20 The Need of Other Elements

Luis Fernando Aragón-Vargas

CONTENTS

20.1 INTRODUCTION

Athletes and physically active people consume many ingredients with purported ergogenic effects, a few of which have already been well documented, while most others have not. A good example is dietary nitrate, mostly in the form of beetroot juice (Hoon et al. 2013; Jones 2014). Some of these components may interact negatively with the major, conventional ingredients in sports drinks; only those that have been studied in association with the rehydration properties of beverages will be discussed in this chapter. Because the main ingredients in rehydration beverages have already been discussed previously in this book, and some others have already been reviewed extensively, emphasis will be placed on some recent work on other elements as they relate to post-exercise rehydration. And since potential ingredients will be presented from the perspective of the renal paradox—the fact that fluid intake by dehydrated humans results in a significant urine output and a compromised rehydration—the chapter begins with a presentation of this concept.

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20.2 THE RENAL PARADOX AND THE POTENTIAL ROLE OF POTASSIUM

When it comes to post-exercise rehydration, the renal system does not function quite as expected. From a homeostasis perspective, one would expect the kidneys to retain water as long as the body is in negative fluid balance, but when humans drink fluids, urine production follows. A large overload is not necessary for urine output to exceed *balance* (Pérez-Idárraga and Aragón-Vargas 2014). This phenomenon is apparent with water intake, but even when reasonable concentrations of sodium are used in the drinks, there is a considerable water excretion in the presence of hypohydration. This may be called the *renal paradox*: high urine output after fluid intake undermines the very goal of drinking in a hypohydrated state. One of the major goals in the formulation of a rehydration beverage is to achieve better fluid retention by recurring to sodium, potassium, or even protein, while other resources have been explored with different degrees of success, such as moderate hydration protocols (Kovacs et al. 2002; Mayol Soto and Aragón Vargas 2010; Pérez-Idárraga and Aragón-Vargas 2011a).

As an example of this renal paradox, Jimenez et al. (2002) had participants dehydrated by exercise or passive heat and then rehydrated with a homemade beverage containing 5% glucose and 40 mEq/L of NaCl. This sodium content, together with the level of dehydration (2.7% of body mass [BM]) and the ingested volume (92% of sweat losses), would be expected to favor fluid retention. Nevertheless, rehydration resulted in 400–500 mL of urine loss over 3 h of recovery, out of about 1800 mL of fluid intake. Urine output was significantly higher than under the no rehydration conditions ($p < .05$).

As discussed in this book (Chapter 19), sodium has been used in sports drinks as an electrolyte to promote fluid retention of physically active people who dehydrate from sweating. Sodium promotes acute plasma volume expansion during exercise, which is desirable to maintain performance. It also reduces diuresis resulting in lower water losses than when drinking pure water. It is possible, however, that aggressive rehydration with large fluid volumes causes the mechanical signal (baroreceptors) to be stronger than the osmotic and chemical signals which, during hypohydration, would normally help fluid retention by preventing diuresis. In other words, the human body is able to detect when it is hypohydrated and shifts into fluid conservation mode, but if it gets information about an acute plasma volume expansion, this is incorrectly interpreted as being hyperhydrated and diuresis is increased. By the time the error is detected, the body is hypohydrated again. In support of this hypothesis, the previously mentioned study by Jimenez et al. (2002) showed a clear association between acute changes in plasma volume and urine output.

One strategy to solve the problem of inducing excess diuresis would be to identify osmolytes which may promote water movement to the intracellular space, thereby preventing acute plasma volume expansion and helping the body keep the ingested water. In a discussion of the mechanisms of cell volume regulation, Pasantes-Morales et al. (2006) described volume regulation substances (p. 56): "…the organic osmolyte pool involved in volume regulation is formed by a heterogeneous group of small molecules, including aminoacids (taurine, glutamate, glycine, alanine), polyalcohols (myoinositol, sorbitol), and other compounds such as creatine, phosphocreatine. (…)". They also mentioned the two major electrolytes that could be involved: potassium and chloride. Only some of those substances have been experimentally tested; the possible success of any particular osmolyte would depend on the ability to acutely and transiently increase its intracellular content.

In a research report not published in a peer-reviewed journal (Aragón-Vargas and Shirreffs 2014), the authors attempted to design a sports drink for effective post-exercise rehydration, using potassium and other osmolytes at considerably higher concentrations than normally used, while sodium was included in small amounts (about one-third of a conventional sports drink). The rationale was that the particular composition of the experimental drinks would promote intracellular hydration, thus promoting fluid retention, as explained in the previous paragraph. The drinks evaluated in the study were a commercially available flavored water with added creatine (A), a high-electrolyte commercially available sports drink (B), a conventional sports drink with added potassium and creatine (C), a 6% carbohydrate, low-sodium, high-potassium drink (D), and Evian® bottled water as a standard for comparison purposes (see Table 20.1). In a repeated-measures design, ten healthy, young volunteers did one familiarization trial and then five experimental trials assigned on five consecutive weeks. They arrived in the laboratory in a fasted, euhydrated state and were dehydrated by intermittent exercise in the heat to approximately 2% of BM loss. After dehydration and some rest, they began a 1 h rehydration period with one of the five beverages allocated according to a balanced randomized design; they drank a volume equivalent to 150% of BM loss. At the end of rehydration, they were monitored for a total of4 h, taking blood samples and collecting all urine every 60 min.

Initial conditions were similar among drinks for pre-exercise BM, dehydration level, time to dehydration, mean sweat rate, sweat loss, and fluid intake volume ($p > .05$). The study, however, failed to find a significant difference in total urine output among trials ($p = .120$), even though acute plasma volume changes tended

TABLE 20.1
Drink Composition

	Drink				
	A	B	C	D	E
Carbohydrate solution (%)	1	6	6	6	0
Na^+ (mmol/L)	6.5	35	18	7	0
K^+ (mmol/L)	4.5	10	50	50	0
Creatine monohydrate (g/L)	3.3	0	3.3	0	0

Source: Aragón-Vargas, L. F. and Shirreffs, S. M., Rehydration following exercise in the heat: A look at alternative formulations and the role of plasma volume expansion in excess diuresis, http://kerwa.ucr.ac.cr/handle/10669/11115, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.

to follow the expected pattern. This has also happened in other studies: in one experiment using drinks with 0%, 2%, 5%, and 10% glucose concentrations (Evans et al. 2009), plasma volume changes were negative with the 10% glucose solution at the 10 and 60 min time points, but this did not result in lower urine output.

More recently, a study attempted to achieve better fluid retention by using high-potassium beverages (Pérez-Idárraga and Aragón-Vargas 2014). Because the study included fresh coconut water as one of the experimental drinks, it is further described in the specific section of this chapter (20.5.1), but is mentioned here to demonstrate the effect of potassium concentrations in beverages on diuresis. Urine output and fluid retention were compared after rehydration with plain water, fresh coconut water (naturally high in potassium), a conventional sports drink, or a specially formulated, high-potassium drink. Cumulative urine output was significantly higher after rehydrating with water than after the sports drink or the specially formulated drink ($p < .05$), but not than after fresh coconut water ($p = .147$). Fluid retention was only significantly higher for the sports drink compared to plain water ($p = .013$).

The possibility that potassium or other important intracellular molecules in a rehydration beverage may help shift fluids away from the extracellular space, preventing rapid plasma volume increases and hence limiting excess diuresis, has not been confirmed, but it warrants further study. Another possibility for limiting excess diuresis would be to use drinks that are absorbed more slowly, as in the protein studies that follow.

20.3 MAJOR ELEMENTS

20.3.1 Protein

Nutritional products with protein or combinations of amino acids represent an important share of all supplements used by athletes. Because a major goal of protein ingestion is to support or enhance post-exercise muscle recovery by promoting a positive nitrogen balance at a critical time, amino acids or protein have been used in rehydration beverages. It is important to understand to what extent these ingredients contribute to or deter from the rehydration effectiveness of the drinks.

In a discussion about intestinal fluid absorption, Schedl et al. (1994) suggested that because amino acids use sodium-coupled transport systems that are independent from glucose transporters, they could enhance sodium and water absorption beyond the use of carbohydrate and sodium alone. While this possibility has been explored, mainly for the formulation of oral rehydration solutions to treat diarrhea, success has been limited if the goal is to improve the results obtained from multiple carbohydrate solutions. This and other hydration-related effects of amino acids have been recently reviewed by Baker and Jeukendrup (2014).

