In horses, blood flow to the hoof is associated with digital perfusion and temperature. Temperature changes in the skin at the coronary band could indicate changes in blood flow to the coronary band and possibly the hoof. An elevated hoof temperature has been suggested to be an early clinical sign of laminitis or inflammatory conditions, such as hoof abscesses. However, for CBT to be used as an indicator of hoof disease, its dependence on other factors must be known. Few studies have been conducted to investigate CBT, and only measurements on the forelimb hooves of horses kept at a constant or biphasic ambient temperature have been reported. The carbohydrate content in the diet may also influence CBT. Grass contains various concentrations of carbohydrates, including fructan. High doses of fructan have been used experimentally to induce laminitis, and oral doses as small as 1 g of fructan/kg can cause a prodromal stage of laminitis.

Evaluation of coronary band temperatures in healthy horses

Jesper G. Rosenmeier, DVM; Anders B. Strathe, PhD; Pia H. Andersen, DVM, DVSci

Objective—To measure coronary band temperature (CBT) in healthy horses fed high-fructan or low-carbohydrate diets and to analyze the association of CBT with diet, time of day, and ambient temperature.

Animals—6 healthy horses.

Procedures—Horses were fed 3 diets (treatment 1, 1 g of fructan/kg fed daily in the morning; treatment 2, 1 g of fructan/kg fed daily in the afternoon; and treatment 3, a low-carbohydrate [72%] diet) in a 3 X 3 Latin square study design. For each horse, the CBT of all 4 limbs as well as rectal and ambient temperatures were recorded by use of infrared thermometry and standard thermometers hourly from 8 AM to 10 PM for 4 consecutive days after the initiation of each diet. Each horse received each diet, and there was a 10-day washout period between each diet change. Data were analyzed by use of a mixed linear model.

Results—4,320 CBTs were obtained from the 6 horses. The CBT ranged from 9.6° to 35.5°C. Coronary band temperature followed a diurnal pattern and was positively associated with ambient temperature but was not associated with diet.

Conclusions and Clinical Relevance—CBT of healthy horses varied significantly during the day and among limbs. These results should be considered whenever increased CBT is used as an indication of incipient laminitis or in other clinical investigations. (Am J Vet Res 2012;73:719–723)

In horses, blood flow to the hoof is associated with digital perfusion and temperature. Temperature changes in the skin at the coronary band could indicate changes in blood flow to the coronary band and possibly the hoof. An elevated hoof temperature has been suggested to be an early clinical sign of laminitis or inflammatory conditions, such as hoof abscesses. However, for CBT to be used as an indicator of hoof disease, its dependence on other factors must be known. Few studies have been conducted to investigate CBT, and only measurements on the forelimb hooves of horses kept at a constant or biphasic ambient temperature have been reported. The carbohydrate content in the diet may also influence CBT. Grass contains various concentrations of carbohydrates, including fructan. High doses of fructan have been used experimentally to induce laminitis in horses, and oral doses as small as 1 g of fructan/kg can cause a prodromal stage of laminitis.

The purpose of the study reported here was to investigate the daily variation of CBT in healthy horses stabled in an environment with known ambient temperature and fed diets with various amounts of fructan. Our hypothesis was that daily variations in CBT of healthy horses exist and do not differ among limbs. We also hypothesized that CBT would be influenced by ambient temperature and concentrations of fructan in the diet.

Materials and Methods

Animals—Six horses (2 geldings and 4 nonpregnant mares) representing 3 breeds were used in the study. All horses were healthy and had no history of laminitis. Age ranged from 5 to 9 years, and body weight ranged from 500 to 635 kg. The study was approved by the Ethics Committee of the Department of Large Animal Science at Copenhagen University and did not include any invasive procedures.

The study was performed in late April to early June at the University Research Station of Copenhagen University in accordance with a 3 X 3 Latin square design with the 6 horses randomly allocated (a number was assigned to each horse, and 2 numbers were blindly drawn for each group) to 3 groups. Horses were confined individually in box stalls for 2 weeks before and throughout the study. Stall temperature varied with the
outside temperature. Horses were unshod, and their hooves were trimmed 1 week prior to the study. The horses were examined for lameness before and after each diet change, and they were excluded from the study at any time lameness was > 1 on a scale of 1 to 5.

