AMERICAN COLLEGE of SPORTS MEDICINE
POSITION STAND

Exercise and Fluid Replacement

This pronouncement was written for the American College of Sports Medicine by: Victor A. Convertino, Ph.D., FACSM (Chair); Lawrence E. Armstrong, Ph.D., FACSM; Edward F. Coyle, Ph.D., FACSM; Gary W. Mack, Ph.D; Michael N. Sawka, Ph.D., FACSM; Leo C. Senay, Jr., Ph.D., FACSM; and W. Michael Sherman, Ph.D., FACSM.

SUMMARY

American College of Sports Medicine. Position Stand on Exercise and Fluid Replacement. *Med. Sci. Sports Exerc.*, Vol. 28, No. 1, pp. i–vii, 1996. It is the position of the American College of Sports Medicine that adequate fluid replacement helps maintain hydration and, therefore, promotes the health, safety, and optimal physical performance of individuals participating in regular physical activity. This position statement is based on a comprehensive review and interpretation of scientific literature concerning the influence of fluid replacement on exercise performance and the risk of thermal injury associated with dehydration and hyperthermia. Based on available evidence, the American College of Sports Medicine makes the following general recommendations on the amount and composition of fluid that should be ingested in preparation for, during, and after exercise or athletic competition:

1) It is recommended that individuals consume a nutritionally balanced diet and drink adequate fluids during the 24-h period before an event, especially during the period that includes the meal prior to exercise, to promote proper hydration before exercise or competition.

2) It is recommended that individuals drink about 500 ml (about 17 ounces) of fluid about 2 h before exercise to promote adequate hydration and allow time for excretion of excess ingested water.

3) *During* exercise, athletes should start drinking early and at regular intervals in an attempt to consume fluids at a rate sufficient to replace all the water lost through sweating (i.e., body weight loss), or consume the maximal amount that can be tolerated.

4) It is recommended that ingested fluids be cooler than ambient temperature [between 15° and 22°C (59° and 72°F)] and flavored to enhance palatability and promote fluid replacement. Fluids should be readily available and served in containers that allow adequate volumes to be ingested with ease and with minimal interruption of exercise.

5) Addition of proper amounts of carbohydrates and/or electrolytes to a fluid replacement solution is recommended for exercise events of duration greater than 1 h since it does not significantly impair water delivery to the body and may enhance performance. During exercise lasting less than 1 h, there is little evidence of physiological or physical performance differences between consuming a carbohydrate-electrolyte drink and plain water.

6) During intense exercise lasting longer than 1 h, it is recommended that carbohydrates be ingested at a rate of 30–60 $g \cdot h^{-1}$ to maintain oxidation of carbohydrates and delay fatigue. This rate of carbohydrate intake can be achieved without compromising fluid delivery by drinking 600–1200 $ml \cdot h^{-1}$ of solutions containing 4%–8% carbohydrates ($g \cdot 100\ ml^{-1}$). The carbohydrates can be sugars (glucose or sucrose) or starch (e.g., maltodextrin).

7) Inclusion of sodium (0.5–0.7 $g \cdot l^{-1}$ of water) in the rehydration solution ingested during exercise lasting longer than 1 h is recommended since it may be advantageous in enhancing palatability, promoting fluid retention, and possibly preventing hyponatremia in certain individuals who drink excessive quantities of fluid. There is little physiological basis for the presence of sodium in an oral rehydration solution for enhancing intestinal water absorption as long as sodium is sufficiently available from the previous meal.

INTRODUCTION

Disturbances in body water and electrolyte balance can adversely affect cellular as well as systemic function, subsequently reducing the ability of humans to tolerate prolonged exercise. Water lost during exercise-induced sweating can lead to dehydration of both intracellular and extracellular fluid compartments of the body. Even a small amount of dehydration (1% body weight) can increase cardiovascular strain as indicated by a disproportionate elevation of heart rate during exercise, and limit the ability of the body to transfer heat from contracting muscles to the skin surface where heat can be dissipated to the environment. Therefore, consequences of body water deficits can increase the probability for impairing exercise performance and developing heat injury.

