Exercise-Associated Hyponatremia During Winter Sports

Kristin J. Stuempfle, PhD, ATC, FACSM

Abstract: Exercise-associated hyponatremia (EAH) is hyponatremia that occurs ≤ 24 hours after prolonged physical activity. It is a potentially serious complication of marathons, triathlons, and ultradistance events, and can occur in hot and cold environments. Clear evidence indicates that EAH is a dilutional hyponatremia caused by excessive fluid consumption and the inappropriate release of arginine vasopressin. Cerebral and pulmonary edema can cause serious signs and symptoms, including altered mental status, respiratory distress, seizures, coma, and death. Rapid diagnosis and urgent treatment with hypertonic saline is necessary to prevent severe complications or death. Prevention is based on educating athletes to avoid excessive drinking before, during, and after exercise.

Keywords: exercise-associated hyponatremia; cold; athletes; winter sports

Kristin J. Stuempfle, PhD, ATC, FACSM[1]

[1]Gettysburg College, Gettysburg, PA

Introduction

Over the past 25 years, exercise-associated hyponatremia (EAH) has emerged as a potentially serious complication of endurance exercise. It is defined as the occurrence of hyponatremia (serum or plasma $[Na^+] < 135$ mmol/L) during or up to 24 hours after prolonged physical activity.[1] Exercise-associated hyponatremia occurs in athletes participating in endurance events such as marathons,[2–7] triathlons,[8–10] and ultradistance races.[11–13] Exercise-associated hyponatremia also occurs in soldiers[14–16] and hikers.[17,18] It has been most widely reported in temperate and hot weather,[2,3,6–12,14–18] but it has been observed in cold weather as well.[4,5,13,19]

Exercise-associated hyponatremia was first described in 1985 in 4 athletes who participated in ultradistance runs in South Africa.[12] A similar paper followed in 1986 that reported EAH in 2 athletes who participated in ultradistance runs in the United States.[11] A great amount of research has followed these initial reports. For some time, the etiology of hyponatremia was debated—some supported a dilutional (fluid overload) mechanism,[11,12] whereas others favored a depletional (sodium deficit) mechanism.[8] More recently, increasing consensus supports the dilutional mechanism.[1] This consensus is reflected in the latest fluid replacement guidelines of the American College of Sports Medicine (ACSM),[20] the International Marathon Medical Directors Association (IMMDA),[21] and the US military.[14] In contrast with past guidelines that encouraged excessive drinking to prevent hypohydration,[14,22] the updated guidelines clearly warn that fluid overconsumption can result in hyperhydration and EAH. This article focuses on the incidence, etiology, pathophysiology, risk factors, clinical manifestations, diagnosis, treatment, and prevention of this serious condition.

Incidence

The largest EAH incidence study (N = 488) in a marathon occurred at the 2002 Boston Marathon.[2] Thirteen percent of runners had EAH, including 1% with critical hyponatremia (serum $[Na^+] < 120$ mmol/L). The reported EAH incidence in other marathons has ranged from 0% to 22%.[3–7]

In a large study (N = 330) at the New Zealand Ironman Triathlon, 17% of finishers had EAH.[9] Fourteen percent of athletes had mild EAH (serum $[Na^+]$, 130–134 mmol/L) and generally were asymptomatic. In contrast, 3% of athletes had severe EAH (serum $[Na^+] < 130$ mmol/L) and generally were symptomatic. Other studies of Ironman triathlons have reported an EAH incidence from 1% to 27%.[8,10]

A literature review compiled all studies that examined change in serum $[Na^+]$ and bodyweight during endurance events (N = 2135).[23] Six percent of athletes had biochemical hyponatremia (serum $[Na^+]$

Correspondence:
Kristin J. Stuempfle, PhD, ATC, FACSM,
Department of Health Sciences,
Gettysburg College,
Campus Box 432,
300 North Washington St.,
Gettysburg, PA 17325.
Tel: 717-337-6448
Fax: 717-337-6467
E-mail: kstuempf@gettysburg.edu

129–135 mmol/L), and 1% had critical hyponatremia (serum [Na^+] < 129 mmol/L). Interestingly, 13% were hypernatremic (serum [Na^+] > 145 mmol/L), which was attributable to dehydration. Although hypernatremia may be more common during endurance exercise, hyponatremia is more likely to result in severe morbidity and mortality.

