FEEDING MANAGEMENT OF HORSES UNDER STRESSFUL CONDITIONS

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Most performance horses train and compete under a variety of stressful conditions that adversely affect health and performance. Feeding management is of critical importance to reduce many of these problems. Additionally, pre-competition feeding can significantly affect performance. Feeding management affects a number of different aspects of equine health and performance including gastrointestinal function, hydration, electrolyte status, and substrate selection during exercise. This paper will review these key areas of performance horse nutrition and give practical recommendations about how to feed horses under stressful conditions.

Digestive Function

Horses have evolved over millions of years as grazers, with specialized digestive tracts adapted to digest and utilize diets containing high levels of plant fiber. They are capable of processing large quantities of forage to meet their nutrient demands. In an attempt to maximize growth or productivity, horses are often fed diets which also contain high levels of grains and supplements. Unfortunately, this type of grain supplementation often overshadows the significant contribution that forages make in satisfying the horse's nutrient demands.

Horses are classified anatomically as nonruminant herbivores or hindgut fermenters. The large intestine of the horse holds about 80 to 90 liters (21 to 24 gallons) of liquid and houses billions of bacteria and protozoa that produce enzymes which ferment plant fiber. The by-products of microbial fermentation provide the horse with a source of energy and micronutrients. The equine digestive tract is designed in this fashion to allow the horse to ingest large quantities of forage in a continuous fashion. The small capacity of the upper part of the tract is not well suited for large single meals, a fact which is often ignored by horsemen. Large single meals of grain overwhelm the digestive capacity of the stomach and small intestine resulting in rapid fermentation of the grain carbohydrates by the microflora in the hindgut. This fermentation may result in a wide range of problems including colic and laminitis.

The fact that horses are hindgut fermenters has several implications for the person feeding the horse. First, since horses are designed to live on forages, any feeding program that neglects fiber will result in undesirable physical and mental consequences. Horses have a psychological need for the full feeling that fiber provides. Horses fed fiber-deficient diets will in extreme cases become chronic woodchewers. It is also important to maintain a constant food source for the beneficial bacteria in the hindgut. Not only does their fermentation of the fiber provide a great deal of energy for the horse, but their presence prevents the proliferation of other, potentially pathogenic bacteria. Horses, like man, need a certain amount of bulk to sustain normal digestive function. Horses have an immense digestive system designed to process a large volume of feed at all times. Deprived of that bulk, the many loops of the bowel are more likely to kink or twist, and serious colic can result.

The optimal quantity of forage intake varies by discipline. Endurance horses benefit from high forage intakes during both training and competition. Research conducted in Germany (Meyer et al., 1987) has underscored the importance of fiber in maintaining gut health. Their experiments have shown that a diet high in fiber resulted in an increased water intake. Further, animals supplemented with a simple hay and salt diet had 73% more water in their digestive tracts after exercise and approximately 33% more available electrolytes than animals on a low-fiber diet. The additional water and electrolytes in the digestive tract of the animals fed high-fiber diets is probably due to the high water-holding capacity of plant fiber. More importantly, the water and electrolyte pool created by a high-fiber diet can be used to combat dehydration and electrolyte imbalances which derail so many performance horses.

In Thoroughbred racehorses, excess gut fill during competition may be detrimental because additional energy must be expended to carry the extra weight of the ingesta. Therefore, a feeding strategy must be followed that tapers forage intake before a race. KER conducted a study to determine the effects of restricted hay intake on the metabolic responses of horses to high-intensity exercise (Rice et al., 2001). We hypothesized that, compared to ad libitum hay intake, a regimen of restricted hay feeding starting three days before a standardized exercise test would decrease body weight and reduce energy expenditure during running.

Four conditioned Thoroughbred horses were studied in a 2 x 2 crossover design. Initially, the length of time required for adaptation to ad libitum (AD LIB) intake of grass hay was determined. Thereafter, the metabolic responses to sprint exercise (SPR) were examined in two dietary periods, each five days in duration: 1) AD LIB, where horses had free-choice access to hay; and 2) Restricted (RES), where hay intake was restricted (~1% of body weight) for three days before the exercise test. Feed and water were removed four hours before the exercise test.

