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Review

The Role of Thermography in the Management of Equine Lameness

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SUMMARY

Equine thermography has increased in popularity recently because of improvements in thermal cameras and advances in image-processing software. The basic principle of thermography involves the transformation of surface heat from an object into a pictorial representation. The colour gradients generated reflect differences in the emitted heat. Variations from normal can be used to detect lameness or regions of inflammation in horses. Units can be so sensitive that flexor tendon injuries can be detected before the horse develops clinical lameness. 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.

KEYWORDS: Equine; thermography principles; lameness; research.

INTRODUCTION

The electromagnetic spectrum is composed of wavelengths that range from the shortest gamma rays, to X-rays, ultraviolet light, visible, infrared, microwave, and the longest radio waves. Within this spectrum, humans perceive only a very small region known as visible light. Infrared radiation, which is detected by thermal cameras, is emitted by all objects proportional to their temperature. This radiation can be absorbed, emitted, reflected, or transmitted. Emissivity refers to the object's ability to absorb and emit infrared radiation and is considered more significant than reflection, which is the ability to simply reflect the infrared radiation. An object's classification as reflector or emitted is a function of its inherent material properties. Brick, for example, has excellent emissivity but is a poor reflector, while metals generally have the opposite properties. Emissivity is important in considering thermal images since the ability of a material to emit or reflect heat should be considered in the interpretation of an image. Thermal cameras generate images based on the amount of heat generated rather than reflected. More specifically, they actually detect differences in temperatures of the target and surroundings. This is important in designing the time and environment in which thermal scans are performed. For example, at midday, a horse may appear to blend into the background because its body temperature is similar to that of the wooden stall door in the background. However, after nightfall, the stall door will have liberated the majority of its heat and the horse will exhibit a much more striking contrast to the background.

Similar to visible light, infrared radiation can be optically focused, collected, and transformed via detector arrays to an electronic signal. The detectors within the camera are complex arrays composed of barium strontium titanate (BST), which is temperature sensitive. These detectors have pyroelectric properties that are influenced by the temperature and infrared radiation generated by an object. When temperature changes occur in the BST, a pyroelectric

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signal is interpreted by intricate circuitry within the detector and an electronic signal is generated. This signal can then be translated via integrated circuits and software into a video signal and displayed with varying colours reflecting differences in the heat emissions gathered from the target. Since the variable measured is heat and not light, thermal cameras are not affected by the intensity or quantity of light in the scene. This property is also enhanced since infrared cameras generally operate in the long-wave infrared region (7–14 μm) which is less affected by sunlight compared to the shorter waves.

Objects transfer heat energy to their surrounding environment via three mechanisms. Conduction refers to the transfer of energy between two solid bodies with different temperatures that are in direct contact. Heat can also be conducted within the same body when there is a discrepancy in temperature from one regional area to another. The second mechanism is convection, whereby heat is transferred via the movement of a liquid or gas such as water or air. Finally, radiation refers to heat transfer by the electromagnetic radiation that an object emits in all directions without the need for any solid or fluid medium. The thermographic cameras now available to veterinary practitioners are state-of-the-art devices that generate detailed images with exquisite sensitivity to temperature variation. The common cameras used include the DTIS-500 camera (Emerge Vision Systems), ThermaCam (Inframetrics), and Thermacam PM595 (Flir Systems). Thermography is a non-invasive, non-contact diagnostic technique that measures heat emitted from a targeted surface and displays the information as a pictorial representation. Variations in the colour pattern reflect thermal gradients (Fig. 1). The warmest areas are depicted as white or red, while the coolest regions appear blue or black. It can augment other modalities in diagnosing equine lameness and back pain. While thermography does not reveal specific pathologies, it facilitates the localization of increased (inflammation and/or injury) or decreased heat (reduced blood flow or vasomotor tone).

Skin temperature directly reflects the underlying circulation and tissue metabolism; therefore, normal thermographic patterns can be mapped to correspond to the horse's superficial vascularity and body contour (Turner, 1991). An understanding of the normal variations in equine thermal patterns is crucial to interpretation of the scans in clinical cases. Skin overlying or in close proximity to major vessels (cephalic and saphenous veins, for example) will generally appear warmer. Areas distant from a major blood supply, such as the dorsal metacarpus/metatarsus, fetlock, and pastern, appear cooler. Because of its arterio-venous plexus, the coronary and laminar corium just proximal to the hoof wall is the warmest region of the distal limb. The route of the median palmar vein in the forelimbs (Fig. 2) and the metatarsal vein in the hind limbs produces a warm region between the third metacarpus/metatarsus and the flexor tendons. The tendons are relatively cool from the palmar/plantar view, with the area between the bulbs of the heels emitting the most heat (Turner, 1991).

