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In human and equine athletes, loss of body fluid in sweat during prolonged exercise exceeds voluntary fluid replacement. This leads to a condition that has been termed involuntary dehydration. The magnitude of dehydration can be estimated by measuring body mass loss during the endurance event. This body mass loss usually persists for hours to days in the recovery period and water and electrolyte deficits are usually not fully replaced until one or more meals have been consumed following the exercise bout. Unfortunately, loss of body water and electrolytes can contribute to development of several medical or “metabolic” problems either during the exercise bout or even after successful completion of competition. Dehydration has long been considered the most important risk factor for development of medical problems in equine endurance athletes. However, recent evidence suggests that other factors, including a decrease in effective circulating volume and autonomic dysregulation leading to compromised tissue perfusion, may be equally if not more important factors.

Body fluid loss during endurance exercise:
During endurance exercise performed by human athletes and horses, body fluids are lost primarily in the form of sweat. In contrast, dogs competing in endurance events lose fluids in the form of respiratory water loss and via urine (Figure 1). Sweating is essential for effective thermoregulation in both human athletes and horses but in both species 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. However, not all sweat produced evaporates as large amounts can drip from the body and the evaporative cooling potential of this “wasted” sweat is lost. This loss of sweat is exacerbated when evaporation is compromised by ambient conditions of high humidity, due to the already high atmospheric water vapor pressure that limits the gradient between the skin surface and the surrounding air.

In horses, sweating rates during endurance exercise are directly related to core body temperature and have been demonstrated to remain fairly steady during core body temperature and have been demonstrated to remain fairly steady during treadmill exercise, despite lack of fluid replacement. With varying endurance work intensity (and increases in core body temperature) under moderate ambient conditions, total sweat losses during treadmill exercise bouts of 45 km have ranged from 3-7% of body mass. Similarly, field studies of endurance rides have also shown body mass losses ranging from 3-7% by the end of 80-160-km rides. During actual competition horses are offered water and feed to promote fluid and fuel replacement at multiple times during the rides and in field studies in which body mass loss has been measured at multiple times during the rides, a consistent finding has been that the majority of body mass loss occurs during the first half of the competition and that body mass remains fairly steady from that point forward. Because body fluid in sweat continues throughout exercise, maintenance of body mass during the later stages of the ride can only be explained by water and feed intake at a rate matching ongoing fluid
losses. Again, the net loss of body fluid that is sustained by endurance athletes can be characterized as involuntary dehydration because it occurs in the face of readily available rehydration fluids.

**Mechanism of involuntary dehydration:** In both equine and human endurance athletes, insufficient thirst, due to concurrent loss of water and electrolytes in sweat, appears to be the most important mechanism causing involuntary dehydration. However, two species differences appear to make the magnitude of involuntary dehydration greater in equine endurance athletes. First, equine sweat remains nearly isotonic during prolonged exercise while human sweat becomes hypotonic, in comparison to plasma tonicity. 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 because a rise in plasma tonicity is the most potent stimulus for thirst, a lesser osmotic thirst stimulus of thirst likely plays a greater role in horses than in human athletes. Second, transcellular 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). Thus, the equine athlete has a larger “fluid reserve” that can be called upon to replace sweat fluid losses during endurance exercise. As a consequence of these species differences, horses appear to be able to tolerate a relatively greater total loss of body fluid reserves during prolonged endurance competition.

**Consequences of body fluid losses:** Over the past several decades medical problems affecting both human and equine endurance athletes have been all too well publicized via lay publications and television broadcasts. For example, television coverage of major marathons has shown world-class athletes including Alberto Salazar staggering near the finish line while other athletes including Paula Radcliffe have nearly collapsed en route or shortly after finishing marathon and ultramarathon competitions. Of greater concern to veterinarians, horses have collapsed and even died during prestigious international endurance competitions as a consequence of the “exhausted horse syndrome.”

