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Oral Rehydration Beverages for Treating Exercise-Associated Dehydration: A Systematic Review, Part I. Carbohydrate-Electrolyte Solutions

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Objective: Exercise-associated dehydration is a common problem, especially at sporting events. Although recommendations have been made to drink a certain volume per kilogram body mass lost after exercise, no clear guidance about the type of rehydration beverage is available. We conducted a systematic review to assess the effectiveness of carbohydrate-electrolyte (CE) solutions as a rehydration solution for exercise-associated dehydration.

Data Sources: MEDLINE (via the PubMed interface), Embase, and the Cochrane Library databases were searched up until June 1, 2022.

Study Selection: Controlled trials involving adults and children were included when dehydration was the result of physical exercise and when drinking carbohydrate-electrolyte solutions, of any percentage carbohydrate, was compared with drinking water. All languages were included if an English abstract was available.

Data Extraction: Data on study design, study population, interventions, outcome measures, and study limitations were extracted from each included article. Certainty was assessed using Grading of Recommendations Assessment, Development and Evaluation.

Data Synthesis: Of 3485 articles screened, 19 articles in which authors assessed CE solutions (0%–9% carbohydrate) compared with water were included. Although variability was present among the identified studies, drinking 0% to 3.9% and especially 4% to 9% CE solution may be effective for rehydration.

Conclusions: A potential beneficial effect of drinking CE drinks compared with water was observed for many of the reviewed outcomes. Commercial CE drinks (ideally 4%–9% CE drinks or alternatively 0%–3.9% CE drinks) could be suggested for rehydration in individuals with exercise-associated dehydration when whole foods are not available.

Key Words: fluid balance, hypohydration, sports drinks, first aid

Key Points

- Drinking 0% to 3.9% and especially 4% to 9% carbohydrate-electrolyte solution may restore volume/hydration status after exercising when whole foods are not available.
- Limited evidence suggests that consuming commercial drinks with 0% to 3.9% and especially 4% to 9% carbohydrate-electrolyte solution provides acceptable rehydration for exertion-related dehydration or hypohydration.
- If clean, drinkable water is available, its cost, relative to carbohydrate-electrolyte drinks, makes it an acceptable alternative.

Human body water accounts for 50% to 70% of the total body mass and is regulated within a confined range. Performing exercise leads to increased sweat loss that generally exceeds fluid intake, even more so in hot humid conditions. If this fluid loss is not sufficiently replenished, dehydration (ie, the process of losing body water) may lead to hypohydration (the end result, that is, a state of less than normal body water content).[1] Even low levels of hypohydration (2% of body mass) may impair thermoregulation; produce cardiovascular strain; and if allowed to progress, can lead to impaired physical and cognitive performance, syncope due to hypotension, and finally, heat-ated illness that can be fatal.[2–7] In such situations, promoting postexercise drinking to restore fluid balance is of the utmost importance. For rapid and complete rehydration, the volume of drink and its composition are key.[8,9] Although the American College of Sports Medicine Guidelines on Nutrition and Athletic Performance recommend drinking 1.25 to 1.5 L of fluid per kilogram body mass lost, no clear advice is available regarding the specific type of rehydrating fluid.[10] The National Athletic Trainers' Association position statement on fluid replacement for the physically active recommends the following: (1) "educate physically active people regarding the benefits of fluid replacement to promote performance and safety and the potential risks of both hypohydration and hyperhydration on health and physical performance;" (2) "quantify sweat rates for physically active individuals during exercise in various environments;" and (3) "work with individuals to develop fluid-replacement practices that promote sufficient but not excessive hydration before, during, and after physical activity."[11]

Researchers have suggested that a healthy person participating in moderate physical activity should require no other beverages than water, whereas athletes participating in long or intense exercise may require additional carbohydrates, electrolytes, or both in their rehydration fluids.[12] This may help to maintain blood glucose and carbohydrate oxidation and electrolyte balance. However, determining hydration choices is difficult because individuals differ in their rate of gastric emptying, intestinal absorption, bowel transit time, and renal function, as well as sweat rates.[11]

Against this background, the aim of this systematic review was to identify effective first aid rehydration interventions that can restore fluid balance. To our knowledge, we are the first to perform a systematic review to assess the effectiveness of carbohydrate-electrolyte (CE) solutions for rehydration. A typical recovery strategy after activity does not include fluid ingestion alone and may require the intake of whole foods. The focus of this systematic review was to assess the rehydrating properties of beverages without the associated intake of food.

This review is the first of a 2-part review on the treatment of exercise-associated dehydration. In this first part, we review the effectiveness of CE solutions; in the second part, we review alternative rehydration solutions such as milk, coconut water, and beer.[13] The following research question was formulated in population, intervention, comparison, outcome (PICO) format: Among adults and children with exercise-associated dehydration, does drinking CE solutions compared with drinking water change volume/hydration status, heart rate, serum sodium, serum or plasma osmolality, need for advanced medical care, and patient satisfaction? This systematic review was conducted as part of the development of evidence-based treatment recommendations by the First Aid Task Force of the International Liaison Committee on Resuscitation (ILCOR).

METHODS

Search Strategy

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist. The methods for both parts of the review are described in this section. All steps were performed simultaneously for both parts. A protocol was submitted at PROSPERO (CRD42020153077).

Three databases were searched for studies meeting our criteria: the Cochrane Library, MEDLINE (using the PubMed interface), and Embase (using the Embase.com interface). Search strategies were developed by 2 reviewers (V.B. and N.D.B.), using both index terms and text words. We searched the databases for relevant literature up until June 1, 2022. Search strategies can be found in the Supplemental Appendix, available online at https://dx.doi.org/10.4085/1062-6050-0682.22).

Selection Criteria

After removing duplicates, 2 reviewers (V.B. and N.D.B.) independently screened the titles and abstracts and then assessed the full texts by applying the selection criteria. Reference lists of included studies were screened to identify additional relevant studies. Any discrepancies between authors were discussed, and if necessary, a third reviewer (E.D.B., E.S., or D.Z.) was consulted. Studies were eligible if they met the inclusion criteria outlined in Table 1.

Outcomes were selected a priori by the ILCOR First Aid Task Force. In selecting these outcomes, the task force considered not only known and commonly reported outcomes in relation to hydration but also whether outcomes were clinically relevant and easily measured in real-life situations.

Cumulative urine output is calculated as the sum of the urine volumes measured during the recovery period. When individuals are consuming a fixed volume of a drink, a reduced urine output indicates a better retention of the consumed drink and, hence, is beneficial by enhancing the rehydration process.[14]

Net fluid balance is calculated as the sum of the volume of sweat loss during exercise and urine loss during exercise and recovery periods subtracted from the volume of drink consumed.[15] Restoration of the net fluid balance is beneficial, and larger values indicated that the sweat loss has been replaced effectively.

Plasma volume is decreased by exertion-related dehydration in proportion to the level of fluid loss due to sweating. Positive changes in plasma volume are beneficial during rehydration. Fluid replacement should be targeted at plasma volume restoration to ensure that circulation and sweating can progress at optimal levels.

Hemoglobin and hematocrit values are based on whole blood and, therefore, are dependent on plasma volume. If a person is severely dehydrated, the hemoglobin and hematocrit values will be higher, and restoring these measures to their baseline values would suggest effective rehydration.

The combination of exercising, heat stress, and hypohydration contributes to high levels of cardiovascular strain (high heart rate). Lower heart rates are beneficial during the recovery period.[16]

During rehydration, the restoration and maintenance of a high serum or plasma osmolality and serum electrolyte concentrations are desirable and avoid the stimulation of diuresis.[17]

Because different rehydration periods were used in the studies, we decided to only include time points after completion of drinking water or the rehydration fluid. Given that this review focused on the out-of-hospital setting after exertion-related dehydration, we limited relevant time points to 1 and 2 hours after completion of drinking; any later time point was excluded (except for cumulative urine volume, for which the endpoint of the study was included). If 1- or 2-hour results were not reported, any other time point within 2 hours after completion of drinking was included. For patient satisfaction outcomes, we included time points starting from immediately after the completion of drinking until 2 hours after the completion of drinking. In addition, studies in which authors only reported mean values without SDs, effect sizes, or *P* values were excluded.

Table 1. Inclusion and Exclusion Criteria

	Inclusion	Exclusion
Population	Adults and children with exercise-associated dehydration.	Adults and children with dehydration linked to urological, gastrointestinal, circulatory, and neurological disorders. Studies in which dehydration status was induced by sauna or sweatboxes.
Intervention	Any type of CE solution that is widely or commonly available. CE solutions of any percentage of carbohydrate. The percentages mentioned for the CE solutions in the Results section are related to the carbohydrate content.	Intravenous fluid administration. Products that currently are not commercially available.
Comparison	Plain water: tap or bottled water.	Any other rehydrating liquid (oral or intravenous).
Outcome	Volume/hydration status (measured as cumulative urine output, net fluid balance, hematocrit, hemoglobin, and plasma volume change). Heart rate. Serum and plasma osmolality and serum sodium concentration. Need for advanced medical care. Patient satisfaction (thirst perception, perceived intensity of gastric fullness or cramps, nausea, and abdominal discomfort).	Urine electrolyte concentration, specific gravity, and osmolality; salivary osmolality; plasma sodium and potassium concentration; serum potassium and chloride concentration; fraction of beverage retained/fluid retention; percentage rehydration of dehydration; rehydration index; glucose concentrations in blood or serum; respiratory rate; and core temperature.
Study design	Randomized controlled trials and nonrandomized studies (nonrandomized controlled trials, interrupted time series, controlled before-and-after studies, and cohort studies).	Unpublished studies (eg, conference abstracts, and trial protocols), editorials, case series, and animal studies.
Timeframe and language	All years. All languages if an English abstract is available.	Articles in a language other than English, for which no English abstract is available.