After measurement of body weight, horses completed a warm-up followed by 2 min at 115% of maximum oxygen uptake, then a 10-min walking recovery (REC).

During the three days before SPR, hay intake in AD LIB averaged (± SE)10.1 ± 0.9 kg, whereas intake during RES was 4.3 ± 0.2 kg. Pre-exercise bodyweight was significantly lower in RES (528 ± 5 kg) than in AD LIB (539 ± 4 kg)(Figure 1). During SPR, total mass-specific VO_2 was higher (P=0.02) in RES (243 ± 8 ml/kg/2 min) than in AD LIB (233 ± 10 ml/kg/2 min). Conversely, accumulated oxygen deficit was higher (P<0.01) in AD LIB (89.4 ± 2.2 ml O_2/kg) than in RES (82.4 ± 1.7 ml O_2/kg). Peak plasma lactate was also higher in AD LIB (22.2 ± 1.2 mM) than in RES (19.1 ± 2.1 mM), and VO_2 during recovery was 10% higher (P=0.12) in AD LIB.

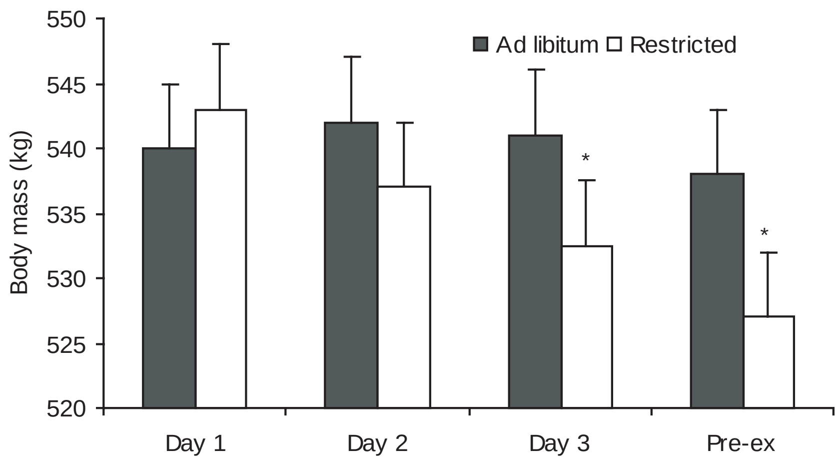

Figure 1. Body weight in the AD LIB and RES hay intake groups for the three-day period preceding the exercise test. Pre-ex = Body weight measured five min before the exercise test. *Significant (P<0.05) difference Ad libitum vs. Restricted.

The main findings of this study were:1) compared to ad libitum hay feeding, three days of restricted (1% of body weight) hay intake was associated with an approximately 2% decrease in body weight, and 2) the reduction in body weight associated with restricted hay feeding resulted in an increase in the mass-specific rate of oxygen consumption during sprint exercise, with a corresponding decrease in anaerobic energy expenditure. The anaerobic contribution to energy expenditure during exercise was lower in RES than in AD LIB as evidenced by lower values for accumulated oxygen deficit (Figure 2) and peak plasma lactate concentrations.

Currently, it is recommended that performance horses receive hay at a minimum of 1% of body weight per day to satisfy requirements for long-stem fiber and to minimize digestive upsets. In this context, relative to the restriction protocol used in this study, more severe or long-term restrictions of hay intake are not recommended. Nonetheless, on the basis of our results, further studies that examine the relationship between fiber intake, body weight, and exercise metabolism and performance are warranted.

