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Electrolyte and Plasma Changes After Ingestion of Pickle Juice, Water, and a Common Carbohydrate-Electrolyte Solution

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Context: Health care professionals advocate that athletes who are susceptible to exercise-associated muscle cramps (EAMCs) should moderately increase their fluid and electrolyte intake by drinking sport drinks. Some clinicians have also claimed drinking small volumes of pickle juice effectively relieves acute EAMCs, often alleviating them within 35 seconds. Others fear ingesting pickle juice will enhance dehydration-induced hypertonicity, thereby prolonging dehydration.

Objective: To determine if ingesting small quantities of pickle juice, a carbohydrate-electrolyte (CHO-e) drink, or water increases plasma electrolytes or other selected plasma variables.

Design: Crossover study.

Setting: Exercise physiology laboratory.

Patients or Other Participants: Nine euhydrated, healthy men (age = 25 ± 2 years, height = 179.4 ± 7.2 cm, mass = 86.3 ± 15.9 kg) completed the study.

Intervention(s): Resting blood samples were collected preingestion (−0.5 minutes); immediately postingestion (0 minutes); and at 1, 5, 10, 15, 20, 25, 30, 45, and 60 minutes postingestion of 1 mL/kg body mass of pickle juice, CHO-e drink, or tap water.

Main Outcome Measure(s): Plasma sodium concentration, plasma magnesium concentration, plasma calcium concentration, plasma potassium concentration, plasma osmolality, and changes in plasma volume were analyzed. Urine specific gravity, osmolality, and volume were also measured to characterize hydration status.

Results: Mean fluid intake was 86.3 ± 16.7 mL. Plasma sodium concentration, plasma magnesium concentration, plasma calcium concentration, plasma osmolality, and plasma volume did not change during the 60 minutes after ingestion of each fluid ($P \geq .05$). Water ingestion slightly decreased plasma potassium concentration at 60 minutes (0.21 ± 0.14 mg/dL [0.21 ± 0.14 mmol/L]; $P \leq .05$).

Conclusions: At these volumes, ingestion of pickle juice and CHO-e drink did not cause substantial changes in plasma electrolyte concentrations, plasma osmolality, or plasma volume in rested, euhydrated men. Concern that ingesting these volumes of pickle juice might exacerbate an athlete's risk of dehydration-induced hypertonicity may be unwarranted. If EAMCs are caused by large electrolyte loss due to sweating, these volumes of pickle juice or CHO-e drink are unlikely to restore any deficit incurred by exercise.

Key Words: acetic acid, hydration, osmolality, sport drinks

Key Points

- Ingesting small volumes of pickle juice or carbohydrate-electrolyte drink produced no changes in plasma electrolyte concentrations, osmolality, or volume up to 60 minutes postingestion in rested, euhydrated men without exercise-associated muscle cramps.
- Plasma electrolyte concentrations did not change within 1 minute of pickle juice or carbohydrate-electrolyte drink ingestion.
- Ingesting small volumes of pickle juice or carbohydrate-electrolyte drink may not result in plasma hyperosmolality or hypervolemia and may not alleviate exercise-associated muscle cramps by restoring electrolytes or expanding plasma and/or interstitial volume.

Athletes commonly develop exercise-associated muscle cramps (EAMCs),[1–3] and researchers[4–6] think that fluid and electrolyte disturbances often are the cause. This theory is based on the observation that many athletes who develop EAMCs during exercise have large fluid and electrolyte losses at the time of cramping.[5] Although the exact cause of EAMCs remains unknown, health care professionals advocate that athletes prone to cramping ingest fluids and add modest amounts of sodium (0.3–0.7 g/L) to their drinks.[4] Some authors[7] have recommended adding different quantities of salt to sport drinks (≈3–6 g/L) based on the frequency of muscle cramping during activity. Sport drinks are commonly recommended[4,8] because they contain both electrolytes and fluid.

Approximately 25% (92 of 370) of certified athletic trainers advocate drinking pickle juice, which is an acidic brine, to treat and prevent EAMCs.[9] Some clinicians have claimed that drinking 30 mL to 60 mL of pickle juice relieves an EAMC within 30 to 35 seconds after ingestion[10]; the relief was credited to plasma electrolyte restoration.[11] Experimental evidence to support these assertions is lacking.

Other health care professionals discourage athletes from ingesting pickle juice. They fear that the high salt and low fluid content will contribute to dehydration-induced hypertonicity, thereby prolonging dehydration and increasing the risk of hyperthermia and poor performance.[12–14] Scientific evidence supporting these assertions is also lacking.

Based on the volume of pickle juice ingested and its electrolyte content, calculated differences in plasma sodium have indicated that negligible changes in plasma electrolytes should occur (<1.5 mEq/L [<1.5 mmol/L]). Moreover, acidic and hyperosmotic solutions, such as pickle juice, should delay gastric emptying and, thus, water and electrolyte absorption if ingested without concurrent ingestion of hypotonic fluids.[15] The rapidity with which pickle juice is claimed to relieve an EAMC made us question whether electrolytes could be absorbed after pickle juice ingestion in the timeframe described to alleviate an EAMC (ie, 30–35 seconds).[10] Moreover, we wondered how 2 other commonly recommended fluids for the prevention and treatment of EAMCs (a carbohydrate-electrolyte [CHO-e] drink and water) would affect selected plasma variables.

Several athletic trainers believe traditional therapies, such as fluid and electrolyte replacement, do not effectively treat EAMCs.[6] This belief may have led some clinicians to experiment with treatments (eg, ingesting pickle juice) that are anecdotally purported to relieve EAMCs but that have little or no supporting scientific data.[9] If ingesting pickle juice relieves EAMCs within the time frame described,[10] investigators should elucidate optimal treatment guidelines. However, if drinking it is dangerous, as some health care professionals claim,[12–14] those who use it to treat and prevent EAMCs should stop.

