Maintaining Fluid and Electrolyte Balance During Exercise

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The well-documented benefits and popularity of sports and fitness have led to an increased demand for products that not only replace sweat losses but also provide fuel for continued high-intensity metabolic demands. The twin risks of hypohydration and hyponatremia can lead to morbid and even fatal outcomes if rational replacement regimens are not followed, especially in endurance athletes and during hot or humid conditions. The avoidance of these complications of physical activity with oral replacement products has been documented primarily in high-impact, prolonged-duration events. Replacement fluid should contain water, sodium, and perhaps potassium to avoid overhydration-induced hyponatremia. Carbohydrates are added if muscle exertion is to continue for prolonged periods (>60 minutes in duration). The overuse of oral replacement products may yield the dilution of serum and intracellular electrolytes, hyperglycemia, and gastrointestinal distress. Baseline hydration and glucose status should be optimized before activity, and alterations in the amount and type of fluid ingested may be required for special populations such as children and individuals with chronic disease.

KEY WORDS: Exercise, sports, fluid, electrolytes, fluid replacement.

The importance of physical activity to well-being cannot be overstated. The physiological, psychological, and social benefits of regular exercise are plentiful and profound. Examples of such benefits include positive effects on weight, bone strength, metabolic factors (such as glucose and cholesterol), organ function, sleep, mood, and self-image. Coupled with the proliferation of team sports and increased choices for individual exercise, the fitness movement has created an increased demand for the care of athletes. Anyone who participates in physical exercise is at risk for injury and illness arising from such activity. A common preventable complication of sports activities is the loss of fluid and electrolytes during the events. This is exacerbated by exertion in extreme conditions of temperature and humidity. A lack of adequate access to replacement fluid during organized team sports during play may contribute to blunted performance during a game. Endurance sports (such as marathon running) and “extreme” sports (such as ironman contests and triathlons) create a supranormal need for replacement, especially after the first hour of competition. This article explores the frequently encountered physical exertion–induced losses of fluid and electrolytes, with a focus on team and endurance sports. Following that is a critical assessment of commonly used oral replacement regimens.

NORMAL PHYSIOLOGY

Daily food and beverage intake maintains euvolemia and normal concentrations of sodium and potassium. Losses of fluid through sweat amount to < 500 mL daily, provided an individual is at rest and in a comfortable environment at room temperature and moderate humidity. Increasing the core body temperature through physical activity such as sports and exercise is attenuated by the evaporation of body water through the skin. During periods of exertion of > 60 minutes or in hot (>25°C to 30°C) or humid (>75% to 80% relative

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humidity) conditions, the insensible losses of water and sodium (and potassium to a lesser extent) in sweat put a patient at risk for hypovolemia, dehydration, and imbalances in serum sodium and potassium.1 Findings of weak pulse, cool skin, altered mental status, confusion, nausea, and diminished sweat and urine output indicate clinically significant dehydration requiring the cessation of physical activity.

SPORTS-INDUCED FLUID AND ELECTROLYTE IMBALANCES

Hypohydration

During vigorous exercise of > 20 minutes in duration, water loss exceeds electrolyte loss, especially in hot conditions.2 Hypohydration arises from the loss of at least 2% of body water without adequate replacement. Losses of > 2% produce incremental deficits in physical performance; losses of > 5% cause substantially decreased ability to continue with physical activity and put an individual at risk for life-threatening dehydration, heat stroke, and heat exhaustion.3 Refer to Table 1 for heat-related syndromes. Hypohydration accelerates muscle fatigue during exercise and impairs cooling. Sweat is conserved during cooling, and skin perfusion is diminished in an attempt to maintain intravascular volume. Oral fluid replacement during activity has been shown to attenuate tachycardia from prolonged vigorous exercise.4 Endurance-trained athletes have very high fluid requirements during activity, and even with forced frequent oral replacement regimens lose an average of 2.5 kg of body weight per race.5 For example, ongoing fluid losses for cycling and running are approximately 1 L/h.

The benefits of warm-up training on fluid balance before endurance events have been demonstrated in cyclists, who accumulated increased plasma volumes after 6 days of intensive physical training. The rise in volume was partially attributed to the down-regulation of aldosterone and epinephrine release.6 The ideal replacement fluid would equally match water and electrolyte losses from sweat. This would be very difficult since the quantities of loss vary greatly between individuals and with the intensity of the exertion and extremes of ambient temperature.