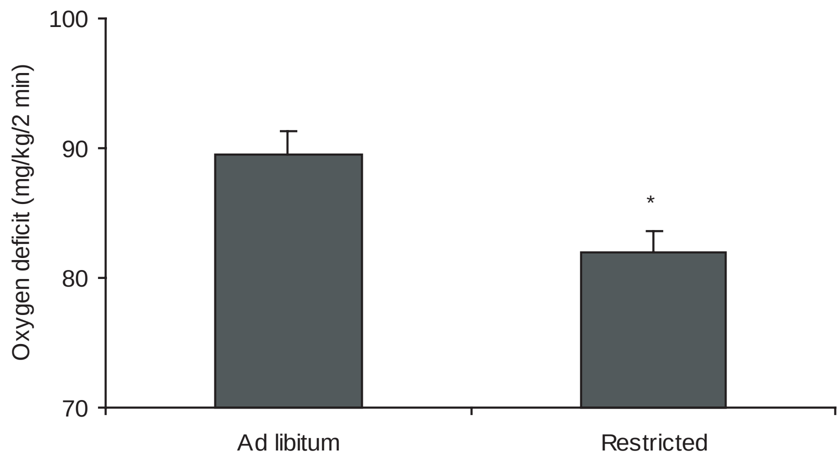

Figure 2. Accumulated oxygen deficit during 2 min of exercise at 115% of maximal oxygen uptake in the AD LIB and RES treatments. *P<0.05 RES vs AD LIB.

Gastric Ulcers

Performance horses are generally kept in confinement during training without access to grazing. This combined with large quantities of grain intake leads to a number of gastrointestinal problems such as gastric ulcers and colic. Many studies since the mid-1980s have documented that gastric ulcers are commonplace in racehorses. An early postmortem study in Hong Kong (Hammond et al., 1986) of 195 Thoroughbred racehorses showed that 80% of the horses in active training had ulcers. The incidence of ulcers in horses retired from racing for one month or longer was 52%. Murray et al. (1989) examined the stomachs of 187 horses ranging in age from one to 24 years. Eighty-seven horses had clinical problems including recurrent colic, poor body condition, or chronic diarrhea. One hundred horses had no clinical signs of gastrointestinal problems. Ninety-two percent of the horses with clinical problems had gastric ulcers. Surprisingly, 52% of the horses displaying no clinical signs also had lesions. Racehorses in training had a higher incidence of ulcers (89%) than non-racers (59%).

More recently, two studies evaluated the incidence of gastric ulcers in California racehorses. In one postmortem study of 169 horses, 88% of Thoroughbred horses in training had ulcers (Johnson et al., 1994). A gastroendoscopic study of 202 Thoroughbred horses in training showed that 81% had ulcers (Vatistas et al., 1994). Each of these studies produced remarkably similar results. Eighty to ninety percent of racehorses in training have gastric ulcers. Most of these lesions occur in the region of the stomach above the margo plicatus, with very few lesions in the glandular portion. The upper half of the stomach consists of squamous epithelial cells that are very similar to the tissue found in the esophagus. Ulcers in this part of the stomach are more similar to esophagitis (heartburn) in humans than the ulcers that occur in the glandular region of the human stomach. It has also been determined that equine gastric ulcers are not caused by *Helicobactor pylori* bacteria, which are a common cause of ulcers in humans.

Dr. M.J. Murray of the Marion du Pont Scott Equine Medical Center in Leesburg,Virginia has proposed that the major cause of gastric ulcers in horses is prolonged exposure of the squamous mucosa to gastric acid. Unlike the glandular portion of the stomach, this tissue does not have a mucous layer and does not secrete bicarbonate onto its luminal surface. The only protection that this portion of the stomach has from gastric acid and pepsin comes from saliva production. If adequate saliva is not produced to buffer the gastric acid and coat the squamous epithelium, gastric irritation occurs and lesions may develop.

The high incidence of ulcers observed in performance horses is a man-made problem resulting from the way that we feed and manage these horses, since ulcers are extremely rare in horses maintained solely on pasture. Horses evolved as wandering grazers with digestive tracts designed for continual consumption of forage. Meals of grain or extended periods of fasting lead to excess gastric acid output without adequate saliva production.