Abbreviation: CE, carbohydrate-electrolyte.

Data Extraction

Two reviewers (V.B. and N.D.B.) independently extracted data on the study population, intervention, outcome measures, and study limitations. Data are presented as mean differences with 95% CIs, where possible. If no sufficient data were available to calculate 95% CIs, only mean differences and *P* values were reported. Significant *P* values were $<.05$. GRADEPro software was used to tabulate the data.[18]

Certainty Assessment

We assessed the certainty of evidence according to the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.[19] The certainty of evidence can be downgraded for limitations in study design, inconsistency, indirectness, imprecision, or publication bias. Limitations in study design were assessed using the Risk of Bias 2 tool for randomized studies and the Risk of Bias in Non-Randomized Studies of Interventions tool for nonrandomized studies.[20,21] The initial certainty of evidence of all studies was high. Based on the assessment, the final level of certainty can be *high* (ie, the authors have high confidence that the true effect is similar to the estimated effect), *moderate* (ie, the authors believe the that the true effect is probably close to the estimated effect), *low* (ie, the true effect might be markedly different from the estimated effect), or *very low* (ie, the true effect is probably markedly different from the estimated effect).[19] The certainty of evidence is reflected in the wording of the conclusions or recommendations, as stated in the GRADE methodology.[22]

RESULTS

Study Identification and Selection

A total of 4445 references were identified. After removing duplicates, we screened 3485 articles based on title and abstract and then assessed 107 full-text articles. Of these, 84 studies were excluded. A total of 20 studies were included in this review, with 12 studies examining rehydration by CE solutions and 8 studies examining both CE and alternative solutions.[16,23–41] Authors of the 3 remaining studies examined alternative solutions only, and the results can be found in Part II of this review.[13]

We only discuss the results of the 20 studies in which authors examined CE solutions in this paper. The characteristics of these studies, including study design, population, relevant comparisons, and outcome measures, are summarized in Table 2. A total of 15 studies were randomized controlled trials (RCTs), and 5 studies were nonrandomized studies. Ten studies were published between 2011 and 2021, and 10 studies were published between 1992 and 2010.[16,23–41] All were crossover studies with a total of 273 (233 male, 40 female) healthy children (age $\geq$ 7 years) and young adults performing exercise in a controlled environment until a predefined point of hypohydration was reached.[16,23–41]

The percentage carbohydrate in the solutions ranged between 0% and 8.75%, and the type of carbohydrate used was either isomaltulose, glucose, a combination of glucose

Table 2. Characteristics of Included Studies Continued on Next Page

Study (Year)	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Amano et al[23] (2019)	Japan	RCT (within subjects)	10 healthy, physically active young men (age = 21.2 ± 1.1 y, height = 1.72 ± 0.04 m, BM = 64.4 ± 5.5 kg) Dehydration by cycling to induce 2% BM loss	Interventions: 2.0% and 6.5% CE solution (carbohydrate = isomaltulose) Control: water The beverages were consumed within the first 30 min after cessation of exercise. Participants consumed a volume equal to BM loss during the intermittent exercise bouts, ingesting 50%, 25%, and 25% of the total volume in 10 min intervals over the 30-min period.	Urine output (mL) Plasma volume (mL) Hematocrit (%) Hemoglobin (g/dL) Heart rate (beats/min) Plasma osmolality (mOsm/kg)
Chang et al[24] (2010)	China	RCT (within subjects)	10 healthy men (age = 26.0 ± 1.8 y, height = 172.9 ± 6.6 cm, BM = 67.9 ± 8.0 kg) Dehydration by moderate exercise until 2.2% BM loss	Intervention: 6.6% CE solution (POCARI SWEAT[a]; type of carbohydrate unknown) Control: water Start rehydration 20 min after exercise and 1% of BM loss at first time point. Test beverages were consumed 3 times during the first 20 min of the rehydration period (at 0, 10, and 20 min) in a volume equal to their BM loss.	Plasma volume (%) Cumulative urine output (g)
Evans et al[30] (2017)	United Kingdom	RCT (within subjects)	8 non–heat-acclimatized, recreationally active participants (5 men, 3 women; age = 21 ± 2 y, height = 179 ± 8 cm, BM = 71.1 ± 13.2 kg) Dehydration by exercise in the heat to induce up to 1.8% BM loss or until participants could no longer exercise	Intervention: 50-mmol/L NaCl solution Control: water Participants underwent a 60-min rehydration/refeeding period, during which they drank a volume of fluid equal to 150% BM lost during exercise in 4 aliquots given at 15-min intervals followed by a 3-h monitoring period without food or drink.	Cumulative urine volume (mL) Net fluid balance (mL)
González-Alonso et al[25] (1992)	United States	Nonrandomized study (within subjects)	19 college students who routinely exercised (16 men, 3 women; age = 22.8 ± 2.8 y, BM = 73.9 ± 12.8 kg) Dehydration by cycling or running until ±2.5% BM loss	Intervention: 6% CE solution (Gatorade[b]; carbohydrate = 2% glucose + 4% sucrose) Control: regular tap water 45 min after exercise, participants drank a volume of the rehydration drink containing 53% of the fluid lost. This signaled the beginning of the 2-h rehydration period. After 45 min, the remaining 47% of the rehydration drink was ingested to replace 100% of fluid lost.	Urine volume (mL) Serum osmolality (mOsm/kg) Serum Na concentration (mEq/L) Hemoglobin/hematocrit concentration Feelings of stomach fullness and pressure

Table 2. Continued From Previous Page

Study (Year)	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Hostler et al[16] (2010)	United States	RCT (within subjects)	18 firefighters (16 males: age = 30.9 ± 8.6 y, height = 174.6 ± 9.0 cm; BM = 93.9 ± 10.8 kg; 2 females: age = 22.0 ± 4.2 y, height = 161.5 ± 6.4 cm, BM = 56.5 ± 4.9 kg) Dehydration by exercise on a treadmill to mimic the exertion of fire suppression.	Intervention: 6% CE solutions (Gatorade[c]; type of carbohydrate unknown) Control: water Rehydration period: 20 min between bouts 1 and 2. Participants received rehydration volume equal to the mass lost during exercise. For those who lost <0.2 kg, 200 mL of fluids was provided.	Heart rate (beats/min)
Ismail et al[35] (2007)	Malaysia	RCT (within subjects)	10 healthy, physically active men (age = 20.7 ± 0.9 y, height = 169 ± 1.6 cm, BM = 60.2 ± 2.6 kg) Dehydration by running on a treadmill until ±3% BM loss	Intervention: 3.7% CE solution (Isomax[d]; carbohydrate = glucose) Control: plain water 30 min after exercise, participants drank the equivalent of 50% of BW loss; 30 min later, they drank 40% of BW loss; and the remaining 30% of the rehydration beverage necessary to replace 120% of BW loss was ingested at 60 min.	Cumulative urine output (mL) Net fluid balance Plasma volume Serum Na Serum osmolality Thirst perception Nausea Fullness Stomach upset
Kalman et al[39] (2012)	United States	RCT (within subjects)	12 exercise-trained men (age = 26.6 ± 5.7 y, height = 175.4 ± 4.1 cm, BM = 77.2 ± 6.3 kg) Dehydration by walking/jogging to induce 2%–3% BM loss	Intervention: 5%–6% CE solution (type of carbohydrate unknown) Control: supermarket brand bottled water Participants were allowed 60 min to drink their test solution (about 125% of actual BM lost).	Plasma osmolality Heart rate Subjective measures (VAS): thirst, bloatedness, and stomach upset
Lau et al[26] (2019)	United States	Nonrandomized study (within subjects)	10 healthy young men having good fitness (age = 25.0 ± 2.7 y, height = 173.7 ± 6.4 cm, BM = 74.0 ± 12.0 kg) Dehydration by running until 2% BM loss	Intervention: 1.8% CE solution (OS-1[e]; carbohydrate = glucose) Control: spring water Immediately after dehydration, participants drank either water or OS-1[e] and consumed the volume in 10 min. The amount of fluid intake equaled BM loss: 1324 ± 17 mL for the water and 1285 ± 17 mL for the OS-1[e] condition.	Hematologic profile (hematocrit and hemoglobin) Serum osmolality Serum Na
Niksefat et al[33] (2019)	Iran	Nonrandomized study (within subjects)	10 healthy male football players (age = 21.6 ± 0.8 y, BM index = 23.16 ± 2.84) Dehydration by cycling until 2% BW loss	Intervention: 8.75% CE solution (type of carbohydrate unknown) Control: water Participants were given drinks in volumes equivalent to BW lost divided in 4 equal portions, provided every 10 min (30-min rehydration period).	Cumulative urine output (mL) Hematocrit (%) Serum osmolality (mOsmol/kg) Serum Na (mmol/L)