Therefore, the purpose of our study was to determine if ingesting small volumes of pickle juice, CHO-e drink, or water (1) would cause increases in plasma sodium concentration, plasma potassium concentration, plasma magnesium concentration, plasma calcium concentration, plasma osmolality, or plasma volume and (2) would elicit these changes in less than 1 minute. We hypothesized that ingesting small volumes of these fluids would have no effect on plasma electrolytes, plasma osmolality, or plasma volume.

METHODS

Design

We used a 3 × 11 factorial design with repeated measures on time. Fluid treatments were counterbalanced and order was randomized using a balanced Latin square. The independent variables were fluid (pickle juice [whole dill pickles, Vlasic Pickles; Pinnacle Foods Group LLC, Cherry Hill, NJ], CHO-e drink [The Gatorade Co, Chicago, IL], tap water) and time (preingestion [−0.5 minutes]; immediately postingestion [0 minutes]; and 1, 5, 10, 15, 20, 25, 30, 45, and 60 minutes postingestion of fluid). Our dependent variables were plasma sodium concentration, plasma potassium concentration, plasma magnesium concentration, plasma calcium concentration, plasma osmolality, and changes in plasma volume. Urine specific gravity, volume, and osmolality were measured to characterize hydration status and the effects of each fluid on hydration status. Osmolar clearance and free water clearance were also calculated to determine solute and water loss or retention preingestion and 60 minutes postingestion of fluid.

Participants

Nine healthy men (age = 25 ± 2 years, height = 179.4 ± 7.2 cm, mass = 86.3 ± 15.9 kg) completed this study. Individuals were excluded if they were female; had experienced an upper extremity injury within the 12 months before the study; or self-reported a neurologic, cardiovascular, neuromuscular, or blood-borne disease. The study was approved by our university's institutional review board, and participants provided written informed consent.

Procedures

Before experimentation, participants were instructed to maintain their current diets, to refrain from eating for 10 hours before testing, and to avoid strenuous exercise for 48 hours before testing. Participants were reminded to drink water continually throughout the day before data collection and were allowed to drink only water during the 10-hour fast. A diet log for each participant was not kept, but participants were asked if they had complied with instructions before testing each day.

On testing days, participants reported to an exercise physiology laboratory, emptied their bladders, and were weighed in shorts and T-shirts with an electronic bench scale (Champ; Ohaus, Pine Brook, NJ) calibrated to the nearest 10th of a kilogram. Participants were seated in a semirecumbent position and were given 15 minutes to drink 6 mL/kg body mass of tap water to hydrate them. After this 15-minute period, participants remained seated for an additional 60 minutes. After this 60-minute period, the first urine sample was collected, and body mass was measured. Urine volume, osmolality, and specific gravity were measured to determine hydration status.

Participants were reseated and rested for 30 minutes. They remained seated from this point to the conclusion of the experiment. During the 30-minute rest period, a sterile, single-use, 20-gauge venous catheter (BD, Franklin Lakes, NJ) was inserted into a superficial vein in each participant's arm. The catheter was attached to a 3-way stopcock (Covidien, Mansfield, MA) via small extension tubing. At the end of this 30-minute period, a 5.0-mL blood sample was collected and served as the baseline measurement. One milliliter of blood from this sample was used to analyze hematocrit and hemoglobin (0.5 mL for each); the remaining 4 mL of blood was sealed and stored in a 6.0-mL lithium heparin Vacutainer (BD) and placed into an ice bath until the last blood sample was collected. After this and subsequent blood samples, the catheter and extension tubing were flushed with approximately 0.5 mL of 0.9% sterile saline (Hospira Inc, Lake Forest, IL). Before subsequent samples, 1 mL to 1.5 mL of blood was withdrawn and discarded as waste to ensure the samples were not contaminated with saline. Blood samples required approximately 10 seconds to collect.

After the baseline blood sample (time, −0.5 minutes), participants were given 30 seconds to ingest 1 mL/kg body

Table 1. Composition of Pickle Juice, Carbohydrate-Electrolyte Drink, and Water (Mean ± SD)

	Fluid		
	Pickle Juice[a]	Carbohydrate-Electrolyte Drink[b,c]	Water
Osmolality, mOsmol/kg H_2O	778.0 ± 0	362 ± 0	4.0 ± 0
Sodium concentration, mEq/L (mmol/L)	415.2 ± 0.28 (415.2 ± 0.28)	18.0 (18.0)	16.1 ± 0.07 (16.1 ± 0.07)
Potassium concentration, mEq/L (mmol/L)	26.6 ± 0.28 (26.6 ± 0.28)	3.0 (3.0)	Not detectable
Calcium concentration, mg/dL (mmol/L)	47.6 ± 0.12 (11.9 ± 0.03)	0	1.96 ± 0.004 (0.49 ± 0.001)
Magnesium concentration, mEq/L (mmol/L)	16.8 ± 0.06 (8.4 ± 0.03)	0	0.50 ± 0.002 (0.25 ± 0.001)

[a] For all dependent variables, pickle juice was greater than carbohydrate-electrolyte drink and water ($P \leq .05$).
[b] For all dependent variables, carbohydrate-electrolyte drink was greater than water ($P \leq .05$).
[c] All analyses of carbohydrate-electrolyte drink, except for osmolality, were calculated from the nutrition label because of an unknown ingredient causing errors during electrolyte analysis.

mass of 1 of the 3 fluids. Fluid temperature was approximately 1°C. Immediately after the 30-second ingestion period (time, 0 minutes), a 5-mL blood sample was collected. Blood samples were then collected at 1, 5, 10, 15, 20, 25, 30, 45, and 60 minutes postingestion of the fluid. At the end of the 60-minute collection period, the catheter was removed, a second urine sample was collected, and body mass was measured. The same procedures were performed for subsequent testing sessions. Testing sessions were separated by at least 72 hours and occurred at approximately the same time of day.