Horses secrete acid continually whether they are fed or not. The pH of gastric fluid in horses withheld from feed for several hours has consistently been measured to be 2.0 or less (Murray, 1992). Horses that received free-choice timothy hay for 24 hours had mean gastric pHs that were significantly higher than fasted horses (3.1 in fed versus 1.5 in fasted horses)(Murray and Schusser, 1989). Higher pHs in hay-fed horses should be expected since forage consumption stimulates saliva production. Meyer et al. (1985) measured the amount of saliva produced when horses ate either hay, pasture, or a grain feed. When fed hay and fresh grass, the horse produced 400-480 grams of saliva per 100 g of dry matter consumed. When a grain-based feed was offered, the horses produced only about half (206 g/100 g dry matter) as much saliva.

Most horses in training are confined for most of the day and fed large grain meals. Often, racehorses are fasted for an extended period before exercise, allowing gastric acid to accumulate in the stomach. Intense exercise further increases the production of gastric acid so that the squamous mucosa of the stomach gets thoroughly bathed in acid during work.

Treating ulcers involves either inhibiting gastric acid secretion or neutralizing the acid produced. There are three classes of drugs that can be used to inhibit gastric acid secretion:

1) Histamine type-2 antagonists (H2 antagonists). H2 antagonists act by competing with histamine for histamine type-2 receptor sites on the parietal cell, and therefore blocking histamine-stimulated gastric acid secretion. The two most popular H2 antagonists used in horses are cimetidine

(Tagamet) and ranitidine (Zantac).

2) H+/K+ ATPase inhibitors. Direct inhibition of the proton pump can be achieved by substituted benzimidazoles. The only proton pump inhibitor licensed in the United States and Europe is omeprazole.

3) Prostaglandin analogues.

An alternative to suppression of acid production is to neutralize stomach acid and protect the squamous mucosa from exposure to acid. The natural buffering mechanism in the horse is from saliva production and indeed the most effective way to treat ulcers is simply to turn the animal out on pasture. In situations where this is not possible, administration of antacids may be a useful adjunct to acid suppression therapy in horses.

Time of Feeding Before Competition

One of the most frequently asked questions regarding feeding the performance horse is when to feed before a competition. Three experiments were conducted by Kentucky Equine Research in conjunction with the Waltham Centre for Equine Nutrition and Care to evaluate if feeding hay with and without grain affects glycemic response and hematological responses in Thoroughbred horses at rest and during a simulated competition exercise test (CET) on a high-speed treadmill (Pagan and Harris, 1999). The first experiment evaluated how feeding forage along with grain influences plasma variables and water intake. The second experiment was conducted to determine whether these changes affect exercise performance. The third experiment was performed to determine how forage alone affects exercise response.

Feeding hay either before or with grain significantly reduced the glycemic response of the grain meal. Insulin production post feeding was also reduced. In addition, when hay was fed, total plasma protein (TP) became significantly elevated within one hour. Interestingly, feeding only grain resulted in essentially no change in TP, even though the level of grain intake was the same that elicited a large change when hay alone was fed. Water intake was significantly influenced by time of hay feeding. Following hay feeding, water intake was greatly increased. The increase in water intake also corresponded to increased TP, suggesting that decreased plasma volume may have triggered a thirst response. Feeding grain before exercise with or without hay reduced free fatty acid availability and increased glucose uptake into the working muscle (Figure 3). This would not be beneficial for horses competing in the speed and endurance phase of a three-day event.

Feeding only forage before exercise had a much smaller effect on glycemic and insulin response to exercise than a grain meal. Additionally, feeding forage did not affect FFA availability. In horses fed a pre-exercise meal of hay, TP was elevated before and during exercise, and heart rate was elevated during the gallop in the horses receiving ad libitum hay the night before exercise. Both of these responses in the hay-fed horses were probably due to increased gut fill and a movement of water from the plasma into the gut. Horses that grazed in paddocks the night before exercise did not suffer from reduced plasma volume or elevated heart rates during exercise. This is probably because water was able to equilibrate between the plasma volume and gut so there was no reduction in plasma volume before exercise.

