In: 9e Congrès de Médecine & Chirurgie Equine de Genève / 9. Kongresses für Pferdemedizin & Chirurgie in Genf / 9th Congress on Equine Medicine & Surgery in Geneva, Chuit P. and Montavon S. (Eds.). International Veterinary Information Service, Ithaca NY (www.ivis.org), Last updated: 15-Dec-2005; P1906.1205

Nutritional Management of Endurance Horses

R.J. Geor

Ontario Veterinary College, University of Guelph, Canada.

Introduction

Endurance racing is perhaps the most demanding of equine sporting disciplines, with horses required to complete distances of up to 160 km in a single day (and over longer distances during multi-day races). Moreover, particularly at the international level, the recent trend has been for very high racing speeds. For example, the winner of the 2005 World Equine Endurance Championship race in Dubai covered the 160 km distance at an average speed of 22.5 kilometers per hour (~14 miles per hour). Maintenance of these high work rates poses several challenges for the endurance horse. First, high energy demands may result in the depletion of substrate stores, particularly muscle and liver glycogen. Second, as the evaporation of sweat is the major mechanism for heat dissipation during exercise, there is a substantial loss of body water and electrolytes (especially sodium and chloride). Field studies of endurance rides have shown body mass losses (a reasonable reflection of fluid losses) ranging from 3 - 7% at the end of 80 - 160 km rides (Schott et al 1997; Barton et al 2003). Development of substrate depletion, hyperthermia, and disturbances to fluid, electrolyte and acid-base homeostasis may result in elimination of the horse from the ride (so called "metabolic failure"). Anecdotal reports from elite level endurance races have indicated that approximately 30 - 35% of horses are eliminated before completion, with 60% eliminated due to lameness and 25% due to metabolic problems associated with severe dehydration, heat stress, synchronous diaphragmatic flutter (SDF), muscle cramping, and/or rhabdomyolysis. The extent to which variations in feeding management alter risk for development of these metabolic problems is not known and further research is needed to address this issue. However, there is a general consensus that sound nutritional management is crucial for optimal endurance exercise performance. This includes consideration of diet composition, maintenance of optimal body condition, and strategies for provision of feed, electrolytes and water on race day. The purpose of this paper is to review the principles of feeding management for endurance horses.

Energy and Protein Requirements - Energy is the Key Nutritional Consideration

Energy represents the component of the diet that can be used by the body for work, which includes maintenance of all systemic and cellular processes. There are two major considerations regarding the energy needs of endurance horses engaged in regular training and competition. The first is the increment in energy requirement associated with the energy demands of exercise. An increase in energy (i.e. caloric) intake is required for avoidance of weight loss (and, probably, loss of performance). The second consideration is the effect of the energy sources (fiber and non-fiber carbohydrates, fats and oils, or amino acids) on health and performance (Harris and Kronfeld 2003). The latter can impact body substrate stores, the metabolic response to exercise and, potentially, athletic performance.

Relationship between Energy Supply and Endurance Performance

The capacity for endurance exercise is highly dependent on the availability of substrate for the synthesis of adenosine triphosphate (ATP), the body's energy currency. The endurance horse travels at speeds that can be maintained almost entirely by aerobic metabolism, with glucose and fatty acids the primary substrates for ATP re-synthesis in muscle. Glucose is derived from the breakdown of liver and muscle glycogen and de novo synthesis of glucose in the liver, while fatty acids (long-chain, non-esterified fatty acids or NEFA) are released from triglyceride stores in adipose tissue and in muscle. A 450-kg horse has approximately 3000 - 4000 g muscle glycogen (1 - 2% of skeletal muscle weight), 100 - 200 g liver glycogen (6 - 8% of liver weight), 1400 - 2800 g muscle triglyceride, and 35,000 - 45,000 g as adipose tissue triglyceride (Harris 1997). In the context of endurance exercise, the endogenous store of triglyceride is virtually inexhaustible. On the other hand, the supply of glucose is more limited and depletion of endogenous carbohydrate stores (muscle and liver glycogen) is likely one factor that contributes to development of fatigue in endurance horses (Farris et al 1998; Lacombe et al 2003). Importantly, diet can affect substrate storage (particularly liver and muscle glycogen) and the ability to utilize fat during exercise (e.g. the effects of pre-exercise meals or adaptation to a higher fat diet). Thus, the link between diet and endurance exercise performance is apparent. Practical considerations for optimization of muscle and liver glycogen storage pre-race and other strategies for manipulation of fuel supply during exercise are discussed below.

