Digestive and metabolic effects of altering feeding frequency in athletic horses

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Abstract

The aim of this study was to investigate the effect of feeding frequency on total tract digestibility and plasma glucose, insulin, urea, gastrin and cortisol concentrations at rest and following exercise in seven Standardbred horses in race training. The horses were fed every 12 h (twice a day, 2TD) and every 4 h (six times a day, 6TD) for 25 days, in a cross-over design. The diet (64% grass hay, 36% concentrates on weight basis) was fed at twice the maintenance energy requirement. Blood samples were taken every hour for 24 h on day 17, total collection of urine and faeces was made on days 19–21 and an intensive exercise test was performed on day 25. Altering feeding frequency caused small variations in diurnal plasma glucose, urea, gastrin and cortisol concentrations and did not affect total tract nutrient digestibility. There was an increase in the mean diurnal plasma urea concentration on the 2TD regime and low levels of plasma insulin were observed 7 h after feeding 2TD. The response to intensive exercise on heart rate, plasma lactate and plasma glucose was similar on both treatments but the plasma insulin concentration was higher following exercise in the 2TD regime, indicating that post-exercise glucose metabolism was altered. In conclusion, this study shows that feeding athletic horses only 2TD caused metabolic signs resembling those observed during feed deprivation (low levels of plasma insulin and an increased diurnal plasma urea concentration) and an altered post-exercise glucose metabolism, but did not affect the digestive response.

Keywords: cortisol, diurnal rhythm, gastrin, insulin, meal frequency, exercise

Introduction

Wild horses spend most of their time grazing1. This behaviour results in a regular flow of digesta and a continuous supply of nutrients. The digestive physiology of the horse, i.e. a continuous secretion of bile, a rapid prececal digestive flow2, a limited starch digestion capacity3 and a voluminous hindgut, also indicates that a continuous intake of a high-fibre diet is optimal. However, stable-managed horses are often subjected to meal feeding. Meal size, meal frequency and the type of feed ingested may affect the digestive, metabolic and fluid balance physiology of the animal. There are some studies on such effects of feeding frequency on equines, most of which have been made on ponies4–6 or horses7 fed a concentrated feed at maintenance level. During such conditions, there seems to be no effect on nutrient digestibility5,7,8. On the other hand, there can be marked effects on fluid balance regulation following feeding of a few large meals compared with more frequent feeding in the maintenance-fed horses8. Interestingly, in a study on athletic horses with high feed intakes, the effect of feeding frequency on fluid balance was small9, probably due to a feed intake pattern that promotes equilibrium between digestive fluid secretion and fluid absorption. That feeding frequency may affect athletic horses in other ways than maintenance-fed horses is not much investigated.

Depending on the interval between meals, studies of feeding frequency may approximate to studies of feed deprivation. Catabolic responses due to feed deprivation, such as increased plasma or blood urea concentrations2,10 and low levels of plasma insulin11, have been observed in maintenance-fed horses and ponies within less than 24 h. In addition, the glycaemic response to exercise seems to be altered in feed-deprived horses10. However, as far as we know, there
is limited information on the time span necessary for such effects to be observed in horses with higher metabolic rates.

In many earlier studies on the effects of feeding in horses, the experimental designs have little resemblance to feeding of athletic horses or horses’ natural feeding behaviour. If horses are kept on a maintenance diet, fasted prior to the study and offered pelleted and/or concentrate diets in an acute feeding trial, it may alter the response compared with what could be considered normal in the feeding practice of athletic horses. Plasma gastrin responses have, for example, been shown to be more variable when a diet is introduced than after an adaptation period of 7 days. Eating behaviour influences gastric acidity and the development of gastric mucosal lesions in horses. One of the major known stimulants of gastric acid secretion is gastrin. There are a few studies on the plasma gastrin concentration in horses in relation to feeding and the results indicate that the condition of the animals (i.e. fasted or fed), the type of feed and the composition of the feedstuffs have an impact on the plasma gastrin response.