Blood and Urine Analyses

Blood for hematocrit analysis was drawn into heparinized microcapillary tubes, was centrifuged at 3000 rpm (model IEC Micro-MB; International Equipment Co, Needham Heights, MA) for 5 minutes, and was read using a microcapillary reader (model IEC 2201; Damon/IEC, Needham Heights, MA). Hemoglobin was measured by mixing 20 μL whole blood with 5 mL cyanmethemoglobin reagent and by reading the absorbance at 540 nm on a standard spectrophotometer (Junior II; Coleman Instruments, Glen Mills, PA). Hematocrit and hemoglobin were measured in triplicate immediately after sampling and were averaged for each blood sample for statistical analyses and calculations.

After collection of the last blood sample, all blood samples were centrifuged at 3000 rpm for 15 minutes at 3°C (model 5403; Eppendorf North America, Westbury, NY). Plasma was removed from the packed red blood cells, and plasma electrolytes were analyzed using an ion-selective electrode system (model 8 electrolyte analyzer; Nova Biomedical, Waltham, MA). Plasma osmolality was determined using freezing-point depression osmometry (model 3D3; Advanced Instruments Inc, Norwood, MA). Plasma electrolyte concentrations and osmolality were measured in duplicate and averaged for statistical analyses. A plasma osmolality less than or equal to 290 mOsmol/kg H_2O was considered euhydrated.[16]

Urine specific gravity was measured using a handheld refractometer (SUR-Ne; ATAGO USA Inc, Bellevue, WA). Urine volume was measured using appropriately sized graduated cylinders. Urine osmolality was measured using freezing-point depression osmometry. A urine specific gravity less than or equal to 1.02, urine osmolality less than or equal to 700 mOsmol/kg H_2O,[16] and urine volume of approximately 100 mL/h were also used as indicators of euhydration.[17]

Calculations

Hematocrit and hemoglobin measurements were used to calculate change in plasma volume with the Dill and Costill equation.[18] Urine flow rates were also calculated and used to estimate osmolar clearance (C_{osm}) and free water clearance (C_{H_2O}):

$$C_{osm} = (\dot{U} \times OSM_u)/(OSM_p)$$

$$C_{H_2O} = (\dot{U} - C_{osm}),$$

where $\dot{U}$ is the urine flow rate (mL/h), OSM_u is urine osmolality, and OSM_p is plasma osmolality (mOsmol/kg H_2O).

Statistical Analysis

The means (±SDs) of plasma electrolyte concentrations, osmolality, and volume were calculated and used for analysis. A 2-way, repeated-measures analysis of variance (fluid × time) was used to assess differences among fluids over time (version 2001; NCSS, Kaysville, UT). When we found an interaction of fluid and time, we used a Tukey-Kramer post hoc multiple-comparisons test to identify differences among fluids at each time point. If we did not find a fluid × time interaction but found an effect for time, we reexamined each fluid trial separately using a 1-way analysis of variance with repeated measures on time and used the Tukey-Kramer post hoc multiple-comparisons test to identify which time points were different from baseline. The α level was set a priori at .05.

RESULTS

Descriptive statistics of each solution's composition are shown in Table 1. Participants ingested 86.1 ± 16.9 mL of pickle juice, 86.5 ± 16.7 mL of CHO-e drink, and 86.4 ± 16.6 mL of tap water. Participants ingested, on average, 35.7 mmol, 1.6 mmol, and 1.4 mmol sodium with pickle juice, CHO-e drink, and water, respectively.

No plasma ($P \geq .07$) or urine variables ($P \geq .51$) were different among fluids before fluid ingestion, and the values indicated that participants were euhydrated before ingesting each fluid (Tables 2 and 3). Plasma electrolyte concentrations and osmolality during the first 5 minutes of testing are highlighted in Table 2, with the entire duration of testing represented in Figures 1 and 2.

Table 2. **Plasma Variables Preingestion (−0.5 Minutes), Immediately Postingestion (0 Minutes), 1 Minute Postingestion, and 5 Minutes Postingestion of Fluid (Mean ± SD)**

