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Effects of oral powder electrolyte administration on packed cell volume, plasma chemistry parameters, and incidence of colic in horses participating in a 6-day 162-km trail ride.

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Authors

Walker, Wade T
Callan, Robert J
Hill, Ashley E
et al.

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Effects of oral powder electrolyte administration on packed cell volume, plasma chemistry parameters, and incidence of colic in horses participating in a 6-day 162-km trail ride

Wade T. Walker, Robert J. Callan, Ashley E. Hill, Kelly B. Tisher

Abstract — This study evaluated the effects of administering oral powder electrolytes on packed cell volume (PCV), plasma chemistry parameters, and incidence of colic in horses participating on a 6-day 162-km trail ride in which water was not offered *ad libitum.* Twenty-three horses received grain with powder electrolytes daily while 19 control horses received grain only. Horses were ridden approximately 32 km a day at a walk or trot. Packed cell volume and plasma chemistry parameters were analyzed daily. Episodes of colic were diagnosed and treated by a veterinarian unaware of treatment group allocation. Blood parameters and incidence of colic were compared between treatment groups. Electrolyte administration did not alter PCV or plasma chemistry parameters compared to controls. The incidence of colic was significantly higher in treated horses ($P = 0.05$). Oral powder electrolytes did not enhance hydration status or electrolyte homeostasis and may be associated with colic in horses participating on long distance trail rides similar to this model.

Résumé — Effets de l'administration d'électrolytes en poudre oraux sur le volume d'hématocrite, les paramètres chimiques du plasma et l'incidence des coliques chez des chevaux participant à une randonnée de 162 km d'une durée de 6 jours. Cette étude a évalué les effets de l'administration d'électrolytes en poudre oraux sur la valeur d'hématocrite (VH), les paramètres chimiques du plasma et l'incidence de coliques chez des chevaux participant à une randonnée de 162 km d'une durée de 6 jours où l'eau n'était pas offerte *ad libitum.* Vingt-trois chevaux ont reçu du grain avec des électrolytes en poudre tandis que 19 chevaux témoins ont reçu du grain seulement. Les chevaux ont transporté un cavalier pendant environ 32 km par jour au pas de marche ou au trot. La valeur d'hématocrite et les paramètres chimiques du plasma ont été analysés tous les jours. Des épisodes de coliques ont été diagnostiqués et traités par un vétérinaire qui n'était pas informé de l'allocation au groupe de traitement. Les paramètres sanguins et l'incidence de coliques ont été comparés entre les groupes de traitement. L'administration des électrolytes n'a pas modifié la VH ni les paramètres chimiques du plasma par rapport aux témoins. L'incidence de coliques était significativement supérieure chez les chevaux traités ($P = 0,05$). Les électrolytes en poudre oraux n'ont pas amélioré l'état d'hydratation ni l'homéostasie des électrolytes et peuvent être associés à des coliques chez les chevaux participant à des randonnées de longue distance semblables à ce modèle.

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Introduction

Prolonged strenuous exercise can be detrimental to the hydration and electrolyte status of horses. Horses completing single day endurance events and the cross-country phase of eventing lose 2.0% to 7.4% of their body weight (1–4), primarily due to intra and extra-cellular fluid losses which are more profound in horses with decreased performance (5). Dehydrated horses can have a decrease in plasma volume leading to a decreased ability to perfuse the skeletal muscle and skin, resulting in exercise fatigue and hyperthermia (6). Horses

Department of Clinical Sciences, College of Veterinary Medicine and Biomedical Sciences, Colorado State University, Fort Collins, Colorado 80523, USA (Walker, Callan); The California Animal Health and Food Safety Laboratory, University of California, Davis, California 95617, USA (Hill); Littleton Equine Medical Center, Littleton, Colorado 80120, USA (Tisher).

Address all correspondence to Dr. Wade Walker; e-mail: wtw36@cornell.edu

Dr. Walker's present address is Cornell University Hospital for Animals, Ithaca, New York 14853, USA.

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completing single and multiday endurance events maintain substantial decreases in body weight due to fluid losses on the previous day (7–9). Lack of recovery is especially concerning for horses participating in multiday endurance events (6).

