*., 2003). Through it, one can evaluate musculoskeletal injuries arising from an intense exercise routine in equine athletes with high-performance requirements, also helping in training these animals with useful information for competitions (Figueiredo *et al*., 2012). Infrared imaging can be an important tool for evaluating stress, muscle, and skeletal injuries in horses because it can detect changes in peripheral blood flow (Basile, 2012). It is worth noting that these musculoskeletal changes are the main cause of decreased performance in equine athletes of high performance, thus increasing the importance of clinical monitoring techniques such as thermography in the detection of injuries in these animals (Yonezawa *et al*., 2009). The large volume of the equine muscles does not facilitate the diagnosis accuracy (Boffi *et al*., 2006), and frequently the most evident clinical sign is not the pain itself but the drop in performance (Fonseca, 2005). The use of thermography is very helpful in identifying lesions, and a temperature difference of 1º C may already indicate the affected region (Waldsmith, 1993).

In equine medicine, thermography has been used successfully to detect tendonitis, synovitis (Turner *et al*., 1986), periosteal changes, navicular syndrome (Rose *et al*., 1983), laminitis (Turner, 2001), osteoarthritis (Vaden *et al*., 1975), and diagnoses of back pain (Fonseca, 2005). Thermography can also aid in treatment by quantifying regression and monitoring the efficacy of anti-inflammatory therapy (Rose *et al*., 2019), and evaluating the effects of sports practice on animal body heat production (Cruz *et al*., 2018).

2. Methodology

The study in question consisted of a bibliographic review of a narrative nature, using secondary and/or tertiary data, with a description of techniques and results achieved in studies available on the subject in question, including materials that deal with original studies, other reviews theories and/or even case reports (Severino, 2018; Batista & Kumada, 2021). Thus, it began with a search for scientific articles, books, theses and dissertations in databases such as Scielo (https://scielo.org/), CAPES Periodicals (http://www.periodicos.capes.gov.br/) and Directory of Open Access Journals (Directory of Open Access Journals – DOAJ, https://doaj.org/) and Google Scholar (https://scholar.google.com.br/), between October 2021 and March 2022.

The search for the bibliographic materials in question took place through the insertion of descriptors associated with the main theme of the research, adding complementary descriptors to refine it as to the species and purposes of use of the technique in question. Thus, the following terms were used, individually or jointly, with inflections in the singular and plural,

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and spelled in Portuguese and/or English, in order to increase the scope of the analysis of materials:

- Thermography;
- Equine;
- Clinic;
- Diagnosis;
- Lesion;
- Inflammation;
- Treatment;
- Welfare;
- Physical Conditioning

The selection of bibliographic materials of interest was based on the possibility of including their contents in the structuring of topics previously defined for the study, namely, "Principles of Thermography" and "Use in Equine Veterinary Medicine", the latter being subdivided into " Use of Thermography in Equine Medical Clinic" and "Use of Thermography in the Evaluation of Equine Well-Being and Sports Conditioning". These materials, once selected, were read in full and the results contained therein were used to compose the work in question.\

3. Thermography Principles

Reports on clinical assessment through the thermal gradient indicate that it arose from studies by the Greek physician and philosopher Hippocrates (Ring & Ammer, 2012). He used to diagnose diseases based on variations in the body surface temperature of patients by measuring the temperature with the hand back. He also used the application of mud on injured sites, using drying time as a reference to identify points where there was an increase in temperature (Lahiri *et al*., 2012). It was a technique that enabled locating inflamed areas since one of the main signs of inflammation is the increase in local temperature, a consequence of the increased blood supply (Redaelli *et al*., 2014).

In 1800, infrared thermal radiation was discovered using a spectroscope through the evaporation of alcohol obtained from a surface painted with carbon (Holst, 2000; Pereira, 2019). Many advances occurred in technology, and in 1929, the first thermogram was prepared by Czerny, but it was only during the Second World War that infrared radiation began to be used effectively in the night vision systems of German tanks to detect enemy targets in the invasion of Russia (Veratti, 1992; Brioschi *et al*., 2003). Still, in this same period, the infrared forward vision was developed, enabling the development of weapons with heat detectors. In 1970, there was a great leap in development regarding the speed of thermographic image formation, and it was already possible to form it in five minutes with the determination of the temperature by integrated systems (Veratti, 1992).