The specific aim of this position statement is to provide appropriate guidelines for fluid replacement that will help avoid or minimize the debilitating effects of water and electrolyte deficits on physiological function and exercise performance. These guidelines will also address the rationale for inclusion of carbohydrates and electrolytes in fluid replacement drinks.

HYDRATION BEFORE EXERCISE

Fluid replacement following exercise represents hydration prior to the next exercise bout. Any fluid deficit prior to exercise can potentially compromise thermoregulation during the next exercise session if adequate fluid replacement is not employed. Water loss from the body due to sweating is a function of the total thermal load that is related to the combined effects of exercise intensity and ambient conditions (temperature, humidity, wind speed) (62,87). In humans, sweating can exceed 30 $g \cdot min^{-1}$ (1.8 $kg \cdot h^{-1}$) (2,31). Water lost with sweating is derived from all fluid compartments of the body, including the blood (hypovolemia) (72), thus causing an increase in the concentration of electrolytes in the body fluids (hypertonicity) (85). People who begin exercise when hypohydrated with concomitant hypovolemia and hypertonicity display impaired ability to dissipate body heat during subsequent exercise (26,28,61,85,86). They demonstrate a faster rise in body core temperature and greater cardiovascular strain (28,34,82,83). Exercise performance of both short duration and high power output, as well as prolonged moderate intensity endurance activities, can be impaired when individuals begin exercise with the burden of a previously incurred fluid deficit (1,83), an effect that is exaggerated when activity is performed in a hot environment (81).

During exercise, humans typically drink insufficient volumes of fluid to offset sweat losses. This observation has been referred to as "voluntary dehydration" (33,77). Following a fluid volume deficit created by exercise, individuals ingest more fluid and retain a higher percentage of ingested fluid when electrolyte deficits are also replaced (71). In fact, complete restoration of a fluid volume deficit cannot occur without electrolyte replacement (primarily sodium) in food or beverage (39,89). Electrolytes, primarily sodium chloride, and to a lesser extent potassium, are lost in sweat during exercise. The concentration of Na^+ in sweat averages ~50 mmol $\cdot$ l^{-1} but can vary widely (20–100 mmol $\cdot$ l^{-1}) depending on the state of heat acclimation, diet, and hydration (6). Despite knowing the typical electrolyte concentration of sweat, determination of a typical amount of total electrolyte loss during thermal or exercise stress is difficult because the amount and composition of sweat varies with exercise intensity and environmental conditions. The normal range of daily U.S. intake of sodium chloride (NaCl) is 4.6 to 12.8 g (~80–220 mmol) and potassium (K^+) is 2–4 g (50–100 mmol) (63). Exercise bouts that produce electrolyte losses in the range of normal daily dietary intake are easily replenished within 24 h following exercise and full rehydration is expected if adequate fluids are provided. When meals are consumed, adequate amounts of electrolytes are present so that the composition of the drink becomes unimportant. However, it is important that fluids be available during meal consumption since most persons rehydrate primarily during and after meals. In the absence of meals, more complete rehydration can be accomplished with fluids containing sodium than with plain water (32,55,71).

To avoid or delay the detrimental effects of dehydration during exercise, individuals appear to benefit from fluid ingested prior to competition. For instance, water ingested 60 min before exercise will enhance thermoregulation and lower heart rate during exercise (34,56). However, urine volume will increase as much as 4 times that measured without preexercise fluid intake. Pragmatically, ingestion of 400–600 ml of water 2 h before exercise should allow renal mechanisms sufficient time to regulate total body fluid volume and osmolality at optimal preexercise levels and help delay or avoid detrimental effects of dehydration during exercise.

FLUID REPLACEMENT DURING EXERCISE

Without adequate fluid replacement during prolonged exercise, rectal temperature and heart rate will become more elevated compared with a well-hydrated condition (13,19,29,54). The most serious effect of dehydration resulting from the failure to replace fluids during exercise is impaired heat dissipation, which can elevate body core temperature to dangerously high levels (i.e., >40°C). Exercise-induced dehydration causes hypertonicity of body fluids and impairs skin blood flow (26,53,54,65), and has been associated with reduced sweat rate (26,85), thus limiting evaporative heat loss, which accounts for more than 80% of heat loss in a hot-dry environment. Dehydration (i.e., 3% body weight loss) can also elicit significant reduction in cardiac output during exercise since a reduction in stroke volume can be greater than the increase in heart rate (53,80). Since a net result of electrolyte and water imbalance associated with failure to adequately replace fluids during exercise is an increased rate of heat storage, dehydration induced by exercise presents a potential for the development of heat-related disorders (24), including potentially life-threatening heat stroke (88,92). It is therefore reasonable to surmise that fluid replacement that offsets dehydration and excessive elevation in body heat during exercise may be instrumental in reducing the risk of thermal injury (37).

