Oral electrolyte supplementation and prevention of dehydration in horses

Dehydration is common in equine disciplines and can be avoided by effective oral rehydration strategies. Thermoregulatory loss of heat in horses requires sweating which, in turn, can result in considerable loss of water and electrolytes. Maintenance of hydration and prevention of dehydration requires the continuous replacement of lost electrolytes and water. The stomach and small intestine can function as reservoirs to facilitate the uptake of water and electrolytes consumed 1–2 hours prior to competitions, training and transport. Ions and water are rapidly absorbed in the small intestine and taken up by muscles and the skin, where they serve to replace losses resulting from muscle contraction and sweating. An effective electrolyte supplement replaces electrolytes in the proportion that they are lost through sweating; failure to do this results in an electrolyte imbalance. Electrolyte solution osmolality must be maintained at less than that of bodily fluids to promote gastric emptying and intestinal absorption. Palatability of the electrolyte supplement should be high, and horses should be trained to drink the solution voluntarily before any dehydrating event to try to prevent dehydration from occurring.

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Horses lose considerably more electrolytes in their sweat than humans (Lindinger, 2022) (*Figure 1*). The visual evidence can be seen in the presence of salt in the coat and on the ground once the sweat evaporates. Equine sweating rates (when normalised to body surface area or to body mass) are also much greater than in humans (*Table 1*). The high sweating rates, combined with high sweat ion concentrations, translate to very high rates of electrolyte loss during periods of heat stress (*Box 1*). Thus, many horses involved in training, competition and transport may experience periods of severe, potentially life-threatening dehydration and thermal strain that can be prevented (Carlson, 1987; Coenen, 2005). The purpose of this article is to provide easy-to-use guidance on using effective oral electrolyte supplements to prevent – or at least minimise – dehydration in horses. The interested reader is referred to the following more detailed reviews (Jenkinson et al, 2007; Lindinger, 2022).

Electrolytes and water lost through sweating

Horses have a very large total mass of contracting muscles which are capable of producing significant amounts of heat very quickly, but – relative to humans – have a small skin surface area for dissipating this heat. The horses' body mass to surface area ratio is 2.5 times greater than that of a human. Therefore, body heat storage and core body temperature in horses increase rapidly during periods of exercise and heat stress (Geor et al, 2000). Horses try to lose this heat through the skin and the respiratory tract (Jenkinson et al, 2007; Hodgson, 2014), resulting in loss of water from the body: approximately 90% through the skin and sweating (Jenkinson et al, 2007; Lindinger and Waller, 2021); approximately 10% via the respiratory tract (Carlson, 1987; Naylor et al, 1993).

Exercise and heat stress result in the loss of water and electrolytes from both the intracellular and extracellular body fluid

Figure 1. Salt on the ground where sweating horses have been scraped to remove sweat from the coat (photo by GE Ecker).

Table 1. Horse versus human sweating and evaporative cooling

Parameter	Horse	Human
Body mass (kg)	500	80
Contracting muscle (kg)[a]	200	16
Surface area for cooling (m^2)[b]	5.09	1.8
Body mass:surface area ratio	100	40
Sweating rate ($mL \cdot m^{-2} \cdot min^{-1}$)[c]	50	30
% sweat used for cooling[d]	25–30	30–50
Total sweat [ion]s (mmol/L)[e]	200	50
Sweat [sodium concentration] (mmol/L)[e]	120	40
Sweat [potassium concentration] (mmol/L)[e]	60	4
Sweat [chloride concentration] (mmol/L)[e]	180	50
Sweat [calcium concentration] (mmol/L)[f]	3–7	40
Sweat [magnesium concentration] (mmol/L)[f]	3–6	4
Sweating rate (L/hour)[e]	10–15	2–3

[a](Gunn, 1987); [b](Hodgson et al, 1994); [c](Kingston et al, 1997); [d](Jenkinson et al, 2007); [e](McCutcheon et al, 1995; 1999); [f](Carlson and Ocen, 1979; Kerr and Snow, 1983; McConaghy et al, 1995).

compartments (Gottlieb-Vedi et al, 1996; Waller and Lindinger, 2021). The resultant changes in extra- and intracellular ion concentrations are often sufficient to impair nerve and muscle function (Lindinger and Cairns, 2021), and thus physical (Cheuvront and Kenefick, 2014) and mental performance (Adan, 2012).