On the other hand, rehydration beverages with protein have been shown to favor fluid retention. Several earlier studies showed the effectiveness of skimmed milk (discussed in detail in a separate section below), but the research design did not allow to study the effect of protein *per se*. In a parallel line of research, a 2006 study by Seifert et al. looked at fluid retention after rehydration with a 6% carbohydrate plus 1.5% protein beverage (including 53 mg sodium and 18 mg potassium), compared with a conventional sports drink (6% carbohydrate, 46 mg sodium, and 12.5 mg potassium) and plain water (Seifert et al. 2006). Each participant ingested a volume equivalent to 100% of weight loss (~1700 mL in 20 min) after exercise-induced dehydration to 2.5% BM. Water showed the least fluid retention (about 53%) of all drinks, and a greater fluid retention was attained with the beverage with protein (88% ± 4.7%) in comparison with the conventional sports drink (75% ± 14.6%). The authors attributed this latter effect to the additional protein, but because the drinks were not isoenergetic and osmolalities were different, other explanations could not be ruled out. More recently, the effort has focused on teasing out the specific role of protein by comparing solutions otherwise matched in electrolyte and energy content.

James et al. (2011) compared two isoenergetic drinks, formulated with the same electrolyte and fat content but differing only in total carbohydrate and protein. One contained 65 g/L of carbohydrate, while the other had 40 g/L of carbohydrate and 25 g/L of milk protein, and they were ingested in a volume equivalent to 150% of sweat loss after exercise-induced dehydration to about 2% BM. All measures of hydration (total urine output, fluid retention, and net fluid balance) were better with the beverage with carbohydrate and protein than the drink with only carbohydrate after 4 h of monitoring. Later, in a very similar study design, James et al. (2013) confirmed these results but using two different carbohydrate and milk protein beverages instead of one (drink A: 40 g/L carbohydrate + 20 g/L milk protein, and drink B: 20 g/L carbohydrate + 40 g/L milk protein), which were better than a 60 g/L carbohydrate beverage but not different between them. In both studies, the authors attributed the milk protein advantage to a possible slower gastric emptying (not measured). While any fluid in the stomach and intestines at a particular time is not contributing to fluid balance, a somewhat slower gastric emptying and intestinal absorption would be a welcome effect to the extent that it might be preventing excess diuresis.

Interestingly, no beneficial effects on rehydration have been found from adding whey protein to carbohydrate–electrolyte drinks, matching energy density and electrolyte content. James et al. (2012) used a very similar protocol to those described in the previous paragraph to compare a 65 g/L carbohydrate solution with a 50 g/L carbohydrate and 15 g/L whey protein isolate solution and found almost identical urine output, fluid retention, and net fluid balance with both beverages. Hobson and AQ 1 James (2015) compared a 62.2 g/L carbohydrate–electrolyte solution (CES) to the same solution with added whey protein (20.4 g/L; in this case, the drinks were not isoenergetic). They obtained similar urine output, fluid retention, and net fluid balance. In another non-isoenergetic comparison, the addition of 20 g/L whey protein isolate to a mineral water was not more effective for rehydration than mineral water alone (James et al. 2014). For additional details on the effects of protein on hydration, the reader is referred to the review by Baker and Jeukendrup (2014).

In summary, CESs with milk protein have been shown to provide better post-exercise rehydration than conventional CESs. Furthermore, the addition of whey protein to sports drinks has been shown not to hinder rehydration. Therefore, whenever protein intake may be of interest in addition to fluid replacement during exercise recovery, rehydration beverages properly formulated with milk or whey protein may

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be used. Practical recommendations and potential contraindications will likely be developed as these newer formulations are more widely used.

20.3.2 Glycerol

Research on glycerol as a hydrating agent started in 1987, with a study on human subjects at rest (Riedesel et al. 1987). When glycerol is ingested with water, it promotes hyperhydration by creating an osmotic load and favoring water reabsorption (Freund et al. 1995). By limiting free water clearance, fluid retention is improved; this effect is believed to be independent of hormonal responses (Nelson and Robergs 2007). Glycerol-induced hyperhydration is, naturally, transient, as glycerol will be metabolized by the liver and excreted by the kidneys, but because its metabolic clearance from the blood is slow, hyperhydration can be maintained for a few hours (Nelson and Robergs 2007; Riedesel et al. 1987). The use of glycerol is, however, currently banned by the World Anti-Doping Agency (WADA) because it is considered a masking agent (World Anti-Doping Agency 2014). Glycerol intake levels necessary for enhancing hydration are much higher than the dose shown to give positive results in anti-doping tests (Van Rosendal and Coombes 2012).

Several extensive reviews have addressed the use of glycerol for hydration purposes (Goulet et al. 2007; Nelson and Robergs 2007; Van Rosendal and Coombes 2012; Van Rosendal et al. 2009), but they focus on hyperhydration, as does most of the available research. Few studies have looked at glycerol as a potential ingredient in rehydration beverages for post-exercise utilization.

Briefly, most hyperhydration studies have found an increase in total body water with glycerol. A meta-analysis (Goulet et al. 2007) based on 14 comparisons and a total of 99 subjects found an increased body water of 7.7 ± 2.8 mL/kg BM ($p < .01$); their pooled effect size was 1.64 ± 0.80 ($p < .01$). Almost all studies have been performed comparing plain water and water plus glycerol. While the hyperhydration results are rather clear, the cardiovascular or thermoregulatory benefits are less consistent (Baker and Jeukendrup 2014; Goulet et al. 2007; Van Rosendal et al. 2009). General recommendations for hyperhydration prior to exercise are to ingest 1 g of glycerol/kg BM, with approximately 20 mL of water/kg BM (Baker and Jeukendrup 2014), or 1.2 g of glycerol/kg BM with 26 mL of water/kg BM (Van Rosendal et al. 2009).

The first study to look at glycerol as an ingredient in a rehydration beverage was performed by Scheett et al. (2001). Eight males dehydrated to ~3% BM by exercising in the heat, and rehydrated with water or water plus glycerol (1 g glycerol/kg BM) in a volume equivalent to 100% of sweat losses, over 3 h. The focus of the manuscript was on performance during a subsequent task to exhaustion, which was improved in the glycerol trial. The authors reported no significant difference in total urine output between control and glycerol ($p > .05$), but unfortunately the numbers they presented are internally inconsistent. They did report, however, a significant difference in percent change in body weight at the end of the rehydration protocol, for the control (−0.73% ± 0.09% BM) and glycerol (−0.50% ± 0.08% BM) trials ($p < .05$).

The only other study using a conventional post-exercise rehydration protocol was by Kavouras et al. (2006). Eight highly trained male cyclists completed three separate exercise trials that induced 4% dehydration. Subjects were given no fluid during exercise but were then rehydrated within 80 min with water (placebo) or water plus glycerol equivalent to 3% BM. Ninety minutes later they performed an exercise test to exhaustion. Time to exhaustion was improved in the glycerol trial, but no fluid retention, net fluid balance, or urine output data were reported.

Both abovementioned studies reported improved performance (greater time of exercise to exhaustion) and a greater plasma volume expansion with glycerol; the latter was presented in the original studies as the only clear hydration advantage with glycerol use. Even with limited evidence, guidelines for glycerol use as a rehydrating agent post-exercise have been provided (Van Rosendal et al. 2010). However, plasma volume restoration or expansion is a transient result, which may be beneficial only if subsequent exercise is undertaken in thermally adverse conditions. Given that no data are yet available supporting better fluid retention after exercise-induced dehydration, glycerol use is not warranted as an ingredient in a post-exercise rehydration beverage.

Apart from being prohibited for athletes under the jurisdiction of WADA, glycerol has a few contraindications. Some side effects have been reported, such as nausea, diarrhea, vomiting, and headache, but reviewers agree that these are uncommon, considering the large number of studies without any adverse reports (Baker and Jeukendrup 2014; Van Rosendal et al. 2009); they are apparently associated with higher doses or concentrations of glycerol and should not be a problem with more diluted use (Baker and Jeukendrup 2014; Kavouras et al. 2006; Nelson and Robergs 2007; Van Rosendal et al. 2009). Nevertheless, glycerol ingestion is not recommended for pregnant women or individuals with migraine, headache, or liver disorders, with diabetes, or with renal or cardiovascular disease (Van Rosendal et al. 2009).