Plasma Variable	Time, min	Fluid: Pickle Juice	Carbohydrate-Electrolyte Drink	Water
Volume, % change from baseline	−0.5	No measurement	No measurement	No measurement
	0	0.71 ± 4.03	1.0 ± 2.58	0.01 ± 1.33
	1	−0.39 ± 2.43	1.6 ± 3.69	0.35 ± 2.25
	5	1.3 ± 2.63	2.4 ± 3.99	0.77 ± 1.81
Osmolality, mOsmol/kg H_2O	−0.5	284 ± 4	283 ± 3	285 ± 5
	0	283 ± 4	284 ± 4	285 ± 6
	1	284 ± 4	284 ± 3	284 ± 6
	5	283 ± 4	284 ± 3	286 ± 5
Sodium concentration, mEq/L (mmol/L)	−0.5	141 ± 1 (141 ± 1)	141 ± 1 (141 ± 1)	141 ± 1 (141 ± 1)
	0	141 ± 1 (141 ± 1)	141 ± 1 (141 ± 1)	141 ± 1 (141 ± 1)
	1	141 ± 1 (141 ± 1)	140 ± 1 (140 ± 1)	141 ± 2 (141 ± 2)
	5	141 ± 1 (141 ± 1)	140 ± 1 (140 ± 1)	140 ± 1 (140 ± 1)
Potassium concentration, mEq/L (mmol/L)	−0.5	4.4 ± 0.5 (4.4 ± 0.5)	4.4 ± 0.3 (4.4 ± 0.3)	4.4 ± 0.3 (4.4 ± 0.3)
	0	4.4 ± 0.5 (4.4 ± 0.5)	4.4 ± 0.3 (4.4 ± 0.3)	4.4 ± 0.4 (4.4 ± 0.4)
	1	4.5 ± 0.4 (4.5 ± 0.4)	4.4 ± 0.2 (4.4 ± 0.2)	4.3 ± 0.4 (4.3 ± 0.4)
	5	4.4 ± 0.4 (4.4 ± 0.4)	4.4 ± 0.3 (4.4 ± 0.3)	4.3 ± 0.3 (4.3 ± 0.3)
Calcium concentration, mEq/L (mmol/L)	−0.5	4.4 ± 0.16 (1.10 ± 0.04)	4.56 ± 0.12 (1.14 ± 0.03)	4.36 ± 0.28 (1.09 ± 0.07)
	0	4.4 ± 0.12 (1.10 ± 0.03)	4.52 ± 0.12 (1.13 ± 0.03)	4.36 ± 0.28 (1.09 ± 0.07)
	1	4.4 ± 0.24 (1.10 ± 0.06)	4.52 ± 0.08 (1.13 ± 0.02)	4.40 ± 0.32 (1.10 ± 0.08)
	5	4.4 ± 0.24 (1.10 ± 0.06)	4.52 ± 0.08 (1.13 ± 0.02)	4.40 ± 0.32 (1.10 ± 0.08)
Magnesium concentration, mEq/L (mmol/L)	−0.5	0.92 ± 0.08 (0.46 ± 0.04)	0.98 ± 0.06 (0.49 ± 0.03)	0.94 ± 0.06 (0.47 ± 0.03)
	0	0.92 ± 0.08 (0.46 ± 0.04)	0.96 ± 0.06 (0.48 ± 0.03)	0.94 ± 0.08 (0.47 ± 0.04)
	1	0.92 ± 0.10 (0.46 ± 0.05)	0.96 ± 0.08 (0.48 ± 0.04)	0.94 ± 0.08 (0.47 ± 0.04)
	5	0.92 ± 0.10 (0.46 ± 0.05)	0.96 ± 0.06 (0.48 ± 0.03)	0.92 ± 0.08 (0.46 ± 0.04)

Plasma Volume

Changes in plasma volume after ingestion of each fluid are shown in Figure 1 and Table 2. Plasma volume did not differ over time among pickle juice, CHO-e drink, and water ($F_{20,160} = 0.54$, $P = .95$).

Plasma Osmolality and Sodium Concentration

Plasma osmolality did not differ over time among fluids ($F_{20,160} = 0.72$, $P = .80$) (Figure 1). Despite ingesting 35.7 mmol sodium with pickle juice, average plasma osmolality never exceeded 284.1 mOsmol/kg H_2O for the duration of testing.

Plasma sodium concentration differed over time among pickle juice, CHO-e drink, and water ingestion ($F_{20,160} = 1.84$, $P = .02$). Plasma sodium concentration was higher after pickle juice ingestion than after water ingestion at 15 and 25 minutes postingestion and was also higher than after CHO-e drink ingestion at 25 and 30 minutes ($P \leq .05$) (Figure 2). Compared with baseline, none of the drinks

Table 3. **Urine Variables Preingestion (−0.5 Minutes) and 60 Minutes Postingestion of Fluid (Mean ± SD)**

Variable	Fluid: Pickle Juice	Carbohydrate-Electrolyte Drink	Water
Osmolality, mOsmol/kg H_2O			
Preingestion	237.8 ± 150.4	279.8 ± 297.7	180.7 ± 68.9
60 min postingestion	507.7 ± 189.2[a]	368.8 ± 198.8	381.0 ± 189.9[a]
Specific gravity			
Preingestion	1.006 ± .003	1.008 ± .01	1.005 ± .002
60 min postingestion	1.012 ± .03[a]	1.009 ± .01	1.009 ± .005[a]
Volume, mL			
Preingestion	395.3 ± 216.4	471.8 ± 245.8	428.3 ± 153.7
60 min postingestion	165.6 ± 82.9[a,b]	283.9 ± 164.5	215.2 ± 101.0[a]
Osmolar clearance, mL/h			
Preingestion	204 ± 72	220 ± 70	202 ± 67
60 min postingestion	146 ± 51	158 ± 37[a]	140 ± 40[a]
Free water clearance, mL/h			
Preingestion	112 ± 189	157 ± 220	141 ± 126
60 min postingestion	−52 ± 35[a,c]	4 ± 68	−17 ± 47[a,c]

[a] Different from preingestion ($P \leq .05$).
[b] Pickle juice different from carbohydrate-electrolyte drink ($P \leq .05$).
[c] Negative values indicate fluid retention.