Dehydration

An inability to adequately replace water and ions lost through sweating will result in dehydration. Clinical dehydration refers to a loss of fluid ≥3% of body mass, (for example, 15 L for a 500 kg horse) (Carlson, 1987). A more meaningful definition is the loss of body water at a rate greater than the ability to replace it (Thomas et al, 2008). Dehydration is a concern when horses sweat for more than 1 hour, including the post-exercise recovery periods after high-intensity exercise such as race training and competition (Waller and Lindinger, 2005). A dehydrated horse needs to first be administered adequate water and electrolytes prior to further exercise, transport and eating dry feeds.

Dehydration results in a decrease in circulating blood volume as a result of an increased demand for cardiac output to both contracting muscles and the skin during periods of heat stress (Carlson, 1987; Lindinger, 2014). Maintaining a high blood flow to working muscles and skin helps to move heated blood to the periphery where it can be cooled, as well as to provide fluid for the cutaneous sweating mechanism (Jenkinson et al, 2007; Waller and Lindinger, 2021). When dehydration is allowed to progress, the ability to cool the body through all body surface mechanisms (convection, conduction, evaporative cooling) is progressively diminished (Naylor et al, 1993) resulting in hyperthermia. The heart rate of hyperthermic horses can be very high; even when the horse is no longer exercising, the heart rate does not return to resting levels because of the need to continue removing heat from the body (Geor et al, 2000). Dehydrated horses need to be treated rapidly and effectively by stopping activity, providing large-volume oral electrolyte supplementation (Waller and Lindinger, 2021) or intravenous electrolyte therapy (Lester et al, 2013) and implementation of effective cooling strategies (Takahashi et al, 2020). Given that dehydration is a leading cause of impaction colic, rehydration of ingesta via oral administration of fluid is recommended (Plummer, 2009) even though intravenous fluid therapy may be effective to rehydrate hindgut ingesta (Lester et al, 2013) (*Box 2*). Dehydration is also a leading cause of impaction colic as a result of the osmotic loss of fluid in the gastrointestinal tract – thus, rehydration of ingesta within the gastrointestinal tract is indicated (Plummer, 2009). Oral administration of fluid (water and electrolytes) into the stomach (by drinking or gastric intubation) is recommended, and intravenous fluid therapy may also be effective when oral administration is not possible (Plummer, 2009).

Strategies for replacing electrolyte and water loss

Sweating is required to support thermoregulatory cooling – therefore, no attempt should be made to prevent electrolyte and water losses from occurring. The evidence to support this arises from the condition of anhidrosis in horses which severely compromises the ability of horses to exercise (Jenkinson et al, 2007). It is necessary to implement strategies to effectively replace electrolytes and water at the same rate that they are being lost from the body during extended (1 hour or more) periods of transport, exercise and sweating during recovery from short-lasting exercise in hot conditions (Kronfeld, 2001a; Coenen, 2005) (*Figure 2*).