20.3.3 Caffeine

Caffeine is widely used as an ergogenic aid and is often present in the regular diet of athletes and sedentary individuals. There are multiple studies and several important literature reviews addressing the ergogenic properties of caffeine (Armstrong 2002; Burke 2008; Doherty and Smith 2005; Kovacs et al. 1998; Spriet 1995) and its effect on hydration (Armstrong et al. 2007; Maughan and Griffin 2003). This section will only discuss the acute rehydration characteristics, with emphasis on the role of caffeine on post-exercise rehydration.

As explained by Armstrong et al. (2007) in their review paper, caffeine increases renal glomerular filtration and inhibits reabsorption of sodium, resulting in higher water and sodium excretion by the kidneys. In addition to this diuretic effect, other physiological responses to caffeine may impair performance during exercise in the heat: sweat rate may be increased because of the stimulation of the sympathetic nervous system, which would compound dehydration, and core temperature may be increased because of a higher resting metabolic rate. Based on their analysis of the available evidence at the time, the authors of the review proposed that caffeine consumption does not result in water–electrolyte imbalances, hyperthermia, or reduced exercise–heat tolerance. Their conclusions followed the same direction of Maughan and Griffin (2003), who concluded *tentatively* that single caffeine doses found in common beverages have little or no diuretic action and that habitual caffeine users develop tolerance to the effects of caffeine, although they acknowledged that a dose greater than 250 mg of caffeine has an acute diuretic action. Baker and Jeukendrup (2014) concluded, in a more recent review, that moderate caffeine intake in the order of 450 mg (≈6.4 mg/kg for a 70 kg individual) has no chronic negative effects on hydration, heat tolerance, or risk of heat illness. The issues warrant further analysis and discussion.

The emphasis of the review by Armstrong et al. (2007) was on chronic hydration and daily living. Interestingly, Maughan and Griffin (2003) made a similar emphasis. This perspective makes sense as caffeine is ingested with a wide variety of beverages in the regular diet, and not only as an ingredient of hydrating beverages. The question they pose is: does the regular intake of moderate doses of caffeine impair hydration status or thermoregulation? The answer seems to be no. But that is different from the question normally posed for other potential ingredients of a drink intended to replace fluids lost through sweat. If the intent is to formulate a beverage to improve exercise performance or enhance immediate post-exercise recovery, the acute effects of caffeine on diuresis, core temperature, and sweating during exercise in the heat, as well as fluid retention during post-exercise rehydration, must be analyzed.

A few experiments are presented here in detail. First, Falk et al. (1990) asked seven trained males, not habitual users of caffeine, to exercise to exhaustion in thermoneutral conditions, once after caffeine ingestion and once after the intake of a placebo in 100 mL of an artificially sweetened drink. Total caffeine intake was 7.5 mg/kg of body weight, all before the exercise. The authors stated that *ad libitum* water consumption was encouraged during exercise and was not different among conditions, but no ingested volume was reported. This study concluded that the amount of caffeine ingested did not significantly affect water deficit, sweat loss, or thermoregulation, but acknowledged that during exercise performed under a greater heat stress, thermoregulation might be hindered.

Later, another study (Wemple et al. 1997) compared caffeinated versus non-caffeinated sports drinks at rest and during exercise. This is a carefully designed study, although it only tested six highly active subjects (4 males and 2 females) who participated in four randomly assigned, counter-balanced trials, two at rest (4 h) and two involving exercise (1 h rest, 3 h of cycling at 60% VO_2max followed by a maximal performance test). All trials were performed in the heat; participants drank a conventional sports drink, 8 mL/kg of body weight (≈560 mL for a 70 kg individual) at the beginning of each trial, and then 3 mL/kg of body weight (≈210 mL) every 20 min, beginning after 60 min from the start of the trial. One rest trial and one exercise trial were performed with caffeine in the drinks (490–680 mg, the equivalent of 8.7 mg/kg); the other exercise and rest trials were performed without caffeine but drinking the same fluid volume. The authors reported lower urine flow rate during exercise than at rest (as expected), and a higher urine flow rate at rest with the caffeinated drink than with the placebo, but there was no effect of caffeine on urine flow during exercise. The reductions in plasma volume, and the increase in sweat rate, heart rate, and core temperature were consistent during the exercise trials, but the effects of caffeine were not significant. They concluded that the caffeine dose provided in this volume of sports drink increases urine production at rest but not during prolonged cycling in the heat.

Diuresis during exercise is undesirable, not only logistically, but because it exacerbates exercise-induced dehydration. To better understand the effects of caffeine on thermoregulation and fluid–electrolyte losses during prolonged exercise in the heat, Del Coso et al. (2009) performed a double-blind, placebo-controlled, randomized experiment with seven endurance-trained, heat-acclimatized males, each serving as his own control. Each participant cycled for 2 h at a moderate intensity in a hot-dry environment on six different occasions. Three trials included no caffeine: without fluid replacement, drinking water to replace 97% of fluid loss, or drinking a carbohydrate–electrolyte beverage to replace 97% of fluid loss. The other three were identical to the aforementioned three, but included the ingestion of 6 mg caffeine/kg of body weight 45 min before the exercise. Fluid intake was ≈2.4 L, distributed evenly over each trial; drinks were at room temperature. Overall, urine flow was increased by 28% in the caffeine conditions (pooled data), while sweat losses of sodium, potassium, and chloride were increased by about 14% ($p < 0.05$). Caffeine did not alter heat production, forearm skin blood flow, or sweat rate. While rehydration during exercise increased sweat loss, the combination of caffeine ingestion with rehydration had no effect on sweat loss. The combination of water intake and caffeine ingestion increased exercise urine production compared with water alone (664 ± 350 mL vs. 464 ± 278 mL, $p < 0.05$), but the CES with caffeine resulted in a similar urine output compared with CES alone (422 ± 303 mL vs. 486 ± 380 mL, $p > 0.05$). The authors highlighted the fact that because diuresis during exercise in the heat is relatively small compared to sweat losses, net fluid balance was not different between caffeine and no-caffeine trials despite higher diuresis in the former. They also pointed out that caffeine is diuretic even during exercise, but suggested that this effect may be counteracted when it is used in combination with carbohydrate–electrolyte drinks.

Published studies on the acute effects of caffeine during post-exercise rehydration are scarce. A seminal study (González-Alonso et al. 1992) compared water, a 6% CES, and a diet cola during a 2-h rehydration period after exercise-induced dehydration to 2.5% BM. Ten physically active subjects exercised at a self-selected intensity between 60% and 80% VO_2max in the heat (32°C, 40% relative humidity) until they reached the desired dehydration, on four separate occasions. With the exception of a no-fluid trial used only for monitoring, the rehydration protocol involved drinking one of the three beverages in two boluses. The diet cola contained 128 mg/L of caffeine, for an average intake of 250 mg. Fluid retention at the end of monitoring was significantly lower with the diet cola (54% ± 5%) than with water (64% ± 5%) or CES (69% ± 5%) ($p < .05\%$). The authors attributed the lower rehydration obtained with diet cola to the diuretic effect of caffeine, showing a statistically significant difference in urine output between diet cola and the carbohydrate–electrolyte drink (710 ± 100 mL vs. 480 ± 90 mL, respectively, $p < .05$). However, because of the study objectives, the beverages were different in other ingredients besides caffeine, and the difference between diet cola and water was not significant. No clear conclusions may be reached from this paper regarding post-exercise fluid recovery and a possible diuretic effect of caffeine.

The other study (Brouns et al. 1998) related to the acute effects of caffeine during post-exercise rehydration used voluntary fluid intake. Eight well-trained cyclists participated in three exercise tests, at least four days apart, in a randomized cross-over design. They cycled in a warm environmental chamber to a median dehydration of 3.21% BM. *Ad libitum* rehydration took place over 2 h with one of the beverages: mineral water, carbohydrate–electrolyte drink, and caffeinated soft drink. Participants were then monitored for four additional hours. Fluid intake was greater for the CES than for the mineral water (median = 2.86 and 2.15 kg, respectively), but intake of the caffeinated drink was not different from the others (median = 2.77 kg, for about 379 mg of caffeine). Total urine output after 4 h of the recovery period was similar for all drinks, and fluid restoration was not significantly different either ($p > .1$). The authors concluded that a diuretic effect of caffeine at this level of consumption was ruled out, although they pointed out that acute magnesium and calcium excretion was potentiated with the caffeinated beverage.