Diets—The 3 diets, or treatments, used in the study consisted of feed supplemented with grass in the morning (treatment 1), feed supplemented with grass in the afternoon (treatment 2), and feed with no supplemental grass (base diet, treatment 3). Horses were fed at 8:45 AM and 2:45 PM. All horses were fed a base diet that consisted of a commercially available feed with a low carbohydrate (7.2%) content formulated for horses, hay, and supplemental mineral in accordance with their nutritional requirements. For treatments 1 and 2, grass was fed at a rate of 1 kg of grass/100 kg and replaced an energy-equivalent amount of hay in the base diet. Each treatment was fed for 4 days with a washout period of 10 days between treatments. Treatments were alternated in accordance with a Latin square design.

The grass fed was a perennial ryegrass. The grass was harvested from a field that had been seeded 2 years earlier and was fed to the horses within 30 minutes after it was harvested. Prior to the start of the study and after each harvest, a grass sample was dried at 60°C for 48 hours and then sent to a commercial forage analysis laboratory for determination of the percentage of DM, glucose, fructose, sucrose, and fructan. The amount of grass fed for treatments 1 and 2 was calculated to provide each horse with 1 g of fructan/kg on the basis of the mean fructan concentration measured from grass harvested 7 and 14 days prior to the start of the study.

Data collection—Three days prior to the initiation of each treatment, hair was clipped on the dorsal aspect of the coronary band on each limb (Figure 1) and at a control point behind the costal arch of the 17th rib on the left side of each horse. For each horse, the skin temperature at the coronary bands and the control point was measured hourly from 8:00 AM to 10:00 PM by use of an infrared thermometer for the 4 days each diet was fed. At the same times, a rectal thermometer was used to measure the rectal temperature of each horse and a standard thermometer was used to measure ambient temperature.

Infrared thermometry—The manufacturer of the infrared thermometer used in the study stated it had an accuracy and repeatability of at least 0.75°C and 0.50°C, respectively. The thermometer was sent to a commercial technical laboratory to test its accuracy and repeatability at various temperatures, and the following results were obtained: at 10°C, accuracy was 0.3°C and repeatability was 0.5°C; at 20°C, accuracy was 0.5°C and repeatability was 0.3°C; and at 37°C, accuracy was 0.1°C and repeatability was 0.4°C. All CBTs obtained from the horses during the study were recorded in a spreadsheet, and graphs were made by use of a commercial software program.

Statistical analysis—The data were analyzed by use of the following mixed linear model for repeated measures:

\[ y_{ijklm} = \mu + \alpha_i + \beta_j + A_k + H_l + \gamma_m + \alpha \gamma_{im} + \beta \gamma_{jm} + P_{ij} + \delta X_{\text{plan}} + \epsilon_{ijklm} \]

where \( y_{ijklm} \) is the CBT obtained at time \( m \) for limb \( l \) from horse \( k \) that received diet \( i \) during period \( j \); \( \mu \) is the overall mean; \( \alpha_i \) is the main effect of diet; \( \beta_j \) is the main effect of study period; \( A_k \) is the random effect of horse, which was assumed to be normally distributed with a mean of 0 and a variation of \( \sigma_A^2 \); \( H_l \) is the random effect of limb, which was assumed to be normally distributed with a mean of 0 and a variation of \( \sigma_H^2 \); \( \gamma_m \) is the main effect of time; \( \alpha \gamma_{im} \) is the interaction between diet and time; \( \beta \gamma_{jm} \) is the interaction between study period and time; \( P_{ij} \) is the random interaction between study period and limb, which was assumed to be normally distributed with a mean of 0 and a variation of \( \sigma_P^2 \); \( X_{\text{plan}} \) is the ambient temperature corresponding to time \( m \); and \( \epsilon_{ijklm} \) is the error.
for limb \( l \) from horse \( k \) that received diet \( i \) during period \( j \); and \( \epsilon_{ijklm} \) is the within-group residual error, which was assumed to be normally distributed with a mean of 0 and a variation of \( \sigma^2 \).

The least squares means and contrasts for fixed-effects within groups were calculated by use of commercial software. The model was extended so that the within-group residual error term (\( \epsilon_{ijklm} \)) could be correlated. Different correlation structures (autoregressive-moving mean and spatial correlation) were fitted to the within-group residual errors, and the correlation structure chosen for all subsequent modeling was that which minimized the value of the Bayesian information criterion for the model. For fixed-effects, the model was estimated by removing the least significant variables one at a time on the basis of a likelihood-ratio test. Parametric bootstrap simulation was used for fixed-effect variables when the calculated probability of the likelihood-ratio test was < 0.10. Fructan concentrations in grass fed in the morning versus fructan concentrations in grass fed in the afternoon were compared via paired \( t \) tests by use of commercial software. For all analyses, values of \( P < 0.05 \) were considered significant.