Requirements for an effective electrolyte supplement

The main goal of effective electrolyte supplementation is to replace, in the correct proportions and amounts, the electrolytes and water lost through sweating (Kronfeld, 2001a; 2001b; Lindinger and Ecker, 2013). This will help ensure near-optimum functioning of all physiological systems. This concept is relatively simple, however, in practice it has typically been poorly done. Small differences in sweat ion concentration over time and between individuals and with heat acclimation (McCutcheon et al, 1995; McCutcheon et al, 1999; McCutcheon and Geor, 2000) can be ignored, and one electrolyte supplement can be used for all horses to prevent or treat excessive dehydration (Kronfeld, 2001a; Coenen, 2005; Lindinger and Ecker, 2013; Waller and Lindinger, 2021). Since calcium and magnesium are lost in sweat, and because most of this comes from the extracellular fluid compartment, these ions must be replaced from either muscle or ingestion of supplements. Not using supplements results in electrolyte imbalance impairment of neuromuscular function (such as thumps and muscle fasciculations). The presence of dextrose in effective electrolyte supplements enhances palatability, facilitates the absorption of sodium and water in the small intestine and is readily taken up by intestinal epithelial cells and used as an energy source to provide adenosine triphosphate (Shi et al, 1994).

The composition of effective electrolyte supplements should mimic the proportion of ions present in equine sweat. Proportion is more important than the concentration of each ion in the electrolyte solutions (powdered supplement mixed into the required amount of water) so that an appropriate physiological balance between the various electrolyte species is maintained. For example: 'average' equine sweat has a composition of (% dry weight) (Kerr and Snow, 1983; McCutcheon et al, 1999):

- Sodium chloride: 48%
- Potassium: 14%
- Calcium: 0.04%
- Magnesium: 0.05%.

For comparison, an effective electrolyte supplement designed by the author (Perform'N Win, Buckeye Nutrition, Dalton, OH, USA) is (% dry weight) (Lindinger and Ecker, 2013):

- Sodium chloride: 33%
- Potassium: 18%
- Calcium: 0.024%
- Magnesium: 0.03%
- Dextrose: approximately 50%.

Research in humans has shown that oral electrolyte supplementation is most effective when the electrolyte solution is somewhat hypotonic compared to body fluids (Shi et al, 1994; Fayet-Moore et al, 2020). This facilitates rapid gastric emptying and intestinal absorption of water and ions (Lindinger and Ecker, 2013). Electrolytes used in supplements should also be highly bioavailable in contrast to sources of calcium and magnesium used in most commercial electrolyte supplements (oxides and carbonates) – this can result in pronounced depletion of these two minerals during extended periods of sweating. Overt visual manifestations of divalent cation depletion include muscle fasciculation, muscle cramping (de Baaij et al, 2015; Heffernan et al, 2019) and thumps (Mansmann et al, 1974).

Training the horse to drink an electrolyte supplement

There is no published, scientific evidence to support the very important point that horses need to be trained to drink electrolyte supplements and how this can be accomplished. The information below comes from the author's experience and observations over more than 25 years of equine research.

Horses are sensitive to the taste of solid and liquid foods (Randall et al, 1978; Van Diest et al, 2021) so offering liquids with novel taste and mouthfeel, such as an electrolyte supplement, typically results in an initial aversion and low or no rate of consumption. Horses can be trained to drink electrolyte supplements, as long as they are palatable. The approach used by the author when an initial aversion occurs is to dilute the solution 5-fold and not offer an alternative drink. Ideally this training is first performed when the horse has not just been exercised and is relatively inactive. The

Box 1. Practical points regarding equine sweating

- Sweating rates increase with heat stress because of ambient temperature and humidity (McCutcheon et al, 1995; McCutcheon and Geor, 2000) or intensity of exercise.
- Sweating rates in hot, humid conditions are higher than in hot, dry conditions because of the greater thermal stress for a given temperature arising from the decreased ability to evaporate sweat for cooling (McCutcheon et al, 1995).
- High sweating rates can be sustained for more than 2 hours, especially when horses are adequately supplemented with effective electrolyte solutions.
- High sweating rates will result in dehydration when effective electrolyte supplementation is not provided.
- Chloride is the predominant ion lost in sweat (nearly equal to the combined losses of all cations), followed by sodium, potassium, magnesium and calcium.
- Sweating rates (and hence thermoregulatory cooling) decrease as horses become dehydrated.
- Electrolytes are required in body fluid compartments to retain the water. Therefore, consuming only water to try to rehydrate will only dilute body fluid compartments, resulting in renal water excretion together with more electrolytes. Water alone cannot result in rehydration, and may cause further dehydration (Maughan et al, 1994).