The aim of the present study was to investigate the effect of feeding frequency on (1) total tract digestibility; (2) plasma glucose, insulin, urea, gastrin and cortisol concentration at rest; and (3) plasma glucose, insulin and lactate following exercise in athletic horses with high feed intakes (roughage based), well adapted to different feeding frequencies.

**Materials and methods**

**Animals**

Seven Standardbred horses were used (6 geldings, 1 stallion, body weight (BW) 407–522 kg; age 5–10 years). The horses belonged to the Swedish Academy of Trotting and Thoroughbred Racing in Örebro, Sweden. They were used in the education of apprentices and professional race trainers and performed a simulated 2140 m trotting race or interval training (warm-up and 5–6 times 500 m in fast trot) once a week. On days when no intensive exercise was performed, the horses spent the morning hours in paddocks or had light exercise (30–60 min walk and slow trot). The study was approved by the Uppsala Local Ethics Committee.

**Diets and feeding frequencies**

Two feeding frequencies were studied during two 25-day periods according to a cross-over design. The horses were fed either every 12 h (twice a day, 2TD), at 17:30 and 05:30 h or every 4 h (six times a day, 6TD) at 17:30, 21:30, 01:30, 05:30, 09:30 and 13:30 h. 2TD regimes are sometimes used in practice and a 6TD regime resembles the natural feeding behaviour of horses where feed pauses are hardly ever longer than 2 h. The horses had been fed the experimental diet for at least 4 weeks before the study began. The diet was fed on a BW basis and the chemical composition is shown in Table 1. The diet consisted of 7.4 ± 0.3 kg (mean ± SE) grass hay (8.5% crude protein) and 4.1 ± 0.2 kg (mean ± SE) concentrates per day (60–75% oats, 12–17% molassed sugarbeet pulp, 7–10% linseed, 2.5–3.0% soybean meal plus a mineral supplement), corresponding to the Swedish recommendations for energy and protein supply for hard-working horses (21.6 MJ metabolizable energy/100 kg BW, 124 g digestible-crude protein/100 kg BW). The individual daily amounts of hay and concentrates were evenly distributed between the meals and fed simultaneously. The stable was made in two separate sections and horses subjected to the same treatment were housed together to avoid psychological disturbances. The horses were kept in individual boxes (10 m²) on peat bedding and had free access to a salt block (99% NaCl). Water was offered *ad libitum* from buckets.

**Blood sampling and faecal collection**

On day 17 in both treatments, blood samples were taken every hour for 24 h. Additional blood samples were taken every 15 min for 1 h after providing the 17:30 and 05:30 meals. The blood samples were taken via a catheter introduced into one of the jugular veins 18–22 h before first the sample was taken (Intravene, 2.0 × 105 mm, SweVet-Piab, Sjöbo, Sweden). An extension tube was attached to the catheter to facilitate blood sampling. The horses could move freely in their boxes during the experiment and, to avoid discomfort, no samples were taken when the horses were lying down (8% of the samples were not taken due to this). At 03:30 h, almost all horses were lying down and therefore this sample was omitted. All faeces produced during 3 days were collected (although 2 days can be enough) in both feeding-frequency treatments (days 19–21). The horses were fitted with a collecting harness. The bag was emptied manually at least every 90 min and the faeces

| Chemical composition and intake* (gram per day) of organic matter (OM), crude protein (CP), crude fat (EE), starch, free sugars, high-fibre residue (HFR) and ash in horses fed twice a day (2TD) and six times a day (6TD) |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| **OM**          | 7823 ± 193      | **CP**          | 1105 ± 47       | **EE**          | 273 ± 8         |
| **Starch**      | 916 ± 78        | **Free sugars** | 521 ± 26        | **HFR**         | 5560 ± 159      |
| **Ash**         | 453 ± 20        |                 |                 |                 |                 |

*Means ± SE.
were frozen at −20°C. After mixing the faeces from each horse and treatment in a clean concrete-mixer, a 3 kg sample was taken. Owing to technical problems with the collecting harness, one horse was excluded from the faecal analysis and also faecal data from another horse on day 21 (2TD) were excluded. The horses were walked by hand or lunged for 15 min during the collection days.

