

# Infrared Thermography in Equine Practice

Nina Čebulj Kadunc, Robert Frangež and Peter Kruljc\*



## Abstract

Thermography is a non-invasive diagnostic imaging method for the detection of mid to long-wave infrared radiation emitted from the body surface that allows visualization and quantification of changes in skin surface temperature. Within the electromagnetic spectrum, the wavelength of infrared radiation is too large to be detected by the human eye, although it is normally perceived as heat. Electromagnetic heat radiation can be registered with a thermal camera and visualized in the form of a temperature distribution map - a thermogram. The procedure is performed without physical contact with the examined object, including animals. Thermography can be used to determine physiological and pathological changes that induce variations of superficial temperature in a horse. These changes

reflect blood flow patterns and the metabolic rate in the horse due to variations in heat production, such as exercise, injury, illness and environmental influence. Thermography has been used to evaluate several different clinical syndromes not only in the diagnosis of inflammation, but also to monitor the progression of healing. Thermography has important applications in research for the detection of illegal performance-enhancing procedures at athletic events and to determine the welfare of horses. Despite several advantages, it is also important to be aware of certain limitations surrounding the practical application of thermography. Therefore, the method should be used in combination with other diagnostic procedures rather than as a replacement.

**Key words:** horse; thermography; thermogram

## Infrared radiation

The electromagnetic spectrum is composed of wavelengths ranging from the shortest (gamma) rays to the longest (radio) waves, with the entire spectrum between based on wavelength: X-rays, ultraviolet, visible and infrared light, followed by the microwaves. Within this spectrum, the wavelength of the infrared radiation is too large to be detected by

the human eye, though it is normally perceived as heat. Infrared radiation is emitted by all objects proportionate to their temperature as electromagnetic waves of varying wavelengths in the range from 0.7 to 1000  $\mu\text{m}$  (Eddy et al., 2001; Redaelli et al., 2014).

The energy emitted in this specific part of the infrared waveband can

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be detected by thermal cameras. Thermal cameras detect differences in temperatures of the target and surroundings and generate images based on the amount of heat generated rather than reflected (Eddy et al. 2001). In correlation with body surface temperature (BST), a colour image illustrating the appropriate temperature values is then displayed. Using this procedure, BST is measured without physical contact with the examined animal (Eddy et al., 2001; Kastberger and Stach, 2003; Soroko et al., 2014).

Infrared radiation emitted from the animal's body surface covers the wavelengths between 3 and 50  $\mu\text{m}$ . Ambient temperature is the main factor influencing the peak emitted wavelength. The higher the ambient temperature, the higher the BST, resulting in the radiation of shorter wavelengths. At lower ambient temperatures, low BST results in the emission of longer-wavelength radiation, whilst short-wavelength radiation is characteristic for high BST as a result of higher ambient temperatures. Given the typical ambient temperature range encountered, longwave thermal cameras are adequate for animal examinations, whilst short-wave thermal cameras are mostly designed for industrial use (Soroko et al., 2014).

The main characteristic of warm-blooded animals is a nearly constant body temperature. To prevent hyperthermia during workload, the redundant heat produced by muscle contractions must be removed from the body. The main mechanisms for heat transfer from the organism to the surroundings are conduction, convection (airflow) and radiation. An important fraction of excessive heat is removed from the horse body by sweat evaporation (Turner, 1991; Eddy et al., 2001; Soroko et al., 2014). Conversely, in a cold environment, thermogenesis is induced to maintain a stable body temperature.

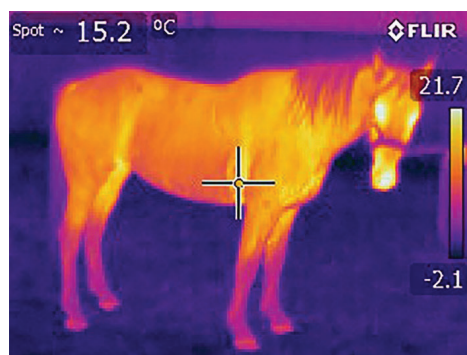
The animal body surface simultaneously loses heat due to emitted infrared radiation and absorbs heat due to infrared radiation emitted or reflected from external sources, such as direct or indirect insolation, other animals or heat-emitting objects. This phenomenon influences the recorded BST (Cena, 1974; Soroko et al., 2014) and can be a major reason for disruption in BST measurements. Therefore, the ability of the body to simultaneously absorb and reflect infrared radiation must be considered when examining animals with thermography (Eddy et al., 2001; Soroko et al., 2014; Soroko and Morel, 2016).