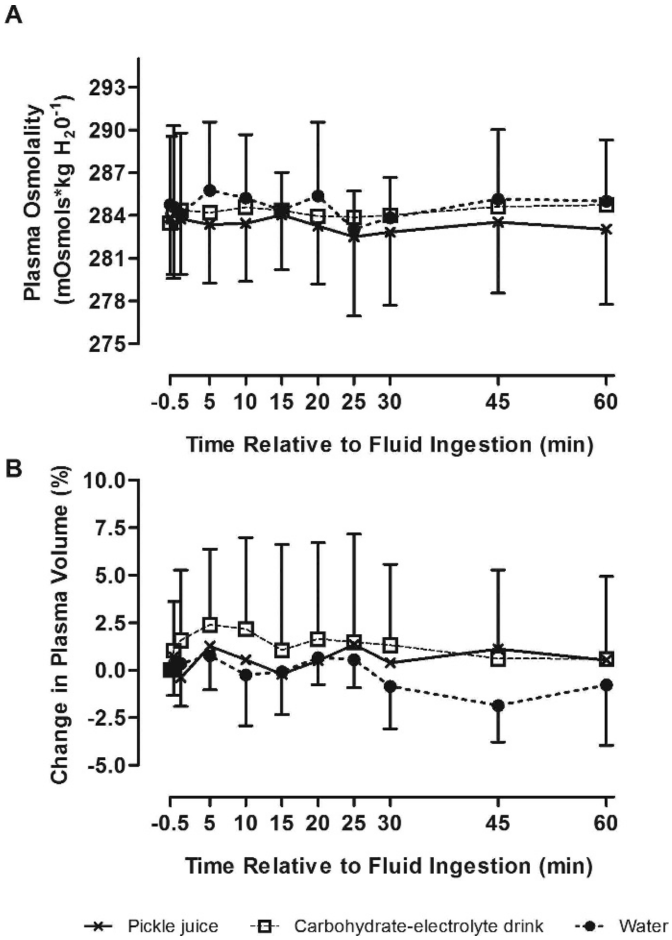

Figure 1. A, Plasma osmolality and B, percent change in plasma volume 60 minutes after ingestion of pickle juice, carbohydrate-electrolyte drink, and water. Error bars denote SDs.

altered plasma sodium concentration over the 60-minute postingestion period ($P \geq .05$).

Plasma Potassium, Magnesium, and Calcium Concentrations

Plasma potassium, magnesium, and calcium concentrations over time are shown in Figure 2. Plasma potassium concentration was different over time among fluids ($F_{20,160} = 1.78$, $P = .03$). It was higher after pickle juice ingestion than after water ingestion at 15, 30, and 60 minutes postingestion. The CHO-e drink ingestion elicited a higher plasma potassium concentration than water elicited at 45 and 60 minutes postingestion. Pickle juice and CHO-e drink ingestion had no effect on plasma potassium concentration over 60 minutes ($P \geq .05$). Water ingestion decreased plasma potassium concentration at 60 minutes compared with baseline ($P \leq .05$). Plasma magnesium ($F_{20,160} = 0.91$, $P = .58$) and calcium ($F_{20,160} = 1.02$, $P = .44$) concentrations were not measurably influenced by fluid ingestion.

Urine Analyses

Descriptive statistics for urine osmolality, specific gravity, volume, osmolar clearance, and free water clearance at preingestion and 60 minutes postingestion of fluid are shown in Table 3. Urine volume ($F_{2,16} = 0.47$, $P = .63$), osmolality ($F_{2,16} = 3.05$, $P = .08$), specific gravity ($F_{2,16} = 2.77$, $P = .09$), and osmolar clearance ($F_{2,16} = 0.01$, $P = .98$) were not different over time among fluids. However, a trend was observed for differences in free water clearance among fluids at 60 minutes ($P \approx .08$).

Time effects were observed for all urine variables ($P \leq .02$). Urine osmolality,[a] specific gravity,[b] volume,[c] and free water clearance[d] at 60 minutes postingestion of pickle juice and water were different from these urine variables at preingestion. Urine osmolality ($F_{1,16} = 0.56$, $P = .47$), specific gravity ($F_{1,16} = 0.07$, $P = .79$), volume ($F_{1,16} = 3.63$, $P = .07$), and free water clearance ($F_{1,16} = 3.9$, $P = .06$) did not differ at 60 minutes postingestion of the CHO-e drink. All urine variables indicated participants were euhydrated at 60 minutes postingestion of all fluids.

DISCUSSION

Our main observation was that pickle juice and CHO-e drink ingestion (1 mL/kg body mass) produced no changes in plasma electrolytes or plasma volume in rested, euhydrated men. Furthermore, urinary excretion of osmoles (eg, electrolytes) and water in response to pickle juice ingestion was unremarkable. Unexpectedly, urinary osmolar excretion was greater after CHO-e ingestion than after pickle juice ingestion; however, the finding was not significant. Our calculations based on the volume ingested and the amount of sodium in pickle juice indicated that these quantities of pickle juice should increase extracellular sodium by no more than 1.5 mmol/L, assuming that all of the sodium ingested was absorbed and located in the extracellular space. Our observed data closely match our predicted values. Variations in plasma sodium concentration and changes in plasma volume after pickle juice ingestion were within 1 mmol/L and 1.4%, respectively.

These changes in plasma sodium concentration and plasma volume likely have an inconsequential clinical effect on EAMCs. Individuals with EAMCs have been observed to have body weight losses ranging from 3% to 3.5%,[3,19,20] plasma volume losses up to 5.2%,[21] and sodium losses up to 87 mmol/h.[5] Thus, our data do not support the hypothesis that ingesting small volumes of pickle juice or CHO-e drink results in plasma hyperosmolality or hypervolemia,[12–14] and our data cast doubt on the theory that either drink would alleviate an EAMC by restoring electrolytes or expanding plasma or interstitial volume (or both).[11]

The second important observation in this study was that plasma electrolytes did not change within 1 minute of pickle juice or CHO-e drink ingestion. As noted, ingestion of 30 mL to 60 mL of pickle juice has been anecdotally reported[10] to relieve EAMCs in 30 to 35 seconds. We observed that no changes in plasma sodium concentration occurred within this time frame. Sims et al[22] also observed that ingesting larger volumes of a high-sodium solution (164 mmol/L sodium) did not change plasma sodium concentration over 60 minutes in resting participants.

[a] Pickle juice: $F_{1,16} = 11.2$, $P = .004$; water: $F_{1,16} = 8.8$, $P = .009$.
[b] Pickle juice: $F_{1,16} = 10.4$, $P = .005$; water: $F_{1,16} = 7.3$, $P = .02$.
[c] Pickle juice: $F_{1,16} = 8.9$, $P = .009$; water: $F_{1,16} = 12.1$, $P = .003$.
[d] Pickle juice: $F_{1,16} = 6.5$, $P = .02$; water: $F_{1,16} = 12.5$, $P = .002$.