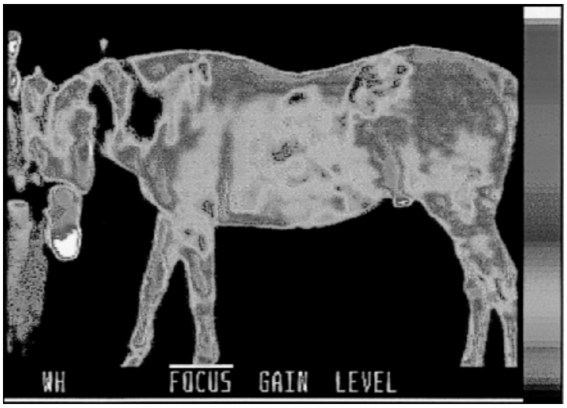


Fig. 1. Thermographic images are a pictorial summary of the heat gradients generated by an object. Variations in heat are represented by different colours. The hottest areas are white and red while the cooler regions are represented by the darker blues and black.

The use of thermography to assist in the diagnosis and prognosis of inflammatory conditions has been available to the human and equine practitioner for several years. Recent technological advancements in the design and image processing of the equipment have made the technology more attractive to equine private practitioners such that the equipment is no longer reserved for affluent practices or universities. With horses, thermography has proved useful in the diagnosis, prognosis, and evaluation of soft tissue injury or disease, and superficial orthopaedic lesions, where the bone is covered by minimal soft tissues (Turner, 1991). Some recent innovations include improved resolution, more user-friendly image processing software, and uncooled camera technology (von Schweinitz, 1999). A system suitable for evaluating horses should include a camera with a 20°–30° lens angle, the capability to position the camera 1.5 to 2 m above the horse's back, and temperature band gradients adjustable to 0.5°–0.6°C (von Schweinitz, 1999; Fig. 3).

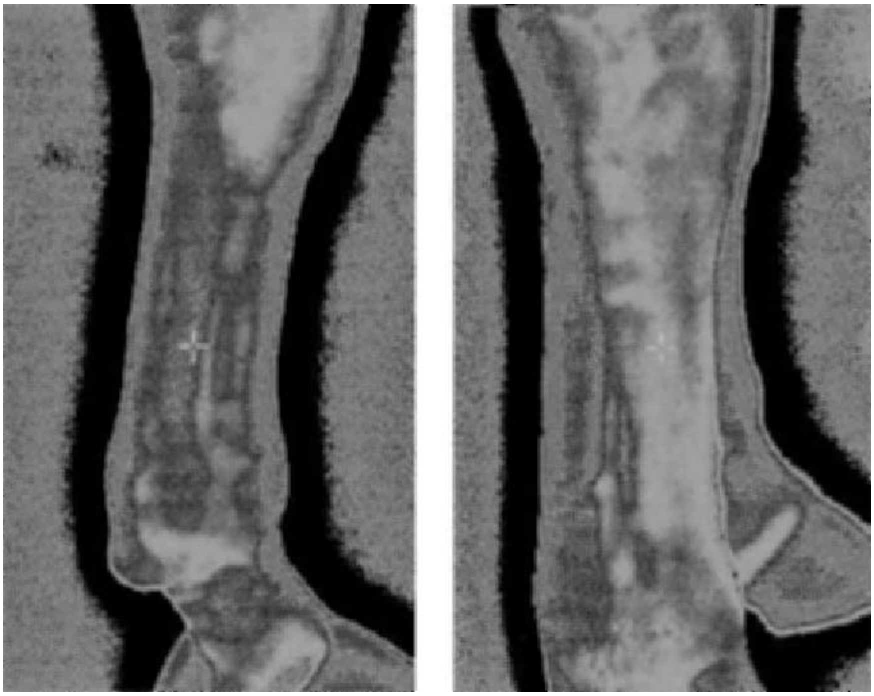


Fig. 2. Regions in close proximity to large vessels will appear to be warmer than more distant regions. Therefore, the medial aspect (A) of the limbs will normally appear warmer than the lateral aspect (B) of the limb.

