

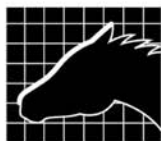
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Challenges of Endurance Exercise: Hydration and Electrolyte Depletion

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INTRODUCTION

Endurance exercise is accompanied by loss of body water and electrolyte stores, primarily in sweat (Carlson, 1983; Sawka, 1990). Performance can generally be maintained in the face of mild to moderate dehydration when ambient conditions are not overly challenging (Sawka, 1990). However, under conditions of high heat and humidity and solar radiation gain, a decrease in performance can occur, especially in horses recently transported to the competition venue that have not been adequately acclimatized (Marlin et al., 1996; Geor and McCutcheon, 1998; Marlin et al., 1999).

Of greater concern, serious medical problems may develop in horses that compete in endurance events. These problems are primarily manifested as gastrointestinal signs, ranging from a lack of appetite during or after competition to colic signs from decreased motility and distention of the intestine (ileus) (Carlson, 1985; Geor and McCutcheon, 1996). Affected horses competing in endurance events are described as having “metabolic problems” and are typically “pulled” from further competition by supervising veterinarians (www.aerc.org). Although many of these horses can recover without specific treatment, others may require aggressive treatment for what has been coined the “exhausted horse syndrome” (Fowler, 1979; Foreman, 1998). Though rare, this syndrome can be fatal despite aggressive treatment. For example, two horses died at the 2002 World Equestrian Games in Jerez, Spain and one horse died at the 2006 World Equestrian Games in Aachen, Germany during the 160-km endurance competition. In addition to the tragic loss of elite equine athletes, these deaths generate considerable negative press towards the clearly demanding, but well supervised, sport of equine endurance riding.

The best recognized abnormal finding in horses at risk for development of metabolic problems and exhaustion is a persistently elevated heart rate at rest breaks or after the competition. An elevated heart rate can simplistically be thought of as an indicator of a decrease in circulating blood volume, with a higher heart rate needed to maintain cardiac output as blood (and stroke) volume decreases. The decrease in blood volume has been attributed to depletion of body fluid stores (dehydration) consequent to sweating. Using this line of reasoning, the most dehydrated horses should be at greatest risk for development of metabolic problems and exhaustion. Although logical, these assumptions have not been shown to be true for human endurance athletes (Noakes, 1995) and convincing evidence is also lacking in equine endurance athletes.

To limit water and electrolyte depletion during endurance competition, administration of electrolytes and active cooling strategies have become common practices over the past couple of decades. During the same time period, venues for three-day events have been redesigned to decrease the total amount of endurance work performed during competition. In addition, environmental monitoring devices have been improved to more accurately assess the thermoregulatory challenge of changing

ambient conditions. Although helpful, these efforts alone cannot be expected to prevent development of metabolic problems in all participating horses. Further, in the sport of endurance riding, competition speeds have increased over the past decade, most notably in the highest level international competitions. Thus, development of metabolic problems and exhaustion continues to be an inherent risk of competition in endurance events. Unfortunately, early recognition of horses at risk for impending exhaustion by supervising veterinarians remains a significant challenge.

Water and Electrolyte Balance

Resting state

Appropriate water balance maintains plasma osmolality in a relatively narrow range and is achieved by matching water intake with water loss. Total body water (TBW) is about 65% of body weight or about 325 L in a 500-kg horse. Most water is consumed by drinking (about 85%) in response to an increase in plasma osmolality, but feed and metabolic water provide about 5% and 10% of daily water, respectively. Water is lost in urine, in feces, and as insensible losses (evaporation across the skin and respiratory tract). Investigations of water balance in horses have revealed a maintenance water requirement of 60-65 mL/kg per day or 27-30 L/day for a 500-kg horse under temperate conditions (Tasker, 1967; Groenendyk et al., 1988). Urine and fecal water losses vary with diet (primarily affected by type of forage) and can range from 20-55% and 30-55%, respectively, of the total daily water loss (Cymbaluk, 1989). The remaining (insensible) loss accounts for 15-40% of daily water loss.

Although balance of daily water intake and output is critical for maintenance of homeostasis, it warrants mention that equids tolerate water deprivation quite well and replace water deficits fairly rapidly when water becomes available. For example, after horses were deprived of water for 72 hours (resulting in a body mass loss in excess of 10% as well as a significant increase in plasma osmolality), the majority of the body mass lost (90% of which was assumed to be water weight) was recovered within the first hour after being provided access to water (Carlson, et al., 1979; Rumbaugh et al., 1982). An important reason for their ability to tolerate water deprivation appears to be a substantial intestinal reserve of water and electrolytes that can be called upon during periods of dehydration for the maintenance of blood volume (Meyer et al., 1989).