Infrared imaging skin thermometry is a diagnostic method that detects, records, and produces images reflecting the microcirculatory dynamics of patients' skin surfaces in real-time (Brioschi *et al*., 2003). In studies of pain in humans by Green *et al*. (1986), thermography demonstrated the specificity of 95% and sensitivity of 99%. In a study with pigs, Graciano (2013) found results that guarantee the effectiveness of thermography as an accurate strategy in the early detection of edema and injuries before clinical signs appear. The technique is described as non-invasive as it causes no damage and does not require any contact with the patient's or the performer's body (Cruz, 2018), and makes the information available in real-time (Tanda, 2016). It is considered a physiological method because it provides dynamic images and real-time analysis, not just static ones like other imaging exam techniques such as X-Ray, for example, besides being able to show changes before the demonstration of clinical signs and perform treatment monitoring without causing interference to it (Redaelli *et al*., 2014).

The thermograph camera measures the intensity of infrared radiation, which is converted into a form of electrical energy by the cathode, producing a grayscale image of the object under examination (Kraft and Roberts, 2001). Infrared radiation is an electromagnetic frequency emitted by any body naturally and directly proportional to its temperature, and infrared thermography captures this radiation using a thermogram, pictorially expressing the surface temperature of an object or body (Eddy *et al*., 2001). The gray image is processed and produced on a color scale in software (Okumus and Yanmaz, 2007).

The preparation of the thermogram by the thermal imager occurs through a complex set of algorithms designated by specific colors that correspond to a temperature value specified in x and y coordinates. The thermogram is formed by units called pixels, and each pixel forming the image corresponds, within the x and y plane of the image, to a precise temperature (Roberto and Souza, 2014). Thermograms are evaluated visually and processed by software that reveals useful data, such as the average temperatures found in the chosen regions (Soroko *et al*., 2018). The device focuses the infrared radiation on two-dimensional array detectors with an electrical output proportional to the power of the radiation that has been detected (Cruz, 2018). Infrared equipment will only distinguish an object against a background if there is sufficient contrast between the two; therefore, to obtain a good quality image, one must ensure thermal contrast, sensitivity, and good thermal resolution (Roberto and Souza, 2014).

The equipment can detect temperatures starting at 0.05 °C (Roberto and Souza, 2014), and, according to Teodora *et al*. (2007), in thermographic evaluation, a temperature increase of more than 1°C in two anatomically symmetrical regions can be considered abnormal. Through these results, it is possible to determine the functioning of the vascular, nervous, and musculoskeletal systems, as well as dermatological, endocrine, and oncological conditions (Brioschi *et al*., 2003). The infrared emissions of the animal are directly related to tissue perfusion and metabolism (Roberto and Souza, 2014). Since heat is one of the signs of inflammation, it is possible to observe signs of an inflammatory process through thermography before clinical signs appear (Gavrila, 1999). Circulatory "status" and blood perfusion dictate the thermal pattern, which is the basis of thermographic interpretation (Fonseca, 2005).

Thermographic images can be taken at a distance of less than 1 meter, or even more than 1,000 meters from the body being evaluated (Mccafferty, 2007). To interpret the thermograms, it is recommended that if the images are formed in a monochrome pattern, the hot spots are represented by lighter colors (up to white), and they indicate warmer sites usually associated with inflammatory processes. The cold spots, in turn, are represented by darker colors (colors that usually vary from black), suggesting colder locations and indicating a reduction in local circulation (Basile, 2012). In the case of the formation of color images, the warm foci will stand out in shades of orange and red, while the cold foci will present themselves in shades of blue, and the yellow locations will be those with an intermediate temperature in the image.

It should also be noted that drugs are not recommended as a method of restraint prior to the thermography examination as they can alter peripheral circulation in the animal's body (Redaelli *et al*., 2014). Furthermore, to ensure the effectiveness of the technique, it is important to standardize or avoid factors such as solar radiation, ambient temperature, humidity, air movement, and artifacts to obtain reliable images (Eddy *et al*., 2001), as this tool has the limitation of being highly influenced by the environment (Santana *et al*., 2018).