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**Figure 1.** Humans, dogs, and horses all compete in endurance exercise events during which deficits in body water and electrolyte content may develop. However, mechanisms of thermoregulation and maintenance of body fluids and effective circulating volume vary between these species. Humans and horses utilize evaporative cooling via sweating while dogs thermoregulate via respiration (panting). Human sweat becomes hypotonic with endurance training while horse sweat remains nearly isotonic due to species differences in sweat glands. In contrast, dogs primarily lose water via evaporative cooling across the respiratory tract. Thus, the magnitude of electrolyte depletion that may develop during prolonged endurance competition also varies with species.
PATHOPHYSIOLOGY OF MEDICAL PROBLEMS THAT DEVELOP DURING AND AFTER ENDURANCE EXERCISE

Exercise hyperthermia and dehydration: In endurance athletes, exercise hyperthermia leads to prolonged (typically excessive) sweating and loss of body fluids. As body fluid reserves become depleted, competition for adequate cardiac output to the skin and active skeletal muscle develops. As a consequence, thermoregulation via evaporative cooling at the skin surface can become limited by both a decrease in sweating rate and a decrease in skin blood flow. Subsequent uncontrolled hyperthermia was thus hypothesized to be the most important mechanism responsible for development of collapse and altered mentation during and after endurance competition. This mechanism gained initial support as a result of a 1969 publication authored by Wyndham and Strydom and entitled “The Danger of an Inadequate Water Intake During Marathon Running.” The profound influence of this study came more from its misleading title than to its scientific content. However, the authors did not study nor did they identify any dangers resulting from an inadequate water intake during marathon running. In fact, the most dehydrated runners in their studies were also the most successful, as they won the competitions. Nevertheless, a positive outcome of the study was international rule changes to allow increased fluid intake during competitive races that up until that time had been largely less discouraged. A less desirable outcome was to induce a zeal among sports medicine practitioners and trainers to extol the dangers of dehydration during exercise and to encourage athletes to drink frequently during endurance exercise, despite absence of thirst. Further, it became commonly accepted that all athletes that collapsed in association with exercise had hyperthermia and dehydration that necessitated treatment with intravenous fluids.

During the same few decades, equine veterinarians officiating endurance rides also observed a number of clinical problems in horses that were collectively described as the “exhausted horses syndrome.” Affected horses showed signs including synchronous diaphragmatic flutter, muscle fasciculations, colic signs attributed to ileus, rhabdomyolysis, collapse, 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 but treatment included fluid replacement in the form of water and electrolytes administered via a nasogastric tube or intravenous catheter.

Exercise-associated hyponatremia: For human athletes, the recommendation of liberal drinking during endurance exercise was strongly promulgated during the last couple of decades of the 20th century (Figure 2). In combination with a dramatic increase in marathon running towards the end of that century, this recommendation actually led to development of a new problem among human endurance athletes: exercise-associated hyponatremia. Hyponatremia, induced by excessive fluid replacement with water or a variety of hypotonic sports drinks, actually resulted in serious neurological impairment and death in a number of “weekend warrior” marathon competitors.

Figure 2. Over the past few decades human athletes have been encouraged to drink frequently during endurance competitions, despite a lack of thirst, leading to an increase in development of life-threatening hyponatremia in slower marathon participants.
Fortunately, despite aggressive management of endurance horses to encourage fluid intake, primarily by frequent administration of electrolytes before and during competition, riders have never been able to get their horses to drink excessive amounts of rehydration fluids (Figure 3). Thus, hyponatremia has not yet been recognized as a serious problem of endurance horses.

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 pathophysiologic mechanism for either collapse or exhaustion in human and equine endurance athletes. In fact, in 1995 Noakes and coworkers in South Africa 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 autonomic vascular tone 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), this group advocated resting in the supine position with the lower extremities elevated for several minutes. In many subsequent events, this recommendation has had good success in initial triage of collapsed endurance athletes, furthering support for hypotension as an important mechanism leading to collapse. 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.

In an attempt to investigate whether or not post-exercise hypotension develops in endurance horses, the author and colleagues recently measured indirect blood pressure in horses that successfully competed 80- to 160-km endurance rides. Surprisingly, we also found a substantial reduction in blood pressure during the early recovery period following ride completion in some but not all horses.