Daily intake and output of electrolytes must also be appropriately matched to maintain body ion contents within relatively narrow ranges. Quantitatively, this balance is greatest for Na^+ , K^+ , and Cl^- ions that provide the osmotic skeleton of body fluids. Further, these ions are not evenly distributed throughout TBW: more than 90% of exchangeable Na^+ and Cl^- is contained within the extracellular fluid compartment (ECF, about one-third of TBW), while more than 98% of K^+ is contained within the intracellular fluid compartment (ICF, about two-thirds of TBW) (Schott and Hinchcliff, 1993). Due to differences in size and electrolyte composition of the ECF and ICF compartments, total exchangeable electrolyte content of a 500 kg horse is ~15,500 mmol Na^+ , ~11,500 mmol Cl^- , and ~30,000 mmol K^+ (Figure 1).

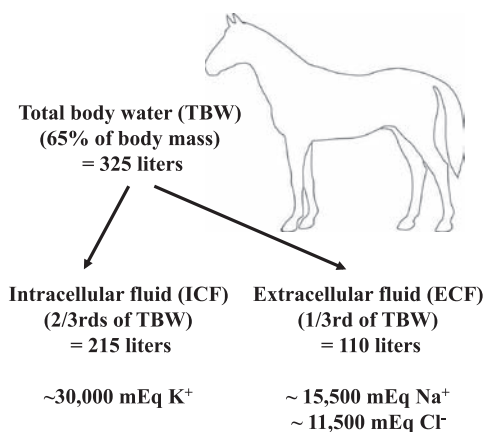


Figure 1. Body fluid compartments of a 500-kg horse.

Electrolytes are consumed in feed and are also lost by three routes: urine, feces, and sweat. Investigations of electrolyte balance have revealed that most horses eating predominantly forage ingest excess K⁺ and Cl⁻. In contrast, Na⁺ intake is more variable and can be marginal (Tasker, 1967; Groenendyk et al., 1988). The maintenance requirement for sodium for a sedentary 500-kg horse is 10 g per day (Anon, 2007) or ~430 Na⁺ mmol per day (provided by ~25 g of NaCl per day). Adequacy of dietary Na⁺ is most practically assessed by measurement of urine Na⁺ concentration; urine Na⁺ can be <10 mmol/L in horses with a marginal-Na⁺ diet, while urine Na⁺ can increase considerably (to >100 mmol/L) in horses that are being supplemented with NaCl (urine Na⁺ can be affected by exercise so these measurements should be made in samples collected from resting horses) (Schott et al., 1992).

During endurance exercise

When exercise is added into the equation, sweat losses can markedly increase the challenge to water and electrolyte balance. Under mild ambient conditions, horses may lose 5-7 L of sweat per hour of steady trotting and cantering (McCutcheon et al., 1995a; Kingston et al., 1997). However, under conditions of high heat and humidity, sweat rates may approach 10-12 L/hour (Carlson, 1983; McCutcheon et al., 1995a). Clearly, large volumes of water can be lost by horses performing several hours of endurance exercise.

Equine sweat contains 100-130 mmol Na⁺, 120-140 mmol Cl⁻, and 20-40 mmol K⁺ per liter (McCutcheon et al., 1995b; Kingston et al., 1997). Thus, during exercise horses can lose 500 to >1000 mmol of Na⁺ per hour in sweat and equine athletes thereby have substantially greater dietary requirements to replace such losses (McCutcheon and Geor, 1996). As an example of the magnitude of sweat electrolyte losses that can occur during endurance exercise, Kingston et al. (1997) measured sweat volume and electrolyte concentrations in horses performing 45 km of treadmill exercise during a

~3.5-hour exercise test. Approximately 25 L of sweat was produced and contained ~3,000 mmol Na⁺, ~3250 mmol Cl⁻, and ~750 mmol K⁺. These values were equivalent to loss of ~175 g of NaCl and ~55 g of KCl in sweat and represent losses of ~20%, ~27.5%, and ~2.5% of exchangeable Na⁺, Cl⁻, and K⁺, respectively, from the ECF and ICF compartments. Similarly, McCutcheon and Geor (1996) estimated sweat losses of ~1500 mmol Na⁺, ~1700 mmol Cl⁻, and ~400 mmol K⁺ during an ~2-hour treadmill exercise test simulating the speed and endurance phase of a three-day event under cool, dry ambient conditions. These estimated sweat electrolyte losses were nearly doubled when the same exercise test was performed under conditions of high heat and humidity. Clearly, horses performing endurance exercise on a regular basis, especially in hot and humid climates, require salt supplementation in the diet to replace sweat losses.