Heat exchange between the body surface and the environment by infrared radiation is essential in the heat balance of the animal (Cena, 1974) but can only take place when there is a temperature difference between the surface of an animal and its environment. The energy emitted from the body surface in the form of infrared electromagnetic radiation is influenced by the physiological processes within the body and environmental conditions, which in turn influences blood circulation under the skin. Detection of infrared radiation is therefore useful for monitoring physiological changes in animals that are reflected by variations in heat production, such as exercise, injury, illness and environmental influence (Purohit and McCoy, 1980; Palmer, 1983; Turner, 2001; Soroko et al., 2014).

## Thermography and the thermographic image (thermogram)

Infrared radiation can be detected and measured using a thermographic camera. The development of thermographic cameras began in the mid-20<sup>th</sup> century, mainly for military and industrial purposes, and shortly after that also for

medical diagnostics. Thermographic imaging developed for use in human medicine was also soon adopted in veterinary medicine (Turner, 2001; Kastberger and Stach, 2003; Purohit 2008; Redaelli et al., 2014; Soroko and Morel, 2016). Modern thermographic cameras provide a suitable technology for use in veterinary medicine, particularly in equine thermography. The cameras are portable and durable, so they can be easily used in challenging natural environments. The spatial resolution of images is high enough to be used from a distance and their thermal sensitivity is less than 0.05 °C. The cameras can capture infrared images and visible-light photographs of the same object simultaneously. As infrared cameras only enable basic evaluation of thermographic images (thermograms), corresponding software is required to accurately analyse scans (Turner, 2001; Kastberger and Stach, 2003; Purohit 2008; Redaelli et al., 2014; Soroko and Morel, 2016).



**Figure 1.** Thermogram of the right side of a horse (measured at an ambient temperature of 15.6 °C). The thermal image shows physiologic differences in pseudocolours related to the circulatory patterns in dermal blood flow.

A thermogram is generated by the conversion of infrared signals into pseudocolour visible-light images. Various nuances of the colour palette

correspond to certain temperatures and create a temperature distribution map of the examined areas. Most commonly, thermograms present the warmest areas in white or red, areas with the intermediate temperature in green and yellow and the coolest areas in blue and black (Soroko and Morel, 2016).

## Factors affecting BST on the horse body

BST directly reflects the circulation and metabolism of the underlying tissue. Consequently, BST thermographic patterns corresponding to superficial vascularity and the body contour of the individual horse can be determined (Turner, 1991; Eddy et al., 2001). An understanding of the normal variations in equine thermal patterns is therefore crucial for understanding and interpreting thermograms. Individual variations of body surface temperatures in horses are influenced by a range of internal factors, such as anatomical structure, density and extent of subcutaneous and muscle tissue, and coat characteristics. Meanwhile, influences of the environmental factors must be taken into account, such as season, type of training and the animal's degree of acclimatisation to the training load (Turner, 1991; Eddy et al., 2001; Soroko and Morel, 2016).

The shape of the horse body surface is uneven as some parts are convex, while others nearly flat or concave. This results in non-uniform emission of infrared radiation energy across the body surface (Cena and Clark, 1973). Concave body parts (such as the area around the base of the neck) and protected areas (such as the area behind the elbow joint) are under a smaller influence of environmental factors and therefore have a higher body surface temperature under normal conditions. Lower surface temperatures are detected around more convex areas (the croup, for example) which are more

directly exposed to environmental factors (Simon et al., 2006; Jodkowska et al., 2011; Redaelli et al., 2014; Soroko and Morel, 2016).

The body surface temperature is significantly influenced by blood flow through the surface vascular network and the metabolism of the underlying tissues (Draper and Boag, 1971; Davy, 1977). Body areas with higher metabolic activity, like the shoulder and croup, have a higher surface temperature. Local perfusion is another important factor influencing the variations of surface body temperature (Simon et al., 2006; Jodkowska et al., 2011; Redaelli et al., 2014; Soroko and Morel, 2016).

