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Oral Rehydration Beverages for Treating Exercise-Associated Dehydration: A Systematic Review, Part II. The Effectiveness of Alternatives to Carbohydrate-Electrolyte Drinks

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Objective: Dehydration associated with exertion is a commonly encountered condition in the first aid setting, particularly at outdoor sporting events. Part I of this systematic review demonstrated that commercial sports drinks can be suggested for effective restoration of fluid balance in dehydrated people. In part II, we perform a systematic review to compare alternative liquids, such as cow's milk, beer, and coconut water, with water for effective oral rehydration after prolonged exercise.

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

Study Selection: Controlled experimental and observational studies involving adults and children were included when dehydration was induced by physical exercise and oral rehydration fluids were administered and compared with regular water. No additional food intake accompanied the rehydration drinks or water. Articles in all languages were included if an English abstract was available.

Data Extraction: Study design, study population, intervention, outcome measures, and study limitations were extracted from each included article.

Data Synthesis: Of 3485 articles screened, 11 articles in which authors compared skim or low-fat cow's milk, coconut water, or beer (0%–5% alcohol) with water were included. Authors of 4 studies showed that drinking skim or low-fat milk, without additional food intake, led to improved volume/hydration status compared with drinking water. Authors of 3 trials showed no differences at multiple times for outcomes related to volume/hydration status after rehydration with fresh coconut water compared with water. Evidence to recommend beer (0%–5% alcohol) for rehydration is insufficient.

Conclusions: Consuming skim or low-fat cow's milk without additional food intake as compared with water appears to improve volume/hydration status in people with exercise-induced dehydration. However, evidence is of very low certainty and should be interpreted with caution.

Key Words: fluid balance, milk, beer, coconut water, alcohol

Key Points

- Drinking skim or low-fat cow's milk for rehydration after exercise has a potential beneficial effect compared with drinking water for many of the reviewed outcomes.
- No differences in urine output and fluid balance were identified when comparing drinking coconut water, without additional food intake, with drinking water.
- Evidence related to drinking beer (0%–5% alcohol) for oral rehydration after exercise is insufficient.

Dehydration refers to the process of losing body water through urine, respiration, feces (especially with diarrhea), or vomiting. With exercise-associated dehydration, body water is mainly lost through sweating.[1] During prolonged and continuous exercise, sweat loss often exceeds fluid intake, and even low levels of dehydration (about 2% of the body mass) can impair thermoregulation and cause cardiovascular strain.[2,3] When allowed to progress, dehydration can lead to impaired physical and cognitive performance, syncope due to hypotension, and finally, potentially fatal heat-related illness.[4,5] In such situations, promoting postexercise oral fluid rehydration to restore fluid and electrolyte balance is of utmost importance. For rapid and complete rehydration, both the fluid volume and composition are key.

Both the National Athletic Trainers' Association (NATA) and the American College of Sports Medicine have published recommendations on fluid replacement for physically active people.[1,6]

In addition to replacing volume, effective rehydration requires replacement of electrolytes lost through sweating.[7–9] The major electrolytes lost in sweat are sodium, chloride, and to a lesser extent, potassium.[10] Although water is commonly used for rehydration after exercise, it typically lacks dietary sodium, resulting in dilution of plasma sodium concentration and osmolality, reducing the drive to drink and stimulating increased urine output. Anything that stimulates urine flow will delay or even prevent the rehydration process. Electrolyte imbalances can result and be exacerbated when excessive loss of sodium in sweat occurs and fluid is replaced with a low-sodium beverage (<0.12 g of sodium per 100 mL).[11] These strategies all surround rehydration without food.

Various urine biomarkers, including urine volume, can be used to evaluate hydration status. *Urine volume* refers to the amount of urine produced by the kidneys and excreted from the body within a designated timeframe. Numerous factors, such as fluid intake, hydration status, environmental conditions, physical activity levels, and certain medical conditions can substantially influence urine volume. Generally, individuals in good health produce an average urine volume ranging from approximately 0.8 to 2 L per day.[12] This quantitative measure provides valuable information about the amount of fluid excreted by the urinary system and proves biologically important in assessing hypohydration.[13,14]

Foods are commonly consumed after exercising, and the electrolyte and water contents of meals contribute to fluid replacement and can enhance fluid retention. However, although the intake of food may influence rehydration, in this systematic review, we focus on the intake of fluids without the intake of food to assess the rehydration properties of different types of fluids.