Electrolytes are the most common supplement-type product administered to eventing horses (10), and are given to promote rehydration in order to maintain plasma volume and electrolyte homeostasis. Experimentally, electrolytes have been administered free choice as a solute in water (11,12), with a dosing syringe (13–15), via nasogastric intubation (16–19), and as a paste (12,20,21). By physically increasing fluid ingestion (16–18) or by elevating plasma osmolality to increase the thirst response (11–13,15,19–21), electrolyte supplementation increases plasma volume via increased water intake. Electrolyte supplementation can be beneficial to the cardiovascular and thermoregulatory systems during exercise (17–19); however, the long-term post-exercise effects on fluid recovery differ (12,13,21).

Although powder electrolytes are frequently administered in the equine industry, information regarding administration is scarce. The supplementation of salt to the normal diet of horses in a laboratory setting increased water intake and electrolyte metabolism when accompanied with *ad libitum* water prior to exercise (22). Little information exists regarding the effects of electrolyte administration in field conditions where water is not freely available.

Symptoms of gastrointestinal discomfort are common in human athletes and have been reported to affect over 50% of marathon runners (23). The etiology for these symptoms is not understood but may be due to mechanical jarring, reduced splanchnic blood flow, hormones, colonic motility, and dehydration (24). Electrolyte solutions are used by human athletes to combat dehydration and maintain optimal bodily function (23); however, hypertonic beverages are associated with an increased incidence and severity of gastrointestinal symptoms (25,26). Unlike humans, electrolyte administration in horses has not previously been associated with abdominal discomfort; however, recent changes in exercise programs and dehydration (27,28) have been shown to be a risk factor for colic as well as a negative prognostic indicator for competitive success (29).

The objective of this study was to determine if administration of a commercially available electrolyte powder to horses participating in a 6-day 162-km trail ride would improve hydration status, maintain plasma electrolyte homeostasis, and alter the incidence of colic under a controlled field environment in which water was not offered *ad libitum.*

Materials and methods

Seventy-four horses of mixed training and management backgrounds arriving at Big Red Park, Colorado (altitude 2635 m) were alternately assigned to treatment and control groups upon arrival. A demographic survey was completed by the owner of each horse to acquire horse signalment and conditioning status as well as rider experience information (Table 1). All horses were rested in camp on day 0, and ridden approximately 32 km on days 1,2,3,5, and 6 for a total of 162 km (Table 2). Day 4 was a rest day. While in camp, horses were on tie lines and given grass hay *ad libitum.* Daily water intake included 2 opportunities in the morning before riding, 1 to 3 water stops on the trail (Table 2), and incremental introduction for 1 h after return to camp until being offered 3 times throughout the evening and night. Horses were allowed to drink *ad libitum* at each water opportunity except for the 1-hour period immediately following the day's ride. Water was offered *ad libitum* 6 to 8 times daily on rest days 0 and 4.

Table 1. Rider and horse demographic variables for 23 electrolyte-treated and 19 control horses participating in a 6-day 162-km trail ride

	Control	Treatment	*P*-value
Continuous variables			
Years on ride (rider)	10.7	11.9	0.67
Years on ride (horse)	3.4	3.22[a]	0.83
Horse age (years)	10.1	11.14[a]	0.47
Altitude of residence (m)	1759.6	1852.4	0.66
Distance to camp (km)	496.3	466.6[a]	0.68
Categorical variables			
Gender			1.00
Gelding	94.7	91.3	
Mare	5.3	8.7	
Breed			0.78
Gaited	15.8	21.7	
Morgan	0.0	8.7	
Paint	10.5	13.0	
Quarter Horse	63.2	52.2	
Thoroughbred	10.5	4.4	
Residence environment			0.24
Pasture	79.0	60.9	
Stall	0.0	4.4	
Run	21.1	13.0	
Mixture	0.0	21.7	
Riding frequency			0.61
≥ 5 times weekly	5.3	8.7	
3 times weekly	42.1	60.9	
1 time weekly	31.6	21.7	
3 times monthly	15.8	8.7	
≤ 1 time monthly	5.3	0.0	
Distance ridden per month (km)			0.02
> 320	5.3	0.0	
240	5.3	26.1	
160	10.5	17.4	
80	26.3	43.5	
40	21.1	13.0	
< 40	31.6	0.0	
Amount of time conditioning (mo)			0.07
< 1	15.8	13.0	
1 to 3	57.9	30.4	
3 to 5	10.5	47.8	
> 5	15.8	8.7	

[a] Information not provided for 1 horse in the treatment group.