Results

Animals—During the acclimatization period, none of the horses developed a fever or diarrhea or had clinical signs of lameness or laminitis. On the second day of administration of the first diet, 1 mare did not eat all the allocated grass and hay, which was attributed to the fact it was in estrus. That mare's appetite returned the following day, and it ate all allocated feed for the rest of the study.

CBT, rectal temperature, and ambient temperature—A total of 4,320 CBTs, 1,080 rectal temperatures, and 1,080 ambient temperatures were obtained during the study. Results of the mixed linear model indicated that there was no effect of treatment on CBT \( (P = 0.20) \). The variations in CBT had characteristic diurnal patterns that were associated with study period \( (P < 0.001) \). This variation was significantly \( (P = 0.005) \) associated with ambient temperature; for every 1°C increase in ambient temperature, CBT increased by 0.62°C.

Figure 3—Example of the second diurnal pattern observed for ambient temperature, rectal temperature, and CBTs for all limbs of 1 horse. See Figure 2 for remainder of key.

Figure 4—Example of the third diurnal pattern observed for ambient temperature, rectal temperature, and CBTs for all limbs of 1 horse. See Figure 2 for remainder of key.

Figure 5—Example of the fourth diurnal pattern observed for ambient temperature, rectal temperature, and CBTs for all limbs for the same horse as in Figure 2 but obtained 2 days after the data for Figure 2. See Figure 2 for remainder of key.

Figure 6—Example of the fifth diurnal pattern observed for ambient temperature, rectal temperature, and CBTs for all limbs of 1 horse. See Figure 2 for remainder of key.
Throughout the study, there were 5 diurnal patterns of temperatures characterized. For the first pattern, ambient temperature gradually increased from morning to afternoon, peaked at approximately 2 PM, and then gradually decreased during the evening hours (Figure 2). The CBT of all 4 limbs increased abruptly in mid to late afternoon before gradually returning to the same temperature as that in the morning. For the second pattern, ambient temperature increased slightly during the morning hours and then gradually decreased in the afternoon and evening (Figure 3). The CBTs of individual limbs increased abruptly at different times over a period of 9 hours. For the third pattern, ambient temperature again increased slightly during the morning hours and then gradually decreased in the afternoon and evening (Figure 4). The CBTs decreased slightly during the morning but increased abruptly at approximately noon and remained elevated for the rest of the day. For the fourth pattern, ambient temperature remained relatively constant throughout the day and the CBT in 1 limb increased dramatically within a period of 1 hour (Figure 5). For the fifth pattern, when ambient temperature was > 13°C, the CBTs generally remained > 30°C with minimal fluctuations (Figure 6). For all patterns, rectal temperature remained constant.

Generally, skin temperature measured at the control point behind the costal arch of the left 17th rib changed in the same direction as the CBT. In the morning, the temperature at the control point was approximately 10°C higher than the CBT of the individual limbs; however, the CBTs increased to approximately the same temperature as that of the control point by early to midafternoon (Figure 7). The magnitude of changes in CBT was similar among horses (Table 1).

Fructan concentrations—The fructan concentration of the grass varied from 13.7% to 46.4% DM (Table 2) during the study. There was no significant (P = 0.32) difference in fructan concentration as a percentage of DM between the grasses harvested in the morning and afternoon.

Discussion

In the study reported here, changes in CBT during the day in individual horses could not be predicted. There was no association between CBT and treatment (diet). Although the fructan concentration in the grass varied from 13.7% to 46.3% DM during the study, the actual amount of fructan fed was maintained at approximately 1 g/kg daily for each horse for treatments 1 and 2. None of the treatments in the present study elicited laminitis, which suggested that factors in addition to feeding diets containing 1 g of fructan/kg for 4 days are