Table 2. Continued From Previous Page

Study (Year)	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Pérez-Idárraga and Aragón-Vargas[36] (2014)	Costa Rica	RCT (within subjects)	12 apparently healthy, physically active volunteers (10 men, 2 women; age = 24.4 ± 3.2 y, height = 1.73 ± 0.06 m, BM = 74.75 ± 11.36 kg) Dehydration by exercise on treadmill or cycle ergometer until 2% BM loss	Intervention: 4% CE solution (carbohydrate = fructose and glucose) Control: bottled water (Cristal[f]) During the rehydration 1-h period, participants consumed a volume equivalent to 120% of BM loss divided into 4 aliquots, 1 every 15 min.	Cumulative urine volume (mL) Net fluid balance (g) Thirst perception Nausea Fullness Stomachache
Saat et al[37] (2002)	Malaysia	RCT (within subjects)	8 healthy men (mean ± SEM age = 22.4 ± 3.3 y, height = 168.5 ± 1.8 cm, BM = 56.6 ± 2.3 kg) Dehydration by exercise in a hot environment until 2.5%–3% BM loss	Intervention: 3.2% CE solution (carbohydrate = glucose) Control: plain water At 30 min after end of exercise, participants drank a first drink of 50% of fluid loss; 30 min later, they drank 40% of the fluid loss; and another 30 min later, they drank the last 30% (for a total of 120% of BM lost).	Cumulative urine volume (mL) Net fluid balance (g) Serum Na (mmol/L) Serum osmolality (mOsm/kg) Fluid sensation (thirst, nausea, fullness, and stomach upset)
Seery and Jakeman[38] (2016)	Ireland	RCT (within subjects)	7 healthy men (age = 26.2 ± 6.1 y, height = 1.79 ± 0.08 m, BM = 86.4 ± 11.5 kg) Dehydration by cycling until BM loss of 1.8% was achieved	Intervention: 3.9% CE solution (Powerade[g]; type of carbohydrate unknown) Control: water (Centra[h]) Rehydration commenced 25 min after the end of dehydration and lasted for 5 h. Participants drank a volume of 150% of BM loss. 1000 mL had to be ingested within the first 30 min, 500 mL every 30 min thereafter until the required volume of fluid was consumed.	Cumulative urine volume (mL) Net fluid balance (mL) Plasma osmolality (mOsm/kg) Subjective feelings (thirst and bloatedness)
Seifert et al[27] (2006)	United States	Nonrandomized study (within subjects)	13 experienced endurance athletes (5 women, 8 men; age range, 20–28 years) Dehydration by cycling until approximately 2.5% BM loss	Intervention: 6% CE solution (Gatorade[i]; type of carbohydrate unknown) Control: flavored water Immediately postexercise, participants ingested 1 of the 3 beverages in an amount equal to BM loss. They were given 20 min to complete ingestion.	Cumulative urine volume (mL) Hemoglobin Hematocrit Change in plasma volume Serum osmolality
Shirreffs et al[40] (2007)	United Kingdom	RCT (within subjects)	11 healthy volunteers (5 men, 6 women; age = 24 ± 4 y, height = 1.66 ± 0.07 m, BM = 65.6 ± 7.2 kg) Dehydration by cycling until approximately 1.7% BM loss	Intervention: 6% CE solution (Powerade[j]; carbohydrate = glucose and maltodextrin) Control: water (Aqua Pura[k]) Drinking (volume equal to 150% of BM lost) commenced exactly 20 min after the end of exercise. Drinks were provided in 4 equal boluses at 15-min intervals giving a total drinking time of 60 min.	Cumulative urine volume (mL) Net fluid balance (mL) Subjective feelings (thirst, bloatedness, and fullness)

Table 2. Continued From Previous Page

Study (Year)	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Utter et al[28] (2010)	United States	RCT (within subjects)	23 healthy male, National Collegiate Athletic Association Division I collegiate wrestlers (mean ± SEM age = 19.6 ± 0.3 y, height = 1.75 ± 0.02 m, BM = 81.0 ± 3.4 kg) Dehydration by standard wrestling practice regimen until 3% BM loss	Intervention: 6% CE solution (type of carbohydrate unknown) Control: bottled water During the first 5–10 min, participants consumed a beverage equal to one-half of BW loss. From 20 to 25 min of recovery, they consumed a second volume of beverage to replace 100% of BW loss.	Plasma osmolality Plasma volume
Valiente et al[29] (2009)	United States	RCT (within subjects)	21 healthy male, National Collegiate Athletic Association Division I collegiate wrestlers (mean ± SEM age = 19.4 ± 0.4 y, height = 1.76 ± 0.02 m, BM = 81.4 ± 3.7 kg) Dehydration by standard wrestling practice regimen until 3% BM loss	Intervention: 6% CE solution (Gatorade[i]; type of carbohydrate unknown) Control: regular bottled water During the first 5–10 min, participants consumed a beverage equal to one-half of BM loss. From 20 to 25 min of recovery, they consumed a second volume of beverage to replace 100% of BM loss.	Plasma osmolality Plasma volume
Volterman et al[41] (2014)	Canada	RCT (within subjects)	38 volunteers (19 male, 19 female): 20 prepubertal to early pubertal (10 boys: age = 9.4 ± 1.1 y, height = 137 ± 7 cm, BM = 32.6 ± 6.3 kg; 10 girls: age = 9.4 ± 0.9 y, height = 135 ± 9 cm, BM = 28.7 ± 5.5 kg); 18 midpubertal to late-pubertal (9 boys: age = 15.4 ± 0.4 y, height = 169 ± 8 cm, BM = 59.3 ± 8.7 kg; 9 girls: age = 14.6 ± 0.6 y, height = 167 ± 5 cm, BM = 57.6 ± 9.2 kg) Dehydration by exercise until 2% BM loss	Intervention: 8% CE solution (Powerade[j]; type of carbohydrate unknown) Control: plain water 3 equal aliquots of the experimental beverage were ingested at 0, 15, and 30 min after the in-chamber protocol. Total volume equated 100% of body fluid loss during exercise.	Cumulative urine output (mL) Body fluid balance (mL) % dehydration Thirst perception Perceived intensity of stomach fullness
Wijnen et al[34] (2016)	The Netherlands	RCT (within subjects)	11 healthy, habitually physically active men (age = 24.5 ± 4.7 y, BM = 75.4 ± 3.3 kg; BM index = 22.4 ± 1.8) Dehydration by cycling until 1% BM loss	Intervention: 7% CE solution (Isostar Hydrate & Perform lemon[l]; carbohydrate = glucose) Control: tap water In the 45 min after exercise, participants received the experimental beverage in an amount equivalent to 100% of BM loss. The beverage was provided in 3 equal portions, 15 min apart, in the same cup.	Cumulative urine output (mL) Fluid balance (mL)

Table 2. Continued From Previous Page

Study (Year)	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Wong et al[32] (2000)	Hong Kong	RCT (within subjects)	9 endurance-trained men (mean ± SEM age = 26.4 ± 1.7 y, height = 178.5 ± 2.5 cm, BM = 71.0 ± 2.7 kg) Dehydration by treadmill runs	Intervention: 6.9% CE solution (Lucozade-Sport[m]; type of carbohydrate unknown) Control: CE-free sweetened placebo Participants were prescribed a volume of fluid equivalent to 200% of BM lost during treadmill run 1. They drank an initial 725 mL of the fluids 30 min after treadmill run 1. The remaining volume of fluid was determined by deducting the first administration of the total volume prescribed. The remaining prescribed volume was ingested in equivolumetric amounts after 1, 1.5, 2, 2.5, and 3 h during the recovery period. The overall time for each ingestion was 10 min. Total recovery period lasted 4 h. Remark: Due to discomfort of drinking such large volumes, not all fluid was consumed: 113%–200% for CE solution trial and 88.5%–200% for water.	Body fluid balance (mL) Cumulative urine volume (mL) % Rehydration Plasma volume (%) Serum Na (mmol/L) Serum osmolality (mOsm/kg) Subjective measures: thirst and abdominal discomfort
Wong and Chen[31] (2011)	Hong Kong	Nonrandomized study (within subjects)	13 well-trained male runners (age = 22.1 ± 3.3 y, BM = 61.2 ± 9.1 kg) Dehydration by treadmill runs until approximately 2% BM loss	Intervention: 6.6% CE solution (Pocari Sweat[n]; type of carbohydrate unknown) Control: distilled water (Watsons[o]) Immediately after the run, the 4-h rehydration period commenced. Total fluid intake was equivalent to 150% of BW lost. Fluid was consumed in 6 equal volumes at 30, 60, 90, 120, 150, and 180 min.	Cumulative urine volume (mL) Plasma volume (mL) Plasma osmolality (mOsm/kg) Heart rate (beats/min) Thirst Abdominal discomfort Stomach fullness

Abbreviations: BM, body mass; BW, body weight; CE, carbohydrate-electrolyte; RCT, randomized controlled trial; VAS, visual analog scale.
[a] Tianjin Otsuka Beverage Co, Ltd.
[b] Quaker Oats Co.
[c] The Gatorade Company.
[d] Ace Canning Corp Sdn Bhd.
[e] Otsuka Pharmaceutical Factory.
[f] Florida Ice & Farm Co.
[g] Coca Cola Ltd.
[h] Musgrave Retail Partners.
[i] Pepsico, Inc.
[j] Coca Cola Ltd.
[k] Roxane UK.
[l] Nutrition et Sante.
[m] SmithKline Beecham.
[n] Otsuka Pharmaceutical Co, Ltd.
[o] Watsons.

with maltodextrin or fructose or sucrose, or unknown. The volume of fluid ingested for rehydration varied between 100% and 200% of body mass lost during exercise (Table 2). In most studies, participants drank 100% of the lost body mass.[16,23–29,33,34,41] In 3 studies, participants drank 120% of the body mass lost; in 4 studies, 150%; and in 1 study each, 125% and 200%.[30,32,35–40]

Synthesis of Findings

The synthesis of findings of all included studies is summarized in Tables 3 through 5, and a narrative overview of the results is given below. Given the large heterogeneity between studies (ie, different protocols for dehydration, large variability in time to rehydrate, and time points measured), it was not possible to perform meta-analyses.