Thermoregulatory and Hemodynamic Changes Accompanying Endurance Exercise

Increased muscular work during exercise requires an increase in fuel utilization. Metabolism of fuel, primarily fat, during endurance exercise generates a substantial heat load, the majority of which must be dissipated to prevent development of excessive hyperthermia. In both human and equine athletes, core temperature increases after the onset of exercise and a sustained increase of 1-2° C (2-4° F) is often found during prolonged exercise in horses (Hodgson et al., 1994; Kingston et al., 1997). An increase in core temperature triggers sweat production, and cooling of the skin surface by evaporation of sweat is the main mechanism of heat dissipation during endurance exercise (Hodgson et al., 1993).

Sweating rates during endurance exercise are directly related to the increase in core temperature (Hodgson et al., 1993) and have been demonstrated to remain fairly stable during steady-state treadmill endurance exercise, despite progressive dehydration (Kingston et al., 1997). Further, in both human and equine athletes, sweating rates are generally excessive. That is, if all sweat produced was fully evaporated, the cooling effect would far exceed the metabolic heat load generated (Hodgson et al., 1994). However, not all sweat evaporates as large amounts drip from the body, and the cooling potential of this "wasted" sweat is lost. Wastage of sweat is further exacerbated by high humidity, as high atmospheric water vapor pressure limits evaporation at the skin surface. Under adverse ambient conditions, respiratory rates are also typically higher and horses may be observed to pant. Thus, active cooling strategies including use of misting fans and direct application of large volumes of cool water to the skin are most beneficial by increasing conductive and convective heat loss when evaporative cooling may be limited (Kohn et al., 1999).

As mentioned above, sweat rates may approach 10-12 L/hour when endurance exercise is performed under adverse ambient conditions. Not surprisingly, sweat production is also the primary route of body fluid loss leading to development of dehydration during endurance exercise. However, it warrants mention that water is also lost as inhaled air and is humidified by evaporation across the respiratory tract during exercise. Increased ventilation contributes to control of core body temperature during exercise (Hodgson et al., 1994), and loss of water via the respiratory tract may be responsible for 15-20% of total body fluid loss during prolonged endurance exercise (Butudom et al., 2003).

During exercise cardiac output also increases in response to the metabolic demands of active skeletal muscle as well as a demand for increased skin blood flow for thermoregulatory cooling (Rowell, 1986).

Further, cardiac output is redistributed away from tissues that are less active during exercise, notably the abdominal organs including the intestinal tract, liver, and kidneys. In the face of depletion of body fluid stores consequent to prolonged sweating, competition for cardiac output may develop between active muscle and skin, leading to a decrease in performance and/or an increase in core temperature (Hodgson et al., 1994). Additionally, when exercise is continued for a period of hours, a prolonged decrease in blood flow may compromise function of less well-perfused organs. Specifically, the barrier function of the mucosal lining of the intestinal tract may become compromised. An intact mucosal barrier prevents absorption of many toxins (i.e., endotoxin) that are normally present in the bowel lumen, but a prolonged decrease in intestinal blood flow during endurance exercise can lead to both decreased intestinal motility and increased absorption of toxins.

Involuntary Dehydration During Endurance Exercise

In both human and equine endurance athletes, loss of body fluid during prolonged exercise exceeds voluntary fluid replacement, and dehydration ensues as a consequence of a mismatch between thirst and the body water deficit. This phenomenon is observed in human endurance athletes despite the fact that water or other rehydration solutions are frequently available during the competition. In contrast to pure water deprivation, athletes lose both water and electrolytes in sweat; consequently, plasma osmolality increases to a lesser extent during exercise and osmotic thirst stimulus is blunted. This condition in which body fluid losses are only partially replaced by drinking during and shortly after the exercise bout has been termed involuntary dehydration (Greenleaf, 1992).

In humans, there is considerable variation in the magnitude of involuntary dehydration tolerated, and a threshold of ~2% body mass loss has been used to separate individuals that are considered “better drinkers” from those that are “poorer drinkers” (Sandick et al., 1984, 1989). Although limited, similar data have been accumulated in the author’s laboratory on several cohorts of two-year-old Arabian horses that performed several 60-km treadmill exercise tests. In these horses, cluster analysis allowed separation into groups of good drinkers, average drinkers, and poor drinkers (Schott et al., 2003).

Assessment of involuntary dehydration

The magnitude of involuntary dehydration can be estimated by measuring body mass loss during the endurance event. In most marathon and ultraendurance competitions, mean body mass loss of successful competitors is typically in the range of 2-4% (Noakes, 1995; Sharwood et al., 2004). However, a common finding is a wide range of body mass loss in successful competitors; for example, Sharwood et al. (2004) measured losses ranging from more than 10% to actual weight gain in a group of 767 successful Ironman triathletes.

