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Exercise-induced hyponatremia: Causes, risks, prevention, and management

■ ABSTRACT

Exercise-induced hyponatremia is most commonly associated with prolonged exertion during sustained, high-intensity endurance activities such as marathons or triathlons. In most cases, exercise-induced hyponatremia is attributable to excess free water intake, which fails to replete the sometimes massive sodium losses that result from sweating. The risk of hyponatremia can be lowered by strategies to ensure fluid balance during exercise by maintaining the proper volume and type of fluid intake. Treatment of exercise-induced hyponatremia is based on whether the patient is volume-depleted, euvolemic, or fluid-overloaded. Because therapy must be tailored to volume status, physicians must make this determination before initiating therapy. If hyponatremia is life-threatening, hypertonic saline may be warranted to increase sodium in the extracellular fluid compartment and restore the natural balance.

■ KEY POINTS

Up to 10% of ultradistance athletes experience exercise-induced hyponatremia, or a post-exercise serum sodium level below 135 mEq/L, but symptoms are often present only with levels below 125 mEq/L.

Female sex and longer race-completion times appear to be associated with greater risk of exercise-induced hyponatremia.

In symptomatic hyponatremic athletes with oliguria, physicians should rule out overhydration before giving intravenous fluids.

Hypertonic saline must be administered with great caution, since overly rapid correction of hyponatremia can result in fatal complications such as central pontine myelinolysis.

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THE DURATION and intensity of “ultradistance” exercise such as marathon running and triathlons can wreak havoc on the body if proper nutrition and fluid balance are not maintained. Exercise-induced hyponatremia, defined as a serum sodium level of less than 135 mEq/L following a high-intensity endurance activity, can occur if fluid and sodium repletion is not maintained during sustained physical exertion.¹⁻⁴

Because exercise-induced hyponatremia is potentially life-threatening, it is important for physicians, especially those treating athletes in acute settings, to be familiar with its causes and management. This article briefly reviews the etiology, risk factors, signs, symptoms, prevention, and treatment of exercise-induced hyponatremia.

■ ENDURANCE SPORTS ARE GROWING

Once the domain of a select group of world-class athletes, participation in ultradistance sports such as marathons and triathlons has grown in recent years. Currently, more than 400,000 athletes run in more than 300 26.2-mile (42-km) marathons in the United States each year.⁵ While elite runners can complete a marathon in less than 3 hours, recreational joggers may require 6 or more hours. Triathlons are combination events that take 8.5 to 16.5 hours to complete. For example, the New Zealand Ironman triathlon consists of a 3.8-km swim, a 180-km bicycle ride, and a 42.2-km run.¹

■ HOW COMMON IS EXERCISE-INDUCED HYPONATREMIA?

Hyponatremia is the most common medical complication of ultradistance exercise and is recognized as potentially serious.⁶ Exercise-induced hyponatremia was first described in 1985 by

Noakes et al,⁷ who referred to it as “water intoxication.” Over the years, as participation in endurance sports has risen, so has research into the possible health effects associated with these activities.⁸ During the 1990s in the United States, exercise-induced hyponatremia was increasingly recognized among soldiers, runners who completed a 42-km marathon in 5 hours or more, and recreational hikers, especially those exploring the desert.^{9,10}

Up to 10% of ultradistance athletes have a serum sodium level of 135 mEq/L or less after a race.⁹ Studies have reported the incidence of exercise-induced hyponatremia to be even higher among triathletes—18% among those completing triathlons in New Zealand and as high as 29% among those completing the Hawaiian Ironman event.⁶

Almond et al¹¹ studied a cohort of marathon runners in the 2002 Boston Marathon to estimate the incidence of hyponatremia and to identify the major risk factors. Of 766 runners enrolled, 488 (64%) provided a usable blood sample at the finish line. Thirteen percent had hyponatremia (serum sodium $\leq$ 135 mEq/L) and 0.6% had critical hyponatremia ($\leq$ 120 mEq/L). Univariate analyses showed that hyponatremia was associated with substantial weight gain, consumption of more than 3 L of fluids during the race, consumption of fluids every mile, a racing time of greater than 4 hours, female sex, and low body-mass index. Multivariate analysis showed that hyponatremia was associated with weight gain, a racing time of greater than 4 hours, and extremes in body mass index. These findings clearly showed that hyponatremia occurs in a substantial fraction of nonelite marathon runners and can be severe.