All horses were offered 907 g of a commercially available grain (Equine Strategy, Purina Mills, St. Louis, Missouri, USA) via grain bag at 6 am and 6 pm, and 454 g at 12 pm. The treatment group had 57 g of oral powder electrolytes (Equilytes, Vetline Larson Laboratories, Fort Collins, Colorado, USA) (Table 3) supplemented in their grain bags at 6 am and 12 pm on day 1 and 28 g of oral powder electrolytes at 6 am and 12 pm on days 2,3,5, and 6 as per the manufacturer's recommendations. Supplementation was administered by a technician and the rider and staff veterinarian were blinded to treatment allocation. Neither grain nor electrolytes was administered on day 0, and only 6 pm grain without electrolyte supplementation was administered to horses in both groups on day 4. Grain consumption was measured subjectively on a scale of 0 to 3 (0 = ate

Table 2. Daily high temperature (°C), distance ridden (km), and number of water stops on the trail during a 6-day 162-km trail ride

Study day	0	1	2	3	4	5	6
High temperature (°C)	26.7	27.8	27.8	27.8	28.3	26.1	27.8
Distance (km)	0	37.0	29.6	37.0	0	31.5	27.4
Water stops on trail	NA	2	2	3	NA	2	1

NA — not applicable.

Table 3. Nutritional contents of the supplemented powder electrolyte[a] administered to 23 horses on a 6-day 162-km trail ride

Electrolyte guaranteed analysis	Percentage
NaCl (min)	7.0
NaCl (max)	9.0
Calcium amino acid chelate (min)	1.4
Calcium amino acid chelate (max)	2.4
Magnesium amino acid chelate (max)	1.1
Potassium amino acid chelate (max)	1.6

[a] Equilytes, Vetline Larson Laboratories, Fort Collins, Colorado, USA.

none, 1 = ate less than half, 2 = ate over half, 3 = ate all) by a veterinary technician blinded to the treatment. Horses without a score of 2 or 3 at every feeding were excluded from the study, as were horses that were not ridden every day.

Blood samples were collected from all horses in 4-mL lithium heparin tubes at 8 pm on study days 0 and 4, and between 2 and 3 h after arrival at camp on study days 1,2,3,5, and 6. Direct packed cell volume analysis was performed using microhematocrit tubes and centrifugation on site in duplicate. The plasma from each sample was separated in a centrifuge at 2400 × *g* for 5 min, placed into empty plasma storage tubes with a pipette, and immediately frozen (−23°C). Plasma total protein, albumin, globulin, glucose, blood urea nitrogen (BUN), creatinine, phosphorus, calcium, magnesium, sodium, chloride, potassium, and bicarbonate concentrations, and anion gap were determined at a private laboratory (Heska Laboratories, Loveland, Colorado, USA) within 30 d of collection.

A technician who was unaware of treatment group allocation monitored all horses hourly throughout the study. Horses that were uninterested in feed or appeared uncomfortable were brought to a veterinarian for further examination. A veterinarian (KBT) blinded to the study group allocation assessed clinical signs, vital parameters, and gastric reflux to subjectively grade each colic episode as slight, mild, moderate, or severe. Horses with an episode of colic were treated via nasogastric intubation with a combination of 1 oz electrolyte solution mixed in 4 L of water (Equine Bluelite; TechMix, Stewart, Minnesota, USA) and 2 L of dioctyl sodium sulfosuccinate 5% (First Priority, Elgin, Illinois, USA) as well as 20 mg acepromazine maleate (Vedco, Saint Joseph, Missouri, USA) and 500 mg flunixin meglumine (Banamine; Merck Animal Health, Summit, New Jersey, USA) intravenously as per ride protocol. Response to treatment and any additional treatments were recorded. The owner of each horse in the study completed a client consent form. Study protocol as well as horse assessment and treatment were approved by the Animal Care and Use Committee at Colorado State University.