The BST of areas overlying veins is normally higher than over arteries due to the more superficial location of veins (for example, jugular veins). Skin lying above or near major vessels (cephalic and saphenous veins, for example) is usually warmer, while skin covering regions with less direct blood supply (such as the metacarpus/metatarsus) appear cooler. The warmest region of the distal limb is the coronary and laminar corium just proximal to the hoof wall, due to presence of the arterio-venous plexus (Turner, 1991; Eddy et al., 2001). Subcutaneous tissues often containing large amounts of stored fat, and therefore absorb heat transferred by deeper-lying arteries and internal organs. Therefore, the arrangement and quantity of subcutaneous tissues also affects the distribution of body surface temperature (Soroko and Morel, 2016).

Skeletal muscles are another important factor influencing BST. Body areas with strong skeletal musculature and a rich blood supply (such as around the neck and upper areas of forelimbs and hindlimbs), have a higher surface temperature compared with the less muscular areas (for example, around the forearm and gaskin) or areas without muscles (such as distal forelimbs, from

carpal joint to the hoof) (Soroko and Morel, 2016).

The coat is also a crucial factor affecting body surface temperature. In environments with low temperatures, such as during winter, the coat becomes longer and thicker. This dense coat strongly absorbs infrared radiation emitted from the skin surface (Cena and Monteith, 1975). Effective insulation against excessive heat loss is held by air trapped in the coat and is a poor conductor of heat with low heat capacity. Consequently, the properties of the coat such as thickness, density, length, and layout have a significant impact on BST distribution (Cena and Clark, 1973; Clark and Cena 1977). Body areas with thinner, less dense or shorter coats, like around the head and flank, have a higher BST compared with areas with thicker, denser or longer hair coats, such as around the croup and pasterns (Turner et al., 1983). Clipping sport horses during the autumn and winter season affects the body surface temperature, with temperatures in clipped areas being higher than in non-clipped areas, thereby affecting thermoregulation. Due to efficient heat exchange by radiation, conduction, and convection, this also prevents sweating, which in turn reduces the risk of hypothermia in a cold environment (Turner et al., 1983). In relation to the length of the coat, body surface temperature distribution also varies between summer and winter. During the summer, hot spots are clearly visible on the thermogram, corresponding to the areas of concentrated superficial blood vessels aimed to increase blood flow and heat exchange between the body and the environment, thus aiding cooling (Eddy et al., 2001; Redaelli et al., 2014; Soroko and Morel, 2016).

Vasoconstriction, which reduces blood flow in superficial blood vessels, is another adaptation to a cold environment. A result of this acclimatization is

a reduced difference between the body surface temperature and the ambient temperature, leading to an appropriate decrease in heat loss (Eddy et al., 2001; Redaelli et al., 2014; Soroko and Morel, 2016).

## BST distribution in the horse

In a resting horse, the BST distribution pattern is a highly individual characteristic, despite being influenced by many environmental factors. BSTs measured by thermography exhibit a high degree of bilateral symmetry (Simon et al., 2006; Jodkowska et al., 2011; Čebulj-Kadunc et al., 2019). BST across an individual horse at rest can range from 19 to 32 °C. The highest BSTs (27–32 °C) are detected on the head, neck, shoulder, upper arm, forearm, and flank and the lowest (24–26 °C) on the distal limb (Flores, 1978). Similar resting BST ranges were also reported by Jodkowska and Dudek (2000) and Jodkowska et al. (2011). They measured the range of highest temperatures (25–28 °C) in the area of the head, the middle part of the neck, chest and flanks, and the lowest temperatures (19–23 °C) in the distal limb. Similar values and distribution of BSTs were also reported in Lipizzaner horses (Čebulj-Kadunc et al., 2019) (Table 1). Resting BSTs in the investigated Lipizzaner horses ranged from 26.5 to

30.4 °C in May and from 22.7 to 28.7 °C in October. The resting BSTs of the same regions were significantly lower in October than in May, and the differences between the BSTs of various regions were significant for both months, indicating different blood supplies to various parts of the skin and different shares of these regions in the thermoregulation functions of the horse.