4.0% to 9.0% CE Solution. Results for 4.0% to 9.0% CE solution are summarized in Table 3.

Volume/Hydration Status. Volume/hydration status was measured as cumulative urine output, net fluid balance, plasma volume change, or hematocrit. We identified 9 RCTs and 4 nonrandomized studies, including 200 participants, in which authors assessed the effect of 4.0% to 9.0% CE solution compared with water on volume/hydration status.[23–25,27–29,31–34,36,40,41] A decrease in cumulative urine output was shown with 4%, 6%, and 6.6% CE solutions.[24,25,27,31,36] However, authors of 5 RCTs and 1 nonrandomized study did not show a difference for cumulative urine output, comparing a 6%, 6.5%, 6.9%, 7%, 8%, or 8.75% CE solution with water.[23,32–34,40,41] Authors of 4 RCTs did not show a difference in net fluid balance 1 hour after participants finished drinking a 6%, 6.9%, 7%, or 8% CE solution.[32,34,40,41] In addition, authors of 3 RCTs did not show a difference in net fluid balance 2 hours after participants finished drinking a 6%, 7%, or 8% CE solution.[34,40,41] Authors of 5 RCTs and 2 nonrandomized studies measured plasma volume (change) 35 minutes to 2 hours after participants finished drinking a 6% to 6.9% CE solution, but authors of only 2 studies showed a difference compared with water.[23,24,27–29,31,32] Authors of 1 nonrandomized study did not report a difference for hematocrit 30 minutes after participants finished drinking an 8.75% CE solution.[33]

Vital Signs. Authors of 3 RCTs and 1 nonrandomized study, including a total of 53 participants, assessed vital signs (ie, heart rate) and did not show a difference at different time points after drinking a 5.0% to 6.6% CE solution compared with water.[16,23,31,39]

Serum and Plasma Osmolality and Serum Sodium Concentration. Authors of 3 RCTs and 4 nonrandomized studies, including a total of 86 participants, assessed serum or plasma osmolality or serum sodium concentration.[23,25,27,31–33,39] Authors of 2 nonrandomized studies showed an increase in serum osmolality 1 and 1.25 hours after participants finished drinking a 6% CE solution; however, authors of 1 RCT and 2 nonrandomized studies did not report a difference in serum osmolality 30 minutes, 1 hour, or 2 hours after participants finished drinking a 6% to 8.75% CE solution.[25,27,32,33] In addition, authors of 2 RCTs and 1 nonrandomized study did not show a difference in plasma osmolality 1 to 2 hours after participants finished drinking a 5% to 6.6% CE solution compared with water.[23,31,39]

Authors of 1 RCT showed an increase in serum sodium concentration 1 hour after participants finished drinking a 6.9% CE solution compared with water.[32] However, authors of 2 nonrandomized studies did not report a difference in serum sodium concentration 1.25 hours after participants finished drinking a 6% CE solution or 30 minutes after participants finished drinking an 8.75% CE solution.[25,33]

Patient Satisfaction. Patient satisfaction was assessed as thirst perception, nausea, stomach fullness, or stomach upset. Authors of 5 RCTs and 1 nonrandomized study, including a total of 95 participants, assessed patient satisfaction.[31,32,36,39–41] Authors of 4 RCTs did not show a difference for thirst immediately after participants drank a 4%, 5% to 6%, 6%, or 8% CE solution compared with water.[36,39–41] Similarly, 3 RCTs did not show a difference for thirst 1 or 2 hours after participants finished drinking a 5% to 8% CE solution.[39–41] Authors of 1 RCT and 1 nonrandomized study did not report a difference for thirst at any time when comparing consumption of a 6.6% or 6.9% CE solution with water.[31,32] Authors of 3 RCTs and 1 nonrandomized study did not show a difference for stomach fullness immediately, 1 hour, or 2 hours after participants finished drinking a 4% to 8% CE solution.[31,36,40,41] Authors of 1 RCT did not show a difference for nausea or stomachache immediately after participants finished drinking a 4% CE solution.[36] A difference for stomach upset immediately, 1 hour, or 2 hours after participants finished drinking a 5% to 6% CE solution compared with water could not be demonstrated in 1 RCT.[39] In addition, authors of 2 RCTs did not show a difference in bloating immediately, 1 hour, or 2 hours after participants finished drinking a 5% to 6% CE solution.[39,40] Finally, authors of 1 RCT and 1 nonrandomized study did not report a difference in abdominal discomfort immediately or 1 hour after participants finished drinking a 6.6% to 6.9% CE solution.[31,32]

Advanced Care. No studies in which authors addressed the need for advanced care were identified.

0% to 3.9% CE Solutions. Results for 0% to 3.9% are summarized in Table 4.

Volume/Hydration Status. Volume/hydration status was measured as cumulative urine output, net fluid balance, plasma volume change, hematocrit, or hemoglobin.

We identified 5 RCTs and 1 nonrandomized study, including 53 participants, in which authors assessed the effect of 0% to 3.9% CE solutions on volume/hydration status compared with water.[23,26,30,35,37,38] A decrease in cumulative urine output was shown after rehydration with a 0% CE solution (saline) and a 3.7% CE solution.[30,35] However, when a 2%, 3.2%, or 3.9% CE solution was compared with water, no difference was shown.[23,37,38] In addition, no difference was shown in net fluid balance 1 hour after rehydration with a 0% (saline) to 3.9% CE solution compared with water.[30,35,37,38] No difference in net fluid balance was shown 2 hours after rehydration with a 0% (saline) or a 3.9% CE solution.[30,38] No difference was shown for plasma volume (change) 1 hour after rehydration with a 2% CE solution.[23] However, in 1 RCT, a difference in plasma volume change was shown 1 hour after rehydration with a 3.7% CE solution.[35] In 1 nonrandomized study, no difference was reported in hematocrit or hemoglobin 1 hour after rehydration with a 1.8% CE solution.[26]

Vital Signs. Authors of 1 RCT did not demonstrate a difference in heart rate after rehydration with a 2% CE solution compared with water.[23]

Table 3. Synthesis of Findings on the Effectiveness of 4% to 9% Carbohydrate-Electrolyte Solution and Certainty Assessment According to the GRADE Methodology **Continued on Next Page**

Certainty Assessment											
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (4%–9% CE Solution Versus Water)	Certainty	Importance	References
Volume/hydration status: cumulative urine output											
4	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 13 versus 13 MD: 277 mL lower $P < .05$[e]	⊕◯◯◯ Very low	Critical	Wong and Chen[31] (2011)
							1.25 h after completion of drinking	Participants: 19 versus 19 MD: 160 mL lower $P < .05$[e]			González-Alonso et al[25] (1992)
							3 h after completion of drinking	Participants: 10 versus 10 MD: 28 mL higher $P > .05$[e,f]			Niksefat et al[33] (2019)
								Participants: 13 versus 13 MD: 465.3 mL lower $P < .05$[e]			Seifert et al[27] (2006)
7	RCT	Serious[g,h]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 9 versus 9 MD: 42 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wong et al[32] (2000)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 125 mL lower $P > .05$[e]			Amano et al[23] (2019)
							2 h after completion of drinking	Participants: 38 versus 38 MD: 0 mL $P > .05$[e,f]			Volterman et al[41] (2014)
							2.5 h after completion of drinking	Participants: 10 versus 10 MD: 241 mL lower $P < .05$[e,f]			Chang et al[24] (2010)
							3 h after completion of drinking	Participants: 12 versus 12 MD: 289 mL lower $P = .03$[e]			Pérez-Idárraga and Aragón-Vargas[36] (2014)
							4 h after completion of drinking	Participants: 11 versus 11 MD: 21 mL lower $P > .05$[e]			Shirreffs et al[40] (2007)
							5 h after completion of drinking	Participants: 11 versus 11 MD: 34 mL lower $P > .05$[e]			Wijnen et al[34] (2016)
Volume/hydration status: net fluid balance											
4	RCT	Serious[g,h]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 11 versus 11 MD: 31.6 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Shirreffs et al[40] (2007)
								Participants: 9 versus 9 MD: 23 mL lower $P > .05$[e,f]			Wong et al[32] (2000)