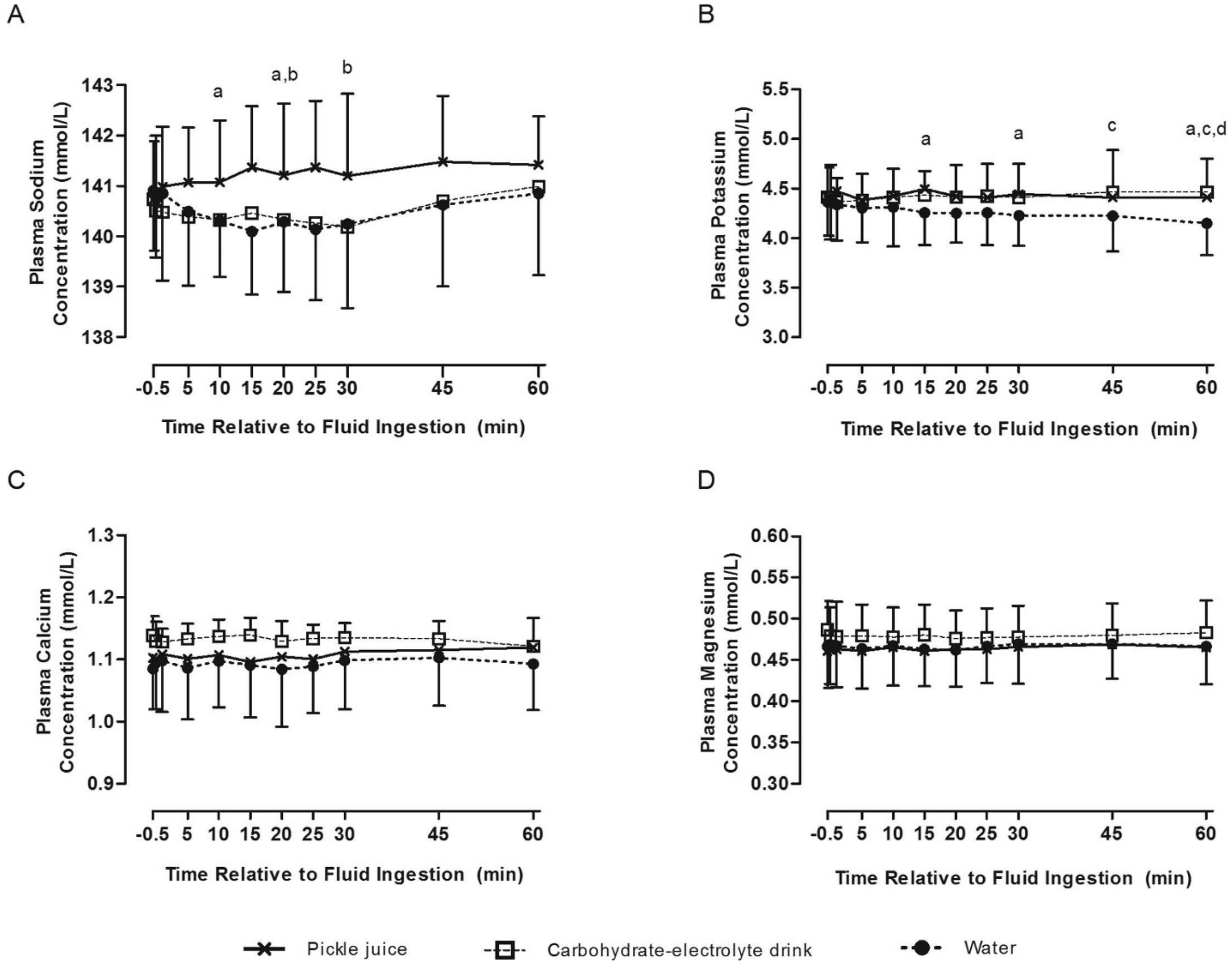

Figure 2. Mean plasma electrolyte concentrations 60 minutes postingestion of pickle juice, carbohydrate-electrolyte drink, and water. A, Plasma sodium concentration. To convert mmol/L to mEq/L, divide the given value by 1. B, Plasma potassium concentration. To convert mmol/L to mEq/L, divide the given value by 1. C, Plasma calcium concentration. To convert mmol/L to mEq/L, divide the given value by 0.25. D, Plasma magnesium concentration. To convert mmol/L to mEq/L, divide the given value by 0.50. [a] Pickle juice different from water. [b] Pickle juice different from carbohydrate-electrolyte drink. [c] Carbohydrate-electrolyte drink different from water. [d] Water different from baseline measurement. The α level was set at $<.05$. Error bars denote SDs.

Based on our data, it is unlikely that pickle juice relieves an EAMC by restoring plasma sodium concentration for 2 reasons. First, these volumes of pickle juice cause negligible increases in sodium that would not replace the large potential losses in sodium due to exercise.[5] Second, acetic acid (a primary ingredient in pickle juice) delays gastric emptying[23]; thus, it is unlikely that the nutrients in pickle juice could be absorbed within 1 minute and made available to a cramping muscle. Ingesting greater quantities of pickle juice has the potential to increase plasma sodium concentration[14]; however, the effect of such a practice is unknown.

Because no changes occurred in plasma constituents after pickle juice ingestion, it is tempting to speculate as to what may cause the alleviation of EAMCs. If pickle juice does relieve EAMCs within the time frame described by others,[10] perhaps an oral reflex or osmoreceptor in the esophagus or gut triggers a central nervous system response, causing the cramp to cease. However, scientific support for such a hypothesis is lacking; therefore, if pickle juice ingestion does relieve EAMCs, future research may be required to determine its effect on oral reflexes.