In general, hypohydration can be avoided if 3 recommendations are followed. First, an athlete should begin exercise well hydrated. It is much more difficult to replace ongoing fluid loss if superimposed on baseline hypohydration. Second, an athlete should consume chilled fluid during exercise. Fluids should be ingested even if thirst is not present. Once thirst occurs, it should be assumed that significant hypohydration (dehydration) is present, and the cessation of physical activity should be strongly considered. The fluid temperature should be cooler than body temperature, but not necessarily “ice cold.” Recommendations with respect to fluid temperature vary from 15°C to 25°C (59°F to 77°F). The quantity consumed should be at least 100 mL (up to 300 mL) every 15 to 30 minutes. Fluid intake may not be necessary for exertion of < 20 to 30 minutes in duration, unless in extremes of temperature or humidity. Last, an athlete should continue to drink water after exercise to replace ongoing losses in the “cool-down” period. The thermal load of exercise continues several minutes beyond the end of physical exertion and sweat losses may persist for up to 15 to 30 minutes.

Hyponatremia

The popular admonishment to ingest fluids (usually water) during and after physical activity may sometimes produce adverse effects. When large amounts (> 2 to 3 L) of water alone are used as replacement fluid, a risk for the hemodilution of some electrolytes is likely. Excessive water intake has been associated with symptomatic hyponatremia. Alteration in mental status, in-
cluding coma and generalized tonic-clonic seizures, have been reported from overhydration with water.\textsuperscript{7,8} A fall in serum sodium below 130 mEq/L (normal serum sodium is 135 to 145 mEq/L) is associated with the onset of altered mentation, which may be misdiagnosed as the hypohydration-induced impairment of central nervous system blood flow. This misinterpretation of clinical findings may result in the administration of more free water and further dilutional hyponatremia; one fatality and several injuries have been linked to this series of events.\textsuperscript{9,10}

The recent death of a 26-year-old woman during a marathon was attributed to hyponatremic encephalopathy. This occurred even though fluid losses incurred by running were replaced by the ingestion of a sodium-and carbohydrate-containing sports drink.\textsuperscript{11} The mechanism of hyponatremia in this setting is unclear, but one possible hypothesis is that the diffusion of water from sports drink–repleted isotonic serum into hypernatremic dehydrated cells in the brain produced cerebral edema, culminating in coma and brainstem herniation.

Much experience has been reported with the occurrence of hyponatremia in athletes involved in triathlon events (swimming, cycling, and running). Triathletes with histories of exercise-induced hyponatremia are not necessarily at risk for recurrence if hydration and electrolyte replenishment are adequate.\textsuperscript{12} However, hyponatremic symptoms may be obscured by massive fluid losses because total body sodium content may be depleted, but serum sodium concentration may remain normal from hemoconcentration. Female triathletes appear to be at a higher risk than male triathletes for exercise-associated hyponatremia,\textsuperscript{13} but recovery with equal rehydration regimens is similar.\textsuperscript{14} The effect of excessive water intake on serum sodium during exercise has been corroborated by reports in athletes engaged in less strenuous activity, such as hiking.\textsuperscript{15}

Other complications of excessive water ingestion have been reported. Rhabdomyolysis arising from postexercise water intoxication has resulted in acute renal failure;\textsuperscript{16} hyponatremia was possibly associated with rhabdomyolysis through an unclear mechanism. The monitoring of complaints of myalgia and serum creatine phosphokinase is recommended in individuals with symptomatic hyponatremia due to excessive intraexercise or postexercise water intake.

**Hypokalemia**

Potassium losses in sweat are difficult to determine and are likely negligible for brief periods of exercise (<30 minutes in duration). In most athletes, potassium replacement is not necessary unless exercise is prolonged or occurs in a hot or humid environment. Complaints of weakness or myalgia of the weight-bearing muscles, irregular or rapid heartbeat, and nausea with abdominal cramps are associated with hypokalemia, which is associated with serum potassium concentrations of <3.5 mEq/L (normal serum potassium is 3.5 to 5.0 mEq/L). Athletes who use diuretic drugs may be at risk for preexercise hypokalemia, which predisposes an individual to muscle cramping during exertion. In such situations, potassium replacement prior to and during exercise is recommended. Hypokalemic effects have been most studied in athletes during hypokinetic (interexercise rest) periods between bouts of training. Interestingly, potassium supplementation during these periods did not blunt rest-induced hypokalemia.\textsuperscript{17} The purported mechanism of potassium loss is a decrement in tubular reabsorption of potassium at rest rather than a total body deficit of potassium.\textsuperscript{18}

**REPLACEMENT REGIMENS**

**Fluid and Electrolyte Replacement**

The goal of fluid intake is to consume more fluid orally than is being lost in sweat. Extracellular fluid rehydration is best achieved with smaller fluid volumes and isotonic sodium solutions, even though the fluid lost in sweat is hypotonic relative to plasma.\textsuperscript{19} Intracellular rehydration is best achieved with higher volumes and lower sodium (hypotonic) solutions. Hemodynamic responses (the optimization of cardiac output as estimated by heart rate and stroke volume) are similar with 100% or 150% fluid replacement and with hypotonic and isotonic solutions.\textsuperscript{20}

The ingestion of electrolytes (sodium and sometimes potassium) is essential in postexercise rehydration, especially after exercise periods of long duration (>60 minutes). The addition of sodium and carbohydrates assists with the intestinal absorption of water and permits more efficient fluid replacement than water alone.