Statistics

Mean values for continuous demographic variables [years on ride (rider), years on ride (horse), horse age, altitude of residence, distance to camp] were compared between treatment and control groups using *t*-tests with the assumption of equal variances. Distribution of categorical variables (gender, breed, residence environment, times/month, distance/month, conditioning) was compared between treatment and control groups using chi-squared tests, or Fisher's exact tests when 1 or more cells contained fewer than 5 observations.

A linear regression model with group (control *versus* treatment) and study day (0–6) as fixed effects and horse as a random effect was used to determine whether PCV and plasma chemistry values differed between control and treatment groups as well as among days of study. All variables were evaluated for normality using Shapiro-Wilks testing and were considered normally distributed with $P > 0.05$. Non-normally distributed variables were Box-Cox transformed, and analyzed in their transformed state.

Packed cell volume and plasma chemistry values between horses that did and did not have colic on each ride day were assessed using conditional logistic regression (with day as the conditional variable). For horses with > 1 colic episode, only the initial colic episode was included as a case; data from later colic episodes were not included in the analysis. Parameters were evaluated in their continuous form if they met the assumption of linearity in the log odds, otherwise they were evaluated in categorical form.

A two-sided Fisher's Exact Test was used to compare cumulative incidence of colic between the control and treatment groups. *P*-values ≤ 0.05 were considered statistically significant (Stata/SE 10.1, StataCorp, College Station, Texas, USA).

Results

Forty-two horses met the inclusion criteria: 19 control horses and 23 treatment horses (Table 1), 29 horses were excluded due to failure to ingest over half of their grain at every meal (control = 16, treatment = 13), and 3 horses were excluded due to failure to participate every day of the ride due to injury to the horse or rider (control = 2, treatment = 1).

There were no differences in the continuous demographic variables [years on ride (rider), years on ride (horse), horse age, altitude of residence, distance to camp] between groups. There were no differences in the distribution of gender, breed, residence environment, or times ridden per month between groups. Compared with the control group, the treatment group was ridden significantly more miles per month ($P = 0.02$) prior to the ride. Although not significant, the treatment group had a trend toward longer periods of conditioning prior to the ride ($P = 0.07$, Table 1) compared with the control group.

Creatinine, globulin, bicarbonate, and magnesium levels were normally distributed. Packed cell volume, BUN, phosphorus, calcium, total protein, albumin, glucose, sodium, potassium, chloride, and anion gap were Box-Cox transformed in order to attain normality. Packed cell volume, plasma total protein, globulin, glucose, BUN, creatinine, phosphorus, calcium, magnesium, sodium, chloride, potassium, bicarbonate, and anion

Table 4. Mean (± SD) PCV and plasma chemistry parameters for 19 horses in control and 23 horses in electrolyte-treatment groups on each day of a 6-day 162-km trail ride