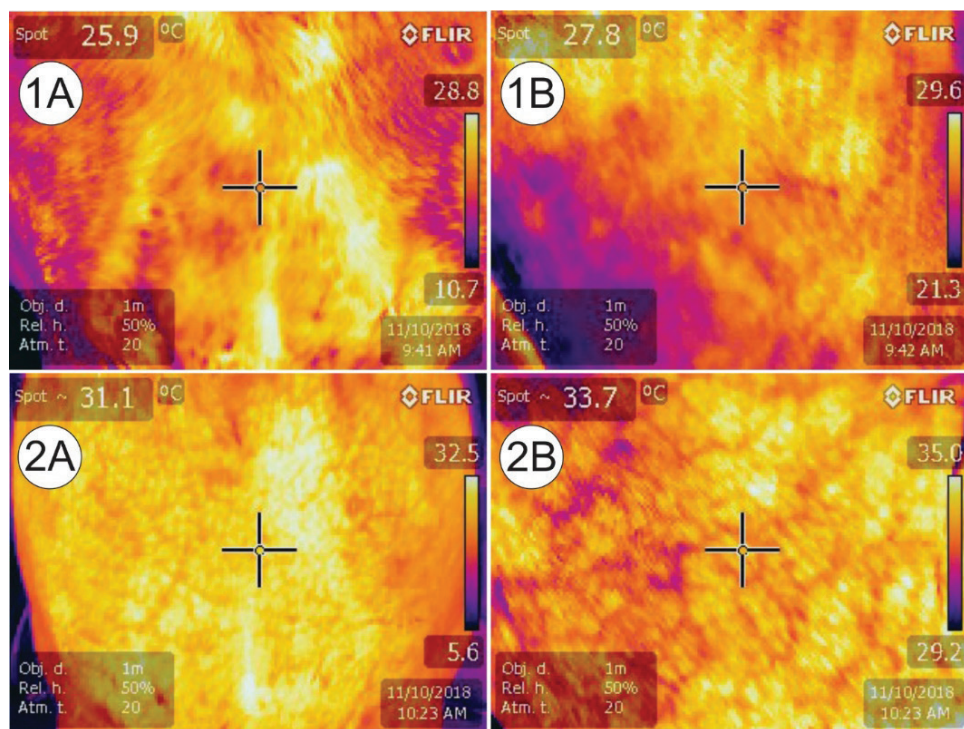
Additionally, higher ambient temperatures were measured in May than in October, indicating the influence of environmental temperatures on the body surface temperatures of Lipizzaner horses, which reduced the efficiency of convection (Čebulj-Kadunc et al., 2019). These differences in temperature ranges between studies highlight the effect and importance of different ambient temperatures (Soroko and Morel, 2016).

At rest, the basal metabolic activity of a horse produces a steady share of heat. During muscle activity, its heat output increases proportionally to the workload. During exercise, almost 75% of the energy used by the locomotor apparatus is dissipated as heat. To maintain the body temperature within the physiological range of 37 to 40 °C, the horse mobilizes thermoregulatory mechanisms, including convection and evaporation (Redaelli et al., 2014). The maximum BSTs in jumping horses after competition were in the range of 25.2 to 34.2 °C, with the highest increase measured at the breast, elbow, forearm, and gaskin, indicating the important role of these regions in heat release during extreme workload. Lower increases in temperature measured at the head, pastern and hoof indicate the minor role of these regions in thermoregulation (Jodkowska et al., 2011). Similar responses of BST to workload were also observed in thoroughbred horses exercised on the treadmill (Simon et al., 2006) and in Lipizzaner horses after graded exercise tests, performed by lunging (Čebulj-Kadunc et al., 2019) (Fig. 2).

**Table 1.** Body surface temperatures ( $\bar{x} \pm \text{s.e.m.}$ ) in various regions of Lipizzaner horses in May and October (Čebulj-Kadunc et al., 2019)

| Body region | Surface temperature (°C) |                |
|-------------|--------------------------|----------------|
|             | May                      | October        |
| Buttock     | 30.2 $\pm$ 0.6           | 26.8 $\pm$ 1.8 |
| Croup       | 26.5 $\pm$ 1.5           | 22.7 $\pm$ 2.2 |
| Back        | 27.7 $\pm$ 1.3           | 24.1 $\pm$ 1.5 |
| Chest       | 30.4 $\pm$ 1.8           | 28.7 $\pm$ 1.1 |
| Neck        | 29.8 $\pm$ 1.6           | 28.0 $\pm$ 1.7 |





**Figure 2.** Thermograms of various body regions in Lipizzaner horses (1 - before exercise; 2 - after exercise; A - chest; B - neck)

## The use of thermography in equine veterinary medicine and equestrianism

Intensive training of the horses is associated with significant physical demands on the musculoskeletal system, contributing to a high incidence of injury, often accompanied by changes in blood circulation and thereby changes in BST. Thermography can detect these changes in BST and hence can be used to diagnose and monitor injury, disease and work overload of the musculoskeletal system (Eddy et al., 2001; Soroko and Morel, 2016).

