Lameness is the leading cause of wastage in horses. That is from an economic stand point, lameness causes the largest amount of economic loss to the horse owner over all other causes. This underscores the need for the early and accurate diagnosis of lameness. Thermography is the pictorial representation of the skin temperature of an object. It is a non-contacting, non-noxious modality. Since heat is one of the cardinal signs of inflammation and therefore injury, thermography is an ideal modality for the evaluation of lameness in horses.

Thermography provides the examiner with the opportunity to examine the entire horse. When combined with a thorough clinical examination, these methods are extremely useful in identifying soft tissue injuries that may have otherwise gone undetected.

Thermography is the pictorial representation of the surface temperature of an object.\textsuperscript{5,12} It is a non-invasive technique that measures emitted heat. A medical thermogram represents the surface temperatures of skin making thermography useful for the detection of inflammation. This ability to non-invasively assess inflammatory change, makes thermography an ideal imaging tool to aid in the diagnosis of certain lameness conditions in the horse.

Heat is perpetually generated by the body, and it is dissipated through the skin by radiation, convection, conduction, or evaporation.\textsuperscript{12} Because of this, skin temperature is generally 5°C (9°F) cooler than body core temperature (37°C). Skin derives its heat from
the local circulation and tissue metabolism. Tissue metabolism is generally constant, therefore variation in skin temperature is usually due to changes in local tissue perfusion. Normally, veins are warmer than arteries because they are draining metabolically active areas. Superficial veins will heat the skin more than superficial arteries, and venous drainage from tissues or organs with a high metabolic rate will be warmer than venous drainage from normal tissues.

The circulatory pattern and the relative blood flow dictate the thermal pattern that is the basis for thermographic interpretation. The normal thermal pattern of any area can be predicted on the basis of its vascularity and surface contour. Skin overlying muscle is also subject to temperature increase during muscle activity. Based on these findings, some generalizations can be made regarding the thermal patterns of a horse: the midline will generally be warmer. This includes the back, the chest, between the rear legs, and along the ventral midline. Heat over the legs tends to follow the routes of the major vessels, the cephalic vein in front and the saphenous vein in the rear.

**SPECIFIC USES**

**The Foot**

Thermography of the hoof has been useful for the diagnosis and evaluation of several conditions of the foot. Laminitis, palmar foot pain, subsolar or submural abscesses, corns and any other inflammatory condition of the hoof are specific conditions where thermography provides valuable information concerning the disease. Obviously, thermography is not needed to definitively diagnose these problems. Thermography does however, provide additional information that is helpful in localizing the problem, assessing the degree of inflammation associated with it, and deciding the best course of treatment.
Thermographic evaluation is particularly helpful with early or occult conditions of the foot, where the physical and/or radiographic examination findings are inconclusive.

Normally, the coronary band is the warmest area of the leg and because of this, inflammation of this area can be difficult to detect.\(^5\) The hooves should be thermographically compared in several ways. Comparisons should be made between all four hooves, front to front and front to rear. A difference of more than 1°C between hooves is significant. In cases where all four feet are involved, comparisons of the hoof temperature with the temperature of the area between the bulbs of the heel should be made. A difference of more than 1°C between any of the four feet is significant.

Laminitis is characterized by inflammation of the laminar structures of the hoof. A change in thermal pattern of the hoof wall is useful in recognizing laminitis. Generally, the coronary band is 1-2°C warmer than the remainder of the hoof. As the hoof begins to approach the temperature of the coronary band, this indicates an inflammatory problem (Figure 1). Thermography can be very beneficial in the progressive convalescent evaluation of a limb contralateral to an injured limb, where laminitis is a potential sequelae to increased weight-bearing stressed placed on that contralateral limb. Thermography makes it possible to detect inflammation in the contralateral foot well before lameness is evident. Preventative therapy can therefore then be instituted sooner in the course of disease and hopefully before the laminitis is irreversible.

Thermography is also an excellent method of evaluating the patient with palmar foot pain syndrome.\(^11\) The author has never identified a consistent thermal pattern associated with these cases, but we have been able to characterize reduced blood flow to the caudal hoof and to identify thermal stresses associated with hoof imbalance. Thermography is one of the few
methods of readily determining the relative blood flow to the palmar foot area. For blood flow assessment, the foot is thermographically evaluated before and after exercise. The normal horse will sustain a 0.5°C increase in temperature of the foot after exercise but about 50% of horses with palmar foot pain syndrome will not sustain this increase in the caudal foot due to the low blood flow. This is in sharp contrast to other focal inflammatory conditions of the hoof such as abscesses, bruises, or fractures, which are characterized by focal areas of increased temperature that correspond to the site of injury (Figure 2). Exercise in these cases intensifies the "hot spot."