To minimize the potential for thermal injury, it is advocated that water losses due to sweating during exercise be replaced at a rate equal to the sweat rate (5,19,66,73). Inadequate water intake can lead to premature exhaustion. During exercise, humans do not typically drink as much water as they sweat and, at best, voluntary drinking only replaces about two-thirds of the body water lost as sweat (36). It is common for individuals to dehydrate by 2%–6% of their body weight during exercise in the heat despite the availability of adequate amounts of fluid (33,35,66,73). In many athletic events, the volume and frequency of fluid consumption may be limited by the rules of competition (e.g., number of rest periods or time outs) or their availability (e.g., spacing of aid stations along a race course). While large volumes of ingested fluids ($\geq$1 l $\cdot$ h^{-1}) are tolerated by exercising individuals in laboratory studies, field observations indicate that most participants drink sparingly during competition. For example, it is not uncommon for elite runners to ingest less than 200 ml of fluid during distance events in a cool environment lasting more than 2 h (13,66). Actual rates of fluid ingestion are seldom more than 500 ml $\cdot$ h^{-1} (66,68) and most athletes allow themselves to become dehydrated by 2–3 kg of body weight in sports such as running, cycling, and the triathlon. It is clear that perception of thirst, an imperfect index of the magnitude of fluid deficit, cannot be used to provide complete restoration of water lost by sweating. As such, individuals participating in prolonged intense exercise must rely on strategies such as monitoring body weight loss and ingesting volumes of fluid during exercise at a rate equal to that lost from sweating, i.e., body weight reduction, to ensure complete fluid replacement. This can be accomplished by ingesting beverages that enhance drinking at a rate of one pint of fluid per pound of body weight reduction. While gastrointestinal discomfort has been reported by individuals who have attempted to drink at rates equal to their sweat rates, especially in excess of $1\ l \cdot h^{-1}$ (10,13,52,57,66), this response appears to be individual and there is no clear association between the volume of ingested fluid and symptoms of gastrointestinal distress. Further, failure to maintain hydration during exercise by drinking appropriate amounts of fluid may contribute to gastrointestinal symptoms (64,76). Therefore, individuals should be encouraged to consume the maximal amount of fluids during exercise that can be tolerated without gastrointestinal discomfort up to a rate equal to that lost from sweating.

Enhancing palatability of an ingested fluid is one way of improving the match between fluid intake and sweat output. Water palatability is influenced by several factors including temperature and flavoring (25,36). While most individuals prefer cool water, the preferred water temperature is influenced by cultural and learned behaviors. The most pleasurable water temperature during recovery from exercise was 5°C (78), although when water was ingested in large quantities, a temperature of ~15°–21°C was preferred (9,36). Experiments have also demonstrated that voluntary fluid intake is enhanced if the fluid is flavored (25,36) and/or sweetened (27). It is therefore reasonable to expect that the effect of flavoring and water temperature should increase fluid consumption during exercise, although there is insufficient evidence to support this hypothesis. In general, fluid replacement beverages that are sweetened (artificially or with sugars), flavored, and cooled to between 15° and 21°C should stimulate fluid intake (9,25,36,78).