In summary, the available evidence suggests that there is no chronic negative effect of moderate caffeine intake on hydration or thermoregulation. There is also some evidence to support the notion that ingestion of caffeine before or during exercise has no biologically significant acute effect on diuresis (especially when combined with carbohydrate–electrolyte drinks), core temperature, or sweating. In the case of the acute effects of caffeine on post-exercise rehydration, two aspects must be considered. First, there would be no rationale for using caffeine during recovery, with the exception of personal preferences. Second, there is a dearth of information on caffeine related to rapid rehydration and recovery after training and competition. More well-designed experiments are warranted before sound recommendations can be made.

20.3.4 Alcohol

With the exception of beer, alcohol (ethanol) is rarely ingested as post-exercise rehydration, because of its proven diuretic effect (Eggleton 1942; Murray 1932). Furthermore, alcohol should be avoided before or during exercise, as it will impair motor control and performance, particularly at higher doses (Lecoultre and Schutz 2009; Shirreffs and Maughan 2006). Recently, a high dose of ethanol has been shown to impair myofibrillar protein synthesis during recovery from exercise (Parr et al. 2014). In the particular case of beer, there is a widespread belief that, because of the presence of some electrolytes and due to the lower alcohol concentrations (in comparison with other alcoholic beverages such as vodka, rum, whiskey, or even wine), beer should be a good choice for rehydration. The possibility of rehydrating with beer is appealing to many; there is, however, some strong evidence that beer is not a good choice if the goal is to replace the fluids lost during exercise.

A widely cited study by Shirreffs and Maughan (1997) used especially formulated beers with 0%, 1%, 2%, and 4% ethanol to test the effects of alcohol consumption on restoration of fluid balance after exercise-induced dehydration. They found non-significant differences between the 0% beer and beer with 1% or 2%. Even with the 4% beverage, no significant differences were found in urine output or net fluid balance, although other variables showed small differences. The authors concluded that only at the higher concentration, there was a small detrimental effect of alcohol on fluid retention. This publication has been used to support the claim that beer is a good rehydration beverage, but there is an important problem: apparently, most beers available for consumption contain more than 4% alcohol. According to some marketing data from early 2014 (“Top 10 Best Beers in the World” 2014), the top-ten list of beers with the highest volume consumption in the world include eight which have > 4% alcohol by volume (ABV) and two with exactly 4% ABV. Out of another list of more than one thousand of the major world beers, only 62 had less than 4% ABV (“Find the Alcohol Content of Your Favorite Beer” 2014).

More recently, other scientists have experimentally addressed the potential qualities and complications of rehydrating with alcoholic drinks after exercise. Irwin et al. (2013) studied 16 healthy males who were first dehydrated to approximately 2.5% BM by exercising in thermally adverse conditions, in order to assess the impairment in cognitive functions resulting from mild or moderate dehydration combined with moderate alcohol consumption, compared with the consumption of alcohol under fully rehydrated conditions. Because of the study objectives, alcohol was administered with a low volume of fluid and only after a period of rehydration with water and electrolytes or no fluid intake, so the study was not strictly about rehydration with alcoholic drinks. The results, nevertheless, showed a deterioration of choice reaction time, executive function, and response inhibition after alcohol consumption. Perhaps the most important finding was that the negative effects were more pronounced when alcohol intake occurred in a dehydrated condition, which suggests that alcohol intake may be more detrimental to cognitive function when rehydration is needed.

Desbrow et al. (2013) studied rehydration with light beer (2.3% ABV) or regular beer (4.8% ABV), alone or with the addition of 25 mEq L^{-1} Na^+. Their purpose was to evaluate the effects of different alcohol concentrations on fluid retention, but also to explore the potential benefits of adding enough sodium to beer, in an attempt to offset the reported increased diuresis that takes place when using regular strength beer (interestingly, this effect was only mentioned anecdotally in the rationale, although it was empirically confirmed in the study). Seven males exercised in a thermoneutral environment but wearing evaporation-restrictive clothing, until dehydrated to ~2% BM. After exercise, they were rehydrated with a volume equivalent to 150% of the total fluid volume lost, or about 2.5 L of beer, resulting in an average ethanol intake close to 60 g with the light beer and 120 g with the regular beer. Following rehydration, urine output was monitored for 4 h. Net fluid balance was negative for all drinks at the end of monitoring, but there were some differences among drinks at the 3 and 4 h time points. The addition of sodium to light beer did not result in a significant improvement of total urine output ($p = .25$) or net fluid balance ($p = .26$). Adding sodium to regular strength beer showed no benefit either (total urine $p = .75$; net fluid balance $p = .77$). Only the combination of low-alcohol and extra sodium was able to improve net fluid balance and total urine output, compared to both full-strength beers. Based on their results, the authors suggested that “beer, irrespective of ingredient profile, is an undesirable postexercise fluid” (p. 598) but, acknowledging the ingestion of high volumes of beer by some individuals after exercise, recommended an emphasis on lower alcohol content to minimize harm during recovery.

Flores-Salamanca and Aragón-Vargas (2014) compared fluid retention, blood alcohol concentration, balance, and reaction time in 11 healthy young men who rehydrated with beer (4.6% ABV), low-alcohol beer (0.5% ABV, often called no-alcohol beer by the industry), or water, after exercising in the heat. Participants dehydrated to ~2% BM and then ingested a volume equivalent to 100% of weight loss of the randomly assigned beverage for each day; this resulted in the regular beer providing almost the same amount of ethanol (60.1 ± 6.5 g) as the light beer in the study by Desbrow et al. (2013), due to the combination of a lower volume and a higher alcohol concentration. Total urine output results are summarized in Figure 20.1. Fluid retention was just about one half with regular beer when compared to low-alcohol beer. Urine output was significantly higher ($p < .05$) after only 30 min of monitoring. Net fluid balance was lower after rehydrating with beer; at the end of monitoring, it was not different from the end of dehydration. In other words, 3 h after ingesting ~1.7 L of regular beer, participants were as dehydrated as they were before drinking.

Figure 20.2 shows the blood alcohol content over time. For the low-alcohol beer and water, it was not possible to register an increase at any time point; with regular beer, however, it reached an average of 0.857 g/L, with a 95% confidence interval of 0.752–0.963 g/L. This is well above legal driving limits in many countries (0.50 g/L). It is to be expected, then, that rehydrating with beer resulted in slower reaction time and impaired balance: reaction time was longer for the beer condition (0.314 ± 0.039 s, mean ± SD) than the low-alcohol beer (0.294 ± 0.034 s, $p = .009$),

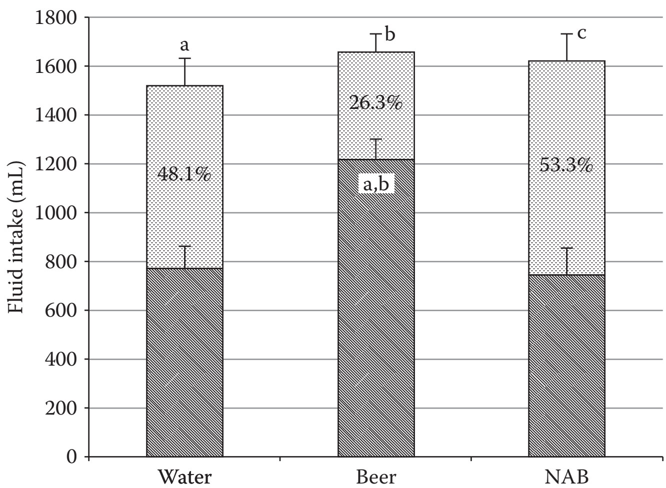

FIGURE 20.1 Fluid intake, total urine output, and retention. NAB: no-alcohol beer (in reality it contained 0.5% ABV). Columns are mean values plus standard error of the mean. F = 8.63, $p = .002$. Lower portion of each column represents urine output, and upper portion is the volume that was retained. (a) Urine volume different from water, $p = .043$. (c) Urine volume different from NAB, $p = .007$. (From Flores–Salamanca, R. and Aragón Vargas, L.F., *Appl. Physiol. Nutr. Metab.*, 39, 1175–1181, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.)