			Day 0		Day 1		Day 2		Day 3		Day 4		Day 5		Day 6	
Parameter	Group	Reference ranges	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD
PCV (%)	Control	31% to 47%	38.4	6.3	40.7	4.1[b]	40.1	2.7[a]	39.2	3.4	36.8	4.0[c]	38.4	2.3	38.4	2.5
	Treatment		39.7	3.0	42.0	3.1[b]	41.1	3.5[a]	40.8	3.9	37.0	3.1[c]	39.2	2.7	39.2	2.7
BUN (mmol/L)	Control	3.6 to 9.6	6.1	1.1	7.2	1.1[b]	7.6	1.1[b]	7.7	1.3[b]	6.6	1.0[b]	7.0	1.0[b]	7.4	1.0[b]
	Treatment		6.1	1.0	7.4	1.3[b]	7.8	1.6[b]	7.9	1.9[b]	6.6	1.4[b]	7.2	1.6[b]	7.7	1.5[b]
Creatinine (µmol/L)	Control	97 to 177	97.2	26.5	106.1	17.7[b]	114.9	17.7[b]	114.9	17.7[b]	106.1	17.7[b]	114.9	17.7[b]	123.8	17.7[b]
	Treatment		97.2	17.7	106.1	26.5[b]	114.9	26.5[b]	114.9	26.5[b]	106.1	26.5[b]	114.9	26.5[b]	123.8	26.5[b]
Phosphorus (mmol/L)	Control	0.62 to 1.32	0.7	0.2	0.9	0.2[b]	1.0	0.2[b]	1.0	0.2[b]	1.2	0.1[b]	1.0	0.1[b]	1.0	0.1[b]
	Treatment		0.9	0.3	1.0	0.3[b]	1.0	0.3[b]	1.0	0.2[b]	1.1	0.2[b]	1.0	0.2[b]	0.9	0.2[b]
Calcium (mmol/L)	Control	2.8 to 3.4	2.5	0.2	2.7	0.4[b]	2.8	0.2[b]	2.8	0.3[b]	3.0	0.1[b]	3.1	0.2[b]	3.0	0.1[b]
	Treatment		2.6	0.3	2.7	0.4[b]	2.9	0.2[b]	2.8	0.3[b]	3.0	0.2[b]	3.1	0.2[b]	3.0	0.1[b]
Total protein (g/L)	Control	58.0 to 76.0	56.0	6.0	59.0	11.0[b]	64.0	5.0[b]	62.0	10.0[b]	67.0	5.0[b]	69.0	5.0[b]	69.0	4.0[b]
	Treatment		58.0	8.0	61.0	10.0[b]	67.0	6.0[b]	64.0	8.0[b]	68.0	4.0[b]	71.0	5.0[b]	70.0	4.0[b]
Albumin (g/L)	Control	2.7 to 3.7	25.5	3.1	27.0	5.7[b]	29.6	1.5[b]	28.9	4.5[b]	30.4	1.1[b]	31.5	1.8[b]	31.0	1.5[b]
	Treatment		27.2	3.7[d]	28.9	5.3[b,d]	31.7	2.6[b,d]	30.7	3.6[b,d]	31.5	2.5[b,d]	33.3	2.5[b,d]	32.5	2.1[b,d]
Globulin (g/L)	Control	26.0 to 46.0	32.0	5.0	32.0	6.0	34.0	7.0[b]	31.0	7.0[a]	38.0	5.0[b]	37.0	6.0[b]	38.0	5.0[b]
	Treatment		31.0	6.0	32.0	7.0	36.0	7.0[b]	35.0	6.0[a]	37.0	5.0[b]	38.0	6.0[b]	38.0	5.0[b]
Glucose (mmol/L)	Control	3.9 to 6.2	4.8	0.5	5.7	1.0[b]	5.8	0.7[b]	5.6	0.9[b]	5.1	0.7[b]	5.5	0.5[b]	5.2	0.3[b]
	Treatment		5.0	0.6	5.7	1.0[b]	5.8	0.7[b]	5.7	0.8[b]	5.3	0.9[b]	5.5	0.5[b]	5.0	0.5[b]
Sodium (mmol/L)	Control	133 to 145	125.0	7.7	126.4	10.7	132.5	3.6[b]	127.9	8.8[b]	134.1	2.3[b]	133.8	4.3[b]	135.2	3.3[b]
	Treatment		125.3	8.9	127.4	10.1	133.0	3.5[b]	129.5	4.4[b]	134.0	1.9[b]	135.0	5.3[b]	134.9	3.7[b]
Potassium (mmol/L)	Control	2.2 to 4.6	2.8	0.5	3.1	0.7[b]	3.0	0.7	3.2	0.5[b]	3.4	0.7[b]	3.2	0.7[b]	2.9	0.5[b]
	Treatment		3.0	0.5	3.4	0.4[b]	3.1	0.6	3.2	0.6[b]	3.3	0.6[b]	3.4	0.5[b]	3.1	0.7[b]
Chloride (mmol/L)	Control	100 to 111	92.2	4.9	91.3	7.9	95.9	2.5[b]	92.9	5.1	97.8	2.0[b]	97.6	3.1[b]	98.9	2.5[b]
	Treatment		92.7	6.6	92.0	7.1	95.7	3.2[b]	93.7	3.3	97.3	2.3[b]	98.2	4.6[b]	97.9	3.7[b]
Magnesium (mmol/L)	Control	0.53 to 1.03	0.7	0.1	0.7	0.0	0.7	0.1[b]	0.7	0.1[b]	0.7	0.0[b]	0.8	0.1[b]	0.8	0.0[b]
	Treatment		0.7	0.1	0.7	0.1	0.7	0.1[b]	0.7	0.0[b]	0.7	0.0[b]	0.8	0.1[b]	0.8	0.1[b]
Bicarbonate (mmol/L)	Control	24 to 34	24.8	2.6	23.9	2.3	24.8	1.8	24.1	3.1	23.5	1.6	23.3	1.1	22.7	1.1[c]
	Treatment		23.9	3.1	24.5	3.0	24.7	2.0	24.6	2.6	23.9	1.7	23.6	2.0	23.1	1.4[c]
Anion gap (mmol/L)	Control	5 to 15	10.3	2.6	14.2	2.4[b]	14.8	2.2[b]	14.4	2.8[b]	16.2	1.2[b]	16.1	1.0[b]	16.6	1.0[b]
	Treatment		11.7	2.7	14.3	2.3[b]	15.6	2.5[b]	14.5	2.1[b]	16.1	1.3[b]	16.5	1.8[b]	17.1	1.1[b]