The rate at which fluid and electrolyte balance will be restored is also determined by the rate at which ingested fluid empties from the stomach and is absorbed from the intestine into the blood. The rate at which fluid leaves the stomach is dependent on a complex interaction of several factors, such as volume, temperature, and composition of the ingested fluid, and exercise intensity. The most important factor influencing gastric emptying is the fluid volume in the stomach (52,68,75). However, the rate of gastric emptying of fluid is slowed proportionately with increasing glucose concentration above 8% (15,38). When gastric fluid volume is maintained at 600 ml or more, most individuals can still empty more than 1000 $ml \cdot h^{-1}$ when the fluids contain a 4%–8% carbohydrate concentration (19,68). Therefore, to promote gastric emptying, especially with the presence of 4%–8% carbohydrate in the fluid, it is advantageous to maintain the largest volume of fluid that can be tolerated in the stomach during exercise (e.g., 400–600 ml). Mild to moderate exercise appears to have little or no effect on gastric emptying while heavy exercise at intensities greater than 80% of maximal capacity may slow gastric emptying (12,15). Laboratory and field studies suggest that during prolonged exercise, frequent (every 15–20 min) consumption of moderate (150 ml) to large (350 ml) volumes of fluid is possible. Despite the apparent advantage of high gastric fluid volume for promoting gastric emptying, there should be some caution associated with maintaining high gastric fluid volume. People differ in their gastric emptying rates as well as their tolerance to gastric volumes, and it has not been determined if the ability to tolerate high gastric volumes can be improved by drinking during training. It is also unclear whether complaints of gastrointestinal symptoms by athletes during competition are a function of an unfamiliarity of exercising with a full stomach or because of delays in gastric emptying (57). It is therefore recommended that individuals learn their tolerance limits for maintaining a high gastric fluid volume for various exercise intensities and durations.

Once ingested fluid moves into the intestine, water moves out of the intestine into the blood. Intestinal absorptive capacity is generally adequate to cope with even the most extreme demands (30); and at intensities of exercise that can be sustained for more than 30 min, there appears to be little effect of exercise on intestinal function (84). In fact, dehydration consequent to failure to replace fluids lost during exercise reduces the rate of gastric emptying (64,76), supporting the rationale for early and continued drinking throughout exercise.

ELECTROLYTE AND CARBOHYDRATE REPLACEMENT DURING EXERCISE

There is little physiological basis for the presence of sodium in an oral rehydration solution for enhancing intestinal water absorption as long as sodium is sufficiently available in the gut from the previous meal or in the pancreatic secretions (84). Inclusion of sodium (<50 $mmol \cdot l^{-1}$) in fluid replacement drinks during exercise has not shown consistent improvements in retention of ingested fluid in the vascular compartment (20,23,44,45). A primary rationale for electrolyte supplementation with fluid replacement drinks is, therefore, to replace electrolytes lost from sweating during exercise greater than 4–5 h in duration (3). Normal plasma sodium concentration is 140 $mmol \cdot l^{-1}$, making sweat (~50 $mmol \cdot l^{-1}$) hypotonic relative to plasma. At a sweat rate of $1.5\ l \cdot h^{-1}$, a total sodium deficit of 75 $mmol \cdot h^{-1}$ could occur during exercise. Drinking water can lower elevated plasma electrolyte concentrations back toward normal and restore sweating (85,86), but complete restoration of the extracellular fluid compartment cannot be sustained without replacement of lost sodium (39,70,89). In most cases, this can be accomplished by normal dietary intake (63). If sodium enhances palatability, then its presence in a replacement solution may be justified because drinking can be maximized by improving taste qualities of the ingested fluid (9,25).

The addition of carbohydrates to a fluid replacement solution can enhance intestinal absorption of water (30,84). However, a primary role of ingesting carbohydrates in a fluid replacement beverage is to maintain blood glucose concentration and enhance carbohydrate oxidation during exercise that lasts longer than 1 h, especially when muscle glycogen is low (11,14, 17,18,50,60). As a result, fatigue can be delayed by carbohydrate ingestion during exercise of duration longer than 1 h which normally causes fatigue without carbohydrate ingestion (11). To maintain blood glucose levels during continuous moderate-to-high intensity exercise, carbohydrates should be ingested throughout exercise at a rate of 30–60 $g \cdot h^{-1}$. These amounts of carbohydrates can be obtained while also replacing relatively large amounts of fluid if the concentration of carbohydrates is kept below 10% ($g \cdot 100\ ml^{-1}$ of fluid). For example, if the desired volume of ingestion is 600–1200 $ml \cdot h^{-1}$, then the carbohydrate requirements can be met by drinking fluids with concentrations in the range of 4%–8% (19). With this procedure, both fluid and carbohydrate requirements can be met simultaneously during prolonged exercise. Solutions containing carbohydrate concentrations >10% will cause a net movement of fluid into the intestinal lumen because of their high osmolality, when such solutions are ingested during exercise. This can result in an effective loss of water from the vascular compartment and can exacerbate the effects of dehydration (43).