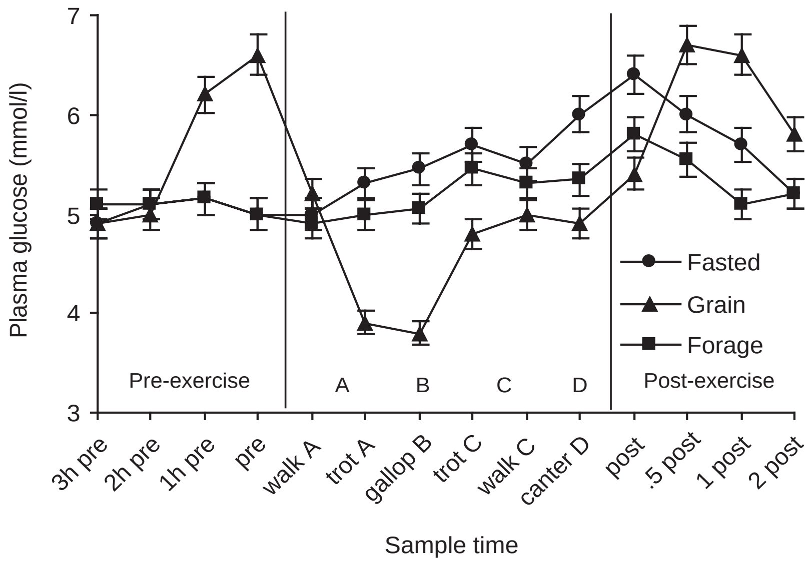

Figure 3. Plasma glucose before, during, and after competition exercise test (CET).

The results of these experiments indicate that feeding hay along with grain will result in a decrease of plasma volume and increase in body weight which may be detrimental to performance. Feeding grain either with or without hay two hours before exercise will reduce FFA availability and increase glucose uptake by the working muscle. This is probably not desirable during prolonged exercise. Feeding only forage before competition does not appear to interfere with FFA availability and has no adverse effects other than possibly reducing plasma volume and increasing body weight. If forage is fed in small amounts or if time in a grass paddock is limited, then these effects will probably be minimal. Since completely withholding forage may lead to stomach ulcers, the slight risk of reduced plasma volume and increased gut fill is more than outweighed by the potential benefit to the horse's long-term health and well-being.

Electrolyte Supplementation

Electrolytes are a critical component of a performance horse's nutritional program since they play an important role in maintaining osmotic pressure, fluid balance, and nerve and muscle activity. During exercise, sodium (Na^+), potassium (K^+), and chloride (Cl) are lost in large quantities through sweating. Loss of these electrolytes causes fatigue and muscle weakness and decreases the thirst response to dehydration. It is vitally important that performance horses begin competition with optimal levels of fluids and electrolytes in their bodies and that these important nutrients are replaced throughout prolonged exercise.

Sweat Losses

It is important to have some idea of the magnitude of electrolyte loss a horse incurs during exercise before a feeding program can be developed to replace these losses. Because most electrolyte losses in the horse occur through sweating, one method of calculating electrolyte requirements can be based on different amounts of sweat loss. Table 1 contains the levels of Na^+, Cl, and K^+ required per day by a horse at rest and after exercising hard enough to lose 5, 10, 20, or 40 liters of sweat.

Table 1. Total daily electrolyte requirements (grams/day) as a function of sweat loss.

		Sweat loss (liters/day)			
Electrolyte	*Rest*	*5 liters*	*10 liters*	*20 liters*	*40 liters*
Sodium (Na+)	15-20	33	50	85	155
Chloride (Cl)	27-33	55	83	139	251
Potassium (K+)	40-50	46	52	64	88

The amount of sweat loss will depend on a number of factors such as duration and intensity of exercise, temperature, and humidity. In general, horses exercising at low intensity (12-18 km/hr) will lose between 5 and 10 liters of sweat per hour. During higher intensity exercise (30-35 km/hr), sweat loss levels reach as high as 15 liters per hour. At the 1996 Olympic Games in Atlanta, horses lost an average of 18.4 kg of body weight during the speed and endurance phase of the three-day event, which translates to a sweat loss of around 15 liters.