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**Table 1**—Mean ± SD, median, and range of CBTs for 6 healthy horses that were fed each of 3 diets (treatment 1, 1 g of fructan/kg fed daily in the morning; treatment 2, 1 g fructan/kg fed daily in the afternoon; and treatment 3, a low [7.2%] carbohydrate diet) for 4 consecutive days with a 10-day washout period between each diet change in a 3 × 3 Latin square study.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean ± SD</th>
<th>Median</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lowest CBT (°C)</td>
<td>13.5 ± 2.3</td>
<td>13.7</td>
<td>9.7–16.2</td>
</tr>
<tr>
<td>Highest CBT (°C)</td>
<td>34.6 ± 0.5</td>
<td>34.5</td>
<td>33.9–35.5</td>
</tr>
<tr>
<td>Largest difference in CBT between 2 limbs in a horse at the same time (°C)</td>
<td>15.5 ± 1.3</td>
<td>15.0</td>
<td>14.3–17.1</td>
</tr>
<tr>
<td>Largest CBT increase within same limb between 2 successive times (°C)</td>
<td>13.5 ± 1.7</td>
<td>12.8</td>
<td>12.0–15.7</td>
</tr>
<tr>
<td>Largest CBT decrease within same limb between 2 successive times (°C)</td>
<td>9.1 ± 3.3</td>
<td>10.0</td>
<td>4.0–12.7</td>
</tr>
</tbody>
</table>

**Table 2**—Fructan as percentage of DM in grass fed in the morning (treatment 1) or afternoon (treatment 2) to 6 healthy horses for 3 study periods in a 3 × 3 Latin square study design.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Study period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Morning (%)</td>
<td>33.9 29.0 32.7 25.9</td>
</tr>
<tr>
<td>Afternoon (%)</td>
<td>27.1 33.8 29.3 23.7</td>
</tr>
<tr>
<td>Difference (%)</td>
<td>6.8 4.8 3.4 2.2</td>
</tr>
</tbody>
</table>

Grass samples were obtained from late April to early June. The mean value of the 8 measurements (4 morning and 4 afternoon) for each period was 29.4%, 40.3%, and 26.0% for study periods 1, 2, and 3, respectively.
required to cause laminitis in horses. Also, elevations in CBT were not pathognomonic for laminitis.

Mammals are capable of refined thermoregulation as the ambient temperature changes. The distal portion of horse limbs is relatively devoid of muscles and fat to provide insulation; therefore, it is an ideal site to evaluate a horse’s innate ability to thermoregulate. The ability of blood vessels to constrict or dilate in response to changes in ambient temperature is an integral component of thermoregulation.11 Arteriovenous anastomoses connect arteries to veins outside of the capillary network. The anastomoses in the dermis of the coronary band of the horse foot consist of small, simple direct shunts12 formed by epithelioid cells. Blood flow resistance within a capillary bed is greater than that within an arteriovenous anastomosis, therefore, the rate of blood flow through a capillary bed is slower than the rate of blood flow through an arteriovenous anastomosis.4 Thus, the opening and closing of arteriovenous anastomoses allows for more efficient thermoregulation. Results of the present study indicated that CBT increases as ambient temperature increases. This may be caused by an autoregulatory escape mechanism that results in vasodilation.1 It is unknown whether that vasodilation is mediated locally or centrally, but increasing concentrations of vasoactive metabolites in hypoxic tissue may play a role in the mechanism of vasodilation. The present study indicated that CBT differs considerably among limbs on the same horse, which makes a centrally mediated mechanism for vasodilation less likely.

In the present study, the greatest increase in CBT within a single limb between 2 adjacent hourly measurements was 15.7°C. The maximum difference in CBT among the 4 limbs of a horse at a particular time ranged from 14.3° to 17.1°C. These findings indicate that arteriovenous anastomoses may open and close rapidly and have an important, but not yet fully elucidated, role in thermoregulation. No effort was made to keep the ambient temperatures constant in the present study because we wanted to evaluate CBT under natural stable conditions.

Extreme increases in CBT were observed when ambient temperature was < 15°C, which is consistent with observations made by other investigators.11 Those investigators11 hypothesized that an ambient temperature ≤ 15°C induces capillary dilatation in equine limbs in an attempt to maintain the temperature of the limbs within an acceptable physiologic range. Because the CBT within limbs of healthy horses increased by as much as 12° to 13°C in the present study, further investigation of blood flow and thermoregulation of the equine foot is necessary before CBT can be used as an effective indicator of laminitis.11 In the study reported here, the association between the temperature of the hoof surface and CBT was not evaluated. Although it seems plausible that hoof surface temperature and CBT should be associated, it remains to be investigated.

In healthy horses, the CBT differed significantly within and among limbs during the course of a day. Changes in CBT followed a diurnal pattern and were positively associated with ambient temperature. These results indicate that caution is advised for the use of CBT for clinical or experimental assessment of hoof disease in horses.

References