Few investigators have examined the benefits of adding carbohydrates to water during exercise events lasting less than 1 h. Although preliminary data suggest a potential benefit for performance (4,7,48), the mechanism is unclear. It would be premature to recommend drinking something other than water during exercise lasting less than 1 h. Generally, the inclusion of glucose, sucrose, and other complex carbohydrates in fluid replacement solutions have equal effectiveness in increasing exogenous carbohydrate oxidation, delaying fatigue, and improving performance (11,16,79,90). However, fructose should not be the predominant carbohydrate because it is converted slowly to blood glucose—not readily oxidized (41,42)—which does not improve performance (8). Furthermore, fructose may cause gastrointestinal distress (59).

FLUID REPLACEMENT AND EXERCISE PERFORMANCE

Although the impact of fluid deficits on cardiovascular function and thermoregulation is evident, the extent to which exercise performance is altered by fluid replacement remains unclear. Although some data indicate that drinking improves the ability to perform short duration athletic events (1 h) in moderate climates (7), other data suggest that this may not be the case (40). It is likely that the effect of fluid replacement on performance may be most noticeable during exercise of duration greater than 1 h and/or at extreme ambient environments.

The addition of a small amount of sodium to rehydration fluids has little impact on time to exhaustion during mild prolonged (>4 h) exercise in the heat (73), ability to complete 6 h of moderate exercise (5), or capacity to perform during simulated time trials (20,74). A sodium deficit, in combination with ingestion and retention of a large volume of fluid with little or no electrolytes, has led to low plasma sodium levels in a very few marathon or ultra-marathon athletes (3,67). Hyponatremia (blood sodium concentration between 117 and 128 $mmol \cdot l^{-1}$) has been observed in ultra-endurance athletes at the end of competition and is associated with disorientation, confusion, and in most cases, grand mal seizures (67,69). One major rationale for inclusion of sodium in rehydration drinks is to avoid hyponatremia. To prevent development of this rare condition during prolonged (>4 h) exercise, electrolytes should be present in the fluid or food during and after exercise.

Maintenance of blood glucose concentrations is necessary for optimal exercise performance. To maintain blood glucose concentration during fatiguing exercise greater than 1 h (above 65% $\dot{V}O_{2max}$), carbohydrate ingestion is necessary (11,49). Late in prolonged exercise, ingested carbohydrates become the main source of carbohydrate energy and can delay the onset of fatigue (17,19,21,22,51,58). Data from field studies designed to test these concepts during athletic competition have not always demonstrated delayed onset of fatigue (46,47,91), but the inability to control critical factors (such as environmental conditions, state of training, drinking volumes) make confirmation difficult. Inclusion of carbohydrates in a rehydration solution becomes more important for optimal performance as the duration of intense exercise exceeds 1 h.

CONCLUSION

The primary objective for replacing body fluid loss during exercise is to maintain normal hydration. One should consume adequate fluids during the 24-h period before an event and drink about 500 ml (about 17 ounces) of fluid about 2 h before exercise to promote adequate hydration and allow time for excretion of excess ingested water. To minimize risk of thermal injury and impairment of exercise performance during exercise, fluid replacement should attempt to equal fluid loss. At equal exercise intensity, the requirement for fluid replacement becomes greater with increased sweating during environmental thermal stress. During exercise lasting longer than 1 h, a) carbohydrates should be added to the fluid replacement solution to maintain blood glucose concentration and delay the onset of fatigue, and b) electrolytes (primarily NaCl) should be added to the fluid replacement solution to enhance palatability and reduce the probability for development of hyponatremia. During exercise, fluid and carbohydrate requirements can be met simultaneously by ingesting 600–1200 $ml \cdot h^{-1}$ of solutions containing 4%–8% carbohydrate. During exercise greater than 1 h, approximately 0.5–0.7 g of sodium per liter of water would be appropriate to replace that lost from sweating.

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