While many athletes with mildly reduced serum sodium levels may not present for medical care, patients with serum sodium levels of less than 125 mEq/L often have symptoms and are more likely to seek medical care.¹

■ ETIOLOGY

Two factors play key roles in the development of hyponatremia in athletes:

- Dehydration and salt depletion
- Excess fluid intake during exercise.

Dehydration and salt depletion

Dehydration results from loss of large volumes of water and salt due to sweating. Up to 1,800 mL of sweat can be lost per hour, depending on the athlete's body size, his or her exercise intensity, and the environmental humidity and temperature.¹² Typically, the sodium content of sweat ranges from 25 to 75 mEq/L. Sodium losses, however, seem to be equivalent among ultradistance athletes regardless of their sodium level at the end of a race; differences in sodium levels at the end of a race are more likely due to the tonicity and volume of beverages used for repletion.⁶ Since sweat is hypotonic, if an athlete does not drink, free water loss will exceed sodium loss and dehydration will most likely result in *hypernatremia*, not *hyponatremia*. With excessive water intake relative to sodium replacement, the athlete will become overhydrated and have dilutional hyponatremia.⁶

Excess fluid intake

Evidence to date suggests that excess fluid intake is the most common cause of exercise-induced hyponatremia.⁶ Many athletes with exercise-induced hyponatremia lose weight during exercise because their fluid replacement is less than the weight lost due to respiration, sweat, urination, and oxidative breakdown of glycogen and adipose stores.⁹ These athletes are usually asymptomatic and have mild hyponatremia.⁹ In contrast, symptomatic hyponatremic athletes gain weight or lose the least weight. These are the athletes who are overhydrated with free water and have the lowest serum sodium levels (Figure 1).^{9,13} Hence, there is an inverse relationship between serum sodium concentration and the amount of exertional fluid loss.^{9,13} There also is an inverse relationship between weight gain during a race and serum sodium concentration (Figure 2).^{1,9} Most athletes with a serum sodium concentration of less than 125 mEq/L are symptomatic and either gained weight or did not lose weight during exercise.

■ SYMPTOMS OFTEN LIMITED TO MORE SEVERE CASES

Exercise-induced hyponatremia is often asymptomatic, particularly in patients in whom serum sodium is only mildly reduced.

Symptoms often do not manifest until serum sodium is less than 125 mEq/L

The more excess fluid, the lower the serum sodium

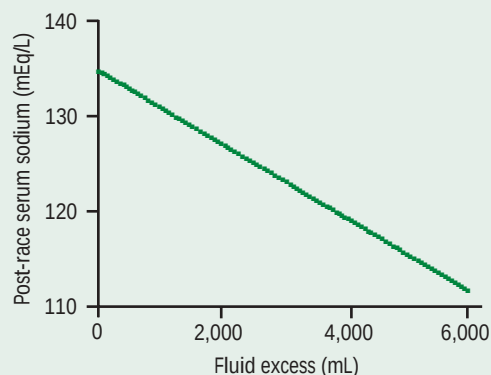


FIGURE 1. Among ultradistance athletes, the serum sodium concentration is inversely related to the fluid excess excreted during post-race recovery ($P = .02$). Reprinted, with permission, from Noakes⁹ and based on data from a study of 8 marathon runners reported by Irving et al.¹³

The more weight gained during a race, the lower the serum sodium

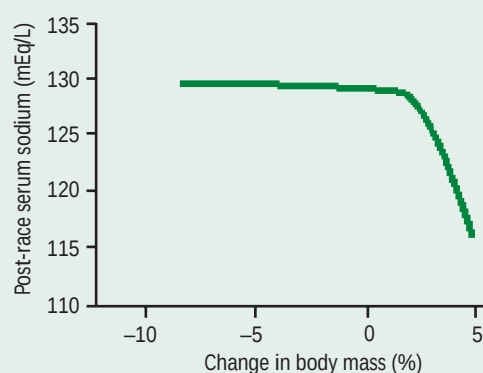


FIGURE 2. Among ultradistance athletes, weight gain during a race is inversely related to post-race serum sodium concentration. Reprinted, with permission, from Noakes⁹ and based on data from a study of triathletes in the 1997 New Zealand Ironman event reported by Speedy et al.¹

Up to 10% of ultradistance athletes have a serum sodium level of 135 mEq/L or less.⁹ Those who are symptomatic usually have a level of less than 125 mEq/L.⁹

Symptoms can be mild and nonspecific

Hyponatremic athletes present with vomiting more frequently than do nonhyponatremic athletes.⁴ Mild symptoms of hyponatremia, which may be nonspecific, include malaise, nausea, light-headedness, dizziness, and fatigue.⁶

...or potentially ominous

Altered mental status, confusion, headache, incoordination, seizures, and coma are ominous signs that may indicate developing cerebral edema, which is life-threatening.⁶

RISK FACTORS

Risk factors for hyponatremia among ultradistance athletes include the athlete's sex and the time it takes to finish a race.