SD — standard deviation, PCV — packed cell volume, BUN — blood urea nitrogen.
[a] Significantly higher ($P < 0.05$) compared with baseline values.
[b] Significantly higher ($P < 0.01$) compared with baseline values.
[c] Significantly lower ($P < 0.01$) compared with baseline values.
[d] Significantly higher ($P < 0.01$) than control group.

gap did not differ significantly between control and treatment groups on any day of the study. Albumin was significantly higher in the treatment group compared with the control group on study days 0 to 6 ($P < 0.01$).

Packed cell volume and plasma chemistry values (Table 4) on each day of the study were compared to baseline values. Packed cell volume was significantly higher for all horses in the study on days 1 ($P < 0.01$) and 2 ($P < 0.05$) and lower on study day 4 ($P < 0.01$). Blood urea nitrogen, creatinine, phosphorus, calcium, total protein, albumin, glucose, and anion gap were all significantly higher on days 1 to 6 ($P < 0.01$). Sodium and magnesium were significantly higher on days 2 to 6 ($P < 0.01$), and globulin was significantly higher on study day 3 ($P < 0.05$) as well as study days 2, 4, 5, and 6 ($P < 0.01$). Potassium was significantly higher for all horses on study days 1, 3, 4, and 5 ($P < 0.01$) and chloride was significantly higher on study days 2, 4, 5, and 6 ($P < 0.01$). Bicarbonate values were significantly lower on study day 6 ($P < 0.01$).

Odds of colic were significantly associated with increased phosphorus ($P < 0.05$). No other blood parameters were associated with occurrence of colic. The incidence of colic was significantly associated with treatment group. None of the control horses (0.0%) had an episode of colic, while 5 of the treated horses had an episode of colic (21.7%, $P = 0.05$). One of these horses had a total of 3 colic episodes throughout the week.

All initial colic episodes occurred a day after a rest day (3 on day 1; 2 on day 5) with 2 episodes in the late morning and 3 episodes in the early evening. All 5 horses with a colic episode were Quarter Horses (4 geldings and 1 mare) with an age range of 5 to 11 y (mean ± SD: 7.2 ± 2.5 y) and a distance hauled to base camp ranging between 16 and 965 km (mean ± SD: 396 ± 347 km).

Colic severity scores for initial colic episode ranged between slight and moderate (1 slight, 3 mild, 1 moderate) with heart rates from 32 to 60 beats/min (mean ± SD: 50.8 ± 11.5 beats/min), respiratory rates from 20 to 34 breaths/min (mean ± SD: 25.6 ± 6.2 breaths/min), temperatures from 37.2°C to 38.4°C, and capillary refill times of 2 s or less. No horses with colic had significant reflux and all responded to medical treatment within 1 h. All horses with colic were able to complete the study protocol after resolution of discomfort.