No recent evidence-based guideline is available regarding the effectiveness of a specific type of rehydrating fluid for treating exercise-associated dehydration. In part I of this review, Borra et al identified very low certainty evidence that drinking 4.0% to 9.0% carbohydrate-electrolyte (CE) fluids after exertion-related dehydration may be effective for restoring hydration status and electrolyte balance.[15] Commercial sports drinks, however, are an expensive option and are often not affordable for athletes, particularly those in low-income countries. Alternative beverages (eg, tea, milk, or coconut water) have been suggested for oral rehydration because they might be readily available in first aid settings, and some individuals may have a cultural preference for them.[16] Skim or low-fat cow's milk has a balanced electrolyte (about 15–20 mmol/L) and macronutrient composition (about 30–40 g of protein per liter, 50–55 g of carbohydrates per liter, and 1–2 g of fat per liter).[17,18] Coconut water has an especially high potassium concentration (about 50–55 mmol/L) but a relatively low sodium concentration (about 5–10 mmol/L).[19,20] It has a carbohydrate content of about 35 to 45 g/kg and has little protein (1–7 g/kg) and fat (1–2 g/kg).[21] Recently, beer has been promoted via commercial advertisements as a good choice for rehydration, but support for this claim is limited.[22] With the exception of the levels of sodium and alcohol, beer has good nutritional properties: 20 to 30 g of carbohydrates per kilogram, 2 to 5 g of protein per kilogram, and little if any fats.[23] However, excessive intake of alcohol in the recovery period is discouraged due to its diuretic effect.

The purpose of this portion of our systematic review was to identify alternatives to CE drinks that can restore fluid balance and relieve symptoms associated with dehydration within 1 to 2 hours after physical activity, without additional food intake. The following research question was formulated in population, intervention, comparison, outcome (PICO) format: Among adults and children with exertion-related dehydration, does drinking alternative beverages to CE drinks compared with drinking water change volume/hydration status, heart rate, serum sodium, serum or plasma osmolality, or need for advanced medical care and patient satisfaction? This question was prioritized by the First Aid Task Force of the International Liaison Committee on Resuscitation (ILCOR), and the systematic review was performed as part of the development of evidence-based treatment recommendations.

METHODS

Search Strategy

This systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses checklist.[24] The search strategy is presented in part I of this review.[15] The protocol was submitted at PROSPERO (CRD42020153077).

Selection Criteria

Screening of titles and abstracts, full texts of articles, and reference lists of included studies was described in part I of this systematic review.[15] Studies were eligible if authors addressed the PICO question and met the inclusion criteria outlined in Table 1. In addition, we did not report on data from studies in which authors reported mean values but no SDs, effect sizes, and *P* values. Moreover, for most outcomes, we limited relevant time points to between 1 and 2 hours after completion of drinking, essentially as described previously by Borra et al.[15] Finally, the systematic review was limited to rehydration drinks for which more than 1 study was identified.

Data Extraction

Data extraction was described in part I of this study.[15]

Certainty Assessment

The certainty assessment was described previously.[15]

RESULTS

Study Selection

Of 3485 articles identified, 10 randomized controlled trials (RCTs)[17,19,20,22,23,25–29] and 1 nonrandomized study were included in part II of this systematic review. Table 2 summarizes the characteristics and outcome measures of the included studies. Of these studies, 73% (n = 8)[17,18,22,23,25,27–29] were published between 2011 and 2021, with 27% (n = 3)[17,18,25] published between 2016 and 2021. All studies involved human volunteers exercising in a

Table 1. Inclusion and Exclusion Criteria

	Inclusion	Exclusion
Population	Adults and children with dehydration induced by physical exercise directly leading to a certain amount of sweat loss (measured by percentage of body mass loss).	Adults and children with dehydration with urological, gastrointestinal, circulatory, and neurological disorders. Studies in which dehydration status was passively induced by sauna or sweatbox.
Intervention	Oral alternative rehydration liquids that are widely or commonly available such as milk, yogurt drinks, tea, coconut water, and beer. The fluids should have been consumed after exercising and not before or during the dehydration phase.	Carbohydrate-electrolyte solutions (see part I of this study) and any fluids which were administered intravenously.[15]
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. The 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.

controlled environment. No evidence from extreme sporting events met the strict selection criteria. Participants included 148 physically active adolescents or young adults; authors of only 3 studies[26,27,29] included female participants (n = 27; 18.2%). In total, 3 different comparisons of interest were reported in the included studies. Authors of 4 studies[17,18,26,27] elaborated on the potential of skim or low-fat milk compared with water, 4 studies[19,20,28,29] on coconut water, and 3 studies[22,23,25] on beer (with different percentages of alcohol).

Synthesis of Findings

The synthesis of findings from all included studies is summarized in Tables 3 through 5, and a narrative overview of the results is given below. Given that the individual participant data were not available from the studies, meta-analyses could not be performed.[30] Furthermore, across all comparisons and outcomes, marked heterogeneity in study design and outcomes precluded meta-analysis.

Beer With 0% to 5% Alcohol. We identified 3 RCTs, including 38 participants, in which authors evaluated the effect of beer on the volume/hydration status after exercise-associated dehydration compared with water (Table 3).[22,23,25] This critical outcome was measured as cumulative urine output, net fluid balance, plasma volume change, and hematocrit percentage. Authors of 2 studies did not demonstrate a difference in cumulative urine output from rehydration with beer with regular (4.5%–5%), low (low-alcohol; 0.5%–2%), or no alcohol content (nonalcohol; 0%) compared with water.[23,25] Flores-Salamanca and Aragón-Vargas showed that drinking regular beer (4.5%–5%) compared with water resulted in an increase in cumulative urine output.[22] Consumption of regular beer for rehydration compared with water was not shown to affect net fluid balance, change in plasma volume, or hematocrit percentage.[23,25] Similarly, low- or nonalcoholic beer was not shown to improve net fluid balance after rehydration compared with water.[25] Jiménez-Pavón et al found no difference in serum sodium concentration after rehydration with regular beer compared with water.[23] We did not identify any evidence to address the outcomes of heart rate, need for advanced care, or patient satisfaction.