In human athletes, there is a strong inverse relationship between body fat content and endurance running performance. Although data from horses is limited, there also is evidence that body fatness, as reflected by body condition score (BCS), may influence performance in endurance races. In one study of horses competing in the 100-mile Tevis Cup, the mean BCS of horses that successfully completed the rides was 4.5, whereas horses that were eliminated for metabolic failure (e.g. colic, heat exhaustion, synchronous diaphragmatic flutter or tying up) had a mean condition score of 2.9 (Garlinghouse et al 1999). Horses that were eliminated for non-metabolic reasons such as lameness and overtime had a mean condition score of 4.3. The researchers were careful to point out that their results may not apply to endurance competition as a whole given the difficult nature of the Tevis Cup course. Nonetheless, the implication from these studies is that there is an optimal level of "fatness" for horses competing in endurance events, and that training and feeding programs need to be adjusted accordingly. Endurance performance of horses with a low BCS (e.g. <3) may be limited by the supply of energy from fat reserves. In addition, a loss of lean tissue (muscle mass) may contribute to diminished performance in horses with poor body condition. On the other hand, over-conditioned horses (BCS >6) may be at a disadvantage due to carriage of excess weight and the insulating effects of subcutaneous adipose tissue. In general, feeding programs for endurance horses should target a BCS of around 4 to 4.5.

Energy Requirements

As for all horses engaged in regular athletic activity, the energy needs of endurance horses are increased relative to the maintenance requirement as a function of work duration and intensity. The National Research Council (1989) used the following formula to estimate maintenance energy requirements (as digestible energy [DE]) in horses with bodyweight between 200 kg and 600 kg:

DE (MJ/day) = 4.184 x (1.4 + 0.03 x bodyweight [kg])

Therefore, for a 450-kg horse the maintenance requirement is about 62 MJ DE/day. In general, the intensity and duration of exercise, type of terrain, the weight of the rider and tack, the ability of the rider, the level of training of the horse, environmental conditions, and composition of the diet will all influence overall energy needs. Although at present there are no practical means for precise determination of the additional energy requirements of horses in training, the equation developed by Pagan and Hintz (Pagan and Hintz 1986) is helpful for illustration of the impact of running exercise on energy needs. This prediction equation provides an estimate of the DE required above maintenance using oxygen consumption (VO2) data collected from horses running on a level track:

DE (kJ per kilogram of horse, rider and tack) = 4.184 x {[e(3.02 + 0.0065Y) - 13.92] x 0.06}/0.57

where Y is the speed (meters per minute) and 0.57 accounts for the efficiency of utilization of DE.

For example, for a 450-kg horse carrying a 75-kg rider and running at an average speed of 250 - 300 meters per hour (15 - 18 km/h), the DE costs are approximately 20 - 25 MJ per hour. If this horse undertakes a 3-h training bout at these speeds the total DE requirement (maintenance + exercise increment) for that day is 120 to 137 MJ, i.e. about twofold higher than maintenance. Note that the DE costs of an endurance race (e.g. distances of 100 km to 160 km) will be even higher resulting in a daily energy requirement of about three times maintenance; it will not be feasible for the horse to replace this energy deficit on race day. However, the actual increment in DE requirement averaged over a longer period of regular endurance training is probably lower. Indeed, survey data from riders of top level endurance horses in the U.S. suggest that average daily DE intake is in the range of 100 - 110 MJ (Crandell 2002). From a practical viewpoint, frequent (e.g. weekly) assessment of body weight and/or BCS is necessary to determine the appropriateness of the feeding program; upward or downward adjustments in DE intake are often needed for maintenance of constant bodyweight and condition.

Protein Requirements

Additional protein over maintenance may be needed with exercise and training because of the accompanying muscular development, the need for muscle repair and to replenish the nitrogen lost in sweat. However, the precise protein requirements for exercise are unknown. The 1989 NRC recommended 9%, 10.4% and 11% crude protein (CP) in the total ration for horses undertaking light, moderate and intense exercise, respectively. In the aforementioned survey of feeding practices for endurance horses, the overall protein content of the diet averaged 10.2% CP, but ranged from 6.2% to 15.7% depending on the type of forage offered (Crandell 2002). Higher protein diets may be undesirable because of the effects of excess dietary protein on heat production, acid-base balance, water requirements and, potentially, respiratory health (Kronfeld 2001; Graham-Thiers et al 2001). Oxidation of the phosphorus and sulphur in protein adds to the acid load on the body. In this context, Graham-Thiers and colleagues evaluated the effects of a restricted protein diet (7.5% CP with added lysine and threonine) on acid-base balance in horses in moderate work (Graham-Thiers et al 2001). When compared to a 14.5% CP diet, protein restriction resulted in a slight increase in resting blood pH and mitigation of exercise-associated acidemia during repeated sprints. These effects may provide a performance advantage during exercise, although the actual effect of dietary protein level on exercise performance has not been determined. There is evidence that dietary protein level alters urea metabolism in horses. In one study, horses consuming 1741 g CP per day (>3 g/kg BW) excreted more urea in sweat and had higher plasma urea when compared to horses consuming 836 g CP per day (Miller-Graber et al 1997), and it has been estimated that a change in dietary CP from 10% to 15% would increase water requirement by approximately 5% because of an obligate increase in urine production for clearance of endogenous urea loads (Kronfeld 1996). Moreover, the higher urinary urea load could adversely affect the respiratory health of confined horses because urea is converted to ammonia, a known respiratory irritant. Based on these considerations, it is recommended that the CP content of an endurance horse ration be no higher than 12%.