Figure 3. In contrast to their human counterparts, horses can absorb substantial amounts of water and electrolytes from the large colon during prolonged exercise, leading to a typical “tucked-up” appearance to the abdomen toward the later stages of competition. Further, oral electrolyte pastes are commonly used to stimulate drinking in endurance horses.
studied (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 splanchnic tissues that receive limited cardiac output during exercise.

All in all, human and equine endurance athletes have both similarities and differences with regard to hydration status during and after endurance exercise. 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 is detected in these athletes, aggressive cooling and support with intravenous fluids remains the accepted approach 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.

**DOES ADMINISTRATION OF ELECTROLYTES REALLY HELP 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's research team has 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 (36-mile) simulated endurance ride on a treadmill, with and without electrolyte supplementation. 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 (Figure 4). In this study, we gave the horses an amount of electrolytes that would be expected to be lost in 25 liters of sweat (5 oz of NaCl and 2.5 oz of 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. However, we did find increases in urine production and urine sodium and chloride concentrations with electrolyte supplementation suggesting that full replacement of anticipated sweat electrolyte losses may not be necessary during endurance exercise.

Our next goal was to take these research findings into the field. Thus, we identified a group of eight riders that were going to compete in two 80-km rides over the same course about a month apart. The rides were held in July and August in northern Michigan under moderate (unchallenging) ambient conditions. The original goal was to compare water intake and competitive performance when horses competed without electrolyte supplementation or when supplemented with an amount of electrolytes anticipated to be lost in sweat during the ride (about 30 liters). Unfortunately, riders were reluctant to participate without any electrolyte supplementation (even though they were not highly competitive); consequently, the study was modified to compare responses to a high dose (HD, equal to 30 liters of sweat loss) versus a low dose (LD, equal to 10 liters...
of sweat loss). Treatments were randomized so four horses received HD or LD in the first ride and the opposite treatment was received in the second ride. HD electrolyte supplementation did result in greater water intake (as reported by rider questionnaire) than LD electrolyte supplementation; however, there was no effect of supplementation on ride time or reported performance by the riders. It is important to reiterate that these were non-elite horses and competition distance was only 80-km. An unexpected finding was development of hypernatremia (plasma sodium concentration values exceeding 150 mmol/l in some horses) with the HD treatment, although no clinical adverse effects were observed. This finding suggested that some horses did not drink adequately in response to HD electrolyte supplementation and that caution is warranted when oral electrolyte pastes are used. As a result, we consider that a reasonable goal can be replacement of about 30-50% of the electrolytes anticipated to be lost in sweat as horses can also draw on electrolyte reserves in the large intestine during and after exercise.

Although not observed in any of our studies, another adverse effect of concentrated oral electrolyte pastes that has been anecdotally reported at endurance rides is irritation of oral membranes. To further study potential adverse effects of contact of hypertonic electrolyte slurries with mucosa, investigators at Oklahoma State University studied the effects of repeated administration of a concentrated electrolyte slurry, administered hourly for 8 hours, on the number and severity of ulcers in the gastric squamous mucosa. The investigators did find a mild increase in both number and severity of squamous ulcers, as compared to horses that received only oral syringes of water. Further, horses treated with electrolytes also developed oral mucosal hyperemia and edema. The relevance of these findings to competitive endurance athletes remains unknown but it does raise concerns that use of a high dose of oral electrolyte pastes may not be without some risk. Finally, concerns have also been raised about the potential for orally administered concentrated electrolyte pastes to transiently exacerbate dehydration by “pulling” water into the gut prior to absorp-
tion of the electrolytes. Unfortunately, at present there are no clear data that either support or refute these concerns.