Skim or Low-Fat Cow's Milk. Authors of 3 RCTs and 1 nonrandomized study including 68 participants studied the rehydration potential of skim or low-fat cow's milk after exercising compared with water (Table 4).[17,18,26,27] Authors of all included studies showed a decrease in cumulative urine output after rehydration with skim or low-fat milk compared with water. Authors of 3 studies showed an increase in net fluid balance after 1 hour (mean difference [MD] = 655, 368, and 111 mL higher) and 2 hours (MD = 675, 621, and 179 mL higher) after rehydration with skim milk compared with water.[17,26,27] In addition, Sayer et al found an increase in net fluid balance at 30 minutes to 1.5 hours after rehydration with low-fat milk (MD = 0.26 L higher) or at 1.5 to 2.5 hours after rehydration with low-fat milk (MD = 0.36 L higher) compared with water.[18]

Authors of 2 studies, including 19 participants, evaluated plasma osmolality.[17,18] Sayer et al reported an increase in plasma osmolality at 1.5 to 2.5 hours after rehydration with skim milk compared with water (MD = 3 mOsm/kg higher), but Seery and Jakeman did not demonstrate a difference in plasma osmolality at 1 and 2 hours after rehydration.[17,18] Authors of all 4 studies also evaluated the patient satisfaction of the rehydration drinks.[17,18,26,27]

No difference between milk and water could be demonstrated in the perception of thirst at any time point.[17,18,26,27]

Table 2. Characteristics of Included Studies Continued on Next Page

Study (Year) and Country	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Flores-Salamanca and Aragón-Vargas[22] (2014)	Costa Rica	RCT (within subjects)	11 apparently healthy, physically active male college students (age = 24.4 ± 3.7 y, height = 1.78 ± 0.07 m, BM = 75.4 ± 0.2 kg). Dehydration by cycling: about 2% BM loss.	Interventions: low-alcoholic beer[a] (0.5% alcohol), regular beer[b] (4.6% alcohol) Control: water	Urine output (mL) Net fluid balance (mL)
Ismail et al[19] (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: about 3% BM loss.	Intervention: young coconut water Control: plain water	Cumulative urine output (mL) Net fluid balance (mL) Plasma volume change Serum Na concentration Serum osmolality Patient satisfaction (thirst, nausea, fullness, and stomach upset)
Jiménez-Pavón et al[23] (2015)	Spain	RCT (within subjects)	16 physically active men (age = 21.1 ± 1.4 y, height = 1.78 ± 0.04 m, BM = 74.1 ± 6.5 kg). Dehydration by running: about 2.5% of BM.	Intervention: regular beer (4.5% alcohol) Control: water	Urine output (mL) Fluid balance (mL) Hematologic profile (hematocrit and hemoglobin) Serum Na concentration Plasma volume change
Kalman et al[28] (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 or jogging: 2%–3% BM loss.	Interventions: pure coconut water[c], coconut water from concentrate Control: supermarket brand bottled water	Plasma osmolality Heart rate Blood pressure Patient satisfaction (thirst, bloatedness, and stomach upset)
Pérez-Idárraga and Aragón-Vargas[29] (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 running and cycling: about 2% BM loss.	Intervention: fresh coconut water Control: bottled water[d]	Cumulative urine volume (mL) Net fluid balance (g) Patient satisfaction (thirst, nausea, fullness, and stomachache)
Saat et al[20] (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 exercising: 2.5%–3% BM loss.	Intervention: fresh young coconut water Control: plain water	Cumulative urine volume (mL) Net fluid balance (g) Serum Na concentration Serum osmolality Patient satisfaction (thirst, nausea, fullness, and stomach upset)
Sayer et al[18] (2020)	Australia	Nonrandomized (within subjects)	12 male participants (age = 23.5 ± 5.3 y, height = 179 ± 6 cm, BM = 77.3 ± 9.6 kg). Dehydration by cycling: ≥1.8% BM loss.	Intervention: low-fat cow's milk[e] Control: water	Cumulative urine output (g) Net fluid balance (L) Plasma osmolality Patient satisfaction (bloatedness, fullness, and thirst)

Table 2. Continued From Previous Page

Study (Year) and Country	Country	Study Design	Population	Relevant Comparison(s)	Relevant Outcomes
Seery and Jakeman[17] (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: ≥1.8% of BM loss.	Interventions: milk[f] (0.1% skim milk) Control: water[g]	Cumulative urine volume (mL) Net fluid balance (mL) Plasma osmolality Patient satisfaction (thirst and bloatedness)
Shirreffs et al[26] (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: 1.7% of BM loss.	Intervention: milk[h] (0.2% fat) Control: water[i]	Cumulative urine volume (mL) Net fluid balance (mL) Patient satisfaction (thirst, bloatedness, and fullness)
Volterman et al[27] (2014)	Canada	RCT (within subjects)	38 volunteers (19 male, 19 female): 20 pre- 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 mid- 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 exercising: 2% of BM loss.	Intervention: skim milk (0.1% skim milk[j]) Control: plain water	Cumulative urine output (mL) Body fluid balance (mL) Patient satisfaction (thirst and stomach fullness)
Wijnen et al[25] (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 kg/m^2). Dehydration by cycling: 1% loss of BM.	Interventions: nonalcoholic beer[k] (0.0% alcohol), low-alcoholic beer[l] (2.0% alcohol), pilsner[m] (5.0% alcohol) Control: tap water	Cumulative urine output (mL) Fluid balance (mL)