<u>Meeting Energy and Protein Requirements</u>

For most horses in training, a combination of forage and energy concentrate is required to meet energy requirements. Several guiding nutritional principles should be used in the development of a feeding program for an endurance horse, including:

Provision of adequate fibre (roughage) to maintain normal gut and digestive function (and perhaps limit the development of behavioural disturbances);

Targeting an overall energy density that will allow energy requirements to be met at typical fed intakes;

Supplying sufficient hydrolysable carbohydrate to maintain muscle glycogen concentrations;

Provision of the optimal amounts and balance of the other essential nutrients (i.e., protein, minerals, vitamins); and

The inclusion of only the highest quality feedstuffs.

The four main *sources of energy* in horse rations are:

Fermentable carbohydrates (components of dietary fiber or roughage, including hemicellulose, that cannot be digested by mammalian enzymes but can be fermented by microorganisms, primarily in the hindgut i.e., cecum and large colon);

Hydrolysable carbohydrates (simple sugars and starch) that are digested by mammalian enzymes in the small intestine, yielding hexoses;

Oils and fats; and

Protein (not primarily fed as an energy source because metabolism of amino acids to useable energy is inefficient).

Forage is the Foundation

Forage should be the foundation of any ration for horses, and the endurance horse is no exception. In the aforementioned survey of top riders in the US, the average forage content of the ration was 78%, which is much higher in comparison to other types of athletic horses (e.g. the ration of a racehorse may be less than 30% forage). In addition, most of these horses had 24 h pasture turnout (Crandell 2002). Although a requirement for dietary fibre has not been established in horses, some long stem roughage is likely important for maintenance of normal hindgut function and thus for normal digestion. There also is evidence that diets low in long stem fiber favour development of certain stereotypies (Goodwin et al 2001). Therefore, adequate dietary roughage may be important for prevention of some undesirable behavioural traits, particularly in horses kept in confinement. Meyer (Meyer 1987) has suggested that performance horses be fed at least 0.5 kg of roughage per 100 kg body weight (0.5% of body weight). However, we recommend *at least* 1.0 kg forage per 100 kg (i.e. 5.0 kg for a 500-kg horse, as fed basis). There is a general preference for grass (CP 8 - 14%) rather than legume (CP often >20%) hay because of concerns regarding the effects of a higher protein diet (see above). An alfalfa/grass hay mix may be suitable, but alfalfa should comprise no more than 30% of the mix.

It also has been proposed that the feeding of a high-fibre diet, including fibre sources such as beet pulp and soya hulls, may be helpful in maintenance of hydration during exercise due to an increase in the water-holding capacity of the large intestine (Meyer and Coenen 1989; Warren et al 2001). The horse's large intestine contains a fluid volume equivalent to 8 and 10% of bodyweight, with 10 - 20% of total body sodium, potassium and chloride, and there is some evidence that a portion of this fluid can be absorbed during prolonged exercise, thereby partially offsetting sweat fluid losses. The amount of dietary fiber is thought to influence the size of a horse's large intestinal fluid reservoir. In ponies (100 - 300 kg bodyweight), it was demonstrated that feeding a high-fibre diet (hay) when compared to low-fibre diet (complete feed made with grains, bran and beet pulp) resulted in greater water and electrolyte content of the large intestine (183 and 101 ml water/kg body weight, and 398 and 212 mg Na^+/kg body weight in the high and low fibre diets, respectively) (Meyer and Coenen 1989). Furthermore, Warren and co-workers (Warren et al 2001) reported an approximately 15% increase in estimated gastrointestinal tract fluid volume when horses were fed a high fibre (54% neutral detergent fibre [NDF], 31% acid detergent fibre [ADF]) when compared to a low fibre diet (31% NDF, 19% ADF). Meyer and Coenen (1989) also described that low intensity exercise (2.8 - 3.3 m/s for 1 - 3 h) resulted in absorption from the gastrointestinal tract of 22 ± 7 (mean ± SD) ml of water, 43 ± 30 mg Na^+ and 23 ± 14 mg Cl^- per kg of body weight. These averages extrapolated to a 450-kg horse would suggest that during exercise approximately 10 L of water, 19 g Na^+ (840 mEq Na^+), and 10 g Cl^- (290 mEq Cl^-) may be absorbed from the approximately 45 L present in the gastrointestinal tract. Quantitatively, these amounts are modest and do not obviate the need for electrolyte supplementation during endurance races. It should also be noted that the putative benefits of a high fibre diet in terms of improved water and electrolyte balance must be weighed against energetic disadvantages associated with an increase in hindgut weight (bowel ballast). For example, in a 450-kg horse, an extra 4 kg in hay intake can be estimated to increase bowel ballast by between 10 and 24 kg (Kronfeld 2001).