**Carbohydrate Replacement**

Carbohydrates ingested during prolonged exercise (>60 minutes in duration) can be used as an immediate source of fuel for muscles undergoing continued exertion and may improve performance in endurance sports.\textsuperscript{19} To ensure optimal performance, individuals must have replete muscle glycogen stores before exercise. Preexercise glycogen deficits will not be offset by
the ingestion of carbohydrates during exercise and will not delay muscle fatigue from glycogen depletion. Individuals also should ingest carbohydrates during exercise to limit their indirect oxidation via lactate of nonworking muscle. It is recommended to ingest a nonfructose source, usually a glucose or glucose polymer (typically maltodextrin or corn syrup solids), if exercising for > 90 minutes.21

One risk of the ingestion of carbohydrates is the possibility of the delayed absorption of fluid, electrolytes, and substrates. Gastric emptying is proportionally slowed as the concentration of carbohydrates increases in replacement fluid because of hyperosmolar effects. When glucose is used as the carbohydrate source, its concentration is limited to < 2.5% since higher concentrations may delay gastric emptying and fluid absorption.22 In general, total carbohydrate concentrations, which may include a combination of different sources, should be > 5% to provide sufficient fuel for the maintenance of muscle performance during activity. However, total carbohydrate concentrations are limited to < 10% since higher carbohydrate content is associated with an increased risk for gastrointestinal distress (abdominal cramps, diarrhea, and nausea) owing to the high osmolar load.

Some replacement fluid products substitute fructose for glucose since it is a less potent insulin secretagogue and may have less potential for inducing rebound hypoglycemia. However, fructose may slow gastric emptying as much as other carbohydrates. Glucose polymers have a much lower osmolality than natural carbohydrates (fructose, glucose), and a high concentration must be ingested before gastric peristalsis is appreciably slowed.

The use of carbohydrate replacement bars for the purpose of augmenting muscle function before weight-training sessions is often an adjunct to fluid ingestion. These bars may also contain high amounts of fat and protein and therefore have no role in fluid or electrolyte replenishment. See Table 2 for a comparison of some currently marketed oral sports rehydration products.

SPECIAL CONSIDERATIONS

Ambient Environment

In hot climates, a palatable, flavored fluid with high sodium content (> 50 mmol/L), some potassium, and a carbohydrate concentration of 2% to 5% is recommended to optimize the intestinal absorption of sodium and water. Sweat losses during exercise in cold environments should be replaced on a frequent and continuous basis since rapid, large-volume rehydration risks overdiuresis, boosts oxygen consumption via shivering, and raises blood pressure. Fluid should be slightly above room temperature (lukewarm, 20°C to 25°C [68°F to 77°F]) because cold fluid may increase the likelihood of the detrimental effects of rehydration.23

Type of Activity

Activity during team sports is characterized by highly variable and unpredictable fluid and electrolytes sweat losses between players; fluctuations in exercise intensity and muscle work within a game; and structured, intermittent rest periods. Structured interruptions in play offer opportunities for rehydration and carbohydrate replenishment. For ongoing involvement in game activity, an average of 1 L/h should be ingested.

Individual and endurance sports are typically free of rest periods and require continuous, stable, and moderate-intensity activity. See the recommendations in “Treatment Algorithm and Recommendations Summary” for specific suggestions tailored to the needs of such athletes.

Special Populations

Children

Flavored replacement fluid containing 6% carbohydrate and 18 mmol/L sodium solution taken ad libitum is sufficient to prevent dehydration in 10- to 12-year-old boys exercising in hot, humid conditions.24 For short-duration bouts (<20 minutes), water alone fares as well as sodium- and carbohydrate-containing fluids in 9- to 12-year-old boys and girls.25

Diabetes Mellitus

The reduction of insulin dose by 30% to 40% before a 75-km cross-country skiing race maintained normoglycemia during the race after initial hyperglycemia in Type 1 diabetes mellitus (DM) patients.26 Presumably, individuals with DM may be given the same types of replacement fluids as those without DM.

