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Effect of a bandage or tendon boot on skin temperature of the metacarpus at rest and after exercise in horses

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Objective—To determine the skin temperature of the metacarpus in horses associated with the use of bandages and tendon boots, compared with the bare limb, at rest and after 20 minutes of lunging.

Animals—10 adult horses.

Procedures—Skin temperature on the bare metacarpus of both forelimbs was measured at rest and after lunging. Subsequently, a bandage was applied to the left metacarpus and a tendon boot to the right metacarpus and skin temperature was measured at rest and after lunging. Skin temperature was measured with fixed sensors and thermographically.

Results—Mean ± SD skin temperatures of the bare metacarpi were 14.1 ± 2.4°C (left) and 14.1 ± 3.4°C (right) at rest, and 14.4 ± 1.8°C (left) and 13.6 ± 2.6°C (right) after exercise. Skin temperatures under the bandage were 15.3 ± 1.6°C at rest and 24.8 ± 3.6°C after exercise. Skin temperatures under the tendon boot were 15.3 ± 2.6°C at rest and 20.6 ± 2.9°C after exercise. Skin temperatures under the bandage and tendon boot were significantly higher after exercise than at rest. Skin temperatures at rest were not significantly different with a bare limb, bandage, or tendon boot.

Conclusions and Clinical Relevance—Skin temperature of the metacarpus in horses increased significantly during exercise but not at rest when a bandage or tendon boot was used. The authors speculate that both a bandage and a tendon boot accelerate the warmup phase of exercise. Further research should focus on the effects of warmup and maximum exercise on the temperature of other anatomic structures such as tendons. (*Am J Vet Res* 2014;75:375–379)

The application of bandages and tendon boots to the distal aspect of the limbs of horses is widespread and performed for many reasons. Originally, bandages were developed for wound coverings, rehabilitation, and protection of limbs from injury during transport.[1] According to manufacturer's information, another reason for use of bandages and tendon boots is the achievement of a warming effect and improved perfusion of the distal aspect of the limbs at rest and during training exercises.[2,3] It is necessary to take into account that the type of materials, their composition, and correct application techniques are important for protection of anatomic structures by bandages and tendon boots.[4–6] Tendon boots are used in training and are applied during some horse competitions. Bandages and tendon boots are supposed to support the anatomic structures, reduce the maximum extension of the metacarpophalyngeal or metatarsophalyngeal (fetlock) joints and protect the limbs from fractures and trauma; however, there is little scientific data to support their value except in protection against direct trauma.[4,7,8] They might be useful if uncoordinated movements occur because of fatigue.[3,7,8]

The temperature in the core of the SDFT at rest is approximately 37.8°C, whereas the tissue around the tendon is near body temperature at approximately 37°C.[9] However, exercise at high intensity is reported to raise the core temperature of tendons to a mean ± SD temperature of 43.3 ± 0.9°C (without applied bandages or tendon boots), which causes fibroblast death in vitro. Although the tendon fibroblasts seem to be remarkably heat resistant, high temperatures in the core of the tendon should be considered a risk factor for injuries.[9–12]

An infrared camera detects infrared radiation emitted by the body surface and delivers a colored picture that correlates with the distribution of skin temperatures.[13–15] With an infrared camera (ie, thermography),

Abbreviation

SDFT Superficial digital flexor tendon

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it is possible to detect areas of high temperature and differences in the expected symmetric distribution pattern of the skin temperature of the limbs.[13–15] It allows the assessment of temperature noninvasively in a circumscribed region. Applied sensors measure temperature at a distinct spot on the skin surface or may be implanted percutaneously.[16,17] The latter method is rapid, accurate, and minimally invasive.[17]

The accuracy of thermography is debated because ambient temperature and other external conditions, such as radiation from the sun or airflow, may influence the surface temperature of the skin.[14,18–20] Under well-defined conditions, however, this technique has high reproducibility.[21–24]

To the authors' knowledge, investigation of skin temperature with both sensors and thermography has not been performed before in horses. The objective of the study reported here was to compare the skin temperature of the metacarpus under a bandage or a tendon boot with that of a bare limb, at rest and after 20 minutes of lunging by use of sensors and thermography. The hypotheses were that there would be a greater increase in skin temperature associated with the use of bandages and tendon boots after exercise, compared with the bare limb, and that there would be no significant differences between skin temperatures associated with the use of bandages and tendon boots.