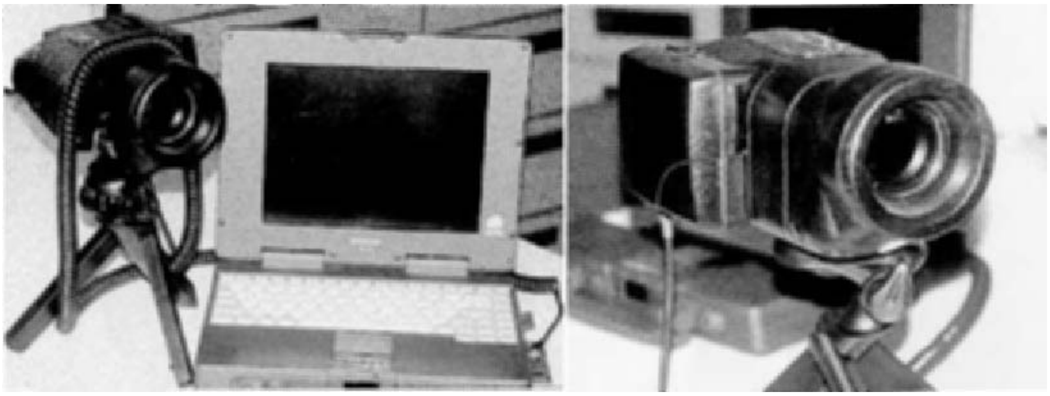


Fig. 3. The thermographic camera is a lightweight hand-held portable device which can be connected to a laptop computer or monitor for image projection. Using integrated software, the images can also be downloaded and processed in the laptop and subsequently stored for data analysis or printed immediately. (The image on the left is reprinted with permission from the *Equine Veterinary Education*).

A controlled environment is essential to a successful thermographic scan (Fig. 4). If available, stocks can be used to facilitate immobilization of the horse and ensure the safety of the personnel and equipment. Scans should be performed in a draught-free area with low light, a temperature of less than 30°C (ideal temperature about 20°C), and a 10–20 min acclimation period (Turner, 1991). The horse must have a clean, dry hair coat and skin, and should not be groomed within 2 h before the scan. Topical agents should not be applied prior to the scan and any residues should be washed off the previous day. The patient should not receive physical therapy within 24 h of the exam and should not have acupuncture in the region of the thermographic scan during the previous week. Exercise and sedation (especially α_2 agonists) should be avoided because of their effects on blood flow and superficial perfusion. Information that should be recorded includes presence of focal lesions,

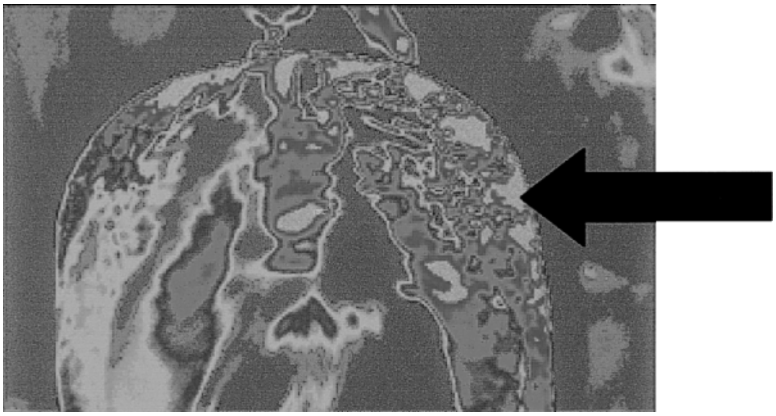


Fig. 4. Thermographic image taken of a horse immediately following exposure to the sun on the right side of the body (*arrow*).

recent injections, and ambient temperature and humidity if excessive (von Schweinitz, 1999).

Before scanning, the thermal sensitivity must be adjusted to detect hairless sites, such as the muzzle or eye, at the uppermost range. Hairless or clipped regions will appear warmer because hair insulates against the emission of infrared radiation. With the horse standing straight and square, the minimum views include the following regions: cranial pectoral, lateral neck and body, lateral pelvic limb, dorsal limbs (all four), caudal hind limbs, thoracolumbar dorsal spine, and lumbosacral dorsal spine (von Schweinitz, 1999). Repeated scans of suspect areas to assure reproducibility will yield more reliable information. Two to three scans should be performed at least one minute apart (Turner, 1991).

There are many factors that can compromise the quality of the scan. In addition to extreme climates, anxious or active patients can have significant skin temperature reductions due to increases in sympathetic tone. Variation in time given to equilibrate the patient after transport, arrival into a temperature-controlled environment, or removal of blankets and bandages can also alter results. Variables in winter hair coats and clipping patterns confound interpretation (von Schweinitz, 1999).