Joint Diseases

Joint inflammation produces characteristic thermal patterns. The best view to study most joints is from the dorsal aspect. Typically, the normal joint is cool compared to the surrounding structures. An exception to this rule is the hock, which has a vertical "hot spot" along the medial aspect that corresponds to the saphenous vein. As a joint becomes inflamed, the thermal pattern changes to an oval area of increased temperature that is centered over the joint and widest horizontally medial to lateral (Figure 3). The exception to this rule is the distal joints where the thermal pattern associated with inflammation of this joint is a circular. The areas of joint capsule attachment tend to be "hotter" but the center of the joint is relatively "cooler" (Figure 4). This may be due to joint swelling or pressure and subsequent loss of microcirculation. No specific correlation can be made between heat and joint damage. The temperature of the joint appears to be related to many factors; the chronicity of the problem, the more chronic the problem, the heat is less intense; the degree of synovial involvement; the actual amount of cartilage damage; and the presence or absence of osteochondral fragments. These factors have a complicated interaction and all
affect the inflammatory response of the joint temperature. The degree to which each affects this response has yet to be determined.

Thermal patterns of joints have been shown to change two weeks before the onset of clinical signs of lameness. In this manner, thermography can be used to assist training and help prevent serious injuries. By locating inflammation before clinical signs are evident, training programs can be changed to reduce stress on the inflamed area thereby preventing serious injury.

**Long Bone Injuries**

Thermography is of less value in the diagnosis of most long bone problems. Since thermography evaluates skin temperature, a bone needs to be in relatively close contact with the skin to affect its temperature. Consequently, bones that are heavily covered with muscle can not be as accurately assessed by thermography. Of the common equine long bone problems, thermography is best utilized to evaluate dorsal metacarpal disease, or stress fractures of the radius or tibia.

Dorsal metacarpal disease, the so-called "bucked shin complex", is categorized into 3 grades. Grade 1 is characterized by eliciting pain upon palpation of the cannon bone but radiographic evidence of bone pathology cannot be identified. Grade 2 is characterized by pain over the cannon bone, but there is radiographic evidence of subperiosteal callus. Finally, grade 3 is characterized by cannon bone pain and radiographic evidence of a stress or fatigue fracture. Grades 2 and 3 maybe indistinguishable and radiographic confirmation of a stress fracture may not be possible for 2 to 3 weeks. Thermal variations between the latter two may help differentiate grade 3 earlier than radiographs. Grade 1 and 2 disease are
characterized by "hot spots" located midshaft over the dorsal cannon bone (Figure 5). The "hot spot" is generally 1-2°C warmer than the surrounding tissues. In contrast, the grade 3 disease has "hot spots" that are not centrally located, and are usually seen on the lateral and medial views in addition to the dorsal view (Figure 6). These areas are characteristically 2-3°C warmer than the surrounding tissues. As mentioned before, thermographic changes typically precede radiographic changes by 2 weeks. With accurate thermography, a tentative diagnosis can be made at an earlier time and appropriate treatment measures taken sooner.

**Tendon Injuries**

Thermal patterns of the normal flexor tendons are bilaterally symmetrical and consist of elliptical isothermic zones. The lowest temperature is centered over the palmar aspect of the tendons and the peripheral areas near the carpus and fetlock are approximately 1°C warmer.

Acute tendinitis invariably causes a "hot spot" over the site of the tendon lesion. The "hot spot" of a tendon lesion can usually be demonstrated up to 2 weeks before physical evidence of swelling and pain around the tendon (Figure 7). With this enhanced ability of detection, tendon lesions of potentially clinical significance can be identified and adjustments in the training protocol can be made to prevent further damage to the tendon.

As the tendon heals the thermal pattern becomes more uniform but remains abnormally elevated, when compared to normal tendon. As the lesion heals and scar tissue is deposited, the skin over the injured area may actually show a decrease in temperature, whereas, the remaining neovascularized tendon continues to have increased thermal emissions. During the assessment of healing, the thermal changes do not correlate well to
the structural reorganization of the tendon matrix as assessed by ultrasonography.\(^2\) The reason is that as the tendon undergoes neovascularization, the thermal pattern diffuses so there is no longer a "hot spot". But, if one compares healing tendon to a normal tendon, there is overall increased thermal emissions from the damaged tendon (Figure 8). Mechanical stress proximal to the injury can aggravate the existing tendon damage. Again, thermography can detect these areas of proximal stress before they cause a clinical problem and, therefore specific imaging can be used to decide if a therapeutic desmotomy should be performed.