Studies that have measured body mass loss in horses competing in endurance events have found average values ranging from 3-7% by the end of competition (Table 1) (Lawrence et al., 1992; Andrews et al., 1994; Ecker and Lindinger, 1995; Schott et al., 1997; Barton et al., 2003; Sampieri et al., 2006; Schott et al., 2006). Overall, a mean value of ~5% body mass loss is approached by the end of endurance competition, somewhat regardless of the competition distance and duration. This body mass

CHALLENGES OF ENDURANCE EXERCISE

Table 1. Body mass loss at the end of competition in horses performing different types and distances of endurance exercise.

Publication	Type of Event	Distance	BM loss
Lawrence et al., 1992	Endurance two-day	150-mile	6.3%
Ecker et al., 1994	Endurance (13 rides)	varied	3 to 7%
Andrews et al., 1994	Three-day Event	19-km	3.9%
Schott et al., 1997	Endurance	160-km	4.9%
Barton et al., 2003	Endurance	159-km	3.7%
Schott et al., 2006	Endurance	160-km	6.1%
Sampieri et al., 2006	Endurance	80-km	4.0%

develops despite the fact that horses have been offered water and feed at various rest stops to promote fluid, electrolyte, and fuel replacement. As with human athletes, a wide range of body mass loss has also been documented in equine endurance athletes with some successful competitors losing more than 10% during the event (Lawrence et al., 1992; Ecker and Lindinger, 1995; Barton et al., 2003; Schott et al., 2006).

The magnitude of involuntary dehydration appears to be greater in equine than in human endurance athletes. Two factors appear to contribute to a greater magnitude of involuntary dehydration in equine endurance athletes. First, equine sweat remains isotonic during prolonged exercise while human sweat becomes hypotonic, in comparison to plasma osmolality (Hodgson et al., 1994). Thus, horses lose comparatively greater amounts of electrolytes in each liter of sweat produced. As a consequence, plasma osmolality rises more slowly in horses than human endurance athletes and produces a lesser osmotic thirst stimulus. Second, fluid reserves in the lumen of the equine gastrointestinal tract are substantially greater (10-12% of body mass) in comparison to those in human athletes (1-2% of body mass) (Schott and Hinchcliff, 1993). Therefore, the equine athlete has a larger "fluid reserve" that can be called upon to replace sweat fluid losses during endurance exercise. This intestinal fluid reserve may provide 12-15 L of water containing 1500-2000 mEq Na⁺ in a 500-kg horse that could be absorbed to replace sweat losses during endurance exercise (Schott et al., 1997).

In studies in which body mass loss has been measured at multiple times during the competition, a consistent finding in horses has been that the majority of body mass loss occurs during the first half of the event and body mass remains fairly steady from that point forward (Schott et al., 1997; Barton et al., 2003; Schott et al., 2006). Because sweating continues throughout exercise, maintenance of body mass during the later stages of the event is best explained by water and feed intake at a rate nearly matching ongoing fluid losses. This statement is supported by the finding of greater voluntary water intake during the later stages of treadmill endurance exercise tests (Kingston et al., 1997; Duesterdieck et al., 1999). Further, it suggests that horses that lose the greatest amount of body mass during the competition are not actually losing more body fluid; rather, they are failing to replace lost fluids by eating and drinking.

Additional methods to assess involuntary dehydration

Measurement of body mass loss is considered the gold standard for assessing rapid changes in hydration with 90% of a weight change attributed to loss or gain of body water (Carlson, 1983). Unfortunately, scales are not readily available at most endurance venues. Although weight tapes measuring girth circumference are commonly used to measure body mass of the horse, changes in girth circumference reflect gain or loss of fat mass and weight tapes are of little utility in assessing hydration changes during exercise. However, use of a weight tape around the midcaudal abdomen may have merit in assessing changes in “gut fill” that should parallel changes in body mass measured on a scale (Schott, unpublished data).

During endurance competitions, veterinarians at checkpoints evaluate hydration by measuring heart rate as well as by assessing a number of subjective parameters including membrane color and refill time, jugular vein fill time, persistence of a “skin tent,” and auscultation of intestinal motility (www.aerc.org). Unfortunately, none of these measures has been shown to compare well with measured body mass changes in working equids (Schott et al., 2006; Pritchard et al., 2008). Nevertheless, the subjective assessment of hydration of horses at checkpoints remains an important practice and is considered useful by control veterinarians in the overall assessment of whether or not horses are considered “fit to continue” (www.aerc.org).