Energy Supplements

Some type of supplemental energy concentrate is generally needed to meet energy requirements and maintain body weight during training and competition. The average quantity of concentrate fed to US endurance horses in training was 2.27 kg/day (Crandell 2002), which is a modest amount when compared to the amount fed to racehorses. A wide variety of energy concentrates can be fed, from straight cereal grains (high starch) to "fat and fibre" feeds in which vegetable oils and fats and highly digestible fibre sources such as sugar beet pulp and soya hulls are the primary energy sources. Traditionally, cereal grains such as oats, corn and barley (alone or in combination) have been a source of energy in rations for athletic horses. Starch, a hydrolysable carbohydrate, is the primary component of cereal grains. Oats are approximately 47 - 50% starch while the starch content of corn and barley is between 65 and 70%. However, the small intestine has low capacity for starch hydrolysis and large grain meals may overwhelm digestive capacity leading to the rapid fermentation of the grain carbohydrate in the hindgut (Clarke et al 1990; Potter et al 1996). High-starch (grain) diets have also been implicated in the pathogenesis some forms of chronic exertional rhabdomyolysis (Valberg et al 1999).

While it is necessary to feed some hydrolysable carbohydrate to athletic horses to assure an adequate supply of substrate for glycogen replenishment, several strategies can be employed to mitigate the risk of digestive disturbances attributable to heavy grain (starch) feeding. First, it is advisable to limit the size of individual grain-based meals to avoid "starch bypass" to the large intestine (e.g. no more than 1.5 kg/meal for a 450-kg horse). Second, only cereal grains with high pre-caecal starch digestibility should be included in energy concentrates for horses. The pre-caecal starch digestibility varies with the type of grain and the nature of any mechanical or thermal processing. For example, whereas oat starch (at up to 3 g/kg per meal) has a pre-caecal digestibility of greater than 90%, approximately 35% of an equivalent dose of cornstarch reaches the caecum undigested. Similarly, the pre-caecal digestibility of unprocessed barley is substantially lower when compared to oats (Cuddeford 2001). However, heat treatments such as micronisation, extrusion and steam flaking significantly improve the pre-caecal starch digestibility of barley and corn. Overall, oats appear to be the safest source of starch for horses, although barley and corn are acceptable if they are subjected to some form of heat treatment.

The third strategy for mitigation of problems associated with the feeding of high starch concentrates is to more use of vegetable oils and non-starch carbohydrates (e.g. sugar beet pulp). Inclusion of these alternative energy sources facilitates a reduction in the level of starch feeding without compromising the caloric density of the ration. Provision of a fat-supplemented diet is a popular dietary strategy for endurance horses. Fat supplementation in horses is characterized by a dose-dependent increase in the activity of lipoprotein lipase and, in some studies, an increase in the activity of skeletal muscle citrate synthase and beta-hydroxy acyl-CoA dehydrogenase (HAD) (Orme et al 1997;Dunnett et al 2002). These adaptations suggest that horses adapted to a fat-supplemented diet have increased capacity for the uptake and oxidation of fatty acids in muscle. Indeed, horses fed a diet providing approximately 25% of digestible energy from fat have lower respiratory exchange ratio (Dunnett et al 2002; Pagan et al 2002) and decreased glucose utilization (Pagan et al 2002) during low intensity (~25 - 35% VO2max) exercise when compared to the control diet. Thus, fat-supplementation enhances lipid oxidation and spares the use of endogenous CHO (plasma glucose, muscle glycogen) during low intensity exercise. Theoretically, such a glycogen-sparing effect could enhance the performance of horses in endurance races, although further research is needed to determine the actual effects of fat supplementation on the performance of horses in endurance races. The ideal amount of dietary fat for endurance horses has not been determined. In studies that have examined the effects of dietary fat on metabolic responses to exercise, the ration provided approximately 20% to 25% of DE from fat (approximately 10% fat on a total diet basis). This level of fat supplementation appears to be considerably higher than that practised by endurance owners and trainers. In one survey, approximately 55% of horses were fed additional fat in the form of oil or rice bran. On a total diet basis, the average percentage fat was 2.3%, with a range of 1.45% to 6.9% (Crandell 2002).

Supplemental fat or oil diets can be supplied in three main ways: 1) Commercial, fat-supplemented feed - one advantage is that such diets should contain the appropriate balance of other key nutrients e.g. protein, vitamins and minerals; 2) High-fat supplements e.g. stabilized rice bran - in some countries rice bran is a popular choice for adding fat to the ration. It should be recognized that rice bran, like wheat bran, has an inverted calcium-to-phosphorus ratio (low calcium, high phosphorus) and supplemental calcium is often necessary when feeding rice bran; or 3) Supplemental vegetable oils e.g. corn or soya oils (note that the feeding of animal fat is not recommended because of low palatability and digestibility vs. vegetable oils). Any supplemental oil or oil supplemented feed should be introduced slowly. Dietary fats are hydrolysed in the small intestine and the capacity to hydrolyse lipids seems to adapt in herbivores over a 10 - 14 day period (Pagan and Kronfeld 2003). A suggested upper limit of oil supplementation is 100 g per 100 kg bodyweight per day. For reference, one standard measuring cup contains 250 ml of oil (~200 g) and provides approximately 6.7 MJ of DE e.g. for a 450-kg horse in moderate work (daily DE needs of 100 MJ), 450 g of oil/day will provide about 25% to 30% of DE requirements.