Table 3. Continued From Previous Page

Certainty Assessment											
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (4%–9% CE Solution Versus Water)	Certainty	Importance	References
								Participants: 11 versus 11 MD: 49.7 mL higher $P > .05$[e,f]			Wijnen et al[34] (2016)
								Participants: 38 versus 38 MD: 48 mL higher $P > .05$[e,f]			Volterman et al[41] (2014)
							2 h after completion of drinking	Participants: 11 versus 11 MD: 47.4 mL lower $P > .05$[e,f]			Shirreffs et al[40] (2007)
								Participants: 11 versus 11 MD: 74.6 mL higher $P > .05$[e,f]			Wijnen et al[34] (2016)
								Participants: 38 versus 38 MD: 76 mL higher $P > .05$[e,f]			Volterman et al[41] (2014)
Volume/hydration status: plasma volume change											
2	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 13 versus 13 MD: 3.91% higher $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Seifert et al[27] (2006)
								Participants: 13 versus 13 MD: 11.0% higher $P < .05$[e]			Wong and Chen[31] (2011)
							2 h after completion of drinking	Participants: 13 versus 13 MD: 3.10% higher $P > .05$[e,f]			Seifert et al[27] (2006)
5	RCT	Serious[g,h]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	35 min after completion of drinking	Participants: 23 versus 23 MD: 0.65% lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Utter et al[28] (2010)
								Participants: 21 versus 21 MD: 0.96% lower $P > .05$[e,f]			Valiente et al[29] (2009)
							1 h after completion of drinking	Participants: 10 versus 10 MD: 3 mL higher $P > .05$[e]			Amano et al[23] (2019)
								Participants: 9 versus 9 MD: 1.0% lower $P > .05$[e,f]			Wong et al[32] (2000)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 4 mL higher $P > .05$[e]			Amano et al[23] (2019)

Table 3. Continued From Previous Page

No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (4%–9% CE Solution Versus Water)	Certainty	Importance	References
					Certainty Assessment						
1								Participants: 10 versus 10 MD: 2.7% higher $P < .05$			Chang et al[24] (2010)
					Volume/hydration status: hematocrit						
1	Nonrandomized study	Serious[a,i]	Not serious	Not serious	Serious[b,c]	None	30 min after completion of drinking	Participants: 10 versus 10 MD: 1.5% lower $P > .05$[e,f]	⊕⊕◯◯ Low	Critical	Niksefat et al[33] (2019)
					Vital signs: heart rate						
1	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	None	1 h after completion of drinking	Participants: 13 versus 13 MD: 2 beats/min lower $P > .05$[e]	⊕◯◯◯ Very low	Critical	Wong and Chen[31] (2011)
3	RCT	Serious[g,h,j]	Not serious	Not serious	Serious[c]	Publication bias strongly suspected[d]	20 min after completion of drinking	Participants: 18 versus 18 MD: 0 beats/min higher $P > .05$[e]	⊕◯◯◯ Very low	Critical	Hostler et al[16] (2010)
							2 h after completion of drinking	Participants: 12 versus 12 MD: 7.0 beats/min higher $P > .05$[e]			Kalman et al[39] (2012)
								Participants: 10 versus 10 $P > .05$			Amano et al[23] (2019)
					Serum osmolality						
3	Nonrandomized study	Serious[a,i]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[d]	30 min after completion of drinking	Participants: 10 versus 10 MD: 3.3 mOsm/kg higher $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Niksefat et al[33] (2019)
							1 h after completion of drinking	Participants: 13 versus 13 MD: 5.9 mOsm/kg higher $P < .05$[e,f]			Seifert et al[27] (2006)
							1.25 h after completion of drinking	Participants: 19 versus 19 MD: 4.5 mOsm/kg higher $P < .05$[e,f]			González-Alonso et al[25] (1992)
							2 h after completion of drinking	Participants: 13 versus 13 MD: 1.2 mOsm/kg lower $P > .05$[e,f]			Seifert et al[27] (2006)
1	RCT	Serious[g]	Not serious	Not serious	Serious[b,c]	None	1 h after completion of drinking	Participants: 9 versus 9 MD: 1 mOsm/kg higher $P > .05$[e]	⊕⊕◯◯ Low	Critical	Wong et al[32] (2000)

Table 3. Continued From Previous Page

	Certainty Assessment										
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (4%–9% CE Solution Versus Water)	Certainty	Importance	References
Plasma osmolality											
1	Nonrandomized study	Serious[g,h]	Not serious	Not serious	Serious[b,c]	None	1 h after completion of drinking	Participants: 13 versus 13 MD: 4 mOsm/kg higher $P > .05$[e]	⊕○○○ Very low	Critical	Wong and Chen[31] (2011)
2	RCT	Serious[g,h,j]	Not serious	Not serious	Serious[c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 10 versus 10 MD: 7 mOsm/kg higher $P > .05$[e,f]	⊕○○○ Very low	Critical	Amano et al[23] (2019)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 8 mOsm/kg higher $P > .05$[e,f]			Amano et al[23] (2019)
							2 h after completion of drinking	Participants: 12 versus 12 MD: 0.7 mOsm/kg lower $P > .05$[e]			Kalman et al[39] (2012)
Serum sodium concentration											
2	Nonrandomized study	Serious[a,g,h,i]	Not serious	Not serious	Serious[b,c]	None	30 min after completion of drinking	Participants: 10 versus 10 MD: 2.3 mmol/L higher $P > .05$[e,f]	⊕○○○ Very low	Critical	Niksefat et al[33] (2019)
							1.25 h after completion of drinking	Participants: 19 versus 19 $P > .05$			González-Alonso et al[25] (1992)
1	RCT	Serious[g]	Not serious	Not serious	Serious[b,c]	None	1 h after completion of drinking	Participants: 9 versus 9 MD: 4 mmol/L higher $P < .05$[e]	⊕⊕○○ Low	Critical	Wong et al[32] (2000)

Abbreviations: MD, mean difference; RCT, randomized controlled trial.
[a] Potential bias due to confounding factors.
[b] Limited sample size.
[c] Lack of data.
[d] Trial funded by industry and no further conflict-of-interest statements provided.
[e] Within-subjects design; 95% CI cannot be calculated.
[f] Data extracted from graph.
[g] Allocation concealment not described.
[h] Blinding of participants, personnel and outcome assessors not described.
[i] No repeated-measures analysis.
[j] No blinding of personnel and outcome assessors.

Table 4. Synthesis of Findings on the Effectiveness of 0% to 3.9% Carbohydrate-Electrolyte Solution and Certainty Assessment According to the GRADE Methodology Continued on Next Page

Certainty Assessment										
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (0%–3.9% CE Solution Versus Water)	Certainty	Importance	Study (Year)
Volume/hydration status: cumulative urine output											
5	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	Publication bias strongly suspected[e]	1 h after completion of drinking	Participants: 8 versus 8 MD: 25 mL lower $P > .05$[f,g]	⊕◯◯◯ Very low	Critical	Saat et al[37] (2002)
								Participants: 10 versus 10 MD: 174.5 mL lower $P < .05$[f]			Ismail et al[35] (2007)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 43 mL higher $P > .05$[f]			Amano et al[23] (2019)
							2 h after completion of drinking	Participants: 7 versus 7 MD: 115 mL lower $P > .05$[f]			Seery and Jakeman[38] (2016)
							3 h after completion of drinking	Participants: 8 versus 8 MD: 416 mL (95% confidence interval = 786, 46 mL) lower $P = .03$[g]			Evans et al[30] (2017)
Volume/hydration status: net fluid balance											
4	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 8 versus 8 MD: 248 mL higher $P = .07$[f,g]	⊕⊕◯◯ Low	Critical	Evans et al[30] (2017)
								Participants: 8 versus 8 MD: 98 g higher $P > .05$[f,g]			Saat et al[37] (2002)
								Participants: 10 versus 10 MD: 127 mL higher $P > .05$[f,g]			Ismail et al[35] (2007)
								Participants: 7 versus 7 MD: 156 mL higher $P > .05$[f,g]			Seery and Jakeman[38] (2016)
							2 h after completion of drinking	Participants: 8 versus 8 MD: 310 mL higher $P > .05$[f,g]			Evans et al[30] (2017)

Table 4. Continued From Previous Page

Certainty Assessment											
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (0%–3.9% CE Solution Versus Water)	Certainty	Importance	Study (Year)
								Participants: 7 versus 7 MD: 156 mL higher $P > .05^{f,g}$			Seery and Jakeman[38] (2016)
Volume/hydration status: plasma volume change											
3	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d,f]	Publication bias strongly suspected[e]	1 h after completion of drinking	Participants: 10 versus 10 MD: 2 mL lower $P > .05^{f}$	⊕◯◯◯ Very low	Critical	Amano et al[23] (2019)
								Participants: 10 versus 10 MD: 1.91% higher $P < .05^{f,g}$			Ismail et al[35] (2007)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 2 mL lower $P > .05^{f}$			Amano et al[23] (2019)
Volume/hydration status: hematocrit											
1	Nonrandomized study	Serious[h]	Not serious	Not serious	Serious[d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD: 2.0% lower $P = .12^{f}$	⊕⊕◯◯ Low	Critical	Lau et al[26] (2019)
Volume/hydration status: hemoglobin											
1	Nonrandomized study	Serious[h]	Not serious	Not serious	Serious[d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD: 0.3 g/dL lower $P = .08^{f}$	⊕⊕◯◯ Low	Critical	Lau et al[26] (2019)
Vital signs: heart rate											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[d]	Publication bias strongly suspected[e]	1 h after completion of drinking	Participants: 10 versus 10 $P > .05^{i}$	⊕◯◯◯ Very low	Critical	Amano et al[23] (2019)
Serum osmolality											
1	Nonrandomized study	Serious[h]	Not serious	Not serious	Serious[d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD: 9.0 mOsm/kg higher $P = .004^{f}$	⊕⊕◯◯ Low	Critical	Lau et al[26] (2019)
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD: 4 mOsm/kg higher $P < .05^{f,g}$	⊕⊕◯◯ Low	Critical	Ismail et al[35] (2007)