CLINICAL APPLICATIONS

Tendons and ligaments

In the acute phase, tendonitis is detected as a focal increased area of heat in the normally elliptical isothermic zone (Fig. 5). As lesions heal, the pattern becomes more normal, but the overall temperature of the tendon remains elevated. 'Hot spots' can be detected thermographically up to two weeks before clinical evidence of swelling or pain. This permits early detection of lesions and appropriate changes in training routines (Turner, 1991). Ligament injuries such as suspensory desmitis can also produce 'hot spots', and thermography can be used in conjunction with the physical examination to detect and/or confirm areas of palpable pain (Turner, 1991).

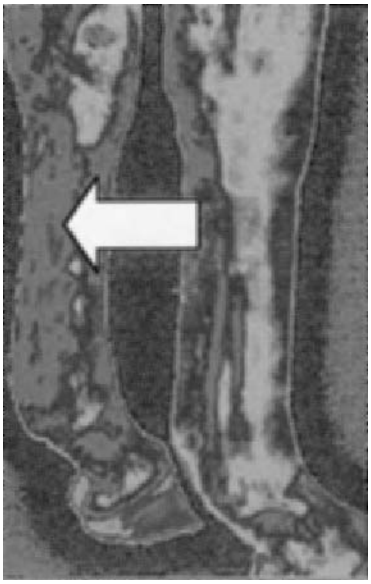


Fig. 5. Injuries to the flexor tendons will cause an increased thermal pattern relative to the adjacent regions (*arrow*).

Feet

Thermography can aid in the detection of numerous diseases of the foot including laminitis, navicular disease, abscesses and corns. It may help reveal disease in the early phase or when physical and radiographic findings are inconclusive. Temperature differences greater than 1°C between any of the

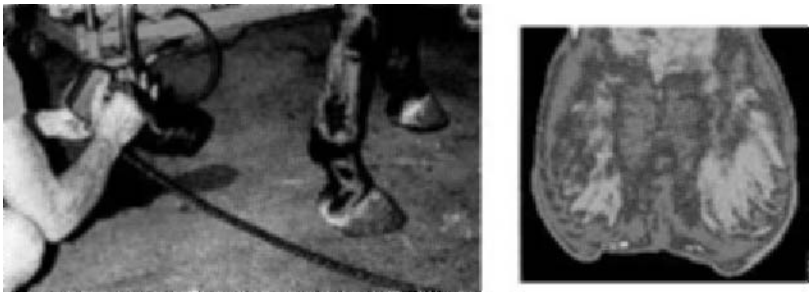


Fig. 6. The caudal aspect of the foot is best imaged with the limb extended slightly caudally (A). The warmest regions in the caudal foot are between the bulbs of the heel (B).

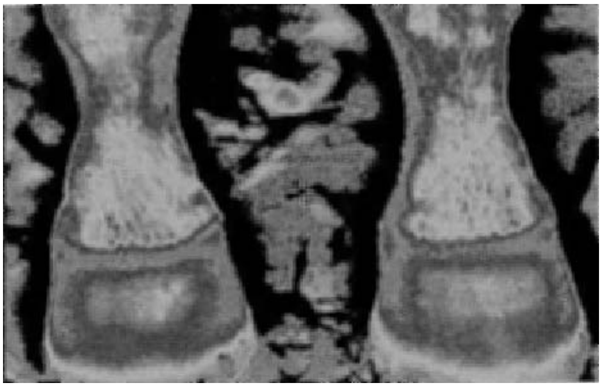


Fig. 7. Thermal image of normal feet. The hottest region is located on the coronary band which corresponds to the superficial blood flow patterns.

hooves are abnormal (Figs 7 & 8). If all four feet are involved, the temperature of the feet between the heel bulbs should be measured. A difference of more than 1°C between the feet is significant (Turner, 1991).

Laminitis is detected as an increased temperature change between the warmer coronary band and the hoof wall. Normally this difference is between 1°C and 2°C. Thermography can be useful in detecting laminitis before clinical signs appear and can be used to monitor patients at high risk of becoming laminitic (Turner, 1991). Navicular disease, unlike most foot abnormalities, is characterized by a reduction in blood flow and temperature rather than by inflammation and a temperature increase. Normally there is a 0.5°C increase in temperature in the foot after exercise. Horses with navicular disease do not have this increase because of compromised blood flow (Turner, 1991).

Joint disease

While radiography is the preferred method for evaluating osseous changes, thermography reveals inflammation associated with capsulitis and synovitis (Fig. 9). Most inflamed joints exhibit an oval area of increased heat centered over the joint when viewed from lateral to medial. The pastern is an exception to this rule. It exhibits a circle of decreased heat surrounded by a peripheral area of increased heat. Thermography of joints can reveal alteration in thermal patterns two weeks prior to onset of clinical signs. This permits alteration in training and close observation to prevent more serious disease (Turner, 1982).