Materials and Methods

Animals—The institutional ethical committee of the University of Veterinary Medicine Vienna approved the study. Ten adult horses (4 geldings and 6 mares) of mixed breeds (7 warmblood horses, 2 ponies, and 1 Arabian) were used in this study. Mean ± SD age was 12 years ± 3.4 years (range, 7 to 20 years) and all horses were free of lameness and had no signs of acute illness or injury.

Experimental procedures—The skin temperature of the metacarpus of each horse was measured in 4 conditions: at rest with bare limbs; at rest with a bandage applied to 1 metacarpus and a tendon boot applied to the other metacarpus; after exercise with bare limbs; and after exercise performed with a bandage applied to 1 metacarpus and a tendon boot applied to the other metacarpus.

On the day of examination, the horses were kept for at least 30 minutes in a stall before the experiment started, with closed doors and windows to avoid exposure to draft or direct solar radiation. The horses were not groomed and received no bandages, tendon boots, or other treatments than those described in the protocol. In the stable, thermographic images (**Figure 1**) were acquired in front of the stall after the ambient temperature of the stable and the adjacent riding hall were recorded with a commercial thermometer.[a] Thermographic images were acquired with a portable infrared camera[b] equipped with a 12.5-mm focal length lens, an uncooled microbolometer, and a focal plane array infrared detector with a spectral range from 7.5 to 14 μm. The emissivity was adjusted to 1.00. A bubble level was fixed to the camera to ensure horizontal orientation. Images were recorded from a distance of 1 meter, maintained with a distance keeper, from the lateral, medial, dorsal, and palmar aspects of the forelimb from the carpus distally.

A modified temperature data logger[c] (2 X 10 cm) with an external sensor[d] was put into small pockets of denim and fixed with a hook-and-loop-fastener and adhesive tape to the metacarpus. The sensor (3 X 4 cm) was located on the skin of the medial aspect of the limb in the region of the suspensory ligament and flexor tendons between zones 1 and 2 of the ultrasonographic zone designations for the metacarpal regions.[25] The data logger recorded the temperature with a sample rate of 50 Hz with a resolution of 0.1°C. At first, a baseline measurement at rest was acquired during 5 minutes. After that, the sensors were removed, data were loaded from the data loggers to a laptop, and sensors and data loggers were fixed again as described. Then each horse was lunged in a riding hall by the same person for 20 minutes (5 minutes at the walk and 5 minutes at the trot in each direction). Immediately after exercise, the sensors, data loggers, and pockets were removed and the data were loaded directly from the sensors to the laptop; then, postexercise thermographic imaging was performed.

On the following day, the procedure started again with resting thermographic imaging before the application of the sensors and data loggers to the limbs. Then a bandage composed of 100% polypropylene fleece with incorporated ceramic particles[e] was attached to the left forelimb. It was wrapped, always by the same person, first in the middle of the metacarpus, then from