Who needs intravenous fluids?

An observational, retrospective, case-control series based on the 2000 Houston Marathon analyzed risk factors for hyponatremia among 5,082 runners who completed the 42-km course in 5 hours 30 minutes or less.⁴ Mean finishing times were longer for females (4 hours 45 minutes) than for males (4 hours 24

minutes). During the event, 237 runners were seen in the medical area and 73 of them were treated in the major medical tent. Among the 55 runners requiring intravenous (IV) fluids, serum sodium levels were as follows:

- 34 had levels greater than 135 mEq/L (nonhyponatremic control group)
- 8 had levels of 130 to 135 mEq/L
- 11 had levels of 120 to 129 mEq/L
- 2 had levels less than 120 mEq/L.

Both of the runners whose serum sodium level was less than 120 mEq/L were women. The incidence of diagnosed hyponatremia was 5.1 per 1,000 runners among women vs 3.6 per 1,000 runners among men.

This study also found that hyponatremic runners had significantly lower levels of potassium, chloride, and blood urea nitrogen compared with nonhyponatremic runners.⁴

Longer finishing times linked to higher risk

The same study also revealed that runners with longer finishing times were at higher risk of developing hyponatremia (Figure 3).⁴ One theory to explain this is that slower runners have more opportunities to consume fluids while also having lower fluid requirements.⁶

Other proposed risk factors

Although the use of nonsteroidal anti-inflammatory drugs (NSAIDs) has been the-

Up to 1,800 mL of sweat can be lost per hour during exercise

The longer the finishing time, the greater the risk and severity of hyponatremia

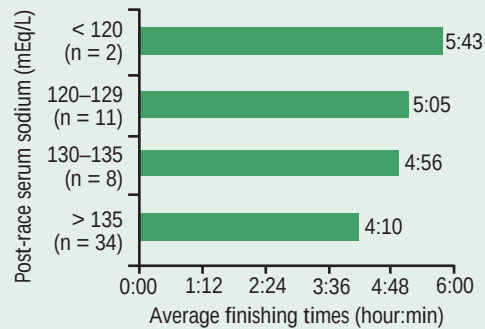


FIGURE 3. Finishing times for marathon runners according to the presence and degree of hyponatremia. The most severe cases of hyponatremia (serum sodium < 120 mEq/L) were associated with the longest average finishing time, whereas nonhyponatremic runners (serum sodium > 135 mEq/L) had the shortest average finishing time. The cross-group difference was statistically significant ($P < .001$). Based on data from the observational trial by Hew et al.⁴

Altered mental status may signal developing cerebral edema

orized to be related to development of exercise-induced hyponatremia, a clear relationship has not been established, since a similar incidence of NSAID use has been found among hyponatremic and normonatremic athletes.^{4,6} The theory behind this proposed association is that NSAIDs reduce renal prostaglandin production, which consequently reduces the glomerular filtration rate, causing exercise-induced hyponatremia.⁶ Of note, Almond et al¹¹ found no association between NSAID use and the development of hyponatremia in marathon runners.

Environmental factors may also contribute to the risk of fluid imbalance. In particular, the combination of high temperatures and high humidity may lead to excessive sweating and ineffective cooling, resulting in fluid or sodium imbalance. Hot, humid environments also drastically increase the risk of dehydration.¹²

PREVENTING HYPONATREMIA IN ATHLETES: FLUID BALANCE IS KEY

The best strategy for preventing hyponatremia is to maintain the proper volume and type of fluid intake to ensure fluid balance during exercise.

For noncompetitive athletes, fluid intake of 500 mL/hour is recommended during prolonged exercise.⁶ A joint position statement from the American College of Sports Medicine, the American Dietetic Association, and Dietitians of Canada¹² addresses proper fluid balance to ensure optimal performance during exercise. Adequate fluid and food intake before, during, and after exercise can help to maintain blood glucose during exercise, maximize exercise performance, and improve recovery time.¹² Table 1 provides recommendations for optimizing fluid balance.