Long bone injury

Thermography has limited use in evaluating bony abnormalities because the majority of bone is separated from the skin by soft tissues. However, thermography is very useful in the diagnosis of dorsal metacarpal disease (sore shins or bucked shin complex). Grade 1 (pain, but no radiographic pathology) and grade 2 (pain with radiographic evidence of callus) disease appears as a hot spot over the dorsal third metacarpal bone that is 1–2° warmer than surrounding tissue. Grade 3 lesions (pain and radiographic evidence of a stress or fatigue fracture) appear as hot spots on the lateral or medial aspect of the third metacarpal bone rather than on the dorsal aspect. Grade 3 lesions are 2–3° warmer than surrounding tissue. Since thermographic changes precede radiographic changes by two weeks, detecting grade 3 disease early may prevent a stress fracture from becoming complete with continued training (Turner, 1991).

Hind limb myopathy

Hind limb myopathy can be difficult to document and monitor objectively. Myositis can be detected as a generalized increased thermal pattern over the affected gluteal region (Fig. 10). Inflammation in the cranial thigh appears as hot spots associated with the quadriceps proximal to their insertion of the

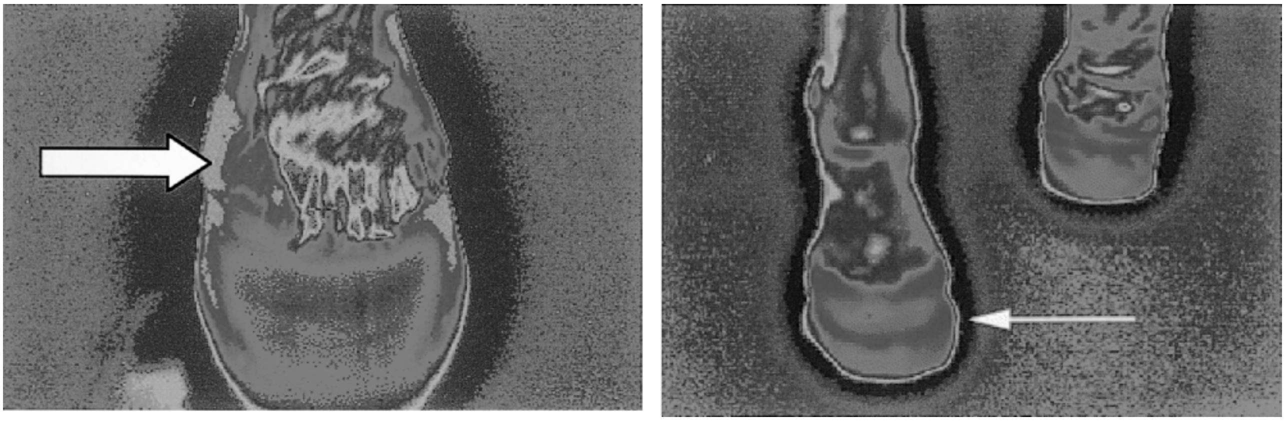


Fig. 8. A: Thermal image of a foot abscess which eventually drained at the coronary band. Notice the increased heat pattern located on the lateral aspect (*arrow*). B: Thermal image displaying the heat pattern of laminitis. Notice the increased pattern on the coronary band as well as the bands of heat on the dorsal aspect of the hoof (*arrow*).

Fig. 9. Increased heat patterns associated with an inflammed fetlock joint.

patella. Caudal thigh inflammation is most commonly visualized at the musculotendinous junction of the semitendinosus muscle, and less frequently as inflammation caudal to the third trocanter of the femur. The loin, sacroiliac region, body of the gluteal muscle, and the biceps femoris appear hot when the croup region is injured (Turner, 1996). In a study of horses with croup or caudal thigh myopathy, 20 of 23 horses with palpable areas of pain had corresponding abnormal areas noted during thermographic scans. Once areas of inflammation have been observed, thermography can be used to evaluate progress in the convalescence period (Turner, 1989).