Exercise test
In the morning (08:00–12:00 h) of day 25 in both experimental periods, an exercise test (ET) was performed on a track. During the ET, the horses trotted five 500 m intervals at a speed of 11.1 ± 0.2 m s⁻¹, corresponding to a heart rate of around 200 beats per min (Heart Rate Recorder Optipuls, Borlänge, Sweden). After each interval, the horses returned the 500 m in slow trot. The return took 2–4 min depending on whether or not blood samples were taken (see below). All ETs were preceded by a 14 min warm-up in slow trot. Immediately after the last interval, the horses were returned to the stable in slow trot (13 min). The heart rate was measured before, during and after the ET. In the evening before the ET days, a catheter was inserted into a jugular vein and flushed with heparinized saline (0.2% heparin) overnight and with isotonic saline between samplings. Blood samples were taken at rest, following the warm-up, before and after the last two intervals (within 60 s) and 15, 20, 30, 40 and 50 min after the last interval. A last blood sample was taken before the next feeding. The ETs were performed at the same time of day for each horse on both occasions. The horses were exercised in fixed pairs and driven by the same person on both occasions. The weather and track conditions were similar on the two ET days (11–17°C, 62–69% relative humidity and sunshine). Owing to temporary lameness (origin: carpus, fetlock and hoof) in three horses, only four of the horses completed both ETs and only these are included in the statistical analysis of exercise data.

Analysis
The blood samples were collected in lithium heparinized tubes kept on ice until centrifugation and the plasma was thereafter frozen at −20°C. Analysis of glucose (MPR2 1442449), urea (MPR3 777510) and lactate (139084) was made enzymatically by colorimetric methods (Boeringer, Mannheim, Germany). RIA-methods were used for analysis of insulin (Pharmacia, Uppsala, Sweden), gastrin (method described by Sandin et al.)¹⁴ and cortisol (Coat A Count, Diagnostic Products Corporation, Los Angeles, USA).

Chemical analyses of feed and faeces samples were performed on oven-dried samples (until constant weight; 65°C, 24 h) after milling through a 1 mm screen. Dry matter (DM), ash and crude fibre (CF) were determined as described by the Swedish Board of Agriculture¹⁸. Nitrogen (N) content was determined according to Kjeldahl¹⁵ and crude protein (CP) was calculated as N×6.25. Crude fat (EE) was analysed according to the EEC method B²⁰. Starch and sugars were analysed²¹. The content of fibre was estimated by subtraction of the analysed contents of sugars, starch, CP, EE and ash from the DM content, resulting in a high-fibre residue (HFR).

Statistical analysis
All data were subjected to analysis of variance (GLM procedure in the Statistical Analysis Systems package; SAS Institute Inc., Cary, NC, USA) using the following model:

\[ Y_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\beta\gamma)_{jk} + e_{ijk} \]

where \( Y_{ijk} \) is the observation, \( \mu \) the mean value, \( \alpha_i \) the effect of animal, \( \beta_j \) the effect of treatment, \( \gamma_k \) the effect of sample (time), \( (\beta\gamma)_{jk} \) the effect of interaction between treatment and sample and \( e_{ijk} \) the residuals; \( e_{ijk} \sim \text{IND} (0, \delta^2) \). For the gastrin, the analysis period was included in the model since it was shown to have an effect. The P value for significance within and between treatments was < 0.05. Values are presented as means ± standard error of the mean (SE, df 6).