Table 4. Continued From Previous Page

Certainty Assessment											
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (0%–3.9% CE Solution Versus Water)	Certainty	Importance	Study (Year)
								Participants: 8 versus 8 MD: 3 mOsm/kg higher $P > .05$[f,g]			Saat et al[37] (2002)
Plasma osmolality											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	Publication bias strongly suspected[e]	1 h after completion of drinking	Participants: 10 versus 10 MD: 1 mOsm/kg higher $P > .05$[f,g]	⊕◯◯◯ Very low	Critical	Amano et al[23] (2019)
								Participants: 7 versus 7 MD: 4.0 mOsm/kg higher $P = .13$[f,g]			Seery and Jakeman[38] (2016)
							1.5 h after completion of drinking	Participants: 10 versus 10 MD: 1 mOsm/kg higher $P > .05$[f,g]			Amano et al[23] (2019)
							2 h after completion of drinking	Participants: 7 versus 7 MD: 1.0 mOsm/kg higher $P = .13$[f]			Seery and Jakeman[38] (2016)
Serum sodium concentration											
1	Nonrandomized study	Serious[h]	Not serious	Not serious	Serious[d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD: 3.4 mmol/L higher $P = .001$[f]	⊕⊕◯◯ Low	Critical	Lau et al[26] (2019)
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 8 versus 8 MD: 1 mmol/L higher $P > .05$[f,g]	⊕⊕◯◯ Low	Critical	Saat et al[37] (2002)
								Participants: 10 versus 10 MD: 2 mmol/L higher $P < .05$[f,g]			Ismail et al[35] (2007)

Abbreviations: MD, mean difference; RCT, randomized controlled trial.
[a] Allocation concealment not described.
[b] Blinding of participants, personnel, and outcome assessors not described.
[c] Limited sample size.
[d] Lack of data.
[e] Trial funded by industry and no further conflict-of-interest statements provided.
[f] Within-subjects design; 95% CI cannot be calculated.
[g] Data extracted from graph.
[h] Potential bias due to confounding factors.
[i] No raw data available. MD could not be calculated.

Serum and Plasma Osmolality and Serum Sodium Concentration. Authors of 1 RCT and 1 nonrandomized study showed increases in both serum osmolality and serum sodium concentration 1 hour after rehydration with 1.8% and 3.7% CE solutions, respectively, compared with water.[26,35] However, authors of 1 RCT did not show a difference in serum osmolality or serum sodium concentration when comparing drinking a 3.2% CE solution with water.[37] Furthermore, authors of 2 RCTs did not show a difference in plasma osmolality 1 or 2 hours after rehydration with a 2% or 3.9% CE solution.[23,38]

Patient Satisfaction. Patient satisfaction was measured as thirst perception, nausea, gastric fullness, or cramps. Authors of 2 RCTs did not show a difference for thirst, gastric fullness, cramps, or nausea immediately after or 1 hour after rehydration with a 3.2% or 3.7% CE solution compared with water.[35,37] In addition, authors of 1 RCT showed no difference for the perception of thirst at any time when comparing rehydration via a 3.9% CE solution with water.[38]

Advanced Care. No evidence was identified to address the need for advanced care.

Limitations of the Included Studies

An overview of the risk of bias of the RCTs, as assessed using the Risk of Bias 2 tool, is given in Table 5.[20] Only 1 RCT had an adequate randomization process.[32] No other authors of RCTs provided information about the randomization or allocation process. In most studies, blinding of participants, investigators, or outcome assessors was not described. It may be assumed that blinding of participants was not possible due to difference in taste between the intervention and the comparison. For objectively assessed outcomes, such as urine output, plasma volume, and hematocrit, lack of blinding would probably not pose a major problem. However, knowledge about the intervention may influence participants' subjective outcomes such as feelings of stomach fullness, thirst perception, nausea, and bloatedness. Authors of 1 study performed adequate blinding by creating a placebo drink with the same taste as the intervention drink.[32]

No concerns regarding missing outcome data were present in any of the studies. Most studies in which authors addressed subjective outcomes had high risk of bias for measurement of outcomes because participants were not blinded and, for the subjective outcomes, participants were also the outcome assessors.[35–41] Only the study by Wong et al had low risk of bias for the measurement of subjective outcomes because they used a placebo drink as a comparison.[32] Regarding the selection of reported outcomes, bias was difficult to assess because a preregistered protocol was not available for any of the studies. However, serious concerns existed for 3 studies in which authors collected urine but did not report cumulative urine output, which was an important outcome in all other studies.[28,29,39] Overall, the included studies exhibited some serious limitations in their study designs, mainly due to risk of bias in the measurement of subjective outcomes. An overview of the risk of bias of the nonrandomized studies, as assessed using Risk of Bias in Non-Randomized Studies of Interventions, is given in Table 6.[21] As the sequence of interventions was not randomly assigned in these studies, some concerns of bias existed due to confounding arising from selection bias. In the studies in which authors measured subjective outcomes (ie, patient satisfaction outcomes), a high risk of bias was present concerning the measurement of these outcomes, as they were self-reported.[25,31] One study was assessed as having high risk of bias in the selection of the reported results, as the authors did not seem to have undertaken a paired or repeated-measures analysis, and some concerns existed regarding the analytical methods used to analyze the paired data.[33]

Overall Certainty of the Body of Evidence

The certainty of the body of evidence was assessed using GRADE.[19] Details can be found in Tables 3 and 4. Overall, the certainty was downgraded (−1) for limitations in study design, based on the risk-of-bias assessment described above. Furthermore, the certainty was further downgraded because of imprecision due to limited sample sizes or lack of data. In addition, in some cases, publication bias was strongly suspected because the studies were often funded by the company providing the CE drinks, who therefore had a direct interest in the effectiveness of these rehydration beverages. This led to concerns about the independence of the decision-making in these trials. Overall, the certainty of the body of evidence was low or very low.

DISCUSSION

Exercise may lead to excessive body fluid loss of up to 1 L/h on average, with higher rates extending to 2 L/h and even 6 L/h.[25,42] To avoid serious hypohydration, with symptoms such as dizziness, decreased sweat rate, confusion, rapid breathing, or fast heartbeat, individuals need to replenish this fluid loss as soon as possible.[1] Guidance about the amount of fluid that should be taken in is available, but no clear guidance on the type of rehydrating fluid is available.[10] Many different types of fluids, such as CE solutions, milk, coconut water, and even beer, have been suggested. The choice of beverage will often be made based on what the dehydrated person is willing to drink and what is accessible at the time of need. Furthermore, first aid providers, who are often recruited to assist at first aid stations at sporting and challenge events, may not be able to determine the exact quantity or percentage of fluid loss or the volume required for adequate rehydration. In Part I of this 2-part systematic review, we searched for the best available evidence on the use of CE solutions to treat exertion-related dehydration in an out-of-hospital setting.

Of 4445 references identified, 20 studies in which authors compared CE solutions of different percentages with water were included in Part I of this systematic review. Authors of 13 studies (9 RCTs and 4 nonrandomized studies) assessed the effect of a 4.0% to 9.0% CE solution compared with water on volume/hydration status.[23–25,27–29,31–34,36,40,41] Authors of 5 studies showed a decrease in cumulative urine output that could not be demonstrated in 6 other studies.[23–25,27,31–34,36,40,41] In addition, a difference was not demonstrated for net fluid balance, plasma volume change, hematocrit, or vital signs. Authors of 2 of 4 studies showed an increase in serum osmolality 1 and 1.25 hours after rehydration using a 4.0% to 9.0% CE solution.[25,27,32,33] A difference in plasma

Table 5. **Overview of Risk of Bias of Randomized Controlled Trials Assessed With the Cochrane Risk of Bias 2 Tool[a]**

Study	Intervention	Outcomes	Randomization Process	Deviations From Intended Interventions	Missing Outcome Data	Outcome Measurement	Selection of Reported Result	Overall
Amano et al[23] (2019)	2.0% CE solution 6.5% CE solution	Volume/hydration status, hyponatremia, and vital signs	?	?	+	+	?	?
Chang et al[24] (2010)	6.6% CE solution	Volume/hydration status	?	+	+	+	?	?
Evans et al[30] (2017)	0% CE solution (50 mmol/L NaCl solution)	Volume/hydration status	?	?	+	+	?	?
Hostler et al[16] (2010)	6% CE solution	Vital signs	?	?	+	+	?	?
Ismail et al[35] (2007)	3.7% CE solution	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Kalman et al[39] (2012)	5%–6% CE solution	Volume/hydration status, hyponatremia, and vital signs	?	?	+	+	!	!
		Patient satisfaction	?	?	+	!	?	!
Pérez-Idárraga and Aragón-Vargas[36] (2014)	4% CE solution	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Saat et al[37] (2002)	3.2% CE solution	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Seery and Jakeman[38] (2016)	3.9% CE solution	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Shirreffs et al[40] (2007)	6% CE solution	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Utter et al[28] (2010)	6% CE solution	Volume/hydration status	?	?	+	+	!	!
Valiente et al[29] (2009)	6% CE solution	Volume/hydration status	?	?	+	+	?	?
Volterman et al[41] (2014)	8% CE solution	Volume/hydration status and hyponatremia	?	+	+	+	?	?
		Patient satisfaction	?	+	+	!	?	!
Wijnen et al[34] (2016)	7% CE solution	Volume/hydration status and hyponatremia	?	+	+	+	?	?
Wong et al[32] (2000)	6.9% CE solution	Volume/hydration status and hyponatremia	+	+	+	+	?	+
		Patient satisfaction	+	+	+	+	?	+

Abbreviations: CE, carbohydrate-electrolyte; Symbols: +, low risk; ?, some concerns; !, high risk.
[a] Water was used as a comparison in all studies.