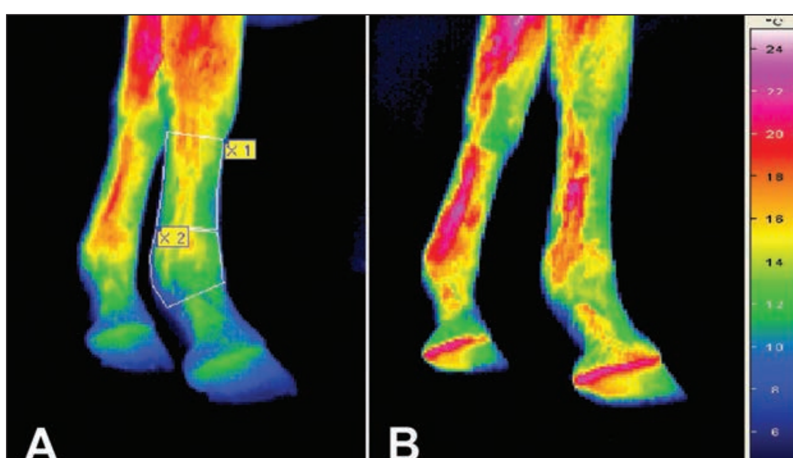

Figure 1—Representative thermographic images of the forelimbs of a horse. A—Thermographic image of the forelimbs of a horse at rest. Notice the drawn regions of interest X1 around the proximal two-thirds of the right metacarpus and X2 around the metacarpophalangeal (fetlock) joint. B—Thermographic image of the forelimbs of a horse after exercise performed while wearing a bandage (left forelimb) and tendon boot (right forelimb) around the metacarpus. The warmest areas of the skin of the metacarpal region are over the medial and lateral palmar artery and vein. The medial aspect of the metacarpus has a slightly greater area with increased temperature, compared with the lateral aspect. Temperature (°C) and corresponding colors are indicated in the scale to the right of the images.

the fetlock joint up to a point immediately distal to the carpus.

A closed tendon boot made of neoprene[f] (thickness, 5 mm) with a bilateral lamination (inside, synthetic fibers; outside, synthetic fiber-cotton mix) was attached distal to the carpus of the right forelimb. Each bandage and tendon boot enclosed the fetlock joint. The tendon boot was available in 2 sizes (small and medium) to allow for different sizes of the forelimbs. The tendon boot was closed on the lateral side of the metacarpus and fetlock joint with 3 hook and loop fasteners. After recording the temperature at rest, the horses were lunged in the same manner as the day before. Immediately after lunging, the bandage and tendon boot as well as sensors and data loggers were removed and thermographic imaging was performed.

The recordings of the data logger were analyzed with the graph software.[g] The minimum and maximum skin temperatures of the bare metacarpi and the skin temperatures associated with the bandage and tendon boots were determined both at rest and after exercise. The thermographic images were analyzed with analytic software.[h] Mean and maximum surface temperatures were calculated from polygonal regions of interest. One polygon circumscribed the lateral metacarpal region (termed X1), and the second polygon enclosed the fetlock joint (termed X2). The mean value was calculated from the pixel temperature data of the polygon from X1 and X2 of dorsal, palmar, lateral, and medial aspects of the limb.

Statistical analysis—All recorded data were analyzed with statistical software.[j] The distribution of the data was tested with the Kolmogorov-Smirnow test, which revealed a normal distribution. Mean ± SD minimum and mean ± SD maximum temperature values measured with the sensor and overall mean ± SD thermographic values and mean ± SD maximum thermographic values were compared by means of a paired *t* test. Differences between temperatures were compared by use of repeated-measures ANOVA. For all comparisons, values of $P < 0.05$ were considered significant.

Results

The mean ± SD ambient temperatures in the stable on days 1 and 2 were 6.1 ± 1.8°C and 6.4 ± 1.3°C, respectively. The mean temperatures in the riding hall on day 1 and 2 were 5.4 ± 3.1°C and 6.7 ± 2.1°C.

At rest, the mean minimum temperature determined with the sensor (**Table 1**) was significantly higher for metacarpi with a bandage, compared with bare metacarpi, and significantly higher for metacarpi with a tendon boot, compared with bare metacarpi. Significant differences between metacarpi with bandages or tendon boots and bare metacarpi were also found after exercise. The mean minimum temperatures of the bare metacarpi at rest and after exercise were not significantly different, whereas the skin temperatures associated with bandages and tendon boots were significantly higher after exercise. After exercise, the temperature associated with a bandage was significantly higher than that associated with a tendon boot.

In contrast, analyses of the maximum temperatures determined with the sensors revealed only signifi-

Table 1—Mean ± SD minimum and maximum skin temperatures measured with sensors on the left and right metacarpal region of 10 horses with a bare limb or with a bandage (left limb) and a tendon boot (right limb) at rest or after exercise.