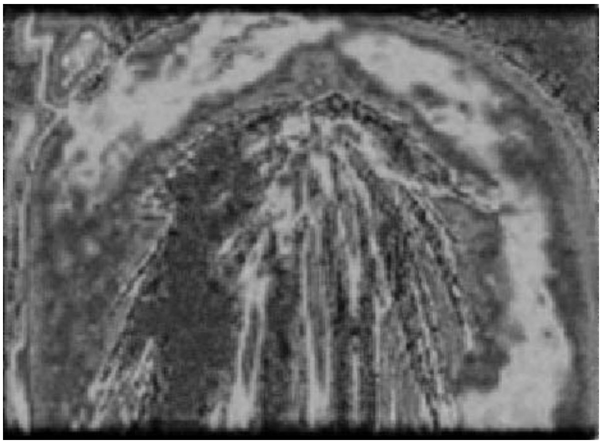


Fig. 10. Increased pattern present on the medial and lateral aspects of the gluteal regions in a horse with myositis.

Neck and back

Thermography is also useful in identifying and localizing spine-related disease (von Schweinitz,

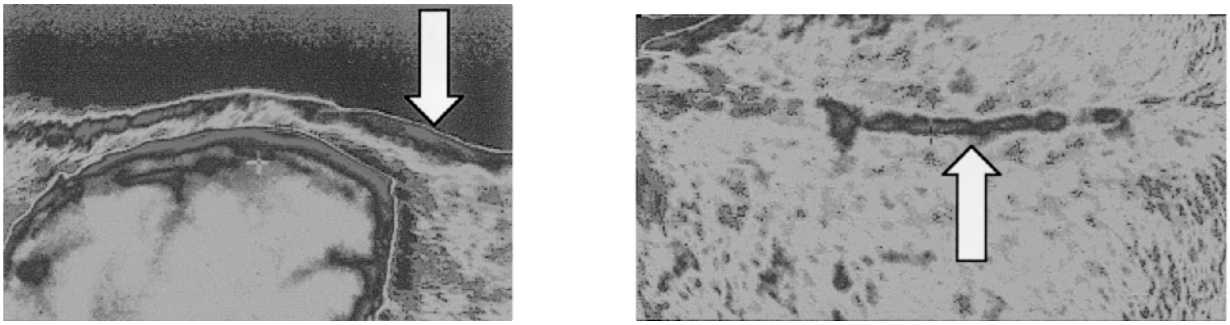


Fig. 11. A: Lateral thermal pattern of the back of horse with palpable pain caused by a poorly fitted saddle. Increased heat is present in the saddle location (*arrow*). B: Dorsal view of the same horse showing increased heat (*arrow*) over the dorsal spinous processes in the saddle region.

1999; Fig. 11). Such problems may manifest as palpable back pain, training difficulties, or behavioural abnormalities. In addition to depicting the physiological status of local tissues, thermography also relates information about neural outflow from the spine. Other tools, including radiology, ultrasound, and nuclear scintigraphy, are limited in their ability to reveal information about equine spinal disease. In a recent study (von Schweinitz, 1999), 53 horses with vague locomotion or behavioral abnormalities and clinical signs consistent with back disease had neuromuscular disease of the thoracolumbar region. Clinical signs in these cases included pain on palpation, pain elicited at acupuncture and trigger points, spinal distortion, restricted flexion, abnormal posture or movement, muscular abnormalities (irritability, asymmetry, atrophy, spasm), and poor hair and skin in the affected areas (von Schweinitz, 1999).

Thermography is useful in these cases because alteration in skin temperature corresponds to changes in the sympathetic autonomic nervous system (i.e. vasomotor tone). Vasomotor tone alteration is often associated with back pain and shows up thermographically as a region of decreased temperature (cold spot). Rather than being inflammatory in origin, chronic back disease in the horse is now considered to be a sympathetic associated pain syndrome. These disorders seem more amenable to treatment with acupuncture, exercise management, and other physical therapies than conventional anti-inflammatory medications (von Schweinitz, 1999).

LIMITATIONS/ADVANTAGES

Like other diagnostic tools, thermography is most useful when its limitations are recognized. Equipment is expensive, and therefore may not be within the financial means of all practices. While thermography provides localization and physiological information, it lacks specificity and cannot define aetiologies. Generally, thermography is best used in combination with other modalities rather than as a replacement for them.