One horse that had a colic episode on day 1 had recurrent colic episodes on days 2 and 4 which were both graded as slight. This horse showed initial response to the treatment protocol on days 1 and 2. On day 4, the horse was again administered standard treatment as well as 2.28 g of oral omeprazole (Gastrogard; Merial, Duluth, Georgia, USA) and 4 g of sucralfate (Watson Pharma, Kansas City, Missouri, USA) orally. There was no recurrence of colic in this horse after secondary treatment.

Discussion

Baseline and day 1 plasma chemistry parameters were hemodilute with plasma total protein, calcium, sodium, and chloride values for both groups falling below normal reference values (Table 4). Acute exposure to high altitude or hypoxia in humans can decrease the secretion of aldosterone which may contribute to hyponatremia (30,31). Hyponatremia was also found in horses acutely exposed to 3800 m elevation (32), possibly due to altitude and cold exposure causing altitude-cold diuresis and renal excretion of sodium (32,33). Initial plasma chemistry parameters did not indicate dehydration so it is likely that the administration of electrolytes to enhance the thirst drive was not necessary at the initiation of the study.

Packed cell volume and all plasma chemistry parameters except bicarbonate increased throughout the week compared with baseline values (Table 4). The increase in PCV, total protein, and albumin indicated hemoconcentration which was likely a result of insufficient access to water. Plasma volume and plasma osmolality were not measured directly; however, increasing PCV and plasma chemistry parameters indicated a reduction of plasma volume and increased plasma osmolality which could have been due to dehydration. Horses enduring high intensity exercise over long distances usually have decreases in plasma sodium, potassium, chloride, and calcium levels most likely due to electrolyte losses in sweat (2,5,14), while horses participating in competition at lower speeds or for much shorter durations generally display increases in plasma electrolytes due to dehydration or decreases in glomerular filtration rate (8,34). Participants in the present study only covered approximately 32 km a day at a walk or trot so sweat losses were likely minimal in comparison to the substantial electrolyte losses in horses participating in competitive long distance races in which electrolyte supplementation is deemed necessary (2,5,6,14). In the present study, the moderate intensity of exercise was likely not sufficient to induce electrolyte depletion via sweat. Differences in supplemented electrolyte parameters between groups were likely not appreciated due to the body's ability to maintain blood analytes via renal excretion even in the face of supplementation.

To ensure that the treatment group received adequate quantities of electrolytes, horses that did not eat at least half of their grain at every meal in the study were excluded. Although every horse in the treatment group received electrolytes, the exact amount of electrolytes consumed by each horse was not quantified. Regardless of the exact amount of electrolytes consumed, we expected the plasma levels of the supplemented electrolytes to be lower in the control group. Studies in humans have demonstrated that moderate intensity exercise results in decreased absorption of water, sodium, chloride, and potassium during exercise (35). Exposure to moderate intensity exercise in the treated horses may have resulted in impaired absorption of the supplemented electrolytes.

Supplementing a bolus of powder electrolytes without continual access to water may have dramatically increased the osmolality of the gastric contents and decreased the rate of gastric emptying in the treated horses. Studies in calves have shown that hypertonic fluids delay abomasal emptying time (36,37). In humans, increased hypertonicity of gastric contents has been reported to delay gastric emptying; however, increased carbohydrate concentrations are thought to be primarily responsible (38). One study in horses concluded that the nasogastric administration of hypertonic fluids did not cause a decrease in gastric emptying compared with an isotonic solution (39); however, large variation in data points suggested measurement error in this study (39). Furthermore, indwelling nasogastric tubes,

which were used to measure gastric emptying, have recently been demonstrated to delay gastric emptying in horses (40) making the results unreliable. It is likely that there was no difference in plasma electrolyte values between the treatment and control groups due to renal excretion, insufficient supplementation, decreased intestinal absorption of electrolytes associated with exercise, decreased gastric emptying, or the synergistic effects of these mechanisms.

Albumin concentration was significantly higher in the treatment group compared with the control group on every day of the ride including baseline samples. Elevations in albumin can be associated with dehydration; however, no other parameters were elevated. When using a *P*-value of ≤ 0.05, it is expected that 5% of findings are due to chance alone. A total of 16 biochemical and outcome parameters were analyzed so a single significant difference in treatment groups could be expected by chance alone. It is possible that the elevated albumin level seen in the treatment group could be due to chance. The same could be said for the incidence of colic in which an even more marginal *P*-value of 0.05 was achieved.