	Bare limb		Covered limb	
Variable	**Left**	**Right**	**Bandage (left)**	**Tendon boot (right)**
Rest				
Minimum (°C)	6.34 ± 2.07^{a}	5.94 ± 2.09^{a}	7.82 ± 1.94^{b,A}	7.53 ± 1.83^{b,A}
Maximum (°C)	14.05 ± 2.37^{a}	14.07 ± 3.35	15.33 ± 1.85^{b,B}	15.31 ± 2.60^{B}
Exercise				
Minimum (°C)	7.40 ± 1.47^{a}	6.51 ± 1.97^{a}	18.21 ± 3.80^{b,c,C}	15.50 ± 2.65^{b,d,C}
Maximum (°C)	14.41 ± 1.80^{a}	13.64 ± 2.63	24.84 ± 3.60^{b,D}	20.57 ± 2.88^{D}

$^{a–d}$Within a row, values with different superscript lowercase letters differ significantly ($P < 0.05$). $^{A–D}$Within a column, values with different superscript capital letters differ significantly ($P < 0.05$).

Table 2—Overall mean ± SD skin temperatures and mean ± SD maximum skin temperatures measured thermographically on the left and right metacarpal region (X1) and metacarpophalangeal (fetlock) joint region (X2) of 10 horses with a bare limb or with a bandage (left limb) and a tendon boot (right limb) at rest or after exercise.

	Bare limb				Covered limb			
	X1		X2		X1		X2	
Variable	**Left**	**Right**	**Left**	**Right**	**Bandage (left)**	**Tendon boot (right)**	**Bandage (left)**	**Tendon boot (right)**
Rest								
Mean (°C)	8.67 ± 3.25	8.97 ± 3.58	8.34 ± 3.05	8.53 ± 3.61	11.57 ± 3.19	11.48 ± 3.09	11.57 ± 3.53	11.88 ± 3.82
Maximum (°C)	11.55 ± 3.82	11.65 ± 4.84	10.17 ± 3.54	10.07 ± 3.80	13.63 ± 3.84	13.86 ± 3.24	13.66 ± 4.20	13.51 ± 3.76
Exercise								
Mean (°C)	8.40 ± 2.03^{a}	8.80 ± 2.20^{a}	9.05 ± 2.05^{a}	8.93 ± 2.18^{a}	15.00 ± 3.59^{b,c}	13.14 ± 3.20^{b,d}	14.41 ± 4.11^{b,A}	13.54 ± 3.36^{b,B}
Maximum (°C)	12.04 ± 3.35^{a}	13.05 ± 3.97^{a}	12.38 ± 3.17^{a}	12.33 ± 3.01^{a}	18.91 ± 4.31^{b,c}	17.80 ± 3.97^{b,d}	18.02 ± 4.31^{b}	17.34 ± 4.30^{b}

^{A,B}Within a column, values with different superscript capital letters differ significantly ($P < 0.05$).
See Table 1 for remainder of key.

cant differences between bare metacarpi and bandaged metacarpi at rest and after exercise. The maximum temperatures associated with a bandage and a tendon boot were also significantly different between rest and after exercise (Table 1).

Evaluation of the thermographically determined temperatures revealed no significant difference between the mean and maximum temperatures at rest among the 3 groups (**Table 2**). In contrast, after exercise, a significant difference was detected between bare metacarpi and those with a bandage or a tendon boot for the mean and maximum temperatures of regions X1 and X2. After exercise, significant differences were detected for the mean and maximum temperatures between metacarpi with a bandage and a tendon boot for region X1. For region X2, only the mean temperatures differed significantly after exercise between metacarpi with a bandage and a tendon boot.

Discussion

The objective of this study was to determine skin temperature on the equine metacarpus at rest or after exercise with or without applied bandages or tendon boots. No significant differences were detected in skin temperature at rest and after exercising of the bare limb. Temperatures increased significantly when a bandage or a tendon boot was used during exercise. From these results, it can be hypothesized that the use of a tendon boot or a bandage increases the temperature of the skin during training. This should be verified in further studies.

Some new materials used in bandages and tendon boots seem to be quite effective for heat retention. The manufacturer of the bandage used in this study claims that incorporated ceramic particles reflect infrared radiation from the skin and contribute to a warming effect.[26]

Reducing heat loss over the skin surface could be beneficial, particularly at low ambient temperatures that cause peripheral vasoconstriction.[27] The influence of ambient temperature on skin temperature has been reported.[24,28,29] In a previous study[24] with higher ambient temperature of 25.9° to 27.8°C, skin temperatures in horses at rest were 29.5° to 34.6°C. In the present study, the ambient temperatures in the stable and riding hall were quite low and the variations of the ambient temperature in the stable and riding hall (between 0.0° and 11.5°C) might have affected the results; this should be evaluated in further studies. The assumed beneficial effects should be verified in studies that elucidate the effects of increased temperature on the tendon tissue.