Even with these limitations, however, thermography has much to offer. It is non-invasive and involves no radiation exposure. When used for serial evaluations, it helps monitor response to treatment. It is more sensitive than palpation for detecting subtle temperature variations. This high sensitivity makes it useful in conjunction with other modalities that provide more specific information (such as radiography, nuclear scintigraphy, and ultrasound). Thermography often reveals physiological changes before they appear as clinical signs or radiographic abnormalities, thus providing early warning and a chance to alter training schedules or initiate treatment. At the University of California Davis Veterinary School, we attempted to correlate the findings of thermographic scans with other diagnostic modalities – specifically ultrasound, nuclear scintigraphy, and radiology. We were interested in determining whether we could detect injuries or lesions with thermography that could then be confirmed or disputed with another diagnostic procedure. Horses that presented to the teaching hospital for various orthopaedic or musculoskeletal injuries were evaluated thermographically using routine scanning protocols. Although we were unable consistently to evaluate the horses at a specific time, we attempted to minimize temporal variation by scanning the horses within an enclosed room which generally was maintained at a constant temperature. The horses included in this preliminary study included those presented for nuclear scintigraphy of limbs for potential humeral and tibial stress fractures, ultrasound examination of the distal limbs for tendon or ligament injury, and horses where a radiographic examination was performed based on the findings of a lameness examination. Horses were included only if they displayed a current lameness.

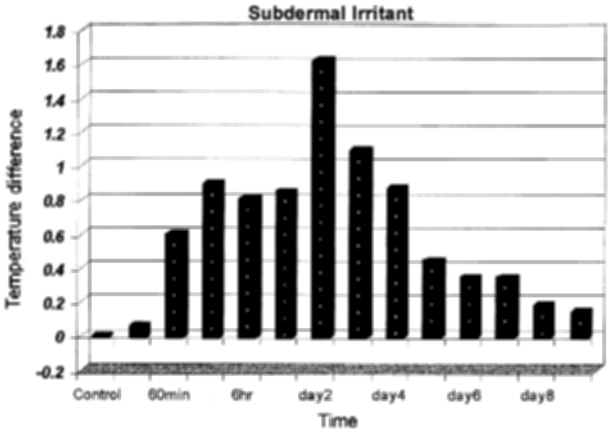
In some cases, the regions of the lameness was known (e.g. the horse improved with a low 4 point nerve block), but in others, such as the nuclear scintigraphy cases, no specific site was designated. For this study, we evaluated a total of 64 horses divided into 15 with ultrasound, 20 with nuclear scintigraphy, and 29 with radiographic examinations. Thermography was 62.5% successful in collaborating the location/source of the injury with these three diagnostic modalities. In horses presenting for ultrasound examination, the affected site was warmer than the surrounding area or contralateral structure in 10/15 (66.7%) cases. Thermography correlated with nuclear scintigraphy in 15/20 (75%) cases. Horses with stress fractures of the tibia were identified fairly consistently while humeral stress fractures were less reliably noted. This is likely due to the increased muscle mass over the humerus compared to the medial aspect of the tibia which would blunt heat transmission from a stress fracture and associated soft tissue inflammation. Compared to the other two diagnostics, thermography correlated less effectively with radiography (15/29; 51.7%). This is probably the result of a reduced ability of thermography to detect subtle or chronic bony lesions causing lameness. For example, horses with degenerative joint disease of the hock (bone spavin) while lame, did not exhibit an increased thermal difference. Potentially, the amount of heat generated from chronic and low grade arthritis is not sufficient to reveal a detectable difference. Other lesions such as degenerative joint disease of the pastern and coffin joints (ringbone) did not exhibit a consistent thermal difference. Again, it is possible the associated inflammation may not be sufficient to detect.

RESEARCH APPLICATIONS

In addition to 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.*, 1989). In this study, a gel wrap cooled to 4°C and heated to 40°C was applied to the metacarpus. With cold therapy, the treated limb remained 2.5°C cooler than the untreated leg by 2 h, and by 4 h the dorsal metacarpus remained 4°C cooler than the control leg. The heated wrap produced temperature differences between the limbs which actually increased with time. Thirty minutes after removal of the wrap, the difference was 2.8°C and increased to 3.7°C after 75 min. No significant difference was seen between biomagnets and placebos applied to the flexor tendon region for 24 h. Finally, therapeutic ultrasound applied to the flexor tendon region for 10 min significantly increased the thermal pattern on the treated limbs in an intensity-dependent fashion which was sustained for more than one hour.

An area which has received increased interest recently is the use of thermography to detect illegal activity at performance events. Intense pressure to win can, unfortunately, promote the use of illegal performance-enhancing techniques designed to enhance a horse's athletic ability or appearance artifically. Although pharmaceutical screening at competitions reduces the overt use of chemical performance-enhancing agents, some competitors have become creative at evading detection using procedures which would not be detected on a routine drug screen. Examples of these techniques may include the application of counter-irritants such as mercuric iodide to the dorsal aspect of the pastern or metacarpus, subdermal injection of irritants to accentuate limb flexion, regional nerve blocks, infiltration of the injured area with potent analgesic agents, and palmar digital neurectomies since foot pain is a common cause of lameness in performance horses.