More recently, a novel device designed to measure changes in hydration via changes in transmission of electrical currents through the body has been marketed to horse trainers and owners (www.equistat.uk.co). The measurement, termed bio-electrical impedance, measures impedance of several low-voltage currents transmitted through the body (usually with electrodes on one forelimb and one hindlimb). The technology was originally developed as an indirect method to assess body fat mass in humans but has been adapted to investigate changes in hydration in horses (Forro et al., 2000; Fielding et al., 2004; Waller and Lindinger, 2006). Although some experimental results have been promising, the equipment is costly and repeated measurements would be impractical for most competitors.

Finally, it warrants emphasis that subjective assessment of a horse’s performance during competition is best appreciated by the rider. Further, the rider and crew have the best knowledge of how the horse has been eating and drinking, especially during the later stages of competition. It is well accepted that decreases in appetite and drinking are major warning signs of impending exhaustion. Consequently, riders and support teams should share this information with control veterinarians during the event and also need to recognize that they share the responsibility for identifying horses at risk of exhaustion.

Is Dehydration an Important Risk Factor for Exhaustion?

Dehydration and uncontrolled hyperthermia

With progressive dehydration consequent to sweat fluid loss during prolonged exercise, competition for cardiac output between active skeletal muscle and the skin may lead to a decrease in skin blood flow. As a consequence, thermoregulation via evaporative cooling at the skin surface may become limited,

with the ultimate effect of thermoregulatory failure (Sawka, 1990; Hodgson et al., 1994). Following the assumption that the main consequence of exercise-associated dehydration was failure of thermoregulation, uncontrolled hyperthermia has been hypothesized to be a primary cause of fatigue, collapse, and altered mentation in human athletes during endurance competitions (especially under adverse conditions), and position statements have been made regarding treatment of exertional heat illness (Armstrong et al., 2007).

Historically, the hypothesis that thermoregulation failure consequent to dehydration was the most important risk factor for fatigue and exhaustion gained initial support as a result of a publication by Wyndham and Strydom (1969) entitled “The Danger of an Inadequate Water Intake During Marathon Running.” This study had a profound influence on the sport of distance running, but the impact came more from its misleading title than from its scientific content because the authors neither studied nor identified any dangers resulting from an inadequate water intake during marathon running (Noakes, 1995). In fact, the most dehydrated runners in their studies were also the most successful—they won the competitions. A significant outcome of the study was international rule changes to allow increased fluid intake during competitive races that up until that time had been largely discouraged. Over the next couple of decades, sports medicine physicians and athletic trainers began to extol the dangers of dehydration during exercise and encouraged athletes to drink frequently during endurance exercise, despite absence of thirst. Further, it became commonly accepted that all athletes that collapsed in association with endurance exercise had hyperthermia and dehydration that necessitated treatment with intravenous fluids (Noakes, 1995).

During the same few decades, equine veterinarians officiating endurance rides and later at three-day events began to observe a number of medical problems in horses that were collectively described as the “exhausted horse syndrome” (Fowler, 1979; Carlson, 1985; Geor and McCutcheon, 1996; Foreman, 1998). Affected horses showed signs including synchronous diaphragmatic flutter (thumps), muscle fasciculations, colic pain attributed to ileus, rhabdomyolysis, collapse, neurological deficits, and multiple organ failure leading to death. Similar to physicians caring for exhausted human athletes, veterinarians assumed that these medical problems were a consequence of dehydration due to prolonged sweating during the exercise bout. However, unless ambient conditions were challenging (high heat and humidity), actual hyperthermia was rarely documented. As with human athletes, treatment evolved to include aggressive intravenous fluid replacement (Foreman, 1998; Whiting, 2009).

Exercise-associated hyponatremia

For human athletes, recommendations for liberal drinking (in the absence of thirst) to limit dehydration in combination with a dramatic increase in the popularity of marathon running towards the end of the last century led to development of a new problem among human endurance athletes: exercise-associated hyponatremia. Hyponatremia can result in nausea, pulmonary edema, and serious neurological impairment and has become the leading cause of death in marathon participants (Ayus et al., 2005). Interestingly, of the 767 Ironman triathletes mentioned previously, there was no association between magnitude of body mass loss and either race time or finish temperature. However, there was a negative correlation between race time and Na^+ concentration at the finish (Sharwood et al., 2004). An inverse

relationship between race time and Na^+ concentration at the finish has also been found in marathon runners (Hew et al., 2003). Rather than greater sweat Na^+ losses in the athletes that are exercising longer, the lower Na^+ concentration at the finish is attributed to greater drinking of hypotonic fluids during the race by slower competitors that have more time to drink along the course.