Table 6. Overview of Risk of Bias of Nonrandomized Studies, Assessed With Risk of Bias in Nonrandomized Studies of Interventions Tool[a]

Study (Year)	Intervention	Outcome	Confounding	Selection of Participants Into the Study	Classification of Interventions	Deviations From Intended Interventions	Missing Data	Measurement of Outcomes	Selection of Reported Results	Overall
González-Alonso et al[25] (1992)	6% CE solution	Volume/hydration status	?	+	+	+	+	+	+	?
		Patient satisfaction	?	+	+	+	+	!	+	!
Lau et al[26] (2019)	1.8% CE solution	Volume/hydration status and hyponatraemia	?	+	+	+	+	+	+	?
Niksefat et al[33] (2019)	8.75% CE solution	Volume/hydration status and hyponatraemia	?	+	+	+	+	+	!	!
Seifert et al[27] (2006)	6% CE solution	Volume/hydration status and hyponatraemia	?	+	+	+	+	+	+	?
Wong and Chen[31] (2011)	6.6% CE solution	Volume/hydration status, hyponatraemia, and patient satisfaction	?	+	+	+	+	+	+	?
		Patient satisfaction	?	+	+	+	+	!	+	!

Abbreviations: CE, carbohydrate-electrolyte. Symbols: +, low risk; ?, some concerns; !, high risk.
[a] Water was used as a comparison in all studies.

osmolality was not demonstrated. In 1 of 3 studies, an increase in serum sodium concentration was shown.[25,32,33] No difference was observed for any of the patient satisfaction outcomes.

Authors of 6 studies assessed the effect of 0% to 3.9% CE solutions compared with water.[23,26,30,35,37,38] Authors of 2 of 5 studies reported a decrease in cumulative urine output.[23,30,35,37,38] In addition, no difference in fluid balance, hematocrit, or hemoglobin was demonstrated. Furthermore, authors of 2 studies showed an increase in serum osmolality and serum sodium concentration.[26,35] However, no difference in serum or plasma osmolality or serum sodium concentration was demonstrated in 2 other studies.[37,38] In addition, no difference was observed for any of the patient satisfaction outcomes.

Although variability was present among the identified studies, a potential beneficial effect of using CE drinks compared with water was seen for many of the reviewed outcomes. Differences noted in urine production between the various drinks used for rehydration could be a result of the composition of the drinks. Ingested drinks with high energy content (ie, from higher carbohydrate concentration) empty from the stomach more slowly than drinks containing less or no energy products. Therefore, they will potentially reduce or delay diuresis when compared with water. In other words, when large volumes of dilute drinks such as water are consumed, a fall in serum electrolyte concentrations and osmolality may occur, and urine production and excretion are stimulated. However, a high electrolyte concentration in a rehydration drink will maintain high serum or plasma electrolyte concentration and osmolality and thereby reduce the excretion of dilute urine. Consequently, low cumulative urine outputs and, hence, high net fluid balances can be associated with improved fluid retention and thus effective rehydration.[41,43]

In this systematic review, we focused on the effectiveness of ingesting fluids for replacing fluid loss after exercise. Although this strategy may be effective in a first aid setting (ie, over a short recovery period), foods are also commonly consumed after exercise to maximize total recovery.[43]

Strengths

A strength of this review is that rigorous and transparent methods using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses and GRADE methodology were used to identify the best available evidence on this topic. Moreover, this is the first systematic review in which the effectiveness of CE solutions for rehydrating individuals after exercising compared with the criterion standard of water is addressed. Finally, the findings from this review were used as a direct scientific basis by the ILCOR First Aid Task Force to develop the Consensus on Science with Treatment Recommendations.[44,45] This consensus document allows international first aid guideline organizations to provide recommendations for professional and recreational athletes, their families and coaches, and first aid responders.

Limitations

This study had several limitations. We identified only low to very low certainty evidence because of limitations in study design, imprecise results (due to limited sample sizes and lack of data), and publication bias. Furthermore, all studies were conducted in a laboratory environment, with exertion-related dehydration induced by asking participants to strictly follow standardized exercising protocols, with or without a thermal vest. Studies of rehydration after extreme events such as ultramarathons were not identified.

The rehydration protocols varied greatly between studies. Differences existed not only in the percentage of carbohydrates in the study solutions but also in the timing of ingestion of the fluid during or after exercise and in the volume ingested (ranging from 100% to 200% of the body weight loss during exercise). In addition, different rehydration intervals were used, and outcomes were measured at different times during or after completion of drinking. Therefore, we decided a priori to only include times after completion of drinking rehydration solutions. Given that this review focused on the out-of-hospital setting after exertion-related dehydration, relevant times were limited to 1 and 2 hours after participants completed drinking rehydration solutions; we excluded any later time points except for cumulative urine volume, for which the endpoint of the study was included and varied between 2 and 5 hours, during which participants remained in the laboratory and refrained from consuming any foods or drinks other than what was included in the study. For patient satisfaction outcomes, we included times beginning immediately after completion of drinking until 2 hours after completion of drinking rehydration solutions. We also specifically looked at sodium levels reported after rehydration in the included studies.

CONCLUSIONS

Drinking 0% to 3.9% and especially 4% to 9% CE solutions may be effective for restoring volume/hydration status after exercising when whole foods are not available. Limited evidence suggests that rehydration for exertion-related dehydration or hypohydration using commercial 4% to 9% CE drinks or, if these are not available, 0% to 3.9% CE drinks does occur and is acceptable. However, if clean, drinkable water is available, its cost, relative to CE drinks, makes it an acceptable alternative.

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REFERENCES

1. Spano MA, Kruskall LJ, Thomas DT. *Nutrition for Sport, Exercise, and Health*. Human Kinetics; 2023.
2. Kenefick RW, Sawka MN. Heat exhaustion and dehydration as causes of marathon collapse. *Sports Med.* 2007;37(4–5):378–381. doi:10.2165/00007256-200737040-00027
3. Adams WM, Ferraro EM, Huggins RA, Casa DJ. Influence of body mass loss on changes in heart rate during exercise in the heat: a systematic review. *J Strength Cond Res.* 2014;28(8):2380–2389. doi:10.1519/JSC.0000000000000501
4. Crandall CG, Gonzalez-Alonso J. Cardiovascular function in the heat-stressed human. *Acta Physiol (Oxf).* 2010;199(4):407–423. doi:10.1111/j.1748-1716.2010.02119.x
5. Masento NA, Golightly M, Field DT, Butler LT, van Reekum CM. Effects of hydration status on cognitive performance and mood. *Br J Nutr.* 2014;111(10):1841–1852. doi:10.1017/S0007114513004455
6. Savoie FA, Kenefick RW, Ely BR, Cheuvront SN, Goulet ED. Effect of hypohydration on muscle endurance, strength, anaerobic power and capacity and vertical jumping ability: a meta-analysis. *Sports Med.* 2015;45(8):1207–1227. doi:10.1007/s40279-015-0349-0
7. Carter R III, Cheuvront SN, Williams JO, et al. Epidemiology of hospitalizations and deaths from heat illness in soldiers. *Med Sci Sports Exerc.* 2005;37(8):1338–1344. doi:10.1249/01.mss.0000174895
8. James LJ, Shirreffs SM. Effect of electrolyte addition to rehydration drinks consumed after severe fluid and energy restriction. *J Strength Cond Res.* 2015;29(2):521–527. doi:10.1519/JSC.0000000000000657
9. Osterberg KL, Pallardy SE, Johnson RJ, Horswill CA. Carbohydrate exerts a mild influence on fluid retention following exercise-induced dehydration. *J Appl Physiol (1985).* 2010;108(2):245–250. doi:10.1152/japplphysiol.91275.2008
10. Thomas DT, Erdman KA, Burke LM. Position of the Academy of Nutrition and Dietetics, Dietitians of Canada, and the American College of Sports Medicine: nutrition and athletic performance. *J Acad Nutr Diet.* 2016;116(3):501–528. doi:10.1016/j.jand.2015.12.006. Published correction appears in *J Acad Nutr Diet*. 2017;117(1):146. doi:10.1016/j.jand.2016.11.008
11. McDermott BP, Anderson SA, Armstrong LE, et al. National Athletic Trainers' Association position statement: fluid replacement for the physically active. *J Athl Train.* 2017;52(9):877–895. doi:10.4085/1062-6050-52.9.02
12. Kenefick RW, Cheuvront SN. Hydration for recreational sport and physical activity. *Nutr Rev.* 2012;70(suppl 2):S137–S142. doi:10.1111/j.1753-4887.2012.00523.x
13. De Brier N, Borra V, Berry DC, Zideman D, Singletary EM, De Buck E; International Liaison Committee on Resuscitation First Aid Task Force. A systematic review on oral rehydration beverages for treating exercise-associated dehydration, part II: the effectiveness of alternatives to carbohydrate-electrolyte drinks. *J Athl Train.* Published online December 20, 2023. doi:10.4085/1062-6050-0686.22
14. Maughan RJ, Watson P, Cordery PA, et al. A randomized trial to assess the potential of different beverages to affect hydration status: development of a beverage hydration index. *Am J Clin Nutr.* 2016;103(3):717–723. doi:10.3945/ajcn.115.114769
15. Casa DJ, DeMartini JK, Bergeron MF, et al. National Athletic Trainers' Association position statement: exertional heat illnesses. *J Athl Train.* 2015;50(9):986–1000. doi:10.4085/1062-6050-50.9.07. Published correction appears in *J Athl Train*. 2017;52(4):401. doi:10.4085/1062-6050-52.4.07
16. Hostler D, Bednez JC, Kerin S, et al. Comparison of rehydration regimens for rehabilitation of firefighters performing heavy exercise in thermal protective clothing: a report from the Fireground Rehab Evaluation (FIRE) trial. *Prehosp Emerg Care.* 2010;14(2):194–201. doi:10.3109/10903120903524963
17. Nose H, Mack GW, Shi XR, Nadel ER. Role of osmolality and plasma volume during rehydration in humans. *J Appl Physiol (1985)*. 1988;65(1):325–331. doi:10.1152/jappl.1988.65.1.325
18. GRADEpro GDT: GRADEpro Guideline Development Tool [Software]. McMaster University and Evidence Prime; 2022. Accessed May 17, 2022. https://www.gradepro.org/