One concern with the addition (top dress) of vegetable oils (or rice bran) to an existing diet is the potential for nutrient imbalances. Consultation with a nutritionist is recommended in these situations. Supplementation with vitamin E (100 - 200 IU per 100g of added oil) is recommended for prophylaxis against oxidant stress when oil is directly added to the ration. This practice may not be necessary when rice bran is the source of added fat as it contains substantial quantities of vitamin E and other natural antioxidants.

Dietary Electrolyte Supplementation

Endurance horses is regular training will require some form of electrolyte supplementation. Sweat contains relatively low levels of calcium (~0.12 g/L), magnesium (~0.05 g/L) and phosphate (<0.01 g/L) but relatively high levels of sodium (~3.1 g/L), potassium (~1.6 g/L) and chloride (~5.3 g/L) (McCutcheon et al 1995). There are also small amounts of various trace elements e.g. iron ~4.3 mg/L, zinc ~11.4 mg/L (Meyer 1987). As the sodium and chloride content of horse feedstuffs is low, salt supplementation is required to offset sodium and chloride losses in sweat. In contrast, potassium losses in sweat are lower and forages tend to have a high content of potassium, which makes potassium balance less of a concern. The sodium requirements for a horse at rest have been estimated at 20 mg/kg/day (assuming that the sodium sources are 90% available) but may increase to as much as 40 - 50 mg/kg/day for horses in training in warm ambient conditions. One approach is to provide horses with free access to a salt block. However, it has been shown that there is great individual variation of voluntary sodium intake from a salt block (Jansson et al 1996; Jansson and Dahlborn 1999). Therefore, it has been recommended to provide supplemental loose salt in the diet rather than salt blocks, e.g. 40 - 60 g/day of common table salt.

Feeding Management Before and During Endurance Races

There are several considerations regarding nutritional management before, during and after endurance races. Particularly important are the timing and composition of pre-race meals and strategies for electrolyte and water replacement during rides. In the 4 - 5 day period before the race, the intensity and duration of training should be tapered. This strategy may allow for an increment in muscle glycogen storage before the race. It also has been suggested that the feeding of a high glycaemic meal (e.g. 1.5 - 2.0 kg sweet feed to horses adapted to cereal-based concentrates) the night before a race may be helpful in "topping up" liver glycogen stores. Anecdotally, there are reports of riders administering electrolyte pastes during the 1 - 2 day period before a race in an attempt to "load" body electrolyte stores. Data on the efficacy of this practice are not available. However, in the absence of a pre-existing electrolyte deficit it is probable that the supplemented electrolytes will be excreted within a few hours of administration.

<u>Timing and Composition of Pre-Race Meals</u>

There has been considerable debate about when and what should be fed horses before they are exercised and/or at a competition. However, there is evidence that the timing and composition of a meal consumed before exercise can influence metabolic response in horses (Lawrence et al 1993; Lawrence et al 1995; Stull and Rodiek 1995;Pagan and Harris 1999). Most notably, the hyperglycaemic and insulinemia associated with the digestion and absorption of grain meals affects the mix of substrates utilized during a bout of exercise. Insulin is a potent inhibitor of lipolysis and fatty acid oxidation in skeletal muscle, and also promotes glucose uptake into muscle via recruitment of the transporter protein GLUT4 to the sarcolemma. Thus, hyperinsulinemia at exercise onset will suppress NEFA availability and lipid oxidation and increase reliance on carbohydrate stores (including plasma glucose) for energy transduction. Accordingly, several equine studies have demonstrated that a grain meal (1 - 3 kg of oats, corn or a mixture of the two) consumed 3 hours or less before exercise results in hyperglycaemia, hyperinsulinemia and decreased plasma NEFA concentration at the start of exercise, and a subsequent marked decrease in plasma glucose concentration during the initial period of exercise (Lawrence et al 1993; Lawrence et al 1995; Stull and Rodiek 1995; Pagan and Harris 1999). This decrease in plasma glucose concentration tends to be short-lived such that during prolonged moderate-intensity exercise (e.g. 60 min at 50% of VO2max), the plasma glucose concentrations of grain fed horses is not substantially different from horses fasted before exercise. On the other hand, plasma NEFA and lipid oxidation remain lower when compared to the fasted state throughout exercise (Jose-Cunilleras et al 2002).

The effects of pre-exercise grain feeding on endurance exercise performance in horses have not been reported. In humans, carbohydrate ingestion during exercise unequivocally improves performance during prolonged (more than 2 hours) moderate-intensity (>50 - 60% of VO2max) exercise, presumably by maintaining glucose supply in skeletal muscle at a time when glycogen stores are depleted (Hargreaves 1999). On the other hand, the performance effects of pre-exercise glucose feedings in human athletes are more equivocal (Hargreaves 1999). For horses performing endurance exercise, the acceleration in carbohydrate oxidation (and suppression of fat oxidation) associated with grain feeding (<2 - 3 h pre-exercise) may result in premature fatigue as a result of carbohydrate depletion. For this reason, it is recommended that grain or concentrate meals be fed no later than 3 hours pre-race.