Cystic Fibrosis

The loss of sodium in sweat is increased in cystic fibrosis. Such patients require higher sodium fluids to avoid dehydration from moderate exercise.27 A sodium concentration of at least 50 mmol/L is suggested for replacement fluid in cystic fibrosis.

Outdoor Laborers

Laborers experience inconsistent sweat loss and variable access to fluid. Water alone is usually adequate for work periods of < 3 to 4 hours. Frequent rehydration
(every 15 to 20 minutes) is necessary to avoid impaired cognition, especially when working with machinery or in elevated work sites.

**Ethanol**

Fluids containing up to 2% ethanol (EtOH) do not produce a delay in rehydration compared with EtOH-free drinks, but drinks with > 4% EtOH do. Low-EtOH-containing beverages such as “near beer,” a malt beverage containing < 0.5% EtOH, and “3.2 beer,” a lower-EtOH-content beer containing 4% EtOH, would not be expected to significantly affect the rate of postexercise rehydration.

**Caffeine**

Despite the mild diuretic affects of caffeine, no deleterious impact on rehydration has been shown with caffeinated fluids. In fact, caffeine may improve performance if consumed 60 minutes before exercise, apparently because of its mild chronotropic and stimulant properties. Caffeine should be avoided by individuals who are sensitive to its cardiovascular and central nervous system effects.

<table>
<thead>
<tr>
<th>TREATMENT ALGORITHM AND RECOMMENDATIONS SUMMARY</th>
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</table>

### Preactivity Intake

1. Ingest a meal containing easily digested carbohydrates not later than 5 to 6 hours before commencement of the activity.
2. Drink 500 mL of fluid 30 to 60 minutes before activity for moderate-intensity but not high-intensity exercise. Beware of hypoglycemia during activity if glucose solutions are ingested 15 to 45 minutes prior to activity. These solutions may be given 5 minutes before activity for improved performance. The carbohydrate source should be easily accessible by muscle cells, typically 18% to 50% glucose or glucose polymer.

### During Exercise

1. Ingest 150 to 300 mL of fluid every 15 to 20 minutes. Water alone is an adequate replacement fluid if activity lasts < 45 to 90 minutes. Fluids containing sodium, potassium, and carbohydrate are recommended for longer bouts of activity.
2. Sodium content should approximate typical losses from sweat and is typically 50 to 70 mEq/L. When combined with carbohydrate content, the sum of sodium and sugar should not exceed isotonicity (154 mEq/L). The optimal potassium content is 30 to 50 mg/240-mL serving.
3. In general, ingest fluid containing 3 to 5 g/100 mL (3 to 5 g%) carbohydrate every 10 minutes up to the first hour (if activity is to continue for > 1 hour), then increase to 10 g/100 mL every 10 minutes thereafter to accommodate elevated glucose oxidation rates. Flavored fluids are usually preferred since the large volumes required will usually exceed that guided by the thirst reflex. Glucose and glucose polymers are considered “ready fuel” for muscles and tend to cause less gastrointestinal distress than sucrose or fructose. Glucose polymer concentrations may approach 200 g/L without significant risk for hyperosmolar effects.

### Postexercise

1. Drink replacement fluid containing isotonic sodium and some potassium. Carbohydrate-containing fluids are not necessary unless activity is to be resumed.
2. Solid food is the best source of electrolyte replacement if activity is completed for several hours. Ingest with water or other fluid for water replacement.

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**Table 2**

<table>
<thead>
<tr>
<th>Product</th>
<th>Na⁺/240 mL (mg)</th>
<th>K⁺/240 mL (mg)</th>
<th>CHO/240 mL (g)</th>
<th>CHO source</th>
<th>KCal/240 mL</th>
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<td>C, F, G, S</td>
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</tr>
</tbody>
</table>

*Source: Adapted from reference 32.*

* a. F = fructose; G = glucose; P = glucose polymers, not specified; S = sucrose; M = maltodextrins; C = high-fructose corn syrup.*
3. Replacement fluids containing carbohydrates as well as electrolytes are recommended for regaining exercise capacity for continued activity.
4. Supplemental daily oral water and sodium supplementation may be required during periods of rest between high-intensity training sessions.

CONCLUSION

The risks of exercise-induced fluid and electrolyte balance are considerably minimized if oral replacement products are used. Athletes should be counseled to force fluid intake even if not thirsty to replenish water and sodium. If activity is prolonged beyond 60 minutes, then carbohydrate sources and potassium should also be included in the ingested fluid. The importance of these recommendations becomes paramount in extremes of temperature and humidity. The possibility of life-threatening hyponatremia remains the most important consideration in high-endurance activities, and athletes should ingest fluid before, during, and after activity.

REFERENCES