4. Use in Equine Veterinary Medicine

Several scientific studies on infrared thermography point out its functionality in human and veterinary medicine because it allows obtaining data with precision and practicality (Roberto & Souza, 2014). The use of thermography in veterinary medicine had its first description when Delahanty and Georgi (1965) used this method in horses, associated with radiography, in four clinical cases for the diagnosis of squamous cell carcinoma, third carpal fracture, tarsal osteoarthritis, and deep cervical abscess, and observed an increase in temperature around the involved area in all cases (Waldsmith, 1994).

It has been applied in equine sports medicine to increase clinical practice, proving to be useful in preventing, diagnosing, and prognosing disorders (Holmes *et al.*, 2003). It can evaluate musculoskeletal injuries in high-performance equine athletes caused by their intense exercise routine (Snyder, 2002). It reveals the equine body temperature in a practical and real-time manner, and it can be employed as a diagnostic method, quantifying the regression of inflammation during treatment with anti-inflammatory drugs (Soroko *et al*., 2018). It is useful to detect fear reactions in physiological evaluations, and when associated with ultrasonography, it is effective for the diagnosis of thoracolumbar injuries (Dai *et al*., 2015, Fonseca *et al*., 2006). Redaelli *et al*. (2019) suggested that thermography use can be a good indicator of physiological stress and be useful for evaluating the effectiveness of resistance training in equines.

The International Equestrian Federation (FEI Veterinary Regulations 12th ed., 2019, Appendix XI) has proposed the use of thermography in the anti-doping program for jumping horses. The guidance is that all four limbs of the equines should be examined before and after a competition, and if there are image asymmetries between the same contralateral limb regions, hot spots, cold spots, or painful regions, the animal should be disqualified from competition to ensure its well-being and integrity.

To this end, it is recommended that horses adapt to the ambient temperature to minimize environmental effects on the measurement, and to this end, the animals should be kept at the examination site for 10 to 20 minutes before the thermography (Nobrega *et al*., 2014). It is necessary to control the humidity and temperature of the examination site, besides being advised to perform it in areas protected from the sun and preferably without airflow to prevent increased heat loss (Redaelli, 2014; Santana *et al*., 2018).

The use of thermography in equine medicine

Figueiredo *et al*. (2012) reported four clinical cases of horses used for racing, three-drums, and conformation examined due to lameness, in which thermography was used in the locomotor apparatus (thoracic limbs, pelvic limbs, head, neck, and spine) of the animals, prior to the clinical examination. It significantly helped in the clinical diagnosis, demonstrating that infrared thermography is a fast and safe test for detecting locomotor disorders and monitoring the resolution process of these disorders.

Pavelski *et al*. (2015) evaluated the infrared thermography of the spines of 15 healthy horses of different breeds, sexes, and ages in a closed room without interference from external environmental factors and controlled temperature. They found a statistical difference in comparing the thermographic temperature measured in the external environment and that obtained inside the room. They also observed that staying inside the room for 30 minutes at a controlled temperature was enough to balance the horses' skin temperatures. According to Fonseca (2005), in a study with 24 quarter horses, thermography is useful to identify and localize diseases related to the spine because thoracolumbar pain involves an alteration of the vasomotor tone through various nervous reflexes and is characterized thermographically in healthy conditions as a region of decreased temperature ("cold spot"). This study used thermography to map injured areas, finding lesions such as supraspinous desmitis, intraspinous desmitis, dorsal intervertebral osteoarthritis, and spinous process syndrome, showing thermography to be an efficient diagnostic tool in all cases. Although the test has great potential to assist in diagnosing low back pain, whether inflammatory or degenerative, the technique's disadvantage is the need for more than one person to perform the mapping of lesions in the thoracolumbar region. According to the authors, thermography is a tool for mapping lesions as a guide for the ultrasound test, and without marking the place with altered temperature in the animal, it would not be easy.

The distal parts of equine limbs are challenging locations for thermographic evaluation due to the thermoregulatory role of this region (Wallsten *et al*., 2012). The surface temperature of horses' distal thoracic limb region, including the hooves, was measured by Westermann *et al*. (2013) using thermography. Moreover, the authors observed that even almost imperceptible air movements could cause a decrease in thermographically determined limb temperatures. In the early phase of laminitis, Turner *et al*. (2004) reported an increase in surface temperatures at the coronary edge relative to the distal hoof and sole. Pimentel *et al*. (2019) thermographically evaluated the hooves of 30 mestizo horses for urban traction in Maceió, AL. The animals were randomly selected without claudication, and three thermographic images were obtained: frontal, lateral, and sole, after 20 minutes of rest in an acclimatization environment, with clean hooves without water. The results did not show significant differences, showing average values close to those described in the literature for healthy animals since the animals evaluated did not present claudication. In the case of navicular syndrome, thermographic patterns are normal or colder due to vasoconstriction (Sampson *et al*., 2009).