Electrolyte Requirements During Endurance Training

Daily electrolyte requirements can be estimated by calculating the total amount of mileage logged weekly by the horse, taking into account the environmental conditions under which the training occurs (Table 2). For example, if an endurance horse were logging 50 km of work per week in a cool environment (20-25° C), it would only require about 60-120 grams (2-4 ounces) of a well-formulated electrolyte supplement to meet its daily electrolyte requirements. The lower range of supplementation would be adequate if the horse were also receiving adequate forage and a grain mix that contained supplemental salt, as well as access to a salt block. Horses at rest will normally consume around 50 grams of salt per day from a salt lick.

Table 2. Total daily electrolyte requirements (grams/day) as a function of training intensity and environment.

	Weekly mileage and training environment					
Electrolyte	*50 km/wk (cool[1])*	*50 km/wk (hot[2])*	*75 km/wk (cool)*	*75 km/wk (hot)*	*100 km/wk (cool)*	*100 km/wk (hot)*
Sodium (Na+)	24	32	27	40	32	48
Chloride (Cl)	40	54	47	67	54	80
Potassium (K+)	43	46	44	49	46	51
Daily electrolyte supplementation[3]	60-120 g 2-4 oz	90-150 g 3-5 oz	75-130 g 2.5-4.5 oz	120-170 g 4-6 oz	90-150 g 3-5 oz	140-200 g 5-7 oz

[1]20-25° C
[2]33-35° C
[3]Based on the composition of KER Summer Games Electrolytes. The amount of daily electrolyte supplementation will depend on the amount of electrolyte already in the ration and whether the horse has access to a salt block.

As training mileage and environmental temperature increase, so does the requirement for electrolyte supplementation. Horses that are training heavily (100 km/week) in a hotter environment (33-35° C) may need 140-200 grams (5-7 ounces) of supplemental electrolytes daily.

The recommendations given above are based on supplementing electrolytes at the same rate daily even though the amount of exercise performed each day will vary. This is probably a reasonable approach to supplementation except for days when the training distance is especially long. For those days, additional supplementation may be warranted. As a rule of thumb, 60 grams (2 ounces) of electrolyte supplementation are required for each hour of exercise in moderate climates. This rate of supplementation will double in hot environments when sweat loss is extensive. A long training ride of 60 km (~4 hours) in moderate temperatures would therefore produce enough sweat loss to require 240 grams (8 ounces) of electrolyte supplementation. This level of supplementation would need to be partially provided during the ride (60 grams at 20 and 40 km) using an oral electrolyte paste with the remainder of the electrolyte administered after the ride.

If the horse will not consume this quantity of electrolyte (120 grams or 4 ounces) in a single meal, 60 grams can be administered as a paste at the end of the ride. When administering oral electrolyte pastes, it is absolutely essential that the horse have access to drinking water. If the horse refuses to drink, do not administer an electrolyte paste.

Supplementation During Endurance Competition

There is a great deal of controversy about how to administer electrolytes during competition. Competitors have used a number of different strategies successfully, and the recommendations given here are not necessarily the only way to achieve success.

During competition, sweat losses can be very large. Using the sweating rates described earlier, an endurance horse will lose between 45 and 60 liters of sweat during a 160-km ride. This represents electrolyte losses of 460-690 grams. Additionally, 9-14 grams of calcium and 5-8 grams of magnesium will be lost through sweating. It is debatable whether all of these losses can or need to be completely replaced during the competition. Research has shown that endurance horses participating in 80-160 km events often have a fluid deficit of 20 to 40 liters despite having access to water and electrolytes during the ride. Canadian researchers have shown, however, that endurance horses with less pronounced fluid and electrolyte alterations during a competitive ride were more successful than those with greater changes (Lindinger and Ecker, 1995). Therefore, it is absolutely essential that a large proportion of the electrolytes and water lost in sweat be replaced during the ride.