Abbreviations: BM, body mass; RCT, randomized controlled trial.
[a] Kaiser.
[b] Imperial.
[c] VitaCoco; The Vita Coco Company.
[d] Cristal; Florida Ice and Farm Company.
[e] Maleny Dairies.
[f] Glanbia Consumer Foods Ireland Plc.
[g] Centra; Musgrave Retail Partners Ireland.
[h] Tesco Ltd.
[i] Aqua Pura; Roxane UK.
[j] Beatrice; Parmalat.
[k] Amstel 0.0; Heineken.
[l] Lingen's Blond; Heineken.
[m] Amstel Pilsner; Heineken.

Table 3. Synthesis of Findings on the Effectiveness of Beers With Different Alcohol Levels and Certainty Assessment According to 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 (Beer Versus Water)	Certainty	Importance	Study (Year)
No alcohol: volume/hydration status (cumulative urine output)											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[c]	Publication bias strongly suspected[d]	5 h after completion of drinking	Participants: 11 versus 11 MD = 16 mL lower $P > .05$[e]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
No alcohol: volume/hydration status (net fluid balance)											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 11 versus 11 MD = 37 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
							2 h after completion of drinking	Participants: 11 versus 11 MD = 31 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
Low alcohol: volume/hydration status (cumulative urine output)											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	Publication bias strongly suspected[d]	3 h after completion of drinking	Participants: 11 versus 11 MD = 29 mL lower $P > .05$[e]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
							5 h after completion of drinking	Participants: 11 versus 11 MD = 29 mL lower $P > .05$[e]	⊕◯◯◯ Very low	Critical	Flores-Salamanca and Aragón-Vargas[22] (2014)
Low alcohol: volume/hydration status (net fluid balance)											
1	RCT	Serious[b]	Not serious	Not serious	Serious[c]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 11 versus 11 MD = 12 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
							2 h after completion of drinking	Participants: 11 versus 11 MD = 16 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
Regular: volume/hydration status (cumulative urine output)											
3	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	Publication bias strongly suspected[d]	At completion of drinking	Participants: 16 versus 16 MD = 58 mL lower $P = .70$[e]	⊕◯◯◯ Very low	Critical	Jiménez-Pavón et al[23] (2015)
							3 h after completion of drinking	Participants: 11 versus 11 MD = 444 mL higher $P = .043$[e]	⊕◯◯◯ Very low	Critical	Flores-Salamanca and Aragón-Vargas[22] (2014)
							5 h after completion of drinking	Participants: 11 versus 11 MD = 102 mL higher $P > .05$[e]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)

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 (Beer Versus Water)	Certainty	Importance	Study (Year)
Regular: volume/hydration status (net fluid balance)											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	Publication bias strongly suspected[d]	1 h after completion of drinking	Participants: 11 versus 11 MD = 152 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
							2 h after completion of drinking	Participants: 11 versus 11 MD = 130 mL lower $P > .05$[e,f]	⊕◯◯◯ Very low	Critical	Wijnen et al[25] (2016)
								Participants: 16 versus 16 MD = 100 mL lower $P = .51$[e]	⊕◯◯◯ Very low	Critical	Jiménez-Pavón et al[23] (2015)
Regular: volume/hydration status (plasma volume change)											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	None	At completion of drinking	Participants: 16 versus 16 MD: 0.2% lower $P = .44$[e]	⊕⊕◯◯ Low	Critical	Jiménez-Pavón et al[23] (2015)
Regular: volume/hydration status (hematocrit)											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	None	At completion of drinking	Participants: 16 versus 16 MD = 0.5% lower $P = .45$[e]	⊕⊕◯◯ Low	Critical	Jiménez-Pavón et al[23] (2015)
Regular: serum sodium concentration											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,g]	None	At completion of drinking	Participants: 16 versus 16 MD = 0 mEq/L $P = .95$[e]	⊕⊕◯◯ Low	Critical	Jiménez-Pavón et al[23] (2015)

Abbreviations: GRADE, Grading of Recommendations, Assessment, Development and Evaluation; RCT, randomized controlled trial; MD, mean difference.
[a] Allocation concealment not described.
[b] No blinding of participants, personnel, and outcome assessors or blinding not described.
[c] Lack of data.
[d] Trial funded by industry, and no further conflict-of-interest statement provided.
[e] Within-subjects design; 95% CI cannot be calculated.
[f] Data extracted from graph.
[g] Limited sample size.