Thermography is not consistent in neurological applications and should be studied further (Redaelli *et al*., 2014). However, Soroko *et al*. (2018) state that tendinopathies in racehorses can be diagnosed early by thermography and then confirmed by radiography and ultrasonography. The technique has been successfully used to detect synovitis and periosteal changes (Turner *et al*., 1986), and in cases of tendinitis, it is possible to relate the findings obtained by thermography to ultrasonography (Fonseca, 2005).

It is impossible to determine articular lesions early through radiographic examination and synovial fluid analysis because the radiographic examination can only indicate bone lesions secondary to articular involvement after 45 days of injury to the articular cartilage and secondary bone involvement. Therefore, complementary examinations are necessary to detect these lesions early so that there is no joint function loss and no decline in athletic performance (Yancik *et al*., 1987; Morgan, 1968; Rasera, 2007).

However, one of the factors for not using thermographic examination in the clinical routine of joint pathologies is the lack of reference values. In this sense, Machado *et al*. (2013) standardized the thermographic examination of the carpal and metacarpophalangeal joints of 45 horses of the Criollo breed that were healthy and in training. This study concluded that these joints are best evaluated in the dorsal aspect so that there is no interference from the temperature of adjacent anatomical structures and that the ideal room temperature to detect differences between joint temperatures should be close to 20ºC. Regardless of this, one should always compare the temperatures of one limb with the contralateral one and correlate the findings with the physical examination.

Figueiredo *et al.* (2012) used infrared thermography to detect intrasynovial injections of bupivacaine into the fetlock and carpus of five mares. They noticed an increase in temperature in the regions after the treatment was applied, demonstrating that it can be used to detect intrasynovial injections in horses. Van *et al*. (2002) used the same tool in more detail to detect injections and palmar digital neurectomy in horses. They concluded that although it is sensitive to detect changes, thermography is not specific to differentiating procedures and injuries that induce inflammatory responses. Injections into the lumbar and suspensory ligament regions produced detectable thermal patterns for two days, as did tibial nerve infiltration with a neurolytic agent, while analgesia of the palmar nerves was significant for 24 h with bupivacaine and five days with ammonium chloride.

Nóbrega *et al*. (2014) investigated the use of thermography as a tissue response diagnostic method after implanting a polymer-based on castor oil polyurethane in Metacarpal bone III of six horses undergoing unicortical ostectomy, and the technique allowed identifying the presence of transient inflammatory response seven days postoperatively via statistical difference compared to the control limb. Rushton *et al*. (2015) used thermography and thermometry on five horses with a history of uveitis and ten normal horses and concluded that uveitic eye temperatures are not significantly higher than nonuveitic eyes. There is a need for further research on this topic. Levet *et al*. (2010) used thermography to evaluate cast wounds on horse limbs and found it to be a valuable and rapid clinical tool.

Use of thermography in the evaluation of well-being and sportive conditioning of horses

According to Roberto and Souza (2014), within veterinary medicine, thermography is a useful tool in animal welfare studies, detecting various inflammatory processes, and in the large area of oncology, both in small and large animal clinics. Equines in training can be subjected to routine thermographic examinations to identify subclinical changes, and training modifications can be made to prevent future injuries (Turner, 2001).

In their study with quarter horses competing in three-drum races, Sala *et al*. (2012) described how the thermographic examination is important for early recognition of injuries in the animals and addressing the athletes' conditioning. They found significant differences in the pelvic muscle temperature immediately after exercise. We also observed that among the muscles investigated in this study, the semimembranous was the most demanded and concluded that thermography is useful in evaluating the physiological status of the musculature of the croup region, which is highly required in this sport. Marlin *et al*. (1998) stated that at the end of the exercise, there is an abrupt reduction in oxygen demand by muscle tissue, and the blood accumulated in the muscles is diverted to the central circulation, thus generating contraction in the vessels that irrigate the muscles.