AQ 2
AQ 3

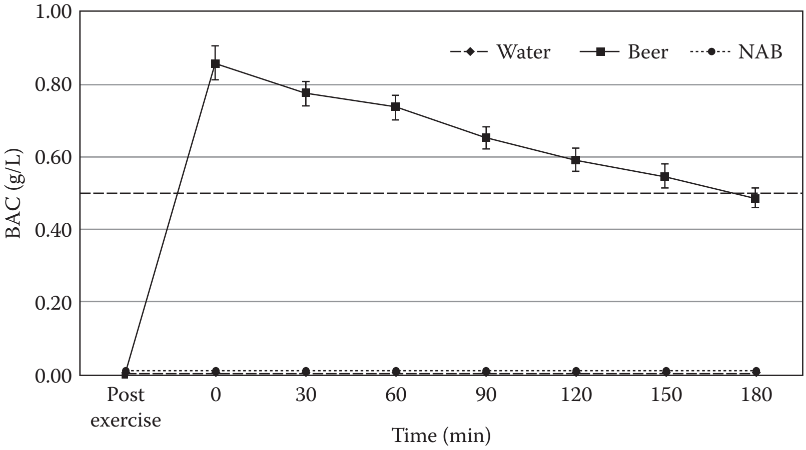

FIGURE 20.2 Blood alcohol content. Points are mean values; bars represent standard error of the mean. Interaction F = 214.1, $p = 4.4 \times 10^{-8}$. Condition main effect F = 442.3, $p = 1.3 \times 10^{-9}$. Time main effect F = 214.1, $p = 4.4 \times 10^{-8}$. (a) Different from post-exercise ($p < .05$). (b) Different from 0 min ($p < .05$) (c) Different from 30 min ($p < .05$). (d) Different from 60 min ($p < .05$). (e) Different from 90 min ($p < .05$). (From Flores-Salamanca, R. and Aragón Vargas, L.F., *Appl. Physiol. Nutr. Metab.*, 39, 1175–1181, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.) AQ 4

but not different from water (0.293 ± 0.049 s, $p = .077$). Balance was significantly impaired for the beer condition from the end of rehydration up to 90 min of follow up, compared with both water and low-alcohol beer.

In summary, recent data show a clear detrimental effect of alcohol on post-exercise rehydration. The presence of alcohol in a rehydration drink is not compatible with the goal of replacing lost fluids quickly and effectively, while it has a negative effect on other aspects of recovery and motor control. This applies to regular beer, despite the presence of a small amount of electrolytes.

20.4 SECONDARY INGREDIENTS

20.4.1 Creatine

Among all nutritional supplements, creatine is one of the most widely utilized by athletes; it is also well studied by scientists. Various oral loading and maintenance protocols have been shown to increase intramuscular creatine, with a concomitant improvement in sports performance in tasks such as jumping, cycling, and sprinting, where short, high-intensity, limited-recovery repetitive bouts are required (Bemben and Lamont 2005; Mujika and Burke 2010). The potential use of this ingredient in rehydration beverages has received little attention, possibly because of concerns that creatine supplementation may impair thermoregulation or hydration status, mostly from anecdotal reports. Most studies on creatine and rehydration have focused on the consequences of chronic creatine use for conventional purposes (improved anaerobic performance). A recent exhaustive review of the literature on fluid replacement beverages omits the topic of creatine altogether (Baker and Jeukendrup 2014).

Several reviews have been published on chronic creatine use and hydration (Dalbo et al. 2008; Ganio et al. 2007), but the most comprehensive review was performed by Lopez et al. (2009). These reviews agree that chronic creatine supplementation leads to a rapid increase in BM, mostly due to an increase in intracellular water. Many of the studies reviewed showed increases in total body water and intracellular water, while no evidence was found of an impaired thermoregulation. Ganio et al. (2007) argued that several studies showed no change or even an advantageous core temperature in creatine-supplemented subjects exercising in the heat. Lopez et al. (2009) concluded from their meta-analysis that there was no substantial evidence at that point to show that chronic creatine supplementation would hinder thermoregulation or fluid balance.

As mentioned in the previous paragraphs, chronic supplementation with creatine results in increased intracellular water and total body water. No studies have been published addressing the acute hydration effects of creatine in a rehydration beverage. The one report that looked at this issue found no fluid retention advantage when creatine was combined with flavored water or a conventional sports drink with added potassium, in comparison with plain water (Aragón-Vargas and Shirreffs 2014). The time course for the entrance of creatine into muscle cells may be too slow to act as an osmolyte and benefit acute fluid retention. At this point, there is no evidence to support the inclusion of creatine in rehydration beverages; at the same time, there is no basis for contraindicating its chronic use because of thermoregulatory or fluid balance concerns.

20.4.2 Artificial Preservatives

Artificial preservatives are often included in bottled, ready-to-drink beverages to avoid spoilage and therefore extend the shelf life of the product. They act mainly by preventing growth of bacteria, molds, fungi, and yeasts, and they represent a less costly alternative to processes such as pasteurization combined with hot or cold filling industrial procedures. There are, however, two disadvantages of artificial preservatives. First, artificial ingredients are not well accepted in many cultures, particularly in association with a beverage used for hydration, as the drink is meant to be ingested in large volumes, and it should share the healthy image associated with exercise. Second, some preservatives such as sodium benzoate and potassium sorbate may negatively modify the palatability characteristics of drinks, which is undesirable as it may decrease voluntary intake (Passe et al. 2004). Specifically, the presence of sodium benzoate at 0.03% has been reported to reduce voluntary fluid intake by 10.8% during 30 min of moderate intensity exercise in thermoneutral conditions (Passe et al. 1997), even though it had no measurable effects on sensory variables.

A study reported originally in abstract form (Rivera-Brown et al. 2007) but available also as a pre-print (Rivera-Brown et al. 2014) sheds light on the role of artificial preservatives in hydration beverages. Palatability and voluntary intake of four

TABLE 20.2
Composition of Commercial Beverages Offered in the Four Experimental Conditions (per 100 mL)

Beverage	CHO (g)	Na^+ (mg)	K^+ (mg)	Preservatives	Vitamins	Osmolality (mOsm/L)
Water	0	0	0	None	None	0
CES	6	46	12.5	None	None	325–380
CESP1	6	46	12.5	Sodium hexametaphosphate	None	325–380
CESP2	8	31	21	Potassium sorbate sodium benzoate (<0.06%)	B12 (0.25 µg) B3 (0.75 mg) B6 (0.10 mg)	381

Source: Rivera-Brown, A. et al., Palatability and voluntary intake of three commercially available sports drinks and unflavored water during prolonged exercise in hot and humid conditions, http://www.kerwa.ucr.ac.cr/handle/10669/11105, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.

commercially available beverages were compared, in 36 athletes (males and females, mean age 19.5 years), during prolonged exercise in a warm and humid environment (WBGT = 30.1 ± 1.1°C). The beverages varied in carbohydrate and electrolyte composition and preservative content (see Table 20.2). On separate days, athletes completed four 90-min sessions, running or race walking outdoors at 80%–85% of age-predicted maximum heart rate. Each time, they ingested in a randomized order and double-blinded design one of four beverages: bottled water, CES, 6% carbohydrate–electrolyte + preservatives solution (CESP1), or 8% carbohydrate–electrolyte + preservatives + B vitamins solution (CESP2) (see Table 20.2).

Beverages were served cold (~9°C) in squeeze bottles and subjects drank as desired as they ran around a marked, 420-m area, while fluid intake was carefully monitored. Palatability was measured during a 1-min exercise break at 15-min intervals: overall acceptance, liking of flavor and liking of sweetness were measured using 9-point hedonic category scales. Perceived intensity of thirst, sweetness, saltiness, tartness, thirst quenching, palatability, and flavor strength were measured using visual analog 10-point scales. This scale was also used to rate perception of exercise difficulty, how hot/overheated subjects felt, and the question "Can you drink a lot of this beverage?"

Overall, males covered 18.0 ± 2.0 km, while the females completed 13.1 ± 1.7 km in each trial, with no significant differences found among conditions (beverages) in terms of environmental variables, sweat rates, or exercise intensity (see Table 20.3). In other words, any dissimilarity in voluntary fluid intake or fluid balance among conditions could be attributed to the qualities of the beverages used in the study. However, the amounts consumed of the four drinks were not different (W = 17.0 ± 4.8; CES = 16.9 ± 5.4; CESP1 = 17.8 ± 5.4; CESP2 = 17.5 ± 5.2 mL kg^{-1}, $p > .05$) (see Figure 20.3 and Table 20.4).