Fortunately, despite aggressive supplementation of endurance horses with electrolytes to encourage fluid intake, riders have never been able to get their horses to drink excessive amounts of rehydration fluids. Thus, hyponatremia has not yet been recognized as a serious problem in equine endurance athletes.

Decrease in effective circulating volume and post-exercise hypotension

As liberal use of intravenous fluids became the norm for treatment of collapsed marathon runners and exhausted endurance horses, a common clinical observation was that athletes of both species often recovered rapidly in response to administration of a volume of fluids that was substantially less than that required for correction of estimated fluid losses. This observation led to the suggestion that decreases in effective circulating volume, rather than the overall magnitude of body fluid loss, may be a more important mechanism for either collapse or exhaustion in human and equine endurance athletes. In fact, Noakes (1995) called into question the importance of the overall loss of body fluids during endurance exercise and encouraged researchers and sport medicine physicians to focus greater attention on dysregulation of vascular tone (attributable to decreased sympathetic outflow and altered compliance of blood vessels) leading to systemic hypotension as a potentially more important factor in development of collapse, especially in the immediate post-exercise period. Rather than administration of intravenous fluids as emergency treatment of collapsed athletes (that have a normal core body temperature and a normal Na^+ concentration), rest in the supine position with the lower extremities elevated for several minutes was recommended (Holtzhausen et al., 1995). In subsequent endurance events, this recommendation has had success in initial triage of collapsed endurance athletes, furthering support for hypotension as an important mechanism leading to collapse (Holtzhausen and Noakes, 1997). Dysregulation of autonomic tone leading to hypotension has been hypothesized to lead to pooling of blood in the lower extremities on cessation of prolonged endurance exercise. As a consequence, development of orthostatic hypotension near the finish, and especially following completion of the exercise bout, may be a more important cause of collapse than the magnitude of body fluid loss.

As mentioned in the introduction, a persistently elevated heart rate remains an important warning sign of impending exhaustion in equine endurance athletes. Of the subjective clinical findings during veterinary examination of horses at checkpoints during the competitions, a decrease in intestinal sounds also remains a concern of control veterinarians. Unfortunately, a decrease in intestinal sounds has yet to be validated as a significant risk factor for failure or exhaustion. Laboratory findings have been variable in failing or exhausted endurance horses with the exception that packed cell volume (PCV) and total protein concentration (TP) have tended to be higher in horses with higher heart rates and in unsuccessful horses (Rose et al., 1977; Carlson, 1985; Schott and Charlton, 1996; Schott et al., 1997, 2006).

There are several factors, in addition to dehydration, that could contribute to a persistently elevated heart rate on cessation from exercise. These include pre-existing disease, pain, elevated core temperature, and a decrease in blood pressure. Although higher values for PCV and TP would support dehydration, these

laboratory changes could also be a consequence of a fluid shift into the bowel lumen. Such a fluid shift could also be consistent with development of ileus, a condition that would also lead to a decrease in intestinal sounds. Thus, the abnormal findings in endurance horses with metabolic disturbances can be multifactorial in origin and contributing factors likely vary between individual horses.

In an attempt to determine whether or not dehydration, assessed by body mass loss, is a significant risk factor for failure or exhaustion, the author compared body mass loss in both successful and unsuccessful horses in several endurance rides ranging from 80 to 160 km (Figure 2). Although these data are limited by inclusion of both lameness and metabolic failures (and by the fact that unsuccessful horses were eliminated at various points of the rides), there is not a clear difference in the magnitude of body mass loss between the groups. To further investigate whether post-exercise hypotension develops in endurance horses, the author and colleagues measured indirect blood pressure in horses that successfully completed 80- to 160-km endurance rides. Surprisingly, we found a reduction in blood pressure during the early recovery period following ride completion in some but not all horses studied (Schott et al., unpublished observations). Because horses would seem to have a comparatively small capacity to pool blood in their lower limbs, we speculate that this transient period of hypotension might more likely be explained by rapid restoration of blood flow to abdominal organs that receive limited cardiac output during exercise.

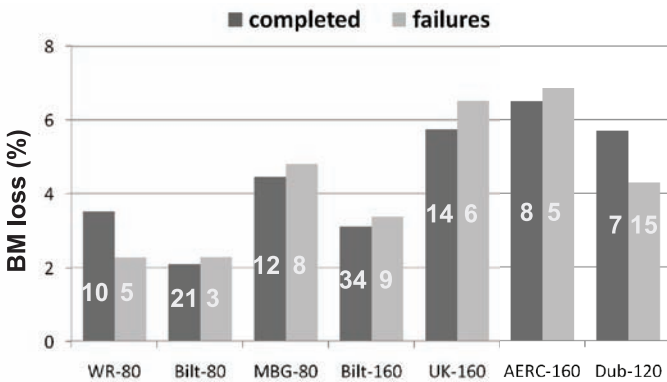


Figure 2. Body mass loss of horses that successfully completed or failed to complete endurance rides of distances varying from 80 to 160 kilometers. Numbers on the bars are the number of horses in each group for which body mass loss was recorded.