Pre-ride electrolyte loading. The endurance horse must start the competition with adequate stores of both water and electrolytes. This can be accomplished in two ways. First, the endurance horse should be on a high level of forage (hay or pasture) intake before a ride. When a horse is fed liberal quantities of forage, it can store extra water and electrolytes in its large intestine. These stores can be called on to replace sweat losses early in the ride. Second, extra electrolytes can be administered the night before and the morning of the ride. The horse's system is finely tuned to balance the amount of electrolytes and water that it stores in its body at rest, so excessive pre-ride electrolyte supplementation should be avoided. Moderate supplementation (60 grams the night before and 60 grams the morning of competition) will insure that the horse has adequate electrolytes within its body and will provide additional electrolyte stores within the gastrointestinal tract.

Electrolyte supplementation during competition. Electrolytes should be supplemented throughout competition. The type of electrolyte supplement used during competition is slightly different than that which is used during training.This electrolyte should provide additional calcium and magnesium along with sodium, potassium, and chloride. If calcium and magnesium losses are not replaced by mobilization of skeletal stores or by supplementation, metabolic disturbances such as thumps may occur. Electrolytes should be administered to horses at each vet check and at water stops along the trail. The best way to administer electrolytes is in the form of a paste. Pastes are commercially available, or they can be made up fresh at the vet check by diluting an electrolyte powder in applesauce, water, or liquid antacid. A reasonable dose of electrolyte powder (or equivalent) is 60 grams at each vet check. Thirty- to 60-gram doses of electrolyte can be administered on the trail. It is worth reemphasizing that the horse must have access to drinking water when receiving concentrated electrolyte pastes. These pastes are hypertonic (a greater concentration of electrolytes) compared to blood and will effectively draw fluid out of the horse into the gut if they are not diluted by drinking water. Administering large doses of electrolytes without adequate water intake will result in serious problems including colic, dehydration, and possibly death.

How well will this electrolyte supplementation program replace losses from sweating? Endura-Max powder and Endura-Max Plus paste are calcium- and magnesium-containing electrolytes formulated specifically for endurance competition. Supplementation with 300 grams of Endura-Max powder (60 grams at five vet checks) along with five tubes of Endura-Max Plus paste on the trail will provide 336 grams of sodium, potassium, and chloride, the quantity of electrolytes lost in 33 liters of sweat. If the horse consumed enough water to complement this level of electrolyte intake, then it would finish the ride with a fluid deficit of between 12-27 liters. While this level of fluid deficiency is as good or better than what has been reported in the literature, why not try to replace all of the electrolytes lost during the ride? The answer lies in the horse's ability to absorb and retain large quantities of electrolytes in a short period of time. Sodium is actively transported across the intestinal wall by an energy-requiring process. The maximal rate of sodium transport is not known. Practical experience has shown that the levels of supplementation described above can be safely administered. Higher levels may be possible, but the risk of complications related to malabsorption will certainly increase.

Post-ride supplementation. Administering 120-240 grams (4-8 ounces) of electrolyte over the 24-hour post-ride period can eliminate most of the post-ride electrolyte deficit. A portion of this can be given as a paste shortly after the conclusion of the ride followed by top-dressing supplementation of electrolyte on the next two or three meals.