Results

Short-term effects
All horses consumed the concentrate immediately after feeding in both the 2TD and 6TD treatments. The hay was consumed next and there were no residues left prior to the next feeding. However, in 2TD, some hay could be left uneaten for 3–4 h.

There were few post-prandial changes in plasma glucose, urea, gastrin and cortisol levels within the first 60 min (Table 2). The plasma insulin concentration started to increase 15–30 min following feeding (Table 2) and then began to decrease 60 min after feeding (Fig. 1). There were no differences (\( P > 0.05 \)) between treatments in plasma glucose, insulin, urea, gastrin and cortisol levels in samples taken every 15 min for 1 h following feeding (Table 2).

Diurnal effects of feeding and total tract digestibility
No health problems were observed during the experiment except for two horses that showed aggression (flattening of the ears, mock biting attacks) in connection with feeding on the 2TD regime. The diurnal variation in plasma glucose, urea, gastrin and cortisol was similar (\( P > 0.05 \)) in both treatments with few
Table 2  Effects on plasma glucose, insulin, urea, cortisol and gastrin following a morning (05:30 h) and evening (17:30 h) feeding in athletic horses fed 2TD and 6TD

<table>
<thead>
<tr>
<th></th>
<th>Glucose (mmol l$^{-1}$)</th>
<th>Insulin (μmol l$^{-1}$)</th>
<th>Urea (mmol l$^{-1}$)</th>
<th>Cortisol (μmol l$^{-1}$)</th>
<th>Gastrin (μmol l$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2TD</td>
<td>6TD</td>
<td>2TD</td>
<td>6TD</td>
<td>2TD</td>
</tr>
<tr>
<td><strong>Morning</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>05:30 h</td>
<td>5.1 ± 0.3</td>
<td>5.2 ± 0.2</td>
<td>6.6 ± 0.8</td>
<td>11.0 ± 1.1</td>
<td>5.7 ± 0.4</td>
</tr>
<tr>
<td>05:45 h</td>
<td>4.9 ± 0.1</td>
<td>4.8 ± 0.1</td>
<td>10.4 ± 1.7</td>
<td>14.5 ± 2.0</td>
<td>5.7 ± 0.4</td>
</tr>
<tr>
<td>06:00 h</td>
<td>5.2 ± 0.2</td>
<td>5.2 ± 0.2</td>
<td>17.7 ± 1.7$^a$</td>
<td>17.2 ± 1.0$^a$</td>
<td>5.8 ± 0.4</td>
</tr>
<tr>
<td>06:15 h</td>
<td>5.3 ± 0.2</td>
<td>5.0 ± 0.4</td>
<td>21.8 ± 2.3$^a$</td>
<td>22.2 ± 2.0$^a$</td>
<td>6.0 ± 0.5</td>
</tr>
<tr>
<td>06:30 h</td>
<td>5.3 ± 0.3</td>
<td>5.1 ± 0.2</td>
<td>22.9 ± 2.4$^a$</td>
<td>18.2 ± 3.0$^a$</td>
<td>6.0 ± 0.4</td>
</tr>
<tr>
<td><strong>Evening</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17:30 h</td>
<td>4.6 ± 0.2</td>
<td>5.0 ± 0.2</td>
<td>6.9 ± 1.0</td>
<td>12.1 ± 1.4</td>
<td>6.1 ± 0.3</td>
</tr>
<tr>
<td>17:45 h</td>
<td>4.9 ± 0.3</td>
<td>5.0 ± 0.3</td>
<td>16.7 ± 2.0$^a$</td>
<td>15.1 ± 1.9</td>
<td>6.0 ± 0.3</td>
</tr>
<tr>
<td>18:00 h</td>
<td>4.9 ± 0.2</td>
<td>5.2 ± 0.3</td>
<td>22.2 ± 2.7$^a$</td>
<td>19.8 ± 1.2$^a$</td>
<td>5.9 ± 0.3</td>
</tr>
<tr>
<td>18:15 h</td>
<td>4.7 ± 0.2</td>
<td>5.2 ± 0.3</td>
<td>18.7 ± 3.5$^a$</td>
<td>23.6 ± 2.0$^a$</td>
<td>6.1 ± 0.5</td>
</tr>
<tr>
<td>18:30 h</td>
<td>5.1 ± 0.3</td>
<td>5.5 ± 0.2$^a$</td>
<td>23.2 ± 3.0$^a$</td>
<td>23.4 ± 2.8$^a$</td>
<td>6.2 ± 0.3</td>
</tr>
</tbody>
</table>