All in all, human and equine endurance athletes have both similarities and differences with regard to hydration status during and after endurance exercise. Both the wide range of body mass loss observed in successful competitors and the fact that most weight is lost during the first half of the competition call into question the importance of the magnitude of dehydration as a risk factor for development of medical problems or exhaustion. Although not emphasized in this discussion, both human and equine endurance athletes that compete under conditions of high ambient temperature and humidity are clearly at increased risk of developing exercise hyperthermia and associated medical problems. When a markedly elevated core body temperature (>40.5° C or 105° F) and persistent tachycardia are detected in these athletes, aggressive cooling and support with intravenous fluids remain the accepted approaches to emergency treatment.

However, it may be likely that both decreased effective circulating volume and dysregulation of autonomic vascular tone, contributing to hypotension, may be more important mechanisms, rather than total body fluid loss, in the majority of athletes suffering from collapse or “metabolic” problems during and following endurance exercise.

Attenuation of Involuntary Dehydration

In an attempt to limit dehydration during endurance exercise, water and a variety of sports drinks are provided to human endurance athletes at multiple sites during the competition. Although beyond the scope of this review, considerable research has been performed to assess the effects of tonicity (largely Na⁺ content), carbohydrate content, flavor, and temperature of these sports drinks offered to human athletes (Convertino et al., 1996; Latzka and Montain, 1999). It is generally acknowledged that little, if any, fluid replacement is needed for endurance exercise lasting 60 minutes or less and there is little advantage of a sports drink over water for events lasting 90 minutes or less. However, the recommendation for exercise lasting several hours is to drink about 500 ml a couple of hours prior to exercise and small amounts (150-300 ml) of a sports drink containing both electrolytes and carbohydrate every 15-20 min during exercise to limit dehydration exceeding a 2% body mass loss (Convertino et al., 1996; Latzka and Montain, 1999). This program of frequent fluid replacement is generally performed in the absence of thirst. In both equine and human endurance athletes, full recovery of body mass loss usually requires one or more days of recovery. Water and electrolyte deficits are usually not fully restored until one or more meals have been consumed in the initial days following the exercise bout (Fellmann et al., 1989; Schott et al., 1997).

Active cooling during exercise

To limit sweat fluid losses, enhancement of metabolic heat dissipation by conductive and convective heat transfer has been pursued through active cooling strategies. These include use of misting fans, shaded areas to limit solar radiation, and intense sponging and washing with cool water at rest breaks (Kohn et al., 1999; Jeffcott et al., 2009). These strategies have been demonstrated to produce a more rapid decline in core temperature and are effective tools for limiting sweat loss under conditions of high heat and humidity (Kohn et al., 1999).

Does administration of electrolytes help horses during endurance exercise?

Over the last decade, the variety of sports drinks and electrolyte supplements available to minimize dehydration in both human and equine athletes has expanded dramatically. Nevertheless, the old adage “you can lead a horse to water, but you can’t make it drink” remains as true today as it ever did. Or does it? Over the past few years the author and colleagues have been studying various strategies to encourage dehydrated horses to voluntarily drink more water and thereby attenuate the magnitude of dehydration. We first studied horses completing a 60-km simulated endurance ride on a treadmill, with and without electrolyte supplementation (Duesterdieck et al., 1999). Horses were offered water to drink

at several rest stops during the simulated ride. When the horses ran without electrolyte supplementation, they lost about 25 kg of fluid as sweat and replaced a little more than half of this loss by drinking about 13 liters of water. However, when they ran with electrolyte supplementation (salts were given as a slurry dosed into the mouth before and during the run), the horses drank about 23 liters of water, replacing nearly all of the fluid lost in sweat. In addition to “tricking” horses into drinking a greater total amount of water by giving electrolytes, supplementation also resulted in horses starting to drink earlier during the course of the endurance test. In this study, we gave the horses an amount of electrolytes that would be expected to be lost in 25 liters of sweat (175 g NaCl and 55 g KCl). This was a much larger dose than typically used by competitors; nevertheless, we found no adverse effects of supplementing with this large amount of electrolytes.