TABLE 20.3
Environmental Variables, Intensity, and Distance Covered Under Each of the Four Conditions

	W	CES	CESP1	CESP2
Wet bulb temperature (°C)	26.5 ± 0.5	26.4 ± 0.6	26.5 ± 0.7	26.5 ± 0.5
Dry bulb temperature (°C)	31.5 ± 2.1	31.2 ± 2.2	31.5 ± 1.4	31.6 ± 2.2
Globe temperature (°C)	42.2 ± 3.5	41.5 ± 4.1	41.4 ± 4.2	42.4 ± 3.9
WBGT index (°C)	30.1 ± 0.9	29.9 ± 1.2	30.0 ± 1.3	30.2 ± 1.1
Relative humidity (%)	66.7 ± 5.8	67.6 ± 6.8	67.9 ± 5.9	66.2 ± 6.7
Heart rate (beats min^{-1})	163.3 ± 5.0	163.9 ± 5.9	163.8 ± 5.9	163.7 ± 7.0
% Maximum heart rate	81.8 ± 2.4	82.0 ± 2.9	81.9 ± 3.0	81.9 ± 3.3
Distance covered (km)	15.6 ± 3.2	15.5 ± 3.2	15.6 ± 3.1	15.5 ± 3.1

Source: Rivera-Brown, A. et al., Palatability and voluntary intake of three commercially available sports drinks and unflavored water during prolonged exercise in hot and humid conditions, http://www.kerwa.ucr.ac.cr/handle/10669/11105, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.

No significant differences were found between conditions, $p > .05$.

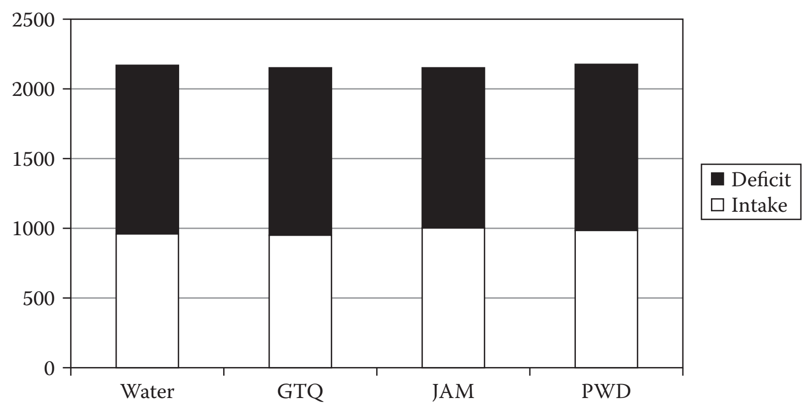

FIGURE 20.3 Fluid balance under the four conditions. (From Rivera-Brown, A. et al., Palatability and voluntary intake of three commercially available sports drinks and unflavored water during prolonged exercise in hot and humid conditions, http://www.kerwa.ucr.ac.cr/handle/10669/11105, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.)

As may be seen on Table 20.4, sweat losses and voluntary fluid intake were remarkably similar for the different beverages, resulting in nearly identical dehydration. In addition, fluid intake was insufficient to match sweat rates.

Careful analysis of sensory data shows that insufficient intake was not related to palatability, as the overall acceptance was close to 8.0 on a 9-point scale for all

TABLE 20.4
Body Fluid Balance

	Water	CES	CESP1	CESP2
Body weight pre (kg)	56.3 ± 7.6	56.4 ± 7.6	56.3 ± 7.6	56.6 ± 7.9
Body weight post (kg)	55.1 ± 7.1	55.2 ± 7.1	55.1 ± 7.1	55.4 ± 7.5
Δ in body weight (kg)	1.2 ± 0.6	1.2 ± 0.7	1.2 ± 0.6	1.2 ± 0.6
Fluid intake (mL kg^{-1})	17.0 ± 4.8	16.9 ± 5.4	17.8 ± 5.4	17.5 ± 5.3
Sweat loss (mL kg^{-1})	37.2 ± 8.7	37.1 ± 9.0	36.9 ± 8.9	37.6 ± 8.8
Sweat rate ($L \cdot h^{-1}$)	1.41 ± 0.45	1.42 ± 0.47	1.41 ± 0.48	1.44 ± 0.48
Fluid loss (mL kg^{-1})	38.3 ± 8.7	38.0 ± 9.0	38.0 ± 9.2	38.5 ± 8.7
Dehydration (% BW)	2.1 ± 1.0	2.1 ± 1.0	2.0 ± 0.9	2.1 ± 0.9
Rehydration (%)	46.9 ± 17.2	47.1 ± 18.7	48.9 ± 16.6	47.1 ± 16.9

Source: Rivera-Brown, A. et al., Palatability and voluntary intake of three commercially available sports drinks and unflavored water during prolonged exercise in hot and humid conditions, http://www.kerwa.ucr.ac.cr/handle/10669/11105, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.

No significant differences between conditions, $p > .05$.

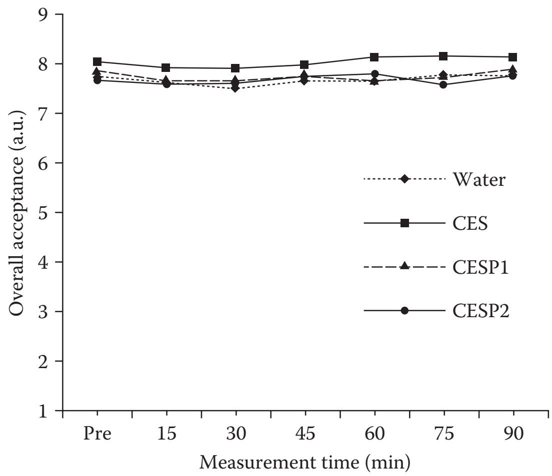

FIGURE 20.4 Overall acceptance of the drinks. (From Rivera-Brown, A. et al., Palatability and voluntary intake of three commercially available sports drinks and unflavored water during prolonged exercise in hot and humid conditions, http://www.kerwa.ucr.ac.cr/handle/10669/11105, 2014. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.)

four beverages, and it did not decline over time (Figure 20.4). There were no significant differences among beverages in terms of liking of flavor, thirst quenching, or declared willingness to drink a substantial volume; on the other hand, the scales were able to detect the expected differences between water and the other three drinks regarding flavor strength, sweetness, saltiness, and tartness. From this study, it may be concluded that the reluctance of young male and female athletes to drink while running or race walking in hot and humid conditions did not seem to be related to the presence of artificial preservatives in these beverages.

In summary, the few available data suggest that while artificial preservatives such as sodium benzoate may have a negative impact on voluntary fluid intake during moderate intensity exercise in warm conditions, the effect disappears when heat-acclimated humans exercise at a moderate-to-high intensity in hot and humid conditions.

20.5 NATURAL DRINKS

Independently from the balance of the evidence in favor or against the presence of different artificial ingredients in beverages at any particular point in time, natural drinks appeal to an important segment of the population. These include fruit juices and diluted drinks, mineral waters, infusions, and even milk. Scientific studies are limited because the composition of any particular natural drink varies widely, depending not only on preparation and freshness but also, in the case of fruit, on ripeness and site of cultivation.

It is also necessary to recognize the weight of what could be called *the cultural ingredient*: acceptability of a natural drink varies widely, depending on cultural aspects. It has long been recognized that voluntary fluid intake is strongly influenced by factors such as flavor, temperature, and texture, making them key elements in the formulation of beverages (Baker and Jeukendrup 2014). In the case of natural drinks, those elements are often not manipulated, yet remain an important component of the effectiveness of the beverages, as the best rehydration fluid in the world will not be optimal unless a sufficient amount is ingested.

Each drink in this section is discussed as it is normally consumed, presenting its acceptability and composition but not necessarily focusing on single ingredients. Natural drinks are included in this chapter because they comprise an important segment of all rehydrating beverages.

20.5.1 Coconut Water

Perhaps the most popular natural drink, coconut water has been studied for decades as a rehydration fluid. A few papers published during or immediately after World War II pointed out its high biological value (Picado Twight 1942), and some medical uses such as child feeding or its administration to dehydrated patients orally or intravenously with very few allergic reactions (Eiseman 1954; Soto et al. 1942). Other papers have reported its utilization in medical emergencies, also for rehydration (Campbell-Falck et al. 2000, Kuberski et al. 1979).

Coconut water is currently packaged and sold in many countries. Typically, commercial processing and the addition of preservatives degrades the flavor, producing an inferior product. The Food and Agricultural Organization (FAO) has been granted a patent for a process that allows manufacturers to bottle coconut water, theoretically preserving its microbiological and organoleptic properties (Rolle 2014).