$^a$ Significant difference within treatment (i.e. from value at 05:30 to 17:30, respectively).

$^b$ Significantly different from 2TD.

Discussion

This study showed that altering feeding frequency in athletic horses caused no major alterations in plasma glucose, urea, cortisol and gastrin concentrations. The plasma lactate and glucose levels during and following exercise were similar in both treatments before, during and until 15 min after exercise. However, there was a significant difference in plasma urea concentration ($P < 0.05$) between periods in the mean diurnal plasma concentration tests (Fig. 3). There were no differences between treatments in plasma lactate and glucose during and following exercise (Table 4). There were no differences between treatments in heart rate between treatments (Table 5).
for 21–69 h. However, the elevation was small and indicates that gluconeogenesis contributes to only a small extent to the energy supply during short-time feed deprivation as earlier suggested.

Although the amount of concentrate fed at each meal in 2TD was 3 times greater than in 6TD (0.53 kg starch per meal in 2TD vs. 0.18 kg starch per meal in 6TD), very few significant changes were observed in the plasma glucose concentration 1–3 h after feeding in both treatments. This might be due to a reduction in the postprandial increase in plasma glucose concentration when a large grain meal is offered in connection with feeding hay. When the horses in the present study were fed 6TD, the diurnal variation in glucose was less than 0.6 mmol l\(^{-1}\) and during 2TD it was 0.9 mmol l\(^{-1}\), with the lowest values observed prior to feeding. A drop in plasma glucose after feed deprivation for 24 h has been observed earlier in ponies and the low level was maintained for another 24 h until it started to increase. However, this is in contrast to the study where glucose levels were similar in ponies fed every 24 h compared with when they were fed every 4 h and to another study where no differences in plasma glucose were observed in horses fed once and three times per day. Altogether, this indicates that plasma glucose is not a useful parameter for assessing the metabolic state following different feeding frequencies or even following short-term feed deprivation.

The similar glucose response could not be due to a higher insulin activity on the 2TD regime since the peak insulin levels were similar in both treatments. A possible explanation for the similar glucose response is that the relative uptake of glucose from the small intestine was reduced when horses were fed 2TD due to a limited starch digestion capacity, which was also indicated by the lowered mean diurnal plasma glucose concentration. However, it has been suggested that this level of starch intake would not exceed the starch digestion capacity. A reduction in the gastric emptying rate, as has been observed in horses offered large, high-starch meals, might also explain why peak insulin levels were similar on both treatments and why plasma insulin remained elevated for 5–6 h when
horses were fed 2TD. Another reason for the lack of difference in peak insulin levels might be that insulin only needs to occupy a small part of the receptors to achieve its maximal effect. High sugar and starch intakes have been shown both to decrease insulin sensitivity and not to affect insulin sensitivity in horses. It cannot be excluded that insulin sensitivity can be affected by feeding frequency. However, the design and the results from the present study do not allow any conclusions to be drawn in this matter.