Box 2. Does the hindgut serve as a reservoir for water and electrolytes?

The volume of the hindgut of a 500 kg horse is about 150 L, of which the contents are high in water and electrolytes (Argenzio et al, 1974). Dehydration of the extracellular fluids in the body may result in an osmotic movement of water and electrolytes (with other small molecules such as volatile fatty acids) into blood and body fluids. While this is beneficial for extracellular fluids and cardiovascular function, it may result in excessive dehydration of the contents of the hindgut, increasing the risk of impaction colics (Plummer, 2009). Considerable time and effort may be needed to effectively restore hindgut hydration. Thus, maintenance of hydration should rely on the stomach and small intestine as the first line of water and electrolyte uptake during transport and exercise.

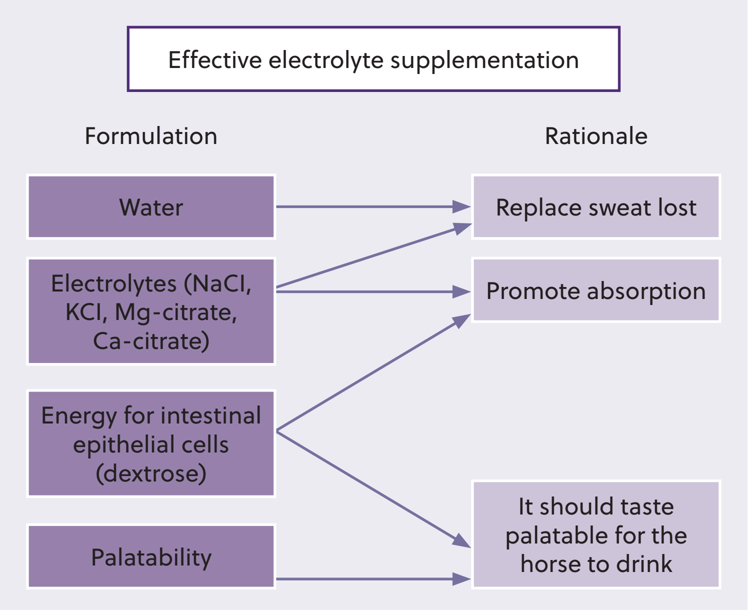

Figure 2. Conceptual diagram illustrating requirements for effective water and electrolyte replacement. Created by the author using Biorender. NaCl: sodium chloride; KCl: potassium chloride; Mg-citrate: magnesium citrate; Ca-citrate: calcium citrate.

horse may choose to not drink for 1 hour, or even up to 6 hours. However, eventually the horse will drink the solution. Following this, the strength can be gradually increased over a period of 3–7 days, and the horse will eventually have no trouble drinking the solution at full strength. Another method of training could be to prevent the horse from engaging in a favourite activity until a required volume of electrolyte solution had been drunk. The keys to success are persistence, giving the horse no alternative drink and gentle encouragement. The horse will, over a period of days, become accustomed to drinking a full-strength electrolyte solution.

The use of pastes and slurries (Schott et al, 2002; Sampieri et al, 2006) should be avoided, because these are typically not accompanied by drinking adequate amounts of water. The retention of concentrated salt solution in the stomach inhibits gastric emptying (Costill and Saltin, 1974; Ryan et al, 1989), irritates the stomach lining (contributing to gastric lesions (Holbrook et al, 2005)) and can result in a reverse osmotic movement of water from body fluids into the stomach and small intestine – making a dehydrated horse more dehydrated.