In veterinary medicine, thermography has been used as a diagnostic tool, complementary to standard radiography and ultrasonographic examinations

since the 1970s (Eddy et al., 2001; Soroko and Morel, 2016). Recent technological advancements in the design and image processing of equipment have made the technology more practical for equine practitioners (Eddy et al., 2001). Since 2010, thermography has been used in the diagnostics, prognosis, and evaluation of a variety of limb injuries, including hoof abscesses, laminitis, tendonitis, inflammation of the fetlock joints, and carpal and tarsal joint inflammations. Several studies have shown the relevance of this method in diagnosis of abnormalities and early signs of pathology of the musculoskeletal system in horses (Turner, 2001; Purohit et al., 2004; Fonseca et al., 2006; Purohit, 2008; Soroko et al., 2013; Soroko and Morel, 2016), and it proved to be successful in monitoring

the effectiveness of anti-inflammatory drugs, recovery from neurological disease and diagnosis of back and limbs diseases (Purohit, 2008; Soroko and Morel, 2016). Using thermography, non-invasive methods for monitoring internal temperature were developed, based on measurements of the surface temperature around the corner of the eye (Johnson et al., 2011; Valera et al., 2012). Other important fields of expertise that successfully use thermography are the evaluation of welfare and acute stress in sports and racing horses (McGreevy et al., 2012; Valera et al., 2012) and assessment of performance in horses during exercise, training and competitions under specific environmental conditions (Turner, 2001; Jodkowska, 2005; Simon et al., 2006; Arruda et al., 2011; Soroko et al., 2014). In addition to the diagnosis of clinical disease, thermography is also useful for evaluating the effects of various topical treatments (such as cold, biomagnets, and ultrasound) on skin temperature (Turner et al., 2001). Thermography has also been evaluated as a potential screening device for the detection of illegal methods used at competitions, such as the application of irritants, infiltration of the injured area with potent analgesic agents, and palmar digital neurectomies (Eddy et al., 2001).

Despite its advantages, it is also important to be aware of certain limitations in the practical application of thermography. The method provides successful localisation and physiological information about changes before they appear as clinical signs or radiographic abnormalities. Nevertheless, it lacks specificity and cannot define the aetiologies of pathological changes. Therefore, thermography should be used in combination with other diagnostic procedures (such as radiography, nuclear scintigraphy and ultrasound) rather than as their replacement (Eddy et al., 2001).

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## Infracrvena termografija u konjskoj praksi

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Termografija je neinvazivna metoda dijagnostičkog oslikavanja za otkrivanje srednjevalnog do dugovalnog infracrvenog zračenja kojeg emitiraju površine tijela, a koje omogućuje prikaz i kvantifikaciju promjena u temperaturi površine kože. Unutar elektromagnetskog spektra, valna duljina infracrvenog zračenja je prevelika da bi ju ljudsko oko otkrilo, premda se obično percipira kao toplina. Zračenje elektromagnetske topline moguće je registrirati termalnom kamerom, a prikazuje se u obliku mape distribucije topline - termograma. Postupak se obavlja bez fizičkog kontakta s ispitivanim predmetom, uključujući životinje. Termografiju je moguće rabiti za određivanje fizioloških i patoloških promjena koje prouzroče promjene površinske temperature konja. Te promjene

odražavaju obrasce protoka krvi i metaboličku brzinu u konja zbog promjena u proizvodnji topline, poput vježbanja, ozljede, bolesti i utjecaja okoline. Termografija se rabi za procjenu nekoliko različitih kliničkih sindroma, ne samo u dijagnozi upale, već i za praćenje napretka zacjeljivanja. Termografija ima važne primjene u istraživanju za otkrivanje ilegalnih postupaka poboljšanja učinkovitosti na sportskim događanjima i za određivanje dobrobiti konja. Unatoč brojnim prednostima, važna je i svijest o određenim ograničenjima povezanim s praktičnom primjenom termografije. Stoga je ovu metodu potrebno rabiti u kombinaciji s ostalim dijagnostičkim postupcima, a ne kao njihovu zamjenu.

**Ključne riječi:** konj; termografija; termogram