It has been indicated that distention is an important mechanism for gastrin release in fasted horses. In the present study, there were very small alterations in the plasma gastrin concentration in response to feeding frequency (i.e. feeding volume). However, these horses consumed large amounts of feed, around 10 kg dry matter per day (c. 22 g DM/kg BW), of which the major part (64%) was roughage and, therefore, the mechanisms releasing gastrin may have been permanently activated. Also, small or no changes in serum gastrin concentration were observed when horses were fed hay ad libitum (intake 15 g DM kg\(^{-1}\) BW in\(^1\), intake unknown in\(^2\)). A permanent activation of the gastrin release mechanism probably resembles the situation of the wild horse, since free-living horses spend the major part of their time grazing. Interestingly, although there was no difference between feeding frequencies in the plasma gastrin response, there was a small but significant elevation during the first period of the experiment compared with the second. There is no obvious explanation for this, but it might be caused by a difference in starch intake between periods since the analysis of the feed samples revealed a slightly higher starch content in the oat offered during the first period. The dietary composition may influence the gastrin response although it is difficult to draw any conclusions from this experiment since the effects of feed composition cannot be separated from feed volume.

There were no differences in the total tract digestibility of nutrients between feeding regimes, indicating that the digestive efficiency was similar in both treatments. This is in accordance with results obtained from other studies. However, if the proportion of preaecaely digested starch was reduced in the 2TD regime (as suggested above), resulting in an increased amount of starch entering the hindgut, a decrease in fibre digestion could be expected, probably due to a change in the composition of the microflora. However, in this study no significant effect on the digestion of the fibre fraction was observed.

The apparent digestibility of organic matter was in the same range as earlier reported in Standardbred horses on a similar diet. However, the crude protein digestibility was slightly higher in the present study. In the study above, maize or sugarbeet pulp was used as the major concentrate ingredient and the crude protein digestibility of these feed sources is lower than for oats. It has also been shown that the CP digestibility may increase as the total inclusion of oats in the diet increases. In three horses, the digestibility of ash and crude fat was considerably higher (13–31 and 14–17%, respectively) when the horses were fed 6TD compared with when they were fed 2TD, indicating that the absorption of minerals and fat was reduced in the 2TD regime. Whether this variation in digestive efficiency among individuals is representative for a larger population remains to be investigated.

Although plasma insulin dropped to very low levels in 2TD, indicating some metabolic stress, there were no alterations in plasma cortisol. The plasma cortisol concentration showed a diurnal rhythm, with the lowest levels observed at 22:30 h and the highest around 05:30 h in both treatments. The circadian rhythm of cortisol is fragile and can be interrupted when horses are introduced to a novel environment. However, feeding 6TD or 2TD did not affect the

Table 3: Diurnal mean concentration of glucose, insulin, urea, cortisol and gastrin in athletic horses fed 2TD and 6TD

<table>
<thead>
<tr>
<th>Glucose (mmol l(^{-1}))</th>
<th>Insulin ((\mu)U ml(^{-1}))</th>
<th>Urea (mmol l(^{-1}))</th>
<th>Cortisol ((\mu)mol l(^{-1}))</th>
<th>Gastrin ((\mu)mol l(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>2TD</td>
<td>5.0 ± 0.0</td>
<td>15.7 ± 0.6</td>
<td>5.9 ± 0.1</td>
<td>148 ± 6</td>
</tr>
<tr>
<td>6TD</td>
<td>5.2 ± 0.0^a</td>
<td>17.3 ± 0.5^a</td>
<td>5.8 ± 0.1^a</td>
<td>148 ± 5</td>
</tr>
</tbody>
</table>

^aSignificantly different from 2TD.

Table 4: Total tract digestibility (%) of dry matter (DM), organic matter (OM), crude protein (CP), crude fat (EE), starch, high-fibre residue (HFR) and ash in horses fed 2TD and 6TD