**Ligament Injuries**

Thermographically, ligament injuries will appear very similar to tendon injuries. "Hot spots" can be expected to be centered over the injured area. An exception to this is in some high supensory injuries of the metacarpi, the dorsal thermal image of the injured leg shows a focal "hot spot" located proximally on the cannon bone (Figure 9). This is interesting considering the inflammation and pain would be expected to be on the palmar aspect of the limb. Clinically, thermography is most useful when trying to correlate if there is heat associated with a sensitive ligament. This is particularly true of the suspensory or interosseous ligament. Sensitivity can often be palpated in the body of the ligament, the clinical significance can be questionable but thermography can determine if there is inflammation associated with the sensitivity. In a similar vain, "splints" or metacarpal callus can cause suspensory desmitis (Figure 10). Thermography can detect if there is inflammation associated with the suspensory ligament adjacent to the "splint". These indications would apply to any ligament.
Muscle Injuries

Thermography may have its greatest clinical application in the assessment of individual muscle injuries which are difficult to diagnose.\textsuperscript{13} Even though serum muscle enzyme elevation may non-specifically indicate muscle damage, the specific muscle or muscles damaged may be difficult to identify. Thermography offers two types of information important in the evaluation of muscle injury: first it can locate an area of inflammation associated with a muscle or muscle group; and second is that it illustrates atrophy well before it becomes apparent clinically.

Muscle inflammation will be most commonly seen thermographically as a "hot spot" in the skin directly overlying the affected muscle.\textsuperscript{13} On a rare occasion, swelling and edema in the affected muscle will be severe enough to inhibit blood flow through the muscle. In this case the injured muscle will be seen thermographically as a "cold spot". Thermographic evaluation of muscle must be made from paired samples, that is comparison of the right and left sides. These comparison images should be nearly identical. Consistent variations from side to side would indicate muscle damage located at either the "hot" or "cold spot".

The most common cause of muscle inflammation is muscle strain. A classification of first, second or third degree strain injuries, described in human athletes, has been applied to horses.\textsuperscript{13} Muscle strains have not been commonly documented in the front leg. The author has most commonly identified pectoralis and shoulder extensor myopathies (Figure 11). Thermographic description of muscle strains of the back and hindlimb muscles have been best described.\textsuperscript{13} These strains have been termed croup and caudal thigh myopathies. Croup myopathies are actually strains of the longissimus, the origin of the gluteus medius (level of the sacroiliac), the body of the gluteus medius, the insertion of the gluteals on the greater
trochanter and the third trochanter of the femur (Figure 12). Caudal thigh myopathies consist of injuries to the biceps femoris, semitendinosus or semimembranosus muscles. Injuries to the biceps femoris and semimembranosus most commonly are mid body muscle strains but, to the semitendinosus injuries usually occur at the musculotendinous junction.

**Vertebral Column**

Diagnosis of injuries to the vertebral column such as luxations, subluxations and fractures can be aided through thermography. Many of these injuries are undiagnosed or diagnosis is delayed because radiography of the equine spine is difficult, and/or may require general anesthesia. Thermography offers a distinct advantage as it is best performed on the standing animal and in suspect cases may be used as a general screening test to determine if referral for radiography under anesthesia is warranted. Injuries to the vertebral column are characterized by either "hot spots", "cold spots", or "root signatures".

The thermographic evaluation is performed from above the animal, "top line view", for the thoracic, lumbar, and sacral vertebrae. Images made from the left and right sides are used to evaluate the cervical vertebrae. Injuries are generally located along the midline. The thermal area directly corresponds to the injury. "Cold spots" noted over the vertebral column, unlike other areas, have not been associated with chronic injuries. Instead, "cold spots" may suggest more recent injuries associated with marked swelling which may affect the autonomic nerve supply. "Root signatures" are linear increases in temperature that follow nerve roots from the vertebral column. They theoretically occur because of irritation to the local sympathetic nerves. They can involve the entire sympathetic trunk where an entire side will have an increased temperature, such as is seen in Horner's Syndrome.
Sacroiliac subluxations have been associate with a very distinct thermal pattern. In these cases there is a focal "cold spot" between the 2 tuber sacrale (Figure 13). We have shown excellent correlation between this thermal image and sonographic evidence of sacroiliac ligament change.\textsuperscript{10}

**SUMMARY**

Thermography is a practical aid in the clinical evaluation of the equine patient. It is particularly germaine to the evaluation of lameness. This modality specifically increases the accuracy of diagnosis. Thermography is the pictorial representation of skin temperature. The technique involves the detection of infrared radiation that can be directly correlated to blood flow. Thermography, in order to be accurate, must be performed in a controlled area free of drafts. The area should be protected from sunlight to avoid erroneous heating of the skin and the hair length should be uniform. Thermography detects heat before it is perceptible during routine physical examination and therefore is useful for early detection of laminitis, stress fractures, and tendinitis. It offers a non-invasive means of evaluating the blood supply to an injured region and offers one of the only reliable non-invasive means to evaluate blood flow to the foot of the horse. Thermography is also useful for the early identification of stress injuries to the contralateral limb of convalescing orthopedic patients. Thermography is an excellent adjunct to clinical examination, as well as being complementary to other imaging techniques such as radiology, ultrasonography and scintigraphy.
REFERENCES