On the other hand, studies in horses have demonstrated that forage meals (<2 kg, as fed) consumed 2 to 3 hours before exercise have minimal effect on substrate availability and oxidation during sustained exertion, although large meals (hay or grain or a combination) consumed near the start of exercise may result in a decrease in plasma volume as a result of fluid shifts into the gastrointestinal tract (Pagan and Harris 1999). Such reductions in plasma volume could compromise cardiovascular and thermoregulatory function during exercise. In general, it seems reasonable to allow the consumption of small forage meals (1 - 2 kg, as fed) in the 1 - 3 h period pre-race.

Water and Electrolyte Replacement

Strategies for water and electrolyte replacement are vitally important for mitigating risk of thermoregulatory failure and other metabolic problems associated with dehydration and electrolyte imbalances (Jose-Cunilleras 2003). A variety of strategies have been used with no consensus on the optimal method. Options include the administration of hypertonic electrolyte pastes before and during the race, the addition of electrolytes to meals offered at rest stops, and provision of hypotonic electrolyte solutions for voluntary consumption. The optimal level of supplementation is also not known and likely varies between horses. In practice, riders will establish the most appropriate replacement strategy for their horse by a process of trial and error, ideally through the evaluation of different approaches during training rides.

Electrolytes can be supplemented by mixing them in grain, beet pulp or pelleted feeds, or by direct oral administration of pastes (commercial or "home made" formulations).

Many riders will administer an initial dose of electrolytes 2 - 3 h pre-race, with subsequent doses given at vet gates (or more frequently depending on ambient conditions) during the race. The results of laboratory studies have suggested that this approach is efficacious providing horses have ready access to drinking water and the administration of an electrolyte paste results in an enhanced drinking response. Electrolyte supplementation as an oral paste before and during a simulated 60 km (37.5 miles) endurance ride on a treadmill resulted in attenuated weight loss after exercise due to greater voluntary water intake during and after the ride (Düsterdieck et al 1999). Furthermore, body weight loss recovered by 48 h after exercise in supplemented horses, whereas the bodyweight of non-supplemented horses remained decreased (Schott et al 1999). In this study, total electrolyte supplementation in horses of mean body weight of 370 kg was 75 g of potassium chloride and 150 g of sodium chloride (~2500 mEq Na^+, ~1000 mEq K^+ and ~3500 mEq Cl^-) given as smaller doses divided before and during treadmill exercise. This supplementation regimen was estimated to replace electrolyte losses in 20 - 25 liters of sweat. Similarly, Coenen and colleagues (Coenen et al 1995) reported greater water intake during and after a 2-h treadmill exercise bout when horses were fed a salt supplement prior to exercise that provided one-half of the sodium and chloride and one-fifth of the potassium administered in the study of Schott and co-workers (Schott et al 1999).

Another option is to offer horses a dilute salt water solution for voluntary consumption. As with the use of hypertonic electrolyte pastes, allowing horses to drink salt water during and/or immediately after exercise appears to enhance total fluid intake during the early recovery period and attenuate weight loss during exercise (Nyman et al 1996;Butudom et al 2002). In a laboratory study, horses received frusemide (1 mg/kg bodyweight) 2 h prior to a 45-km treadmill exercise bout. The combined effect of diuretic administration and endurance exercise resulted in bodyweight losses of 5.2% to 5.7% (20 - 22 kg or approximately 18 - 20 L), which is similar to that observed in competitive endurance rides (Butudom et al 2002). When horses were offered water, 0.45% saline or 0.9% saline immediately after exercise and then given free access to water, total fluid intake during the first hour after exercise was 11.4 L, 16.6 L and 18.5 L, respectively (Butudom et al 2002). Therefore, in horses adapted to consumption of saline solutions it is beneficial to offer salt water (0.9% NaCl, 9 g in 1 liter of water) immediately after exercise as a means to stimulate water intake during the recovery period.

Sodium and chloride should be the major components of an electrolyte supplement, although many riders added small amounts of calcium and magnesium in an attempt to prevent development of hypocalcaemia and hypomagnaesemia during the ride. Recently, it has been proposed that potassium-free electrolyte formulations should be administered to endurance horses during races (Hess et al 2005). Moderate exercise can result in mild to moderate hyperkalemia, and there is some evidence that the administration of potassium-containing electrolyte formulations will exacerbate the hyperkalemia and, potentially, increase risk of cardiac arrhythmias and muscle cramping. More research is required to address this issue.

Regardless of the method of electrolyte supplementation, fresh water should be offered at frequent intervals (every 30 - 40 min, particularly in hot weather) and water intake must be closely monitored, particularly with use of hypertonic electrolyte pastes. The administration of hypertonic electrolyte pastes is contraindicated in horses with a poor drinking response.