Although we measured the temperature of the skin, it can be assumed that the temperature of the underlying structures also increased. Moderate warmup exercise increases blood flow in tissues.[30] Increased blood flow can help to reduce the risk of injuries because of prolonged time to fatigue, which is a reason for tendon, muscle, and bone injury.[31–33]

However; some authors suggest that heat development within the SDFT could cause tendon damage in horses during exercise.[9,10,12] It is not known whether heavy exercise performed with limb bandages or tendon boots is detrimental because of accumulation of heat in the limb. It can be hypothesized that the coverings decrease evaporation heat loss from the skin surface, resulting in a reduced cooling effect. Additionally, the core of the SDFT in horses is a hypovascular area in which heat removal might be compromised. The resulting hypoxia and insufficient cell metabolism might have detrimental effects on tendon cells.[34–37] In the present study, horses were not strenuously exercised, so intrinsic heating of the tendons likely did not occur, and no information on maximum skin temperature development at maximum exercise was obtained.

In the present study, no significant differences were detected in skin temperature at rest or after exercise in the bare metacarpus. In a previous study,[20] it was determined that airflow (evaporative heat loss) efficiently cools the skin of the distal aspect of the horses' limbs. Therefore, in the present study, evaporative heat loss, particularly when horses were trotting, may have contributed to cooling of the skin surface in horses with bare metacarpi. Results of another study[38] indicated that exercise increases blood flow in the foot. It seems logical that increased blood flow should increase skin temperature, particularly under bandages, as occurred in our study. In that study,[38] however, exercise did not result in increased foot temperature in horses that were bandaged for up to 15 hours, compared with horses without a bandage. It can be speculated that the duration of bandaging, the location at which the temperature was measured (at the coronary band distal to the bandage vs under the bandage in the present study) or the ambient temperature (not indicated in the reported of the previous study[38]) had an effect on the results of both studies.

In a previous study[20] in horses, it was determined that airflow efficiently cools the skin of the distal aspect of the limbs. Therefore, in the present study, evaporative heat loss, particularly when horses were trotting, may have contributed to cooling of the skin surface in horses with bare metacarpi.

In the present study, the temperature was measured with a sensor fixed on the skin as well as with an infrared camera. Thermography was performed to obtain information about the temperature distribution of the skin in the metacarpal region. The sensors could only determine skin temperature under the bandage or the tendon boot at certain locations, but their use yielded comparable information to that provided by thermography, although actual temperatures were different, likely because the sizes of the regions in which the temperature was determined were different and the skin temperature varied throughout the metacarpal region.

This study had additional limitations. The order in which the horses were examined was not randomized. Ideally, the direction of lunging, day of lunging, and assignment of left and right forelimbs to groups with or without bandages or tendon boots should have been randomized but were not. In addition, the results only apply to the forelimbs (vs the hind limbs) and the bandages and tendon boots used in the present study and would not necessarily be the same for other bandage or tendon boot materials or constructions.

In the present study, the skin temperature of the metacarpus did not increase significantly when bandages or tendon boots were applied during a period of rest but did increase significantly after exercise. Further studies should evaluate the possible beneficial effects of increased skin and tissue temperatures as well as the risk of overheating the tissues when bandages or tendon boots are used during strenuous exercise.

a. Hama GmbH & Co KG, Monheim, Germany.
b. VarioCam, Infratec GmbH, Dresden, Germany.
c. DL-121TH Voltcraft, Conrad Electronic SE, Hirschau, Germany.
d. Voltcraft, Conrad Electronic SE, Hirschau, Germany.
e. Back on Track GmbH, Moers, Germany.
f. TSM Fesselkopf Bandage, AET GmbH, Hallertau, Germany.
g. DL-120 TH Voltcraft, Conrad Electronic SE, Hirschau, Germany.
h. IRBIS, Infratec GmbH, Dresden, Germany.
j. PASW Statistics, version 17.0, IBM SPSS Statistics, Armonk, NY.

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