Although EAH is reported more commonly in races held under temperate or hot conditions, athletes who participate in winter sports also develop this potentially fatal condition. The highest reported incidence of EAH (44%) comes from a 100-mile race in Alaska (−8°C to 4°C).[13] Exercise-associated hyponatremia also occurred in athletes running at 5°C,[19] in 12.5% of runners in the London Marathon (9°C–12°C),[4] and in 3% of runners in the Zurich Marathon (10°C).[5]

In recent years, at least 6 deaths from EAH have occurred during marathons.[3,24–26] Four deaths in military personal have also been reported.[15]

Etiology and Pathophysiology

In theory, a fluid overload (dilutional hyponatremia) and/or a sodium deficit (depletional hyponatremia) can cause EAH. The growing consensus is that EAH is a dilutional hyponatremia.[1] Multiple lines of evidence strongly support this view. First, in studies in which serum [Na^+] and bodyweight were measured pre- and post-race, a consistent inverse relationship occurred between post-race serum [Na^+] and bodyweight change, indicating a fluid overload. Athletes with the lowest post-race serum [Na^+] actually gained weight in 2 large studies.[9,23]

Second, blood urea nitrogen (BUN) levels distinguish a dilutional hyponatremia (accompanied by either hyperhydration or euhydration and a BUN level < 15 mg/dL) from a depletional hyponatremia (accompanied by dehydration and a BUN level > 15 mg/dL).[27] Blood urea nitrogen levels were significantly lower in hyponatremic (14 mg/dL) compared with normonatremic (19 mg/dL) runners in the Houston Marathon.[3] Pre- to post-race decreases in hematocrit and hemoglobin also suggest a dilutional hyponatremia. Hematocrit and hemoglobin decreased and plasma volume increased in 2 hyponatremic athletes in the New Zealand Ironman Triathlon.[28] Furthermore, in a large study at the New Zealand Ironman Triathlon (N = 330), post-race serum [Na^+] was significantly related to hematocrit. Athletes with the lowest serum [Na^+] had the lowest hematocrit, indicating a dilutional effect.[9]

Third, recovery studies comparing hyponatremic and normonatremic athletes post-race indicate a fluid excess in hyponatremic athletes compared with a fluid deficit in normonatremic athletes. Hyponatremic athletes excreted a net fluid excess (2.95 ± 0.56 L), and normonatremic athletes exhibited a fluid deficit (2.7% ± 0.3% bodyweight) following the 88-km Comrades Marathon.[29] Similarly, hyponatremic athletes excreted a fluid excess (1346 mL) and normonatremic athletes had a fluid deficit (521 mL) following the New Zealand Ironman Triathlon.[30]

Fluid overload in dilutional hyponatremia likely is caused by both excessive fluid consumption and failing to excrete excess fluid.[1] High fluid intake, often in excess of maximal kidney excretory rates (~900 mL/h),[31] is commonly reported in athletes with EAH.[1] Studies quantifying fluid intake have shown a negative correlation between fluid intake and post-race serum [Na^+].[3,5] Higher fluid intake has been reported in hyponatremic versus normonatremic athletes,[3,4] and hyponatremia severity was dose-dependent.[3] Finally, pre-race education on appropriate fluid intake and decreased fluid availability at support stations was associated with decreased EAH incidence at the New Zealand Ironman Triathlon.[32]

Although excessive drinking may independently cause EAH, inappropriate arginine vasopressin (AVP) secretion often is an exacerbating factor[1] and can cause EAH with moderate drinking.[33] Fluid overload should maximally suppress AVP, and failure of this mechanism characterizes the syndrome of inappropriate antidiuretic hormone (SIADH) secretion.[34] Even if drinking rates do not exceed maximal kidney excretory rates, small increases in AVP will markedly increase fluid retention.[34] Recent studies have confirmed inappropriately elevated AVP in hyponatremic marathon runners[35] and have suggested inappropriate AVP release in ultramarathon runners.[36] During prolonged exercise, nonosmotic stimuli of AVP secretion (eg, plasma volume contraction, nausea, vomiting, hypoglycemia, elevated body temperature, and elevated interleukin [IL]-6 levels from rhabdomyolysis) may contribute to EAH development.[27,36]

Theoretically, a sodium deficit (depletional hyponatremia) from excessive sodium loss in sweat and urine or from inadequate sodium intake can cause EAH. Although mathematical models predict EAH with excessive sweat sodium losses,[37] this has not been documented in any laboratory or field investigation. Reports have shown that sodium loss was no greater in individuals who develop EAH than

in those who did not,[29,30] and race diet analysis showed no difference in sodium consumption between hyponatremic and normonatremic athletes.[13]

It appears that winter athletes should be less prone to EAH because cold typically causes hypohydration through cold-induced diuresis, decreased thirst, and respiratory water losses.[38] Additionally, sweat rate and [Na^+] decrease with cold temperatures.[39] However, studies clearly demonstrate that winter athletes develop EAH.[4,5,13,19] This is likely a dilutional EAH caused by excessive fluid consumption and inappropriate AVP release.[13,40] Although cold decreases thirst,[41] athletes who participate in winter sports likely continue drinking for behavioral reasons. Although AVP secretion decreased during rest[42] and following 60 minutes of exercise at 4°C,[41] it increased following a 100-mile ultradistance race at −14°C to −2°C,[40] suggesting nonosmotic AVP stimuli prevail during prolonged exercise. Respiratory water losses may increase with cold, but likely are minimal and would not significantly alter dilutional EAH.[43]