<table>
<thead>
<tr>
<th>Total tract digestibility (%)</th>
<th>DM</th>
<th>OM</th>
<th>CP</th>
<th>EE</th>
<th>Starch</th>
<th>HFR</th>
<th>Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>2TD</td>
<td>65.6 ± 2.5</td>
<td>67.6 ± 1.6</td>
<td>74.7 ± 3.6</td>
<td>53.1 ± 4.2</td>
<td>95.2 ± 1.3</td>
<td>61.9 ± 1.5</td>
<td>39.2 ± 5.7</td>
</tr>
<tr>
<td>6TD</td>
<td>69.0 ± 4.3</td>
<td>69.3 ± 3.3</td>
<td>77.3 ± 4.3</td>
<td>60.9 ± 6.6</td>
<td>97.7 ± 0.6</td>
<td>63.9 ± 3.7</td>
<td>50.3 ± 7.4</td>
</tr>
</tbody>
</table>

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rhythm, at least not in these horses, which had been adapted to this feeding frequency for 17 days. A lack of difference in plasma cortisol concentration between feed-deprived and fed horses has also been observed earlier\(^{10,38}\). However, it was noted that some individuals showed aggression prior to feeding during the 2TD treatment but not when they were fed 6TD.

There were no differences in heart rate and plasma lactate concentration during exercise. This is in accordance with results\(^{24}\) where there were no differences in heart rate and plasma lactate concentration during high-intensity exercise in fasted (15–16 h) and fed horses. During the warm-up phase of the ET, the plasma glucose concentration dropped in both treatments. This is also in accordance with the results\(^{24}\) in horses fed 2.5–3 h prior to exercise. However, in that study\(^{24}\), the plasma glucose concentration remained low during the intensive exercise phase, which was not the case in the present study. It is possible that hepatic glycogenolysis cannot maintain blood glucose levels in connection with intensive exercise if the exercise is performed within 15 min of the warm-up. In our study, the intensity was similar but the interval design (altering fast trot and walk) could have enabled blood glucose levels to increase.

The plasma insulin concentration was elevated following exercise when horses were fed 2TD, although only significant at 20 min post-exercise. This might be due to an increased hepatic release of glucose post-exercise and again indicates an inadequate feed supply. It has been shown that dietary sugar intake is negatively correlated to the utilization of muscle glycogen during exercise\(^{39}\), probably due to an increased use of blood glucose on sugar-rich diets. If a 2TD regime limits blood glucose utilization during exercise, it may reduce the capacity for exercise\(^{40}\). An increase in blood glucose following exercise has been observed in mares deprived of feed for 3 days, whereas it decreased in fed mares\(^{13}\). In the present study, the exercise test was performed 2.5–6.0 h after feeding and it is possible that the insulin and glucose response would have been more pronounced if the horses had been exercised later postprandially since deprivation signs at rest were not observed until 7 h postprandially. The lack of a significant drop in plasma insulin during exercise and a lack of increase in the post-exercise plasma urea concentration when horses were fed 2TD was probably because some individuals already had a low insulin level and an elevated urea level at the start of exercise due to the feeding regime.

In conclusion, this study shows that feeding athletic horses every 12 h had no or only minor effects on the diurnal variation of plasma glucose, urea, cortisol and gastrin compared with feeding every 4 h and that the feeding frequency did not affect mean total tract nutrient digestibility. However, feeding every 12 h resulted in very low levels of plasma insulin and increased plasma urea concentration at rest, which are metabolic patterns earlier observed in connection with feed deprivation.

**Fig. 3** Plasma lactate, glucose, insulin and urea before, during and after exercise in four horses fed every 12 h (2TD, □) and every 4 h (6TD, ◊) for 25 days. Samples were taken before exercise (start), after the warm-up (w-up), before and after intervals number 4 and 5 (BI4, BI5 and AI4, AI5) and 15, 20, 30, 40 and 50 min after exercise and before the next feeding (BF). Filled markers show significant difference within treatment (from value at start) and * shows significant difference between treatments.
In addition, feeding every 12 h resulted in an altered post-exercise glucose metabolism. The importance of the altered post-exercise glycaemic response is difficult to interpret and studies on substrate utilization during exercise and feed deprivation need to be performed.

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References

Effects of feeding frequency in horses