Neurologic fatigue and hyperexcitability[24] and imbalances in electrolytes, such as potassium, magnesium, and calcium, have also been postulated[25] to be associated with EAMCs. If given as part of the diet for long durations, acetic acid increases calcium absorption in rat intestines.[26] Theoretically, increasing extracellular calcium or potassium would decrease neuronal excitability[25] and possibly prevent EAMCs. Despite the fact that, of the fluids we tested, pickle juice contains the greatest quantity of potassium, magnesium, and calcium, there were no changes in these electrolytes at 60 minutes postingestion. A single bolus of pickle juice may not affect calcium absorption in the intestines, but a bolus may affect it if given repeatedly as a prophylactic for EAMCs. This may partially support anecdotal claims[10] of pickle juice's success in preventing EAMCs, but it does not explain the immediate effect of pickle juice relieving EAMCs. Regardless, the lack of changes in these electrolytes after pickle juice ingestion indicates that drinking pickle juice in these quantities is unlikely to restore any imbalance in these electrolytes and is therefore unlikely to relieve an EAMC.

Ingesting 1 mL/kg body mass of pickle juice without concurrent hypotonic fluid intake will not cause plasma hypertonicity or increase an athlete's risk of dehydration, as some health care professionals have theorized.[13,14,27] Plasma osmolality, which is the primary physiologic indicator of hydration,[17] and all urine variables indicated participants were euhydrated 60 minutes postingestion of pickle juice. Therefore, athletes wanting to sodium load before exercise will not increase their plasma sodium concentration levels with these quantities of pickle juice, and they will not increase their plasma sodium concentration levels by drinking these volumes over 5 consecutive days.[28] However, our results do not give license to ignore proper strategies for fluid replacement[29] or guidelines for pickle juice dilution,[14] as we administered only small doses of pickle juice, and transient decreases in blood and plasma volume can occur after ingestion of large volumes of highly hypertonic solutions.[30]

Our study was an initial step toward understanding the physiologic effects of pickle juice ingestion. Future researchers should confirm 2 other factors before concluding that pickle juice does not alleviate EAMCs by restoring plasma electrolytes. The first factor that we must consider is that our study was performed at rest in euhydrated participants to determine if and how quickly electrolytes and plasma osmolality could change after pickle juice ingestion. Thus, we can only speculate regarding pickle juice's effects while athletes are in a dehydrated or exercised condition. However, mild to moderate exercise[31,32] and dehydration[32,33] do not affect gastric emptying and should not detract from our conclusions. Moreover, intestinal absorption of hyperosmotic solutions is decreased in a dehydrated state,[32] further decreasing the likelihood that pickle juice restores sodium quickly enough to relieve EAMCs. Even with increased venous aldosterone concentrations and improved sodium absorption due to exercise,[34] the amount of sodium ingested with these volumes of pickle juice and the substantial sodium deficit that can be incurred as a result of exercise indicate that these volumes of pickle juice cannot measurably restore plasma electrolytes.

The second factor we must consider is the volume of pickle juice ingested in our study. Our participants ingested slightly more than the recommended 30 mL to 60 mL of pickle juice, which is reported[10] to relieve an EAMC within 30 to 35 seconds of ingestion. The effect on plasma and urine variables of ingesting much larger volumes of pickle juice alone or small quantities of pickle juice with larger volumes of hypotonic beverages is unknown. Ingestion of pickle juice concomitantly with large amounts of hypotonic beverages likely would increase the rate of stomach emptying.[35] However, hypotonic fluids require at least 13 minutes to leave the stomach[36]; thus, even with large amounts of hypotonic fluid ingested in addition to pickle juice, it is unlikely that large amounts of sodium can be absorbed in the time frame described to alleviate an EAMC.[10]

CONCLUSIONS

Small quantities of pickle juice or CHO-e drink did not elicit increases in plasma electrolytes, osmolality, or volume up to 60 minutes postingestion in resting, euhydrated men who were not experiencing EAMCs. Health care professionals do not need to worry about causing plasma hypertonicity or dehydration if athletes drink small volumes of pickle juice without concurrent ingestion of hypotonic fluids. The lack of changes in plasma electrolytes and volume casts serious doubt on the theory that pickle juice relieves an EAMC by restoring electrolytes, especially within 1 minute of ingestion. Thus, clinicians may be underestimating the amount of time in their observations of cramp relief, or, if pickle juice does relieve EAMCs, it may be because of an unknown factor (neural or metabolic). Future research to quantify pickle juice's purported effects on EAMCs is required.