Mid- and Post-Race Feeding

There is no consensus on what should be fed to endurance horses at rest stops during a race. However, feed consumption at rest stops is important because appetite is an indicator of overall health, and feed intake may assist in the maintenance of normal gastrointestinal motility, the evaluation of which is used in the assessment "fitness to continue" at veterinary checkpoints. Furthermore, the consumed feed may support energy supply and therefore could be important in sustaining work performance during the latter stages of races when endogenous fuel reserves are depleted (particularly muscle glycogen). In general, horses are offered a "smorgasbord" of feeds at rest stops, i.e. the first priority is to feed palatable feedstuffs with secondary consideration given to the nutrient composition of the feed. Mash or slurry mixtures are popular including feedstuffs such as alfalfa meal, cereals, or wheat bran/stabilized rice bran plus some molasses or carrots to enhance palatability. Plain forage (often soaked) is also offered in most cases. Some nutritionists have advocated the feeding of forage pellets or cubes because, when compared to long-stem forage, there is a more rapid rate of consumption and transit to the caecum. In theory, these attributes could result in enhanced energy availability (short-chain fatty acids production from hindgut fermentation) later in the ride but there are no data to support this assertion. There has been interest in the effects of carbohydrate supplementation (e.g. as glucose polymers) before and during endurance races. As stated above, there is evidence of improved endurance performance in human athletes when carbohydrate is consumed (40 - 75 g/h for a 70-kg subject) during moderate intensity exercise. Data on the efficacy of similar strategies in endurance horses are not available, but anecdotally there have been reports of poor recovery (e.g. heart rate recovery at vet checks) in horses receiving carbohydrate supplements during the ride. Controlled studies are needed to address this issue.

Water should be offered immediately after completion of the race. If the horse exhibits an appropriate drinking response, a further dose of an electrolyte supplement may be given. Hay (free choice) and other feedstuffs offered during the ride should be made available. It is not feasible to replace the incurred energy deficit during the initial 12 - 24 h post-race period. Most endurance horses are given only light exercise (e.g. walking) for a few days post-race and this, combined with a return to the normal feeding pattern, will allow for replacement of lost body mass (e.g. gut fill) and energy reserves (muscle glycogen).

References

Barton MH, Williamson L, Jack S, et al. Body weight, hematologic findings, and serum and plasma biochemical findings of horses competing in a 48-, 83-, or 159-km endurance ride under similar terrain and weather conditions. Am J Vet Res 2003; 64:746-753. - PubMed -

Butudom P, Schott II HC, Davis MW, et al. Drinking salt water enhances rehydration in horses dehydrated by frusemide administration and endurance exercise. Equine Vet J Suppl 2002; 34:513-518. - PubMed -

Clarke L, Roberts MC and Argenzio RA. Feeding and digestive problems in horses: Physiologic responses to a concentrated meal. Vet Clin North Am Equine Pract 1990; 6:433-450. - PubMed -

Coenen M, Meyer H and Steinbrenner B. Effects of NaCl supplementation before exercise on metabolism of water and electrolytes. Equine Vet J Suppl 1995; 18:270-273.

Crandell K. Trends in feeding the American Endurance horse. In: Proceedings of the Kentucky Equine Research, Inc, Equine Nutrition Conference 2002; 135-139.

Cuddeford D. Starch digestion in the horse. In: Pagan J. and Geor RJ, eds. Advances in Equine Nutrition II. Nottingham: Nottingham Press, 2001; 95-104. - Available from amazon.com -

Dunnett C, Marlin DJ and Harris RC. Effect of dietary lipid on response to exercise: relationship to metabolic adaptation. Equine Vet J Suppl 2002; 34:75-80. - PubMed -

Duren S. Feeding the Endurance horse. In: Pagan J, ed. Advances in Equine Nutrition. Nottingham University Press, 1998; 351-363. - Available from amazon.com -

Düsterdieck KF, Schott II HC, Eberhart SW, et al. Electrolyte and glycerol supplementation improve water intake by horses performing a simulated 60 km endurance ride. Equine Vet J Suppl 1999; 18:418-424. - PubMed -

Farris J, Hinchcliff KW, McKeever KH, et al. Effect of tryptophan and of glucose on exercise capacity of horses. J Appl Physiol 1998; 85:807-816. - PubMed -

Garlinghouse SE and Burrill MJ. Relationship of body condition score to completion rate during 160km endurance races. Equine Vet J Suppl 1999; 18:591-595. - PubMed -

Goodwin D, Davidson HPB and Harris P. Foraging enrichment for stabled horses: effects on behaviour and selection. Equine Vet J 2002; 34:686-691. - PubMed -

Graham-Thiers P, Kronfeld DS, Kline KA, et al. Dietary protein restriction and fat supplementation diminish the acidogenic effect of exercise during repeated sprints in horses. J Nutr 2001; 131:1959-1964. - PubMed -

Hargreaves M. Metabolic responses to carbohydrate ingestion: Effects on exercise performance. In: Lamb D and Murray R, eds. Perspectives in Exercise Science and Sports Medicine. The Metabolic Basis of Performance in Exercise and Sport. Carmel, IN: Cooper Publishing, 1999; 93-124. - Available from amazon.com -

Harris PA. Energy sources and requirements of the exercising horse. Annu Rev Nutr 1997; 17:18-210. - PubMed -

Harris PA and Kronfeld DK. Influence of dietary energy sources on health and performance. In: Robinson N, ed. Current Therapy in Equine Medicine, 5th edition. Philadelphia: W.B. Saunders, 2003; 698-704. - PubMed -

Hess TM, Kronfeld DS, Williams CA, et al. Effects of oral potassium supplementation on acid-base status and plasma ion concentrations of horses during endurance exercise. Am J Vet Res 2005; 66:466-473. - PubMed -

Jansson A, Rytthammar Å, Lindberg JE, et al. Voluntary salt (NaCl) intake in Standarbred horses. Pferdeheilkunde 1996; 12:443-445.

