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Review Article

Infrared Thermography: Current Applications in Equine Medicine

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A B S T R A C T

Infrared thermography is an imaging technique, mapping body surface temperature changes which may indicate inflammatory, vascular, or neurological disorders. The proper use of thermography to evaluate surface thermal patterns requires a controlled environment and rigorous adherence to an imaging protocol to eliminate errors of interpretation. Thermography plays an important role as a complementary diagnostic tool in veterinary medicine, indicating any areas of abnormality and suggesting where to concentrate further diagnostic imaging or treatment. During the healing process, it can quantify the regression of inflammation or monitor the efficacy of anti-inflammatory medication. However, the specificity and sensitivity of thermography can be limited for many applications, and it is therefore most valuable as an adjunct to other modalities and should always be performed under veterinary guidance. More research is required to confirm the reproducibility of the technique, especially during long-term follow-up. This review considers the evidence for the utility of thermography in equine medicine practice and presents its current advantages and limitations.

1. Principles of Infrared Thermography: Equipment and Quality Assurance

Any object with a temperature above absolute zero will emit radiant energy according to the Stefan–Boltzmann law, which states that the total radiated power is proportional to the fourth power of the object's absolute temperature. This physical law of radiative heat transfer, relating detected power to the temperature of the target, underpins modern infrared thermography [1].

A thermal camera is a device to focus infrared radiation onto a two-dimensional array of detectors which gives an electrical output proportional to the radiant power detected. A modified version of the Stefan–Boltzmann law is then used to calculate the temperature in each part of the field of view, and the output is expressed as an image color coded for temperature known as a thermogram (Fig. 1). Along with visual inspection, thermograms can be processed by thermographic analysis software to extract useful temperature information from the image such as the mean temperature within defined regions of interest.

The efficiency with which a surface emits infrared radiation is termed its emissivity: a theoretically perfect emitter has an emissivity of 1. Biological materials such as skin and hair coat have generally high emissivities, making these surfaces efficient infrared radiators. In equine thermography, a lack of accurate knowledge about the emissivity of the surfaces of the horse may limit the accuracy of temperature measurement. However, in practice, emissivity is usually assumed to be in the range 0.98–1.0, which will have a minimal impact on temperature accuracy ($<0.5°C$) [2].

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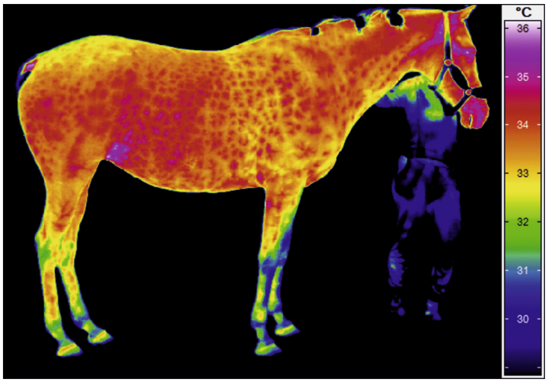

Fig. 1. Infrared thermogram of the right lateral aspect of a healthy horse.

For equine thermography, an ideal thermal camera should

- be portable and rugged, since it will be used in demanding environments,
- have a high spatial resolution, since large animal thermography is often performed at distances of several meters from the subject. High resolution allows for maximum image detail, and it means more pixels are included in the analysis of specific regions of interest. An affordable entry-level imager may have a detector array size of 320 × 240 elements. Superior image detail can be obtained with 640 × 480 pixel arrays,
- have a high thermal sensitivity, which is a property describing the smallest difference in temperature a thermal imager can resolve between two points in the image. Many modern portable cameras have thermal sensitivities of <0.05°C. Note that this thermal sensitivity across the image is not an indication of the absolute accuracy of the temperature readings (which is typically specified by the manufacturer as ±1°C or ±2°C).

In addition, a thermal imager should undergo a rolling programme of quality assurance to ensure its output remains accurate to within manufacturer specifications and repeatable [3]. A “blackbody source” can be used to perform quality assurance on a thermal camera. The cavity of the device is heated across a range of temperatures, and thermograms are recorded to ensure the imager gives the correct readings across the range. This procedure should be performed at least annually by the camera manufacturer, although it may be cost effective for the thermography practitioner to purchase a blackbody for quality assurance “in-house.” The blackbody should give readings traceable to the International Temperature Scale of 1990 (ITS-90) [4].

2. Procedures for Thermographic Examination

Thermography uses an infrared camera to record the distribution of body surface temperature of a horse [5]. It is highly sensitive to superficial temperature changes that may indicate inflammatory, vascular or neurological disorders, or physiological responses to changing environmental conditions [6,7]. Thermography is at least 10 times more sensitive than palpation by the human hand in detecting temperature change [8,9]. Thermography is an adjunctive technique: the images obtained must be further investigated to ascertain the causes of temperature variations [10].

Both internal and external factors have a significant effect on body surface temperature [11]. The proper use of thermography to evaluate surface thermal patterns therefore requires a controlled environment, and the physiological state of the horse must be considered to reduce variability and eliminate errors of interpretation [12]. Indoor thermography measurement standards have been established in equine veterinary practice [13,14], and to enhance the diagnostic value of thermography, a rigorous protocol should be adopted, details of which are available as Supplementary Information.

3. Normal Superficial Temperature Distribution and the Interpretation of Abnormal Findings

A normal thermographic pattern (Figs. 2 and 3) can be mapped to correspond to the superficial vasculature of the horse [6] and has a high degree of symmetry between left and right sides of the body [15]. The warmest areas of the forelimbs are along the main blood vessels: the palmar and digital arteries and also the palmar veins from the lateral and medial aspects [16]. Similarly, the warmest areas in the hindlimbs are along the plantar and digital arteries and also the plantar veins from the lateral and medial aspects [17]. In the healthy horse, body temperature along the midline of the spine of a horse at rest can be up to 2–3°C higher, at the thoracic and lumbar vertebrae, than seen laterally on either side of the back [18]. However, there has been little objective work published on the reproducibility and reliability of body surface temperature within groups of horses to provide a normal baseline for users [12]. Tunley and Henson [19] showed reproducibility of the thermal patterns over the horse back over hourly, daily, and weekly intervals at the confidence limit of 90%. Although Purohit and McCoy [16] demonstrated consistent general characteristics of thermal patterns, the horses in their study presented with a wide range of absolute body surface temperatures. Westermann et al [20] reported that thermographically determined forelimb temperatures were unaffected by 20° changes in camera angle or a 0.5 meter increase in camera distance.

Thermographic evaluation of the distal parts of the limbs is complicated by their enhanced thermoregulatory role. The surface temperature of the distal parts is unstable at low-ambient temperatures, probably because of periodic cutaneous vasodilator activity [11]. Asymmetry in surface temperature of the distal parts of limbs thus appears to be normal under low-ambient temperature conditions and does not necessarily indicate pathology. In the study by Palmer [15], skin surface temperature variations at three different ambient temperatures (5°C; 15°C; and 25°C) were greater in the distal parts of the limbs compared to the other parts of the body. In 88% of the pairs of measurements made from contralateral limb regions, the temperature difference was ≤1°C. However, a few contralateral