Table 4. **Synthesis of Findings on the Effectiveness of Skim or Low-Fat Milk and Certainty Assessment According to 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 (Skim or Low-Fat Milk Versus Water)	Certainty	Importance	Study (Year)
Volume/hydration status (cumulative urine output)											
1	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	None	1.5–2.5 h after completion of drinking	Participants: 12 versus 12 MD = 368 mL lower $P < .01$[d]	⊕◯◯◯ Very low	Critical	Sayer et al[18] (2020)
3	RCT	Serious[e,f]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[g]	2 h after completion of drinking	Participants: 38 versus 38 MD = 175 mL lower $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Volterman et al[27] (2014)
								Participants: 7 versus 7 MD = 635 mL lower $P = .02$[d]	⊕◯◯◯ Very low	Critical	Seery and Jakeman[17] (2016)
							4 h after completion of drinking	Participants: 11 versus 11 MD = 594 mL lower $P < .05$[d]	⊕◯◯◯ Very low	Critical	Shirreffs et al[26] (2007)
Volume/hydration status (net fluid balance)											
1	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	None	0.5–1.5 h after completion of drinking	Participants: 12 versus 12 MD = 0.26 mL higher $P = .001$[d]	⊕◯◯◯ Very low	Critical	Sayer et al[18] (2020)
							1.5–2.5 h after completion of drinking	Participants: 12 versus 12 MD = 0.36 mL higher $P < .001$[d]	⊕◯◯◯ Very low	Critical	Sayer et al[18] (2020)
3	RCT	Serious[e,f]	Not serious	Not serious	Serious[b,c]	Publication bias strongly suspected[f]	1 h after completion of drinking	Participants: 7 versus 7 MD = 655 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Seery and Jakeman[17] (2016)
								Participants: 11 versus 11 MD = 368 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Shirreffs et al[26] (2007)
								Participants: 38 versus 38 MD = 111 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Volterman et al[27] (2014)
							2 h after completion of drinking	Participants: 7 versus 7 MD = 675 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Seery and Jakeman[17] (2016)
								Participants: 11 versus 11 MD = 621 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Shirreffs et al[26] (2007)
								Participants: 38 versus 38 MD = 179 mL higher $P < .05$[d,h]	⊕◯◯◯ Very low	Critical	Volterman et al[27] (2014)

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 (Skim or Low-Fat Milk Versus Water)	Certainty	Importance	Study (Year)
Plasma osmolality											
1	RCT	Serious[e,f]	Not serious	Not serious	Serious[b,c]	None	1 h after completion of drinking	Participants: 7 versus 7 MD = 4.1 mOsm/kg higher $P > .05$[d,h]	⊕⊕○○ Low	Critical	Seery and Jakeman[17] (2016)
							2 h after completion of drinking	Participants: 7 versus 7 MD = 2.2 mOsm/kg higher $P > .05$[d,h]	⊕⊕○○ Low	Critical	Seery and Jakeman[17] (2016)
3	Nonrandomized study	Serious[a]	Not serious	Not serious	Serious[b,c]	None	1.5–2.5 h after completion of drinking	Participants: 12 versus 12 MD = 3 mOsm/kg higher $P = .03$[d]	⊕○○○ Very low	Critical	Sayer et al[18] (2020)

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

However, Sayer et al showed that drinking milk during recovery led to higher perceived levels of gastric fullness and bloating compared with drinking water.[18] Authors of the other studies did not demonstrate a difference between water or skim milk for gastric fullness, bloating, or both at any time after rehydration.[17,26,27]

Coconut Water. Authors of 4 RCTs, including 42 participants, described the efficacy of coconut water (ie, fresh coconut water or coconut water from concentrate) for treating exercise-associated dehydration compared with water (Table 5).[19,20,28,29] For the outcomes related to volume/hydration status (ie, cumulative urine output, net fluid balance, and plasma volume changes), no differences were demonstrated at any time of interest between rehydration with fresh coconut water and regular water.[19,20,29] Similarly, no difference was reported for heart rate at 2 hours after rehydration with fresh coconut water or coconut water from concentrate compared with water.[28]

Ismail et al showed an increased serum sodium osmolality (MD = 3 mOsm/kg higher) and concentration (MD = 2 mmol/L higher) 1 hour after rehydration with fresh coconut water compared with water.[19] However, Saat et al reported no difference for serum sodium osmolality and concentration 1 hour after rehydration with fresh coconut water compared with water.[20] Furthermore, Kalman et al also did not demonstrate a difference in plasma osmolality 2 hours after rehydration with fresh coconut water compared with water.[28] They showed an increase in plasma osmolality 2 hours after rehydration with coconut water from concentrate compared with water (MD = 1.5 mmol/L higher).

Regarding patient satisfaction, no differences in perceived feeling of thirst or gastric fullness were demonstrated between drinking coconut water or regular water at any time recorded.[19,20,28,29] Although Saat et al reported a decrease in nausea and stomach upset immediately and 1 hour after rehydration with fresh coconut water compared with water, authors of most studies did not show a difference in nausea, gastric discomfort, or cramps in the first hour after rehydration.[19,20,28,29] However, at 2 hours after rehydration, Kalman et al showed an increase in gastric discomfort with fresh coconut water or coconut water from concentrate.[28] They did not demonstrate a difference in bloating in the 2 hours after rehydration with fresh coconut water or coconut water from concentrate.