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REFERENCES

1. Bergeron MF. Heat cramps during tennis: a case report. *Int J Sport Nutr*. 1996;6(1):62–68.
2. Cooper ER, Ferrara MS, Broglio SP. Exertional heat illness and environmental conditions during a single football season in the Southeast. *J Athl Train*. 2006;41(3):332–336.
3. Sulzer NU, Schwellnus MP, Noakes TD. Serum electrolytes in Ironman triathletes with exercise associated muscle cramping. *Med Sci Sports Exerc*. 2005;37(7):1081–1085.
4. Binkley HM, Beckett J, Casa DJ, Kleiner DM, Plummer PE. National Athletic Trainers' Association position statement: exertional heat illnesses. *J Athl Train*. 2002;37(3):329–343.
5. Stofan JR, Zachwieja JJ, Horswill CA, Murray R, Anderson SA, Eichner ER. Sweat and sodium losses in NCAA football players: a precursor to heat cramps? *Int J Sport Nutr Exerc Metab*. 2005;15(6):641–652.
6. Stone MB, Edwards JE, Stemmans CL, Ingersoll CD, Palmieri RM, Krause BA. Certified athletic trainers' perceptions of exercise-associated muscle cramps. *J Sport Rehabil*. 2003;12(4):333–342.
7. Bergeron MF. Exertional heat cramps: recovery and return to play. *J Sport Rehabil*. 2007;16(3):190–196.
8. Professional Football Athletic Trainers Society. Preventing whole-body cramps: teams in a pickle over scientific vs. home remedies. *Pro Football Athl Trainer*. 2000;18(winter):6.
9. Miller KC, Knight KL, Williams RB. Athletic trainers' perceptions of pickle juice's effects on exercise associated muscle cramps. *Athl Ther Today*. 2008;13(5):31–34.
10. Williams RB, Conway DP. Treatment of acute muscle cramps with pickle juice: a case report [abstract]. *J Athl Train*. 2000;35(suppl 2):S24.
11. Williams R. Those devilish cramps. *Train Condition*. 2000;December:23–28.
12. Bergeron MF. Sodium: the forgotten nutrient. *Gatorade Sports Sci Inst Sports Sci Exch*. 2000;13(3):1–4.
13. Eichner ER. Muscle cramps: the right ways for the dog days. *Coach Athl Dir*. 2002;72(August):3.
14. Dale RB, Leaver-Dunn D, Bishop P. A compositional analysis of a common acetic acid solution with practical implications for ingestion. *J Athl Train*. 2003;38(1):57–61.
15. Maughan RJ, Leiper JB. Limitations to fluid replacement during exercise. *Can J Appl Physiol*. 1999;24(2):173–187.

16. Sawka MN, Burke LM, Eichner ER, Maughan RJ, Montain SJ, Stachenfeld NS. American College of Sports Medicine position stand: exercise and fluid replacement. *Med Sci Sports Exerc*. 2007;39(2):377–390.
17. Institute of Medicine. *Dietary Reference Intakes for Water, Sodium, Chloride, Potassium, and Sulfate*. Washington, DC: National Academy Press; 2005:73–185.
18. Dill DB, Costill DL. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehydration. *J Appl Physiol*. 1974;37(2):247–248.
19. Schwellnus MP, Nicol J, Laubscher R, Noakes TD. Serum electrolyte concentrations and hydration status are not associated with exercise associated muscle cramping (EAMC) in distance runners. *Br J Sports Med*. 2004;38(4):488–492.
20. Sugarman E, Fowkes Godek S, Burkholder R, Peduzzi C, Dorshimer G, Bartolozzi A. Hydration status and blood measures in an NFL lineman with two episodes of muscle cramping treated with intravenous fluids [abstract]. *J Athl Train*. 2005;40(suppl 2):S41–S42.
21. Maughan RJ. Exercise induced muscle cramp: a prospective biochemical study in marathon runners. *J Sports Sci*. 1986;4(1):31–34.
22. Sims ST, van Vliet L, Cotter JD, Rehrer NJ. Sodium loading aids fluid balance and reduces physiological strain of trained men exercising in the heat. *Med Sci Sports Exerc*. 2007;39(1):123–130.
23. Liljeberg H, Bjorck I. Delayed gastric emptying rate may explain improved glycaemia in healthy subjects to a starchy meal with added vinegar. *Eur J Clin Nutr*. 1998;52(5):368–371.
24. Schwellnus MP, Derman EW, Noakes TD. Aetiology of skeletal muscle "cramps" during exercise: a novel hypothesis. *J Sports Sci*. 1997;15(3):277–285.
25. Bentley S. Exercise-induced muscle cramp: proposed mechanisms and management. *Sports Med*. 1996;21(6):409–420.
26. Kishi M, Fukaya M, Tsukamoto Y, Nagasawa T, Takehana K, Nishizawa N. Enhancing effect of dietary vinegar on the intestinal absorption of calcium in ovariectomized rats. *Biosci Biotechnol Biochem*. 1999;63(5):905–910.
27. Burns J, Clarkson PM. Why don't athletes drink enough during exercise, and what can be done about it? *Gatorade Sports Sci Inst Sports Sci Exch*. 2001;12(1):1–4.
28. Fowkes-Godek S, Bartolozzi AR, Sugarman E, Peduzzi C, Hunkele T, Burkholder R. Blood electrolytes and plasma volume changes in two groups of sodium supplemented NFL players during pre-season [abstract]. *J Athl Train*. 2006;41(suppl 2):S60.
29. Casa DJ, Armstrong LE, Hillman SK, et al. National Athletic Trainers' Association position statement: fluid replacement for athletes. *J Athl Train*. 2000;35(2):212–224.
30. Merson S, Shirreffs S, Leiper J, Maughan R. Changes in blood, plasma and red blood cell volume after ingestion of hypotonic and hypertonic solutions. *Proc Nutr Soc Lond*. 2002;61(3a):108A.
31. Costill DL, Saltin B. Factors limiting gastric emptying during rest and exercise. *J Appl Physiol*. 1974;37(5):679–683.
32. Ryan AJ, Lambert GP, Shi X, Chang RT, Summers RW, Gisolfi CV. Effect of hypohydration on gastric emptying and intestinal absorption during exercise. *J Appl Physiol*. 1998;84(5):1581–1588.
33. Rehrer NJ, Beckers EJ, Brouns F, ten Hoor F, Saris WH. Effects of dehydration on gastric emptying and gastrointestinal distress while running. *Med Sci Sports Exerc*. 1990;22(6):790–795.
34. Morgan RM, Patterson MJ, Nimmo MA. Acute effects of dehydration on sweat composition in men during prolonged exercise in the heat. *Acta Physiol Scand*. 2004;182(1):37–43.
35. Mitchell JB, Voss KW. The influence of volume on gastric emptying and fluid balance during prolonged exercise. *Med Sci Sports Exerc*. 1991;23(3):314–319.
36. Vist GE, Maughan RJ. The effect of osmolality and carbohydrate content on the rate of gastric emptying of liquids in man. *J Physiol*. 1995;486(pt 2):523–531.

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