Thermography has recently been evaluated as a potential screening device in studies that recreated some of the illegal methods used at competitions. An early study by Turner and Scroggins (1989) found thermography could successfully detect the application of irritants on the perineal region to accentuate tail carriage. An investigation of the ability of thermography to detect illegal procedures was recently published (van Hoogmoed *et al.*, 2000). This study was designed to evaluate the ability of thermography to identify irritants applied to a horse's limb and determine how long these effects could be detected. Specifically, counter-irritants were applied topically and injected subdermally on the dorsal aspect of the pastern, and metallic irritants in limb bandages were applied to the limbs to induce metacarpal hypersensitivity. In this study, we found thermography detected changes in skin temperature following subdermal injection of hypodermin for up to eight days. The topical application of mercuric iodide on the pastern produced an increased heat pattern which remained significantly elevated for six days. Metallic bottle caps in the leg wraps produced a unique thermal pattern that persisted for 24 h. The skin directly under the caps remained cool relative to the surrounding skin because sweat drops produced by the presence of the caps lowered the local temperature (Table I).



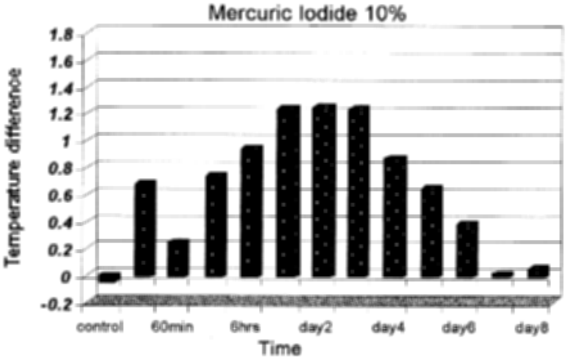


Table I
Summary of the mean (±SD) of the temperature difference between the treated and control limb following three hypersensitization techniques. (Reprinted with permission from *Equine Veterinary Education*).

Time	*Mean±SD*	*P-value*
Control	−0.00±0.23	0.95
30 min	0.06±1.06	0.79
60 min	0.60±0.78	0.003
2 h	0.89±0.55	< 0.0001
6 h	0.81±0.75	< 0.0001
Day 1	0.85±0.45	< 0.0001
Day 2	1.62±0.69	< 0.0001
Day 3	1.10±0.62	< 0.0001
Day 4	0.86±0.47	< 0.0001
Day 5	0.45±0.45	< 0.0001
Day 6	0.35±0.44	0.001
Day 7	0.35±0.42	0.0005
Day 8	0.18±0.32	0.01
Day 9	0.15±0.46	0.12

Time	*Mean±SD*	*P-value*
Control	− 0.04±0.16	0.24
30 min	0.67±0.48	< 0.0001
60 min	0.24±0.33	0.0013
2 h	0.74±0.87	0.0005
6 h	0.93±0.81	< 0.0001
Day 1	1.24±0.54	< 0.0001
Day 2	1.25±0.62	< 0.0001
Day 3	1.23±0.74	< 0.0001
Day 4	0.87±0.75	< 0.0001
Day 5	0.64±0.77	0.0004
Day 6	0.38±0.38	< 0.0001
Day 7	0.02±0.25	0.75
Day 8	0.05±0.38	10.46

Time	*Mean±SD*	*P-value*
Control	− 0.01±0.27	0.91
Immediate	0.90±0.89	< 0.0001
30 min	0.25±0.33	< 0.0001
60 min	0.94±0.53	< 0.0001
90 min	1.15±0.68	< 0.0001
2 h	0.80±0.66	< 0.0001
4 h	1.08±0.90	< 0.0001
6 h	0.74±0.59	< 0.0001
Day 1	0.43±0.58	0.003
Day 2	0.00±0.36	0.967

One limitation of thermography in this type of investigation is a lack of specificity, since it displays a thermal pattern which does not necessarily differentiate between agents. Although the patterns were not unique, for example between the hypodermin and the mercuric iodide, it was apparent the scans were not normal. The results of this study suggest that infrared thermography is sensitive enough to detect the application/injection of various agents in the distal limbs of horses. Further investigation is required to determine whether thermography can detect other techniques such as the injection of anti-inflammatory agents and, potentially, neurectomies. Realistically, with the exception of techniques like bottle caps, which leave a very definitive trademark of illegality, it would be difficult to disqualify a horse based on a single thermographic scan alone. If thermography is used as a screening device to detect illegal activity at competitions, we recommend that it be used in conjuction with other methods such as determination of skin sensitivity or physical examination of the area.

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