Fat Adaptation Spares Glucose Utilization

Fatigue during prolonged submaximal exercise may result from depletion of intramuscular or hepatic glycogen stores (Derman and Noakes, 1994; Snow et al., 1981). Previous research has demonstrated that the inclusion of fat in the equine diet will affect substrate selection and utilization during exercise (Potter et al., 1992, Kronfeld et al., 1994). Field trials with endurance horses have suggested that fat adaptation will protect against drops in blood glucose (Hintz, 1982; Slade et al., 1975) and treadmill studies have demonstrated muscle glycogen sparing effects in horses fed fat-supplemented diets (Griewe et al., 1989; Pagan et al., 1987). The degree to which fat adaptation will affect substrate utilization has not been previously quantified. Therefore, KER conducted a study to determine the effects of a fat-supplemented diet on carbohydrate and fat oxidation in conditioned horses during low-intensity exercise (Pagan et al., 2002). We hypothesized that short-term feeding (<10 weeks) of a fat-supplemented diet would result in adaptations that decrease carbohydrate oxidation and increase the utilization of fat for energy during exercise. This increase in fat utilization would be reflected by decreases in glucose turnover (glucose R_a and R_d) and respiratory exchange ratio during exercise.

Five mature Arabians were studied. The study was conducted as a crossover design with two dietary periods, each of 10 weeks duration: a) a control (CON) diet, and b) a fat-supplemented (FAT) diet. The total amount of digestible energy (DE) supplied by the fat in the CON and FAT diets was calculated to be 7% and 29%, respectively. During each period, the horses completed exercise tests before the start of the period (Week 0) and after 5 and 10 weeks on the diet consisting of 90 minutes of running (treadmill at 3° incline) at a speed calculated to elicit 35% VO_2max. Oxygen consumption (VO_2), carbon dioxide production (VCO_2), and respiratory exchange ratio (RER) were measured at 5-minute intervals. For determination of glucose kinetics, a stable isotope ([6-6-d_2] glucose) technique was used.

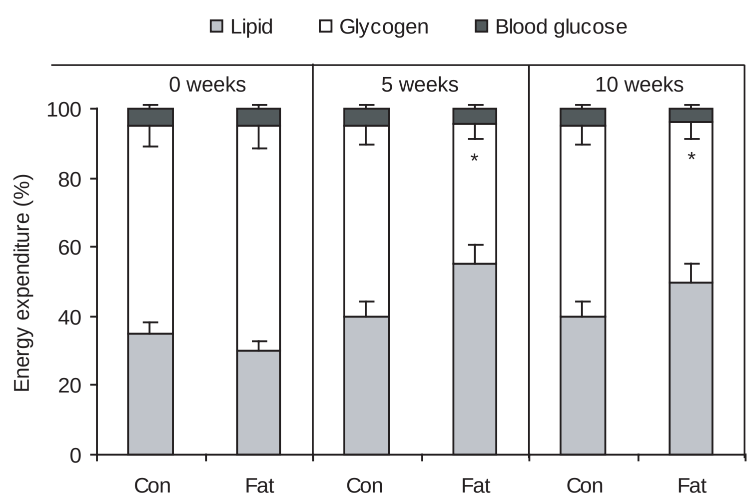

Figure 4. Relative contributions of energy from different substrate sources for three periods during 90 minutes of exercise at 36 ± 1% of maximum oxygen uptake. Values are means ± SE for five horses. *Significantly different from CON, $P < 0.05$.

Compared to a control diet, consumption of a fat-supplemented diet (~29% of DE from fat) was associated with an altered metabolic response to low-intensity exercise (Figure 4) as evidenced by:

1. A more than 30% reduction in the production (glucose R_a) and utilization (glucose R_d) of glucose after 5 and 10 weeks of fat feeding;
2. A decrease in respiratory exchange ratio after 5 and 10 weeks of fat feeding;
3. A decrease in the estimated rate of whole-body carbohydrate, attributable to decreases in muscle glycogen and plasma glucose utilization; and
4. An increase in the whole-body rate of lipid oxidation during exercise.

These metabolic adaptations which were evident after five weeks of fat supplementation would be advantageous during prolonged exercise, wherein the reduced reliance on carbohydrate for energy would preserve this more limited energy resource and delay the onset of fatigue associated with carbohydrate depletion. Further studies are warranted to investigate the mechanisms underlying this response to fat feeding.

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