'Sports drinks' and sodium content of fluids

For athletes participating in intense exercise for more than 1 hour (eg, marathon runners), beverages containing carbohydrates in concentrations of 4% to 8% (ie, "sports drinks") are recommended. During exercise, consumption of sports drinks containing carbohydrates and electrolytes will provide fuel for the muscles, help maintain blood glucose and the thirst mechanism, and decrease the risk of hyponatremia.¹²

Including sodium in the fluid replacement beverage in amounts from 0.5 to 0.7 g/L is also recommended for exercise sessions lasting more than 1 hour, since sodium may drive the thirst center (however, this amount of sodium generally exceeds that found in commercial sports drinks).¹² If the fluid contains sodium, it could help avoid reduced serum sodium levels and thereby lower the risk of hyponatremia. Restricting fluid intake so that it does not surpass sweat loss can also lower the risk of hyponatremia.¹² Runners should sporadically check their body weight before and after training runs to determine their ideal rate of hydration.¹¹

Education, other strategies can make a difference

In an interventional study with historical controls, Speedy et al³ showed that educating athletes about the appropriate rate of fluid intake and limiting the availability of fluids during a triathlon reduced the percentage of athletes treated in the medical tent for hyponatremia from 22% to 3%. This study used numerous strategies to increase awareness of exercise-induced hyponatremia, including reducing the number of drink stations along the race course,

encouraging consumption of sports drinks, providing newsletters with information on appropriate fluid intake to all athletes, and having the medical director of the race hold a briefing to inform athletes of the danger of overhydration.³

■ MANAGEMENT

Acute vs chronic hyponatremia

Management of acute hyponatremia (< 48 hours in duration) differs from management of chronic hyponatremia. Compared with chronic hyponatremia, acute hyponatremia tends to be associated with more severe degrees of cerebral edema for a given level of serum sodium. The primary cause of morbidity and death is brainstem herniation and mechanical compression of vital midbrain structures. Rapid identification and correction of serum sodium is necessary in patients with severe acute hyponatremia to avert brainstem herniation and death.

In chronic hyponatremia, a slow rate of correction is desired to minimize the risk of central pontine myelinolysis.¹⁴ In acute hyponatremia, gradual correction is preferred so as to reduce the likelihood of precipitating cerebral edema and respiratory arrest.¹⁴

Tailor management to volume status

Management recommendations (Table 2) generally apply to symptomatic athletes, since most asymptomatic athletes do not present for medical attention and are thus not treated.

Management of symptomatic athletes with exercise-induced hyponatremia begins with assessment of the patient's volume status, which should guide subsequent therapy. Treatment is based on whether the patient is volume-depleted, euvoletic, or fluid-overloaded. Dilutional hyponatremia due to free water overload should be sought by checking for peripheral edema before routinely administering IV fluids to symptomatic hyponatremic athletes.⁶

Indeed, if an athlete with symptomatic hyponatremia is clinically stable and has no signs or symptoms of significant cerebral or pulmonary edema, several hours of close clinical observation with regular monitoring of serum sodium is often sufficient management while awaiting spontaneous diuresis of

TABLE 1

Recommended fluid intake for optimizing exercise performance and safety

BEFORE EXERCISE	DURING EXERCISE	AFTER EXERCISE
Drink generous amounts of fluid in the 24 hours prior to exercise. Drink 400–600 mL (14–22 oz) of fluid 2–3 hours before exercise. An accompanying meal or snack should provide sufficient solute and nutrition to maintain hydration.	Goal is to maintain fluid balance. Drink 150–350 mL (6–12 oz) of fluid every 15–20 minutes, beginning at the start of exercise and depending on tolerance.	Drink adequate fluid to replace sweat losses. Drink at least 450–675 mL (16–24 oz) of fluid for every pound of body weight lost during exercise.

Adapted from recommendations in a joint position statement on nutrition and athletic performance from the American College of Sports Medicine, the American Dietetic Association, and Dietitians of Canada.¹²

retained fluid. In addition to patient observation until spontaneous diuresis occurs, isotonic fluids may be given.⁶

The goal in correcting acute symptomatic hyponatremia is to increase the serum sodium concentration by 2 mEq/L/hour until symptoms resolve.¹⁵ Athletes weighing more than 70 kg are likely to benefit from a higher rate of sodium administration due to their larger extracellular fluid volume.⁹ However, hypertonic saline (3% sodium [NaCl] solution) must be administered with extreme caution, since overly rapid correction of hyponatremia may result in fatal complications such as central pontine myelinolysis. Davis et al² showed that 3% sodium solution given at a rate of 100 mL/hour corrected exercise-induced hyponatremia in marathon runners at a rate of 3.4 mEq/L/hour.