19. Guyatt GH, Oxman AD, Vist GE, et al; GRADE Working Group. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ.* 2008;336(7650):924–926. doi:10.1136/bmj.39489.470347.AD
20. Sterne JAC, Savovic J, Page MJ, et al. RoB 2: a revised tool for assessing risk of bias in randomised trials. *BMJ.* 2019;366:l4898. doi:10.1136/bmj.l4898
21. Schunemann HJ, Cuello C, Akl EA, et al; GRADE Working Group. GRADE guidelines: 18. How ROBINS-I and other tools to assess risk of bias in nonrandomized studies should be used to rate the certainty of a body of evidence. *J Clin Epidemiol.* 2019;111:105–114. doi:10.1016/j.jclinepi.2018.01.012
22. Santesso N, Glenton C, Dahm P, et al; GRADE Working Group. GRADE guidelines 26: informative statements to communicate the findings of systematic reviews of interventions. *J Clin Epidemiol.* 2020;119:126–135. doi:10.1016/j.jclinepi.2019.10.014
23. Amano T, Sugiyama Y, Okumura J, et al. Effects of isomaltulose ingestion on postexercise hydration state and heat loss responses in young men. *Exp Physiol.* 2019;104(10):1494–1504. doi:10.1113/EP087843
24. Chang CQ, Chen YB, Chen ZM, Zhang LT. Effects of a carbohydrate-electrolyte beverage on blood viscosity after dehydration in healthy adults. *Chin Med J (Engl).* 2010;123(22):3220–3225.
25. González-Alonso J, Heaps CL, Coyle EF. Rehydration after exercise with common beverages and water. *Int J Sports Med.* 1992;13(5):399–406. doi:10.1055/s-2007-1021288
26. Lau WY, Kato H, Nosaka K. Water intake after dehydration makes muscles more susceptible to cramp but electrolytes reverse that effect. *BMJ Open Sport Exerc Med.* 2019;5(1):e000478. doi:10.1136/bmjsem-2018-000478. Published correction appears in *BMJ Open Sport Exerc Med*. 2019;5(1):e000478corr1. doi:10.1136/bmjsem-2018-000478corr1
27. Seifert J, Harmon J, DeClercq P. Protein added to a sports drink improves fluid retention. *Int J Sport Nutr Exerc Metab.* 2006;16(4):420–429. doi:10.1123/ijsnem.16.4.420
28. Utter AC, Quindry JC, Emerenziani GP, Valiente JS. Effects of rooibos tea, bottled water, and a carbohydrate beverage on blood and urinary measures of hydration after acute dehydration. *Res Sports Med.* 2010;18(2):85–96. doi:10.1080/15438620903321102
29. Valiente JS, Utter AC, Quindry JC, Nieman DC. Effects of commercially formulated water on the hydration status of dehydrated collegiate wrestlers. *J Strength Cond Res.* 2009;23(8):2210–2216. doi:10.1519/JSC.0b013e3181bac56e
30. Evans GH, Miller J, Whiteley S, James LJ. A sodium drink enhances fluid retention during 3 hours of post-exercise recovery when ingested with a standard meal. *Int J Sport Nutr Exerc Metab.* 2017;27(4):344–350. doi:10.1123/ijsnem.2016-0196
31. Wong SH, Chen Y. Effect of a carbohydrate-electrolyte beverage, lemon tea, or water on rehydration during short-term recovery from exercise. *Int J Sport Nutr Exerc Metab.* 2011;21(4):300–310. doi:10.1123/ijsnem.21.4.300
32. Wong SH, Williams C, Adams N. Effects of ingesting a large volume of carbohydrate-electrolyte solution on rehydration during recovery and subsequent exercise capacity. *Int J Sport Nutr Exerc Metab.* 2000;10(4):375–393. doi:10.1123/ijsnem.10.4.375
33. Niksefat M, Akbari-Fakhrabadi M, Mousavi Z, Ziaee V, Fallah J, Memari AH. Yogurt drink effectively rehydrates athletes after a strenuous exercise session. *Acta Med Bulg.* 2019;46(1):43–49. doi:10.2478/amb-2019-0008
34. Wijnen AH, Steennis J, Catoire M, Wardenaar FC, Mensink M. Post-exercise rehydration: effect of consumption of beer with varying alcohol content on fluid balance after mild dehydration. *Front Nutr.* 2016;3:45. doi:10.3389/fnut.2016.00045
35. Ismail I, Singh R, Sirisinghe RG. Rehydration with sodium-enriched coconut water after exercise-induced dehydration. *Southeast Asian J Trop Med Public Health.* 2007;38(4):769–785.
36. Pérez-Idárraga A, Aragón-Vargas LF. Postexercise rehydration: potassium-rich drinks versus water and a sports drink. *Appl Physiol Nutr Metab.* 2014;39(10):1167–1174. doi:10.1139/apnm-2013-0434
37. Saat M, Singh R, Sirisinghe RG, Nawawi M. Rehydration after exercise with fresh young coconut water, carbohydrate-electrolyte beverage and plain water. *J Physiol Anthropol Appl Human Sci.* 2002;21(2):93–104. doi:10.2114/jpa.21.93
38. Seery S, Jakeman P. A metered intake of milk following exercise and thermal dehydration restores whole-body net fluid balance better than a carbohydrate-electrolyte solution or water in healthy young men. *Br J Nutr.* 2016;116(6):1013–1021. doi:10.1017/S0007114516002907
39. Kalman DS, Feldman S, Krieger DR, Bloomer RJ. Comparison of coconut water and a carbohydrate-electrolyte sport drink on measures of hydration and physical performance in exercise-trained men. *J Int Soc Sports Nutr.* 2012;9(1):1. doi:10.1186/1550-2783-9-1
40. Shirreffs SM, Watson P, Maughan RJ. Milk as an effective post-exercise rehydration drink. *Br J Nutr.* 2007;98(1):173–180. doi:10.1017/S0007114507695543
41. Volterman KA, Obeid J, Wilk B, Timmons BW. Effect of milk consumption on rehydration in youth following exercise in the heat. *Appl Physiol Nutr Metab.* 2014;39(11):1257–1264. doi:10.1139/apnm-2014-0047
42. Baker LB. Sweating rate and sweat sodium concentration in athletes: a review of methodology and intra/interindividual variability. *Sports Med.* 2017;47(suppl 1):111–128. doi:10.1007/s40279-017-0691-5
43. Maughan RJ. Fluid and electrolyte loss and replacement in exercise. *J Sports Sci.* 1991;9(sup 1):117–142. doi:10.1080/02640419108729870
44. Wyckoff MH, Singletary EM, Soar J, et al; COVID-19 Working Group. 2021 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: summary from the Basic Life Support; Advanced Life Support; Neonatal Life Support; Education, Implementation, and Teams; First Aid Task Forces; and the COVID-19 Working Group. *Resuscitation.* 2021;169:229–311. doi:10.1016/j.resuscitation.2021.10.040
45. Wyckoff MH, Singletary EM, Soar J, et al; Collaborators. 2021 International Consensus on Cardiopulmonary Resuscitation and Emergency Cardiovascular Care Science With Treatment Recommendations: summary from the Basic Life Support; Advanced Life Support; Neonatal Life Support; Education, Implementation, and Teams; First Aid Task Forces; and the COVID-19 Working Group. *Circulation.* 2022;145(9):e645–e721. doi:10.1161/CIR.0000000000001017. Published correction appears in *Circulation*. 2022;145(9):e760. doi:10.1161/CIR.0000000000001050

SUPPLEMENTAL MATERIAL

Supplemental Appendix. Search Strategy.

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