Limitations of the Included Studies

An overview of the limitations in study design for each RCT is shown in Table 6. Details of the randomization and allocation process were not provided in all RCTs. In most studies, the blinding of participants, investigators, outcome assessors, or a combination was not described. However, it can be assumed that a double-blind design was not possible due to inherent differences in taste and texture of the study drinks. Moreover, the objective outcomes based on diagnostic records retrieved from blood and urine analyses are less prone to risk of bias from lack of blinding. The trials in which authors evaluated subjective outcomes were most at risk of bias from lack of blinding. We found, in general, no concerns regarding missing outcome data. Lastly, no information was available about the researchers' prespecified intentions regarding planned outcome measurement and

Table 5. Synthesis of Findings on the Effectiveness of Fresh Coconut Water and Certainty Assessment According to 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 (Fresh Coconut Water Versus Water)	Certainty	Importance	Study (Year)
Volume/hydration status (cumulative urine output)											
3	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 = 76.9 mL lower $P > .05$[f]	⊕◯◯◯ Very low	Critical	Ismail et al[19] (2007)
								Participants: 8 versus 8 MD = 55 mL higher $P > .05$[f,g]	⊕◯◯◯ Very low	Critical	Saat et al[20] (2002)
							3 h after completion of drinking	Participants: 12 versus 12 MD = 207 mL lower $P = .15$[f]	⊕◯◯◯ Very low	Critical	Pérez-Idárraga and Aragón-Vargas[29] (2014)
Volume/hydration status (net fluid balance)											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 8 versus 8 MD = 0 g $P > .05$[f,g]	⊕⊕◯◯ Low	Critical	Saat et al[20] (2002)
								Participants: 10 versus 10 MD = 19 g higher $P > .05$[f,g]	⊕⊕◯◯ Low	Critical	Ismail et al[19] (2007)
Volume/hydration status (plasma volume change)											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 10 versus 10 MD = 1.4% higher $P > .05$[f,g]	⊕⊕◯◯ Low	Critical	Ismail et al[19] (2007)
Vital sign (heart rate)											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[d]	None	2 h after completion of drinking	Participants: 12 versus 12 MD = 6.0 beats/min higher $P > .05$[f]	⊕⊕◯◯ Low	Critical	Kalman et al[28] (2012)
Serum osmolality											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 8 versus 8 MD = 2 mOsm/kg higher $P > .05$[f,g]	⊕⊕◯◯ Low	Critical	Saat et al[20] (2002)
								Participants: 10 versus 10 MD = 3 mOsm/kg higher $P < .05$[f,g]	⊕⊕◯◯ Low	Critical	Ismail et al[19] (2007)
Plasma osmolality											
1	RCT	Serious[a,b]	Not serious	Not serious	Serious[d]	None	2 h after completion of drinking	Participants: 12 versus 12 MD = 0.9 mOsm/kg higher $P > .05$[f]	⊕⊕◯◯ Low	Critical	Kalman et al[28] (2012)

Table 5. Continued From Previous Page

Certainty Assessment											
No. of Studies	Study Design	Risk of Bias	Inconsistency	Indirectness	Imprecision	Other Considerations	Timing of Measurement	Effect (Fresh Coconut Water Versus Water)	Certainty	Importance	Study (Year)
Serum sodium concentration											
2	RCT	Serious[a,b]	Not serious	Not serious	Serious[c,d]	None	1 h after completion of drinking	Participants: 8 versus 8 MD = 2 mmol/L higher $P > .05$[f,g]	⊕⊕○○ Low	Critical	Saat et al[20] (2002)
								Participants: 10 versus 10 MD = 2 mmol/L higher $P < .05$[f,g]	⊕⊕○○ Low	Critical	Ismail et al[19] (2007)

Abbreviations: GRADE, Grading of Recommendations, Assessment, Development and Evaluation; RCT, randomized controlled trial; MD, mean difference.
[a] Allocation concealment not described.
[b] No blinding of participants, personnel and outcome assessors or blinding 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.

analyses. Protocols of the trials were not published or registered, raising some concerns about bias in selection of the reported results. One study was at high risk of bias from selection of the reported results because the authors collected urine but did not elaborate on the results of the critical volume/hydration status outcome.[28] Overall, the included studies had serious limitations in their study designs mainly due to risk of bias regarding measurement of the subjective outcomes.

Looking at the risk of bias of the nonrandomized study, some concerns existed regarding bias due to confounding arising from selection bias, as the sequences of intervention were not randomly assigned.[18] In addition, given that the subjective outcomes were self-reported and the participants were not blinded to the intervention, the measurement of these outcomes was judged to be at serious risk of bias.

Overall Certainty of the Body of Evidence

The Grading of Recommendations, Assessment, Development and Evaluation (GRADE) assessment of the certainty of the body of evidence is detailed in Tables 3 through 5.[31] The 11 included studies were experimental, leading to a high initial certainty level. The certainty of evidence was downgraded (−1) for limitations in study design. The overall certainty of evidence was further downgraded because of imprecision (ie, −1) due to limited sample sizes, a lack of data, or both (95% CIs could not be calculated because individual participant data were not available). Moreover, publication bias was strongly suspected (−1) as most trials were funded by industry partners who had a direct interest in the effectiveness of these rehydration beverages. This conflict of interest directly led to concerns about the independence of the findings in these trials. Downgrading due to indirectness or inconsistency was not needed. In conclusion, we found low to very low certainty evidence for the experimental studies concerning the rehydration potential of beverages for exercise-associated dehydration, meaning that any estimate of effect is very uncertain.