In our next series of studies, we also wanted to know if horses would drink salt water and whether they preferred it cold (10° C), cool (20° C), or warm (30° C). Again, we studied horses running 30 or 45 km on a treadmill. In the first experiment, we provided them with either water or two concentrations of salt water (0.45% and 0.9% NaCl solutions) for the first 5 minutes after exercise (Butudom et al., 2002). In the second experiment, horses were offered 0.9% NaCl at 10, 20, or 30° C with and without electrolyte supplementation (Butudom et al., 2003). We found that an initial drink of salt water improved recovery of sweat fluid losses because horses drank more water when it was offered a few minutes later. In contrast, horses that were offered plain water for their initial drink did not drink further during the initial hour of recovery despite the fact that they remained partially dehydrated. Because drinking is stimulated by an increase in plasma osmolality, an initial drink of water dilutes ECF Na⁺ concentration and abolishes the drinking stimulus. In contrast, with an initial drink of salt water, ECF Na⁺ concentration remains elevated and horses wanted to drink again when provided water only a few minutes later. Thus, an initial drink of salt water “tricked” the horses to drink a greater total amount of fluid during the initial hour of recovery. When we compared different temperatures of salt water, we found that they seemed to like it best (because they drank the most) when it was 20° C—near the temperature it comes out of the hose on a warm summer day.

So, what's the bottom line? The bottom line is that horses exercising for more than an hour or two in hot, humid climes (especially when combined with transport) will likely benefit (and voluntarily drink more water) when they are supplemented with extra NaCl and KCl. An easy recipe for hardworking horses in the summer would be 1-2 oz (1 ounce ≈ 25 g) of an equal mix of table salt and lite salt added to the grain twice daily. Next, an initial drink of salt water during the first few minutes after exercise (or at rest stops during the exercise bout) is another strategy that may be useful on especially hot and humid days. Salt water (0.9% NaCl) can be easily made by adding one ounce of table salt for each gallon of water. However, because horses can be finicky about drinking, they should always be offered plain water after initially offering salt water. In reality, the goal should be to replace only about half of the electrolytes lost in sweat as the horses can also draw on the electrolyte reserves in the large intestine during and after exercise.

What remains unclear in horses is whether or not electrolyte supplementation can improve performance and whether or not equine athletes could also benefit from carbohydrate supplementation during endurance competition. In an attempt to answer the former question, we compared performance in a group of horses that received either a high or a low dose of electrolytes during an 80-km ride (owners

would not enroll for a nonsupplemented control group). In this study, there was no improvement in performance in horses that were provided the higher dose of electrolytes; however, the study was limited because it was performed in nonelite horses competing in 80-km rides under favorable ambient conditions (Sampieri et al., 2006). During competition in elite 160-km endurance races, specific carbohydrate supplementation, in addition to offering various concentrate feeds during the rest breaks, has been tried over the past decade. At present, there has been little research in this area although intravenous glucose supplementation was demonstrated to prolong endurance exercise performance on a treadmill in one study (Ferris et al., 1999).

What also remains unclear is whether or not horses can be administered “too much electrolytes” and whether or not there may be adverse effects of electrolyte supplementation. In theory, excess electrolyte administration should not be a problem as long as competing horses are provided frequent access to water and continue to drink. However, in our studies providing an amount of electrolytes estimated to fully replace sweat electrolyte losses during an 80-km ride, mild hypernatremia and hyperchloremia developed in some horses (Sampieri et al., 2006). Although no clinical problems were observed with these electrolyte changes, this finding provided further support to recommend limiting electrolyte replacement to one-third to one-half of the anticipated losses. Finally, in a recent study of resting horses administered eight doses of concentrated oral salt slurries at hourly intervals, the number and severity of gastric ulcers were exacerbated (Hollbrook et al., 2005). However, horses were also fasted prior to gastroscopy in this study, and the relevance to competing horses remains uncertain.

Conclusion

Despite strict veterinary supervision of horses in endurance competitions, prediction of impending exhaustion remains challenging and not all at-risk horses are identified before medical problems ensue. Further, problems can develop in the hours after successful completion of an event when veterinary supervision is no longer mandatory (Hinton, 1977; Schott and Charlton, 1996). Fortunately, serious medical problems and deaths remain relatively rare events. However, rare events are also a challenge to study. Consequently, risk factors for developing the exhausted horse syndrome have not been fully characterized and likely vary between horses as well as with differing challenges of terrain and ambient conditions of competition venues around the globe. Finally, the magnitude of dehydration can be attenuated by administration of electrolytes as concentrated oral slurries or dissolved in water provided during the competition. However, whether or not electrolyte supplementation improves (or at least maintains) performance remains unclear and potential adverse effects of electrolyte supplementation may exist.

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