It is also common practice to top dress electrolytes on to the feed as one method of delivering them. However, the quantity of electrolytes provided by top dressing is often inadequate, and hydration should be achieved first, prior to allowing the horse to eat dry foodstuffs. In order to mitigate and replace sweat losses during and after endurance activities, foodstuffs supplemented with the calculated and appropriate amounts of water and electrolytes need to be consumed.

What happens if too much electrolyte supplementation is given?

The timing of electrolyte supplementation varies somewhat by discipline, and the following recommendations are based on previous works summarised by Kronfeld (Kronfeld, 2001a; 2001b) and from the author's experience. In general, horses that are not in work do not need to be provided with electrolyte supplementation. There are a variety of methods to try to provide adequate amounts of electrolytes to horses. These include providing electrolytes at mealtimes, after exercise and training and sometimes before exercise and training. As part of recommended preventative strategies, it is clear that electrolyte supplementation should be provided about 1 hour before transport or exercise. When exercise or transport is continued beyond 1 hour, then supplementation should be provided as needed to prevent dehydration, so that losses can be replaced in real time. Post-exercise and post-transport supplementation should also be provided prior to ingestion of dry foodstuffs.

When excessive amounts of electrolytes have been provided, as long as adequate water has been consumed, there should be no negative effects on horse health. Excess electrolytes will be excreted by the kidneys as part of normal renal function, but this may not be the case in a severely dehydrated horse (Muñoz et al, 2010; 2011). When inadequate water is provided, the electrolytes may sit in the stomach and act as an irritant and desiccant (Holbrook et al, 2005). High osmolality in the stomach and duodenum will draw water from the blood, further dehydrating body fluid compartments. Only later will water and electrolytes move in the correct direction, from the gastrointestinal tract back into the blood, but without restoration of hydration. Adequate amounts of water are required with electrolytes to affect maintenance of hydration or rehydration.

Long-duration exercise covers any form of activity where there are intentional rest periods during the activity, such as endurance rides and between the phases in 3-day eventing. Since the difficulties associated with overheated horses at the 1992 summer Olympic games in Barcelona, increasing attention has been given to the work intensity and effective strategies for cooling and hydration (Lindinger and Marlin, 1995; Jeffcott and Kohn, 1999). It is known that a 100 mile endurance ride can be completed and won with no detectable dehydration at any of the veterinary checkpoints, observed by the author at the 1995 Race of Champions. The key points are these:

- Ensure hydration prior to starting the ride or race by using electrolyte supplementation – water alone cannot result in effective hydration
- Take every opportunity to provide electrolyte supplementation
- Ensure the horse drinks adequate amounts of water during the ride, including at every rest break, whenever there is access to potable water (streams, lakes, ponds) and providing work breaks for the horse (such as jogging alongside the horse) when the going is difficult.

Conclusions

Losses of electrolytes and water at the skin for thermoregulatory cooling are directly related to the intensity and duration of exercise, and the ambient conditions of heat and humidity, resulting in thermal stress. Chloride is the predominant ion lost in sweat, followed by sodium, potassium, magnesium and calcium. An inability to replace electrolytes with adequate amounts will result in dehydration and potentially catastrophic heat illness. A dehydrated horse should first be administered adequate amount of water and electrolytes prior to further exercise, transport or eating dry feeds. The main goal of effective electrolyte supplementation is to replace, in the correct proportions and amounts, the electrolytes and water lost through sweating. Electrolyte supplementation should be provided about 1 hour before transport or exercise, because the ingested water and electrolytes can replace losses occurring at the skin in real time.

KEY POINTS

- Heat stress results in increased sweating with significant losses of water and electrolytes.
- Sweating results in dehydration unless effective hydration strategies are used.
- Effective hydration requires supplementation of both electrolytes and adequate amounts of water.
- Dehydration impairs performance, both physical and mental, and places both the horse and rider at risk of injury or death.
- Horses can be trained to drink electrolyte solutions and so prevent dehydration and heat illness from occurring. A hydrated horse is a healthy horse.

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Conflicts of interest

The author has designed commercial equine electrolyte supplements.

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