Due to these concerns about concentrated oral electrolyte pastes, we investigated whether dehydrated horses would drink hypotonic or isotonic salt water and whether they preferred it cold, cool, or warm. We studied horses running 45 km on a treadmill that were mildly dehydrated before the exercise bout by administration of a dose of furosemide and that were not allowed to drink during the exercise bouts. In the first experiment we provided them with an initial drink of either water or two concentrations of salt water (0.45% and 0.9% NaCl solutions) for the first 5 minutes after exercise. Because we found dehydrated horses to initially drink all three of these rehydration solutions equally well after completing the exercise bout, horses were offered an initial drink of 0.9% NaCl at 10, 20, or 30 °C in a subsequent experiment. In both experiments, we found that an initial drink of salt water improved recovery of sweat fluid losses because horses drank more plain water when it was offered from 15-60 minutes of the recovery period after horses had been washed of f and returned to a stall. 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 elevated plasma sodium concentration ([Na⁺]), an initial drink of water dilutes plasma [Na⁺] and abolishes the drinking stimulus. In contrast, with an initial drink of salt water, plasma [Na⁺] remained 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. A further observation was that the initial drink by most horses was 10-12 liters in volume, regardless of the rehydration solution offered. This observation suggested that gastric distension with drinking may be an important factor in limiting initial rehydration following dehydration.

In another experiment (unpublished data) we compared voluntary drinking of a series of rehydration solutions containing both dextrose and electrolytes, at normal to twice normal tonicity, to horses dehydrated by furosemide administration and overnight water deprivation. Important findings included that horses voluntarily consumed both dextrose and electrolyte, at normal to twice normal tonicity, to horses dehydrated by furosemide administration and overnight water deprivation. Important findings included that horses voluntarily consumed both dextrose and electrolyte solutions equally well, as long as they were not hypertonic to plasma (Figure 5). Further, as in our prior studies, the initial drink of water or isotonic solutions appeared to be limited by stomach capacity.

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 hard working horses in the summer would be 1-2 oz (1 volumetric ounce \( \approx 20-25 \) g) of an equal mix of table salt and lite salt added to the grain twice daily. For endurance horses that may be on the trail for 12 or more hours of exercise, supplementation with oral electrolyte pastes (again 1-2 ounces of a mix of NaCl and lite salt) at each rest break (veterinary check point) should result in greater voluntary water intake through the ride and early recovery period. However, when oral electrolytes pastes are used, riders must carefully monitor their horses to make sure that they are drinking adequately; otherwise, significant hypernatremia may develop.

Another option would be to provide an initial drink of isotonic salt water during the first few minutes after arriving at rest stops during the exercise bout as well as providing supplemental salt in concentrate feed mixes offered at these check points. Salt water (0.9% NaCl) can be easily made by adding one volumetric ounce of table salt to each gallon of water. However, because horses can be finicky about drinking, plain water should always be offered after initially ofering salt water. As previously stated, the goal should be to replace only about 30-50% of the anticipated sweat electrolyte loss as horses can also draw on the electrolyte reserves in the large intestine during and after exercise. A recent study by investigators at the University of Guelph showed another potential benefit of electrolyte supplementation as they found more rapid recovery of skeletal muscle glycogen reserves in horses completing a treadmill endurance exercise bout, as compared to when the exercise bout was completed without electrolyte supplementation.

For clients with lots of questions about electrolyte supplementation, have them take a close look at the contents of various electrolyte supplements the next time they go to the feed mill or tack shop. They should try to determine out how much of each product would be needed to replace the electrolytes lost during a good workout (1-2 hours) of trotting and cantering on a hot, humid day: about 10 kg of sweat containing as much as 75 g of NaCl and 30 g of KCl. They will likely find that many of the products contain more sugar than electrolytes, yet we still don’t know if horses really need this sugar like human endurance athletes. Finally, have them compare the cost of giving these supplements to replace the 10 kg sweat electrolyte loss to the cost of 75 g of NaCl and 30 g of KCl (equal to about 1.5 oz of table salt [NaCl and 2 oz of lite salt [\( \frac{1}{2} \) NaCl and \( \frac{1}{2} \) KCl] that they can purchase at the grocery store). I expect that they will find the comparison a bit surprising.

REFERENCES

Equine and human endurance exercise


Complications of endurance exercise


Oral electrolyte pastes

Rehydration solutions