Jansson A and Dahlborn K. Effects of feeding frequency and voluntary salt intake on fluid and electrolyte regulation in athletic horses. J Appl Physiol 1999; 86:1610-1616. - PubMed -

Jose-Cunilleras E, Hinchcliff KW, Sams RA, et al. Glycemic index of a meal fed before exercise alters substrate use and glucose flux in exercising horses. J Appl Physiol 2002; 92:117-128. - PubMed -

Jose-Cunilleras E. Abnormalities of body fluids and electrolytes in athletic horses. In: Hinchcliff KW, Kaneps AJ and Geor RJ, eds. Equine Sports Medicine and Surgery. Elsevier, London; 898-917.

Kronfeld D. Dietary fat affects heat production and other variables of equine performance, under hot and humid conditions. Equine Vet J Suppl 1996; 22:24-34. - PubMed -

Kronfeld D. Body fluids and exercise: Influences of nutrition and feeding management. J Equine Vet Sci 2001; 21:417-428.

Lacombe V, Hinchcliff KW, Geor RJ, et al. Muscle glycogen depletion and subsequent replenishment affect anaerobic capacity of horses. J Appl Physiol 2001; 91:1782-1790. - PubMed -

Lawrence LM, Soderholm LV, Roberts AM, et al. Feeding status affects glucose metabolism in exercising horses. J Nutr 1993; 123:2151-2157. - PubMed -

Lawrence LM, Hintz HF, Soderholm LV, et al. Effect of time of feeding on metabolic response to exercise. Equine Vet J Suppl 1995; 18:392-395. - PubMed -

Miller-Graber P, Lawrence LM and Foreman J. Effect of dietary protein level on nitrogen metabolites in exercised Quarter horses. In: Persson S, Lindholm A and Jeffcott LB, eds. Equine Exercise Physiology 3. Davis, CA: ICEEP Publications, 1991; 305-314.

Meyer H. Nutrition of the equine athlete. In: Robinson NE, ed. Equine Exercise Physiology 2. Davis, CA: ICEEP Publications, 1987; 644-673.

Meyer H and Coenen M. Influence of exercise on the water and electrolyte content of the alimentary tract. In: 11th Conference of the Equine Nutrition and Physiology Symposium 1989; 3-7.

Nutrient Requirements of Horses, 5th edition. Washington, DC: National Research Council, National Academy Press, 1989. - Available from amazon.com -

Nyman S, Jansson A and Dahlborn K. Strategies for voluntary rehydration in horses during endurance exercise. Equine Vet J Suppl 1996; 22:99-106. - PubMed -

Orme CE, Harris RC, Marlin DJ, et al. Metabolic adaptation to a fat supplemented diet in the thoroughbred horse. Br J Nutr 1997; 78:443-458. - PubMed -

Pagan JD and Hintz HF. Equine energetics. II. Energy expenditure in horses during submaximal exercise. J Anim Sci 1986; 63:822-830. - PubMed -

Pagan JD and Harris PA. The effects of timing and amount of forage and grain on exercise response in Thoroughbred horses. Equine Vet J Suppl 1999; 30:451-457. - PubMed -

Pagan JD, Geor RJ, Harris PA, et al. Effects of fat adaptation on glucose kinetics and substrate oxidation during low intensity exercise. Equine Vet J Suppl 2002; 34:33-38. - PubMed -

Potter GD, Hughes SL, Julen TR et al. A review of research on digestion and utilisation of fat by the equine. Pferdeheilkunde 1992; 1:119-23.

Potter GD, Arnold FF and Householder DD. Digestion of starch in the small or large intestine of the equine. Pferdeheilkunde 1992; 1:107-111.

Schott II HC, Düsterdieck KJ, Eberhart SW, et al. Effects of electrolyte and glycerol supplementation on recovery from endurance exercise. Equine Vet J Suppl 1999; 30:384-393. - PubMed -

Stull C and Rodiek A. Effects of post prandial interval and feed type on substrate availability during exercise. Equine Vet J Suppl 1995; 18:362-366.

Valberg S, Mickelson JR, Gallant EM, et al. Exertional rhabdomyolysis in quarter horses and thoroughbreds: one syndrome, multiple aetiologies. Equine Vet J Suppl 1999; 30:533-538. - PubMed -

Warren L, Lawrence LM, and Roberts A. The effect of dietary fiber on gastrointestinal fluid volume and the response to dehydration and exercise. In: 17th Conference of the Equine Nutrition and Physiology Symposium 2001; 148-149.