Cruz *et al*. (2018) analyzed the pattern of thermographic variation in muscle and joint regions of 14 quarter horses competing in pulling vaquejada and found an adaptive adjusted pattern between the animals' surface temperature and environmental indices and interaction between the animals' surface temperature with the type of exercise, and concluded that the afternoon period and continued exercise increased the surface temperature of the regions evaluated. In turn, Silva *et al*. (2018) verified the physiological responses associated with thermal variations diagnosed by infrared thermogram in four clinically healthy quarter horses undergoing intense physical exertion and observed no significant differences in croup and head temperatures before and after exercise. However, thermal amplitude was noted in the head after training due to widespread blood irrigation and redistribution in the region. In contrast, this amplitude was observed before training in the croup region, which may be related to the greater concentration of muscle mass in the region, concluding that the thermal amplitude is an efficient response variable in evaluating surface temperature oscillations in horses subjected to excessive physical exertion.

Yarnell *et al*. (2014) monitored the changes in skin temperature in seven equines associated with aquatic treadmill exercise using thermography. They detected a significant change in pelvic limb temperature, concluding that this may be an alternative method to assess muscle activity and temperature change in an aquatic environment. In his study in Saloá, PE, Bessa (2018) evaluated thermography as an indicative tool of recovery in equines after an explosion, using four horses of the quarter horse breed with the pulling function in vaquejada. Although the animals did not show significant changes in the body temperatures of the regions studied, it can be concluded that thermography is an efficient tool in verifying the recovery of explosion athlete horses.

Thermal energy accumulates during physical exercise, thus raising body temperature. This temperature needs to be dissipated through the individuals' thermoregulatory mechanisms, and the thermal condition of the environment influences it (Carvalho and Mara, 2010; Perissinotto *et al*., 2006). Animals use peripheral vasodilation to maintain homeothermy, causing an increase in surface temperature (Ribeiro *et al*., 2018). To analyze the thermoregulation of an Anglo-Arabian horse in training, Moura *et al*. (2011) used thermography for eight days in the hottest period of the day. They concluded that the thermoregulation of the croup and chest is not much related to vasomotor events since the surface temperature had no significant increase in these regions. In contrast, the axilla and groin regions significantly increased after exercise. They decreased after bathing, demonstrating the capacity of peripheral vasodilation and vasoconstriction at these sites and demonstrating that the bath is an efficient method to assist the thermal exchange of the horse with the environment.

Thermographic imaging aids in understanding body thermoregulation due to changes in surface temperature and the impact of environmental conditions on animal thermal comfort (Barros *et al*., 2016). Oliveira *et al*. (2018) studied the dynamics of the skin temperature of ten healthy horses of the quarter horse breed at rest and at two moments during physical activity using infrared thermography. They concluded that the areas of the neck, thoracic limb, and back did not show a significant effect of exercise on temperature, which is associated with the low vasomotor capacity of the regions. In contrast, the abdominal and pelvic muscle areas showed a significant increase in temperature with a 10-minute exercise, making them the most activated groups during exercise. The skin is an essential organ for the thermoregulatory function of horses because the animal loses heat by conduction through it, and there is an increase in internal heat during physical activity, which makes exercise a disturbing agent of thermal homeostasis, causing the body to promote the redistribution of blood circulation from inactive areas to active areas during exercise, and then to the skin, so that there is an exchange of heat with the environment (Simon *et al*., 2006; Jodkowska *et al*., 2011; Fernandes *et al*., 2012).

Sanchez *et al*. (2015) investigated the feasibility of assessing heat loss from the body surface of five horses during treadmill exercise using dynamic infrared thermography of the neck, shoulder, chest, and croup. They concluded that the technique is suitable for this purpose. The researchers found, still with the animals at rest, that among the regions studied, the neck was the one that presented the highest temperature, followed by the shoulder. After beginning the exercises, the temperature increased in all regions, with the neck still being the hottest. By the end of the recovery period, all temperatures had decreased.

The saddle is responsible for attenuating the contact between the horse's body and the rider. Thermographic image analysis makes it possible to locate pressure peaks resulting from poor saddle fit and visualize whether the correct distribution of the rider's weight on the animal's back has occurred. Soroko *et al*. (2018) confirmed that infrared thermography is a useful tool in assessing saddle fit in racehorses by evaluating the fit of 22 saddles on 65 racehorses. The study showed that the load, the horse age, and the training intensity influence the pressure distribution in the saddles.