The incidence of colic differed significantly between the control and treatment groups with none of the horses in the control group having a colic episode compared to 5 (21.7%) in the treatment group. Environmental conditions, duration and intensity of exercise, access to feed and water, type of feed, and housing conditions were all controlled between groups. Other factors such as age, gender, breed, distance travelled to camp, and residence factors, were equally distributed between groups. The treatment group was ridden significantly more kilometers per month prior to the ride (Table 1) indicating better conditioning. Therefore, the difference in the incidence of colic was not due to demographic variables or lack of conditioning, but likely a result of electrolyte administration to the treatment group.

Symptoms of gastrointestinal discomfort are common in human endurance athletes with upwards of 50% of marathon runners being affected (23). In human athletes, the consumption of high osmolality sports beverages can cause an increased incidence (25) and severity (26) of gastrointestinal symptoms during exercise. Increasing osmolality may delay gastric emptying and be responsible for the complaints of abdominal discomfort in humans (26). To our knowledge, electrolyte administration has not been associated with abdominal discomfort in horses.

Transportation, exercise, changes in feeding patterns, and diet can cause gastric ulcers in horses (41–43) and are risk factors for all horses in this study. Furthermore, Holbrook et al (44) demonstrated that repeated administration of hypertonic electrolyte solutions via a dosing syringe can increase the number and severity of gastric ulcers in the nonglandular portion of the stomach in horses. The authors found that gastric ulceration was not associated with signs of colic (44); however, the horses were not exercised so acidic gastric contents were less likely to irritate the sites of ulceration in the nonglandular portion of the stomach.

All 5 horses suffering from colic initially responded to the medical treatment protocol; however, 1 horse that had an initial episode of colic on day 1, had 2 more episodes on days 2 and 4. Treatment for gastric ulceration was initiated on day 4 and he displayed no further signs of colic suggesting that gastric ulceration may have been the cause of the colic episodes in this horse. All colic episodes in this study were graded as slight to moderate and responded to medical treatment. Given the deleterious effects associated with repeated doses of electrolyte solutions on gastric mucosa (44), the high incidence of gastric ulceration in horses with abdominal pain (45), and because recurrent colic in 1 horse was resolved with gastric ulcer treatment, it is possible that some of the colic episodes in our study were due to gastric ulceration. The study design did not permit measurement of gastric emptying or gastroscopy so we can only speculate that decreases in gastric emptying or gastric ulceration were the cause of colic episodes.

On the initial day of colic episode, phosphorus in horses that had colic was elevated compared with horses that did not have colic on the same day. To our knowledge, this study is the first to report phosphorus elevations in horses with colic that responded to medical therapy. Significant elevations of serum phosphorus in horses with severe intestinal disease requiring resection or euthanasia have been observed (46).

Largely due to the field nature of this study, several flaws in study design require the results to be considered with caution. Most notably, horses were put into treatment groups alternately upon arrival at camp rather than randomly selected. No placebo was administered to the control group as we did not want to introduce unknown physiologic sequelae and the exclusion criteria were based on subjective measures. In order to validate an association with electrolyte administration in the presence of water restriction with signs of colic, a controlled laboratory study should be performed in a placebo-controlled randomized trial in which electrolyte consumption and excretion could be accurately measured. Furthermore, the results of the study should not be extrapolated to highly acclimatized and conditioned competition horses which are accustomed to endurance exercise.

Electrolytes are commonly administered to competition horses (10) and have been generally considered safe. The oral powder electrolyte supplement used in this study did not improve hydration status or electrolyte homeostasis, and was associated with an increased incidence of colic which was most likely due to insufficient water availability. Oral powder electrolytes should be used with caution in horses when water is not freely available, such as on long distance trail rides or prior to hauling. Further controlled laboratory research needs to be performed to evaluate if oral powder electrolyte supplementation alters gastric emptying and intestinal absorption which could result in gastric ulceration or colic in the exercising horse.

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