Fresh coconut water is a crystal clear, biologically sterile fluid found in green coconuts, about 6–9 months old. One green coconut may have about 500–750 mL of fluid. Many people in the tropics see fresh coconut water as the natural choice for hydration. Studies have shown that coconut water is subject to variability in its carbohydrate and electrolyte content, according to place of growth, plant species, and maturation (age upon harvesting) (Child and Nathanael 1950; Vigliar et al. 2006). On average, there are 2–5 g of carbohydrate in 100 mL of fresh coconut water, compared with 6 g in a conventional sports drink. Sodium content (about 4 mEq/L) is low for rehydration purposes, about one-fifth the content in a conventional sports drink. Potassium content (about 50 mEq/L) is much higher than normally found in sports drinks (about 3 mEq/L). Pérez Idárraga and Aragón-Vargas (2014) report 31 mEq/L of chloride. Major carbohydrates are glucose, sucrose, and fructose, in a ratio of about 50:35:15. Coconut water also contains inulin, a fructose-containing carbohydrate that has been shown to boost calcium absorption (Coxam 2007), although coconut water has not been tested in this regard. Osmolality has been reported to be between 282 and 452 mOsm/kg water (Pérez-Idárraga and Aragón-Vargas 2014; Vigliar et al. 2006).

The first experimental study looking at the effectiveness of coconut water for post-exercise rehydration was published as an abstract (Aragón-Vargas and Madriz-Davila 2000). Nineteen teenage boys ran intermittently in the heat until they were dehydrated to 2.3% BM. Each one rehydrated with water, fresh coconut water, or a sports drink on three different occasions, one week apart, in random order. After 3 h of monitoring, their net fluid balance was about 300 g greater ($p < .05$) with both the coconut water and the sports drink than with plain water.

Later, Saat et al. (2002) failed to find any difference in fluid retention between water and fresh coconut water. Recent results have also been inconsistent, with a majority of the studies showing fresh coconut water to be more effective than plain water, and another showing no difference. Ismail et al. (2007), after dehydrating subjects to 3% BM and rehydrating them with a volume equivalent to 120% of sweat losses of plain water, fresh coconut water, sports drink, or sodium-enriched fresh coconut water, obtained a better fluid retention with coconut water (65.1% ± 1.7%) than with plain water (58.9% ± 1.8%). Pérez-Idárraga and Aragón-Vargas (2011b) exercised 11 young participants in the heat to 1.84% ± 0.2% BM dehydration and had them drink within an hour plain water, fresh coconut water, or a sports drink in a volume equivalent to 120% BM loss. Fluid retention was similar for the latter two beverages (71%), but both were better than water (56%, $p < .001$). Another recent paper by Pérez-Idárraga and Aragón-Vargas (2014) was unable to confirm the advantage of fresh coconut water compared with plain water. Twelve physically active participants exercised in the heat to about 2% dehydration and then ingested 120% of weight loss of one of four beverages randomly assigned to each trial: plain water, fresh coconut water, a conventional sports drink, or a high-potassium drink. All beverages were well tolerated and scored high in palatability, but fluid retention was similar between coconut water (62.5% ± 15.4%) and plain water (51.3% ± 12.6%). It is possible that statistics did not reach significance due to the higher number of comparisons (4 instead of 3) on this study.

The studies of the previous two paragraphs refer to post-exercise rehydration with fresh coconut water. A recent paper by Laitano et al. (2014) evaluated the effects of prior ingestion of a commercial coconut water on fluid retention and exercise capacity in the heat. They provided 10 mL/kg BM of a flavored drink, plain water, or commercially available coconut water to eight subjects before performing an exercise capacity trial on a cycle ergometer in the heat. Time to exhaustion was about 24% longer with the commercial coconut water ($p < .05$), and urine output was significantly reduced by 25% when compared with plain water, despite being collected over a longer period (urine collection took place after the end of the exercise capacity trial). Another recent paper evaluated commercially available bottled coconut water and coconut water from concentrate, but failed to provide the beverage composition of the drinks and presented internally inconsistent results (Kalman et al. 2012).

In summary, available research on post-exercise rehydration with fresh coconut water shows either better fluid retention or no difference in comparison with plain water. For that reason and because of its good palatability and tolerance when ingested in large volumes, coconut water is deemed suitable as a rehydration beverage.

20.5.2 Jamaica (Roselle) Flower Infusion

Many herbal infusions are ingested—not necessarily for exercise hydration purposes—in different regions of the world, and some have been studied for their rehydration effectiveness, such as rooibos tea (Utter et al. 2010), regular tea (Chang et al. 2010), and lemon tea (Wong and Chen 2011), but they have been found to be no more effective than plain water. An interesting beverage in this category is Roselle flower infusion, a beverage ingested in large volumes as a refreshing drink in Mexico and other parts of the world. Roselle flower or Jamaica flower (*Hibiscus sabdariffa*) infusion has purported medicinal properties and is popularly thought to be a diuretic; this would make it a bad selection for post-exercise rehydration. A study by Mayol-Soto and Aragón-Vargas (2002) compared Roselle infusion with plain water and a conventional sports drink, with the purpose of verifying whether Roselle tea would induce diuresis beyond the normal effect of a high water volume load. Sixteen young men exercised in the heat and lost approximately 2.3% of their BM. They ingested one of the three beverages on each opportunity, in random order, in a volume equivalent to 150% of sweat lost. While rehydration was almost identical with the three drinks, urine composition and output dynamics were different with each beverage. Because urine output was not higher with Roselle infusion than with plain water, the authors concluded that Roselle tea did not show a diuretic effect 3 h after consumption of ~2.4 L in exercise-dehydrated subjects. Therefore, there seems to be no basis for contraindicating Roselle infusion as a post-exercise rehydration beverage.

20.5.3 Milk and Chocolate Milk

Milk is not necessarily considered a natural drink, because of the high processing normally involved in pasteurization, bottling, and distribution. It is, however, widely consumed by humans, particularly in regions where lactose intolerance (a characteristic strongly associated with race [De Vrese et al. 2001]) is not prevalent. Several

TABLE 20.5
Comparison of a Conventional Sports Drink with Different Types of Milk and Chocolate Milk

	Gatorade®	Whole Milk	2% Milk	Skim Milk	Chocolate Milk
Energy (kcal)	52	155	125	83	213
Energy (kJ)	218	649	525	347	892
Protein (g)	0	8	8	8	8
Fat (g)	0	8.3	5	0.3	5
CHO (g)	15	12	12	12	34
Sodium (mg)	115	126	129	133	150
Potassium (mg)	31	391	398	431	422
Calcium (mg)	0	300	300	300	248

Source: Roy, B.D., *J. Int. Soc. Sports Nutr.*, 5, 15, 2008. Translated from Aragón–Vargas, L.F. La leche... ¿Bebida deportiva? http://www.kerwa.ucr.ac.cr/handle/10669/444, 2009. Used with permission. This work is licensed under a Creative Commons Attribution 4.0 International License.

Data are Reported for 250 mL, as obtained from Nutritional Information Labels from Dos Pinos® Dairy Products (San José, Costa Rica), with the exception of sodium and potassium contents.

reviews have discussed the qualities of milk in association with sports performance, protein synthesis during recovery, and post-exercise rehydration (Aragón-Vargas 2009; James 2012; Roy 2008); this section will focus on the hydration aspect.

Before looking at milk and its potential use as a rehydration beverage, a quick analysis of its composition is warranted (see Table 20.5). Milk is not very different from a conventional sports drink in terms of carbohydrate and sodium content, but it has a higher energy density and it contains fat and protein, together with a higher concentration of potassium and calcium. Probably the most important differences among milk types, for rehydration purposes, are total energy, and fat and carbohydrate content. Skim milk is the most commonly tested dairy product in association with exercise and hydration.

Shirreffs et al. (2007) compared the effectiveness of low fat milk (with or without added sodium) with a conventional sports drink and water. Eleven subjects exercised intermittently in the heat until they reached a dehydration of ~1.8% BM. They replaced 150% of the sweat losses (~2 L) on four different opportunities, one with each beverage, in a cross over design; the total volume was ingested in 1 h. Subjects were monitored for 4 h after rehydration was completed. Partial urine output was remarkably different among the drinks, because water and the sports drink resulted in the typical pattern of a marked increase in urine volume 1 and 2 h after ingestion, but the two milk products did not. Furthermore, total urine output was lower with milk (611 ± 207 mL; mean ± SD) and with milk + sodium (550 ± 141 mL), compared with water (1184 ± 321 mL) or the sports drink (1205 ± 142 mL) ($p < .001$). The authors concluded that milk can be an effective beverage for post-exercise rehydration, as long as the individual has no lactose intolerance.