Andrade *et al*. (2020) performed a quantitative quadrant thermographic analysis of ten similar Australian saddles used in a riding course for one hour with the same exercises and intensity in Mangalarga Marchador animals. The thermographic image of each saddle was divided into nine quadrants and checked before and after the exercises. An increase in temperature was observed in all quadrants evaluated after the exercise, demonstrating that all parts had contact with the animal. However, a higher pressure was noted in the rail region, especially in the central region, which is considered the point of greatest overload, demonstrating the unbalance of the saddle since it is a region that should not have contact with the animal. Prochno *et al*. (2020) evaluated 62 saddles used by 129 jumping horses through thermography of the thoracolumbar region, identifying asymmetry between the panels in 62.8% and central contact with the thoracolumbar spine in 37.2% of the saddles, while 55.8% of the images after training were asymmetrical, proving to be a useful tool in evaluating the fit of saddles used by jumpers.

Studies point out that infrared thermography has a good potential as a non-invasive tool for measuring stress levels in horses during competitions (Valera *et al*., 2012.; McGreevy, Warren-Smith and Guisard, 2012; Bartolomé *et al*., 2013). Redaelli *et al*. (2019) did a pilot study using thermography as an indicator of stress in eight Arabian horses trained for endurance at different intensities before and after training, associating it with other parameters and concluded that verifying eye and hoof crown temperatures can become useful to detect physiological stress because they correlated positively with cortisol. Witkowska-Pilaszewick *et al*. (2020) correlated thermography and blood lactate concentration of 40 healthy racehorses during training, and both blood lactate and trapezius muscle temperature increased immediately after exercise compared to values before training. After 30 minutes, all-temperature values returned to their initial levels, while lactate levels showed their highest values.

The change in eye temperature can be a tool to measure the effects of management or physical effort on the animal's homeostasis. Barussi *et al*. (2011) evaluated pain by ocular thermography in 14 Thoroughbred horses with and without orthopedic conditions. Ocular thermography was one of the most sensitive techniques for stress detection due to the vasodilation of the lacrimal caruncle region that is stimulated by the sympathetic system and thus has a stress response. As a result, animals with clinical orthopedic signs showed a decrease in lacrimal gland temperature compared to the others, suggesting an alteration in blood perfusion in the region after severe pain, but further studies are needed. Yarnell (2012) observed a significant increase in ocular temperature in horses after the grooming procedure, especially after the first five minutes, suggesting that this increase was generated by an activity linked to the sympathetic nervous system and may be a consequence of a stressful stimulus since there was also a correlation between increased temperature and increased salivary cortisol levels.

Also, on eye region temperature, Nathalie *et al*. (2015) evaluated the feasibility and validity of a fear test in 50 sport horses using infrared thermography to detect eye temperature change, identifying a significantly greater increase after presenting a new object to the animals, concluding that the technique is useful in assessing physiological fear reactions in horses. Seabra *et al*. (2019) studied eye temperature changes in response to race training in 13 thoroughbred horses at the Jockey Club with images before and after training and found a significant difference with increased temperature after sporting activity.

5. Conclusion

Infrared thermography is a tool already used in equine medicine for the prevention, early diagnosis, and prognosis of injuries, especially in the locomotor system. It is also gaining prominence in animal welfare and is already recognized by international bodies of equestrian sports as a tool for this purpose. Studies in the area are growing, promising, and satisfactory, and they demonstrate that data can be obtained practically and accurately, which generates a breakthrough in the use of this imaging technology as a method for diagnosing injuries in various regions, from the spine to the most distal parts of the locomotor apparatus of equines. It can be used for joints, bones, muscles, the nervous system, and the like, besides being an important ally in monitoring athlete horses' performance in sports activities to prevent injuries or identify them early, helping to maintain the best competitive performance of these animals. Its advantages include the fact that it is a non-invasive method that does not cause stress to the animals and has a low cost, which enables the dissemination of its use in equestrian routine.

New research that includes analyzes of correlation between thermographic variations findings and clinical and/or physical conditioning changes in horses may serve as a basis for the development of protocols for monitoring the physiological conditions of animals in equestrian competitions, in order to determine whether or not of their participation, ensuring progress in the regulatory frameworks currently in force.

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