DISCUSSION

The aim of this systematic review was to identify the best available evidence on the effectiveness of any alternatives to CE drinks that can restore the hydration balance in people with exercise-associated dehydration. Although drinking water after sporting events or exercise (especially in hot and humid environments) is generally suggested as a good practice, athletes need to be aware of the risks of drinking hypotonic beverages, including water, in quantities that may lead to hyponatremia.[1,32] Remarkably, very little evidence evaluating the rehydration potential of both commercial and noncommercial fluids is currently available. In performing this systematic review, we acknowledge that, in the setting of exertional dehydration, rehydrating as soon as possible is most important. The choice of hydration fluid will often be made based on what is available, what the dehydrated person is willing to drink, and palatability.

The main finding of this systematic review, although the best available evidence is of low to very low certainty, suggests improvement in several indicators of volume/hydration status after hydration with skim or low-fat cow's milk compared with water. However, rehydration with milk,

Table 6. Overview of Risk of Bias of Randomized Controlled Trials Assessed With the Cochrane Risk of Bias 2 Tool[a]

Study (Year)	Intervention	Outcomes	Randomization Process	Deviations From Intended Interventions	Missing Outcome Data	Outcome Measurement	Selection of Reported Result	Overall
Flores-Salamanca and Aragón-Vargas[22] (2014)	Beer with low alcohol content (0.5% alcohol) and regular beer (4.6% alcohol)	Volume/hydration status	?	?	+	+	?	?
Ismail et al[19] (2007)	Coconut water	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Jiménez-Pavón et al[23] (2015)	Regular beer (4.5% alcohol)	Volume/hydration status and hyponatremia	?	?	+	+	?	?
Kalman et al[28] (2012)	Coconut water (from concentrate)	Volume/hydration status, hyponatremia and vital signs	?	?	+	+	!	!
		Patient satisfaction	?	?	+	!	?	!
Pérez-Idárraga and Aragón-Vargas[29] (2014)	Coconut water	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Saat et al[20] (2002)	Coconut water	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Seery and Jakeman[17] (2016)	Skim milk	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Shirreffs et al[26] (2007)	Skim milk	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Volterman et al[27] (2014)	Skim milk	Volume/hydration status and hyponatremia	?	?	+	+	?	?
		Patient satisfaction	?	?	+	!	?	!
Wijnen et al[25] (2016)	Beer with no alcohol content (0.0% alcohol), beer with low alcohol content (2.0% alcohol), and regular beer (5.0% alcohol)	Volume/hydration status and hyponatremia	?	?	+	+	?	?

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

without additional food intake, might be associated with feelings of fullness and bloating when compared with rehydration with water. For coconut water, no differences were demonstrated regarding cumulative urine output, net fluid balance, and plasma volume changes when compared with water.[19,20,29] However, although variability exists among the measured outcomes, drinking coconut water may assist in restoring the serum sodium osmolality and concentration.[19,20] Finally, evidence remains insufficient concerning the effect of consuming beer (0%–5% alcohol) on the reported outcomes.

The rate at which the drinks enter circulation is the first step that dictates fluid retention, and researchers have reported that the rate of gastric emptying is dominantly modulated by the energy density of the consumed liquids.[33–35] Skim or low-fat cow's milk is a nutrient-dense food, containing carbohydrates, protein, electrolytes, and micronutrients at a concentration like that of many commercially available CE drinks. The energy density of milk is like that of CE solutions, and researchers have reported that fluids containing milk protein slowed the rate of gastric emptying and delayed the rate of intestinal water absorption.[33,36] Slower emptying and absorption may sustain a higher plasma osmolality that would attenuate urine production by the kidneys.[37] Evidence is limited that the sensation of stomach fullness is greater after ingesting milk compared with water. After fluid is absorbed and released into circulation, the magnitude and time course of change in plasma osmolality are key determinants of water retention in the circulation. Compared with water and many other rehydration drinks available, milk especially contains relatively high concentrations of sodium, potassium, and chloride, and this high electrolyte concentration likely maintains plasma osmolality and thereby prevents the excretion of dilute urine.[26,27] Therefore, the energy density and the relatively high electrolyte concentration of milk explain its beneficial effects on fluid replacement. The composition and effectiveness of a rehydration beverage needs to be balanced with its desirability and palatability. As such, rehydration with milk may be associated with other issues of patient satisfaction or compliance when compared with water. In addition, rehydration with milk, without additional food intake, by people with lactose intolerance may induce adverse effects such as diarrhea, which could hinder the management of rehydration.