Watson et al. published a study in 2008, comparing the effects of milk and a carbohydrate-electrolyte drink on the restoration of fluid balance and exercise capacity. They dehydrated seven males to ~2% BM with an intermittent exercise protocol in the heat, and rehydrated them with 150% of their sweat losses with a sports drink or skim milk, following them up for 3 h. No comparison with water was attempted in this case. Exercise capacity results are beyond the scope of this chapter, but were almost identical between drinks. While net fluid balance was not different between beverages at the end of monitoring ($p < .051$), it was positive for the milk ($p = .02$ vs. baseline) but not different from zero for the sports drink ($p = .796$). Cumulative urine output was not different at the end of follow-up ($p = .056$), but it was lower for milk at the 2-h time point ($p < .05$). Another rehydration measure, percentage of the drink retained at the end of the recovery period, was greater with the milk than with the carbohydrate-electrolyte drink ($p = .045$). The authors pointed out the ability of skim milk to match a sports drink specifically designed for rehydration and performance, but warned individuals who are lactose intolerant against its use.

A recent study comparing water, a sports drink, and skim milk in children and adolescents confirmed earlier findings with adults (Volterman et al. 2014). Thirty-eight heat-acclimated boys and girls, 7–17 years of age, completed a fixed-time, moderate-intensity exercise protocol in the heat, on three separate opportunities, in a randomized, repeated-measures cross-over design. They dehydrated to ~1.3% BM, and ingested each of the three beverages in a volume equivalent to 100% of BM loss. The authors made several important comparisons by gender and age group, which are beyond the scope of this chapter; most importantly, the rehydration measures showed a better fraction of beverage retention for the skim milk than the sports drink, and both were better than water ($p < .05$). Body fluid balance was negative for all three drinks at the end of the 2 h of monitoring, but it was significantly less negative for the skim milk than for water ($p < .05$), and cumulative urine output was lower for skim milk than both sports drink and water ($p < .001$). Beverage acceptance was measured on a scale from 1 to 9, with 9 being the worst score, and participants reported enjoying the taste of the sports drink (2.3 ± 1.5) better than water (3.7 ± 1.7) and skim milk (3.4 ± 1.5) ($p < .001$). The authors concluded that skim milk was found to be more effective than water and the selected sports drink at replacing fluid losses that occur during exercise in the heat, but mentioned the limitation of skim milk for practical uses since it was not as palatable as the sports drink.

Because of the important role played by voluntary fluid intake in rehydration during and after exercise in the heat. Mateos Román and Aragón-Vargas (2011) completed a study with 31 male soccer players, 10–14 years of age, who rehydrated *ad libitum* with water and partially skimmed milk (session A), or water and partially skimmed chocolate milk (session B) in a randomized fashion while exercising in the heat. The boys exercised in the heat in a controlled environment chamber at a moderate intensity, for a total of 120 min. Each dairy drink was always presented simultaneously with a bottle of water to avoid producing a floor effect, that is, that boys would drink more of a beverage they didn't like simply because they were hot and thirsty; beverage temperature was ~16°C.

The boys arrived to sessions A and B in practically identical conditions, and recorded the same exercise intensity and thermal stress. Sweat rates were very similar (about 460 mL/h), and fluid balance was positive and the same for both sessions at the end of exercise (≈0.76% BM). Boys drank the same volume of water, milk, and chocolate milk but, in general terms, milk and chocolate milk scored better for palatability than water. Chocolate milk was assigned higher scores for sweetness (7.6, $p < .001$), flavor intensity (5.8, $p < .001$), liking (7.9, $p < .001$), and overall acceptance (8.7, $p < .001$) when compared with milk and water; these two were not significantly different. In terms of overall acceptance, though, chocolate milk showed a tendency for declining scores over time, while milk remained constant and water increased over time. The authors concluded that when presented simultaneously with water, both partially skimmed milk and chocolate milk were effective in preventing voluntary dehydration in boys exercising in the heat. Palatability scores were favorable and GI symptoms were not clinically relevant.

To summarize, there is good experimental evidence to support skim milk as an effective beverage for rehydration after exercise in the heat, both in children, adolescents, and adults. Apparently, not only does the sodium content promote fluid retention, but the total energy content in the form of carbohydrate and protein may be inducing a slower gastric emptying, delaying fluid delivery to the bloodstream and causing a smaller plasma volume expansion with the concomitant lower diuresis (Roy 2008). As far as chocolate milk is concerned, more experimental evidence is needed, particularly in the light of its high palatability. Rehydration with milk products is contraindicated for lactose-intolerant individuals.

20.5.4 Mineral Water

Once it has been understood that the presence of electrolytes (minerals) in beverages favors rehydration, it naturally follows that mineral water should be a good choice for this purpose. However, naturally occurring minerals in melted ice and snow filtered thru the mountains and obtained from natural springs are usually present in very low concentrations. In fact, many commercially available waters boast of their low mineral content, a quality called *oligominerale*. In spite of their common use, even by professional teams (Shirreffs et al. 2005), few studies have experimentally evaluated the efficacy of mineral waters for post-exercise rehydration.

Shirreffs et al. (2007) compared the hydration effectiveness of four commonly used drinks after exercise in the heat in eight subjects who dehydrated to about 2% BM. In a repeated-measures design, each participant ingested one of four beverages in randomized order: a sports drink with 6% carbohydrate, 23 mEq/L sodium, 6 mEq/L potassium and 17 mEq/L chloride; mineral water A with no carbohydrate, and virtually no sodium or potassium, and 3 mEq/L chloride; mineral water B with no carbohydrate, 1 mEq/L sodium, 0 mEq/L potassium, and 5 mEq/L chloride; and a homemade beverage mixing four parts of apple juice and six parts of carbonated mineral water (Apfelschörle), providing 6.7% carbohydrate, 8 mEq/L sodium, 30 mEq potassium, and 1 mEq/L chloride. Participants drank a volume equivalent to 150% of sweat losses in 1 h, and were monitored for 4 h. Only the sports drink was able to maintain euhydration by the end of monitoring, suggesting that the mineral content in the waters used was too low to have a positive impact on net fluid balance. The mineral water used by Real Madrid and reported by Shirreffs et al. in 2005 had similarly low concentrations of sodium (2.3 mEq/L), potassium (0.3 mEq/L) and chloride (2.2 mEq/L), and would not be expected to produce better results.

20.6 OTHER INGREDIENTS

Very little work has been published on the rehydration qualities of other potential ingredients such as magnesium (Brilla et al. 2003), calcium (Brancaccio et al. 2012), oxygen, taurine (Janeke et al. 2003), betaine (Sayed and Downing 2011), and vitamins (Snell et al. 2010), even though they have all otherwise been studied in association with sports performance. Some of the experiments have not yet been performed in humans, and most of them have not studied these ingredients independently. None of them seem promising as possible elements in rehydration beverages.

There is some information on glutamine, which has been tested as a potential ingredient in oral rehydration solutions (ORS) for the treatment of diarrhea. Schedl et al. had proposed in 1994 that a glutamine-glucose ORS had the potential to maximize water, electrolyte, and energy transport in the small intestine. Unfortunately, glutamine has not proven to be more effective when compared with a standard World Health Organization ORS (Gutiérrez et al. 2007, Ribeiro Júnior et al. 1994). A recently published experiment, focusing on exercise performance (Hoffman et al. 2010), is probably the only exercise-related study on glutamine and hydration; hormone concentrations associated with fluid balance were reported, but no data were presented regarding fluid retention, net fluid balance, or urine output. Available data on glutamine are not enough to support its use for post-exercise rehydration.

20.7 SUMMARY

A number of natural drinks and ingredients used in hydration beverages have been discussed, focusing on their effectiveness for post-exercise rehydration. Because of excess diuresis, complete, rapid, and sustained restoration of fluid balance remains a challenge. The most effective ingredient to promote fluid retention is sodium, although the possible merits of milk protein, creatine, and additional potassium were presented.

Cultural preferences may lead some individuals to rehydrate with Roselle infusion, mineral water, or coconut water; doing so has been shown not to deter from the goal of restoring body fluid. Skimmed milk has been shown to be more effective than conventional sports drinks and water and may be a good rehydration choice in the absence of lactose intolerance. Furthermore, sports drinks with added milk or whey protein, which may be desirable to provide amino acids and help recovery, have been shown not to impair rehydration. The use of caffeinated beverages, although favored by many consumers and shown not to impair chronic hydration, remains more of an open question for quick post-exercise rehydration. Evidence was provided to show why regular beer is contraindicated when effective post-exercise rehydration is desired, together with evidence about the serious limitations associated with the use of glycerol.

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