In mildly symptomatic patients, oral rehydration with salty solutions is often the safest method of increasing the serum sodium level and improving symptoms.⁶

Two likely clinical pathways

Following exercise, a symptomatic hyponatremic athlete will generally follow one of two basic pathways. Spontaneous diuresis may occur within 1 or 2 hours after completing exercise, or the athlete may produce minimal urine for many hours following

Severe acute hyponatremia requires rapid correction to avert brainstem herniation and death

TABLE 2

Guidance for the treatment of acute hyponatremia in athletes

Urgent treatment indicated only in symptomatic hyponatremic athlete

Determine patient's weight loss or gain

Calculate sodium deficit

Administer sodium-containing solution at a rate that will raise serum sodium no more than 1 to 2 mEq/L/hr, not to exceed 12 mEq in first 24 hours

exercise completion (oliguria). In the latter case, physicians should suspect that the patient is *overhydrated*, not dehydrated, in which case additional fluids would be unwarranted.⁹

In patients with mild symptoms, oral rehydration with salty solutions is safe and often effective

■ REFERENCES

- Speedy DB, Noakes TD, Rogers IR, et al. Hyponatremia in ultradistance triathletes. *Med Sci Sports Exerc* 1999; 31:809–815.
- Davis DP, Videen JS, Marino A, et al. Exercise-associated hyponatremia in marathon runners: a two-year experience. *J Emerg Med* 2001; 21:47–57.
- Speedy DB, Rogers IR, Noakes TD, et al. Diagnosis and prevention of hyponatremia at an ultradistance triathlon. *Clin J Sport Med* 2000; 10:52–58.
- Hew TD, Chorley JN, Cianca JC, Divine JG. The incidence, risk factors, and clinical manifestations of hyponatremia in marathon runners. *Clin J Sport Med* 2003; 13:41–47.
- Shaw S. A tale of two marathons. *Salon.com*, November 24, 1999. Available at: <http://www.salonmag.com/health/feature/1999/11/24/marathon>. Accessed May 2, 2005.
- Speedy DB, Noakes TD, Schneider C. Exercise-associated hyponatremia: a review. *Emerg Med (Fremantle)* 2001; 13:17–27.
- Noakes TD, Goodwin N, Rayner BL, Branken T, Taylor RK. Water intoxication: a possible complication during endurance exercise. *Med Sci Sports Exerc* 1985; 17:370–375.
- Hsieh M, Roth R, Davis DL, Larrabee H, Callaway CW. Hyponatremia in runners requiring on-site medical treatment at a single marathon. *Med Sci Sports Exerc* 2002; 34:185–189.
- Noakes T. Hyponatremia in distance runners: fluid and sodium balance during exercise. *Curr Sports Med Rep* 2002; 1:197–207.
- Noakes TD. Hyponatremia in distance athletes. *The Physician and Sportsmedicine* 2000; 28:71–76.
- Almond CSD, Shin AY, Fortescue EB, et al. Hyponatremia among runners in the Boston Marathon. *N Engl J Med* 2005; 352:1550–1556.
- American College of Sports Medicine; American Dietetic Association; Dietitians of Canada. Joint Position Statement: nutrition and athletic performance. *Med Sci Sports Exerc* 2000; 32:2130–2145.
- Irving RA, Noakes TD, Buck R, et al. Evaluation of renal function and fluid homeostasis during recovery from exercise-induced hyponatremia. *J Appl Physiol* 1991; 70:342–348.
- Decaux G, Soupart A. Treatment of symptomatic hyponatremia. *Am J Med Sci* 2003; 326:25–30.
- Schrier RW. The patient with hyponatremia or hypernatremia. In: Schrier RW, ed. *Manual of Nephrology*. 5th ed. Philadelphia, PA: Lippincott Williams & Wilkins; 2000:21–36.

■ CONCLUSIONS

Prolonged exertion during exercise is commonly associated with hyponatremia. In many cases, this exercise-induced hyponatremia is due to excess fluid intake during exercise, which causes dilutional hyponatremia. The risk of hyponatremia can be lowered through strategies to ensure fluid balance during exercise by maintaining the proper volume and type of fluid intake. Appropriate treatment is based on the patient's volume status, which physicians must assess before initiating therapy. Although oliguria is often assumed to be due to dehydration, it can also be associated with decreased glomerular filtration. Current treatment for hyponatremia is often counterintuitive and dependent on volume status. Often, hypertonic saline is warranted to increase sodium in the extracellular fluid compartment and restore the natural balance.

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