Evidence was insufficient to show that rehydration with coconut water, naturally rich in potassium and carbohydrates, resulted in improved outcomes compared with water for postexercise rehydration.[29] The presence of potassium in a drink may not be as effective as sodium in improving hydration status. Coconut water has been widely used in the tropics as a simple, palatable drink, but it may be more costly in geographic regions where fresh coconuts are not readily available and coconut water is commercialized as a natural sports drink.[28,29] In addition, some people may find coconut water less palatable than water.

Lastly, although alcoholic beverages are commonly consumed after exercising in a nonprofessional context in Western countries, researchers debate that the consumption of alcoholic beverages may have other unwanted effects such as adverse effects on performance, behavioral changes, and potential intoxication.[38] Moreover, alcohol increases the diuretic response in the body, which could interfere with adequate rehydration after exercise.[39] However, because of its nutritional composition and the absence of alcohol, one could suspect that nonalcoholic beer may have greater fluid-retention properties than water.[23] We were unable to detect any difference between the hydration responses to low-alcohol or nonalcoholic beer and water. Although the carbohydrate concentration of beer, in particular of nonalcoholic beer, is close to that found in commercial CE drinks, researchers have previously hypothesized that the electrolyte concentrations were too low to make any difference.[22,23,40] Indeed, investigators have shown that the addition of 25 to 50 mmol of sodium per liter to a low-alcohol beer (2.3% alcohol) may improve its fluid-retention properties.[41,42] The current limited evidence is insufficient to formulate any recommendation on the rehydration potential of low-alcohol or nonalcoholic beers. However, high alcohol intake should not be recommended, as the physiological and health consequences could be unpredictable.

Strengths

The main strength of this systematic review is that the best available evidence on the efficacy of rehydration drinks was, for the first time, identified and assessed via the rigorous and transparent Cochrane and GRADE methodology. The evidence from this review was used as a direct scientific basis by the First Aid Task Force of the ILCOR to develop a Consensus on Science with Treatment Recommendations.[43] This consensus document, in turn, will be used by international medical and first aid guideline organizations to provide recommendations for professional and recreational athletes, their families and coaches, and first-aid responders. In this context, the findings of this 2-part systematic review have several practical implications in the field. First aid providers are commonly recruited to assist at first aid stations located at sporting and challenge events where exercise-induced dehydration is a common problem. Providing the most effective rehydration options to athletes will ensure complete fluid restoration and will avoid the complication of simple dehydration progressing into a potentially life-threatening medical emergency. It is crucial to note that oral hydration may not be appropriate for individuals with severe dehydration associated with hypotension, hyperpyrexia, or mental status changes.

Limitations

The major limitation of this review is that it only provides evidence of low to very low certainty because of serious concerns regarding the design of the included studies, imprecise results, and publication bias. Moreover, the applied experimental methods varied widely between included studies, and, for example, differences existed in level of dehydration, amount of liquids consumed, and monitoring time after rehydration. These variations may compromise the reliability of the findings of this review. All included studies were crossover trials, and unfortunately, the individual participant data required to include a paired analysis in a meta-analysis were not published. Furthermore, we limited the systematic review to rehydration drinks for which more than 1 study was identified. In addition, the inclusion of studies was made based on reported outcomes. Thus, no studies were included for any type of yogurt drink or tea.[44–48] Authors of all included studies conducted exercise in a controlled environment and for a specific period. The laboratory environment may not adequately mimic conditions faced by recreational athletes undertaking habitual training and competition, such as variability in environmental temperature, humidity, and wind strength and differences in the intensity of training and competition.

Recommendations

Future studies should be done to target individuals with simple dehydration caused by participation in sporting events, personal exercise, or both. In this systematic review, we focused exclusively on the effectiveness of various drinks for replacing fluid losses after exercising and correcting dehydration. Although this first aid strategy might be effective over a short recovery period (<4 hours), foods are commonly consumed after exercising, and the electrolyte and water contents of these meals contribute to fluid replacement and can enhance fluid retention.[1,49] Future research might be done to focus on the addition of different foods combined with CE fluid consumption. Nevertheless, the NATA has recommended rehydrating with a fluid volume of 125% to 150% of the body mass lost to account for extra urinary losses.[1] At mass sporting events, specialized medical providers may take precompetition and postcompetition body mass of athletes to provide valuable information for postcompetition rehydration. However, this is not always the case and certainly not at smaller events. In these cases, it remains unclear how medical providers can determine the amount of liquid required for rehydration. Finally, we only focused on proposed rehydration beverages other than CE drinks compared with drinking water for effective rehydration. Based on our findings, the potential of alternative beverages, especially milk, for treating exercise-associated dehydration could be compared with the effectiveness of drinking CE drinks in a future review.

CONCLUSIONS

We found very low certainty evidence that skim or low-fat cow's milk has beneficial effects on rehydration after exercise. The water, energy, and macronutrient content of milk appears to be like that of sports drinks. However, rehydration with milk may be associated with other issues of patient satisfaction or compliance when compared with water. For coconut water, no differences were demonstrated regarding rehydration outcomes in comparison with water. Lastly, insufficient scientific evidence is available to support a recommendation for the use of beer (in any alcohol percentage) as a rehydration drink. However, the use of alcoholic beverages may have unwanted effects, and therefore, beer is not recommended as a rehydration drink for athletes.

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