Risk Factors

Risk factors for developing EAH (Table 1)[1,2] likely interact with each other. The major risk factor for EAH is excessive fluid intake, consistent with multiple lines of evidence indicating that EAH is dilutional.[3,9,23,29,30] Other risk factors also are consistent with dilutional EAH. The only plausible explanation for weight gain during exercise is fluid overload. Females are typically smaller and slower than males, resulting in a lower plasma volume to be diluted and more time to consume fluids. Nonsteroidal anti-inflammatory drugs may impair kidney water excretion, resulting in fluid retention and increased EAH development.[44]

Table 1. Risk factors for EAH[1,2]

Athlete-Related	Event-Related
Excessive drinking during event	Exercise duration > 4 hours
Pre-event overhydration	High availability of fluids
Post-event overhydration	Extreme hot or cold environment
Weight gain	
Low bodyweight	
Female sex	
Slow pace	
Event inexperience	
Nonsteroidal anti-inflammatory drugs	
Other drugs associated with SIADH (eg, selective serotonin reuptake inhibitors)	

Abbreviation: SIADH, syndrome of inappropriate antidiuretic hormone hypersecretion.

Clinical Manifestations

Clinical manifestations of EAH range from having no signs and symptoms to cerebral and pulmonary edema, seizures, coma, and death. Signs and symptoms of EAH roughly correlate with serum [Na^+] but more closely correlate with the rate of change.[34] Exercise-associated hyponatremia with serum [Na^+] between 130 and 134 mmol/L is generally asymptomatic. Signs and symptoms typically develop when serum [Na^+] decreases to < 130 mmol/L[1] or decreases rapidly.[34] However, individual variability is great, and the patient's clinical status is more important than the numerical value of serum [Na^+].[45,46]

Early signs and symptoms of EAH include bloating, puffiness, nausea, vomiting, and headache.[1] As EAH severity progresses, more serious signs and symptoms can develop from cerebral and pulmonary edema. Later signs and symptoms include alteration of mental status (eg, confusion, disorientation, agitation, delirium), respiratory distress (eg, crepitation), seizures, coma, and death.[1,34]

Importantly, some of the above signs and symptoms are nonspecific and can be present following prolonged exercise in the absence of EAH.[1] Vomiting from fluid overload, respiratory distress from pulmonary edema, and seizures and coma from cerebral edema may best identify hyponatremic athletes.[3,47,48]

Diagnosis

Ideally, medical facilities at endurance events should be prepared to measure serum [Na^+] in any athlete who exhibits EAH signs and symptoms.[1] A portable i-STAT® device (Abott Diagnostics, Chicago, IL) rapidly and accurately measures serum sodium from a small, easily obtained sample. Additionally, pre- and post-race weight comparison may reveal weight gain, indicating fluid overload. Fluid intake history can help identify excessive drinking behavior.

Treatment

Hyponatremic athletes who are asymptomatic or have mild-to-moderate signs and symptoms (eg, bloating, puffiness, nausea, vomiting, headache) should be monitored until urination onset, which corrects the hyponatremia

and resolves signs and symptoms.[1] Oral hypotonic fluids (eg, water or sports drinks) and intravenous isotonic saline are contradicted because of potential fluid overload exacerbation and hyponatremia.[1] Consumption of oral hypertonic fluids (4 bouillon cubes dissolved in 4 oz of water, ~9% saline solution) and salty snacks may be warranted.[48]

Hyponatremic athletes with severe neurological signs and symptoms should be treated immediately in the field with hypertonic saline.[1,25,35,45,48–52] This treatment strategy was first established in a hospital setting[25] and subsequently has been used in the field.[35,45,48] Treatment begins with a 100-mL bolus infusion of 3% hypertonic saline to acutely reduce brain edema.[1,49,52] The regimen can be repeated up to 2 additional times if there is no clinical improvement.[1] No cases of osmotic demyelination with rapid correction of acute hyponatremia have been reported.[1,50,53] Oxygen also should be administered because hypoxia increases hyponatremia complications.[54,55]

Hypertonic saline in the field will stabilize the athlete's condition prior to transfer without producing complications. The athlete should be urgently transported to a hospital where serum [Na^+] and neurological status can be closely monitored.[1] Hypertonic saline should be continued in the hospital if necessary.[56] In general, 3% hypertonic saline can be given at a rate of 1 to 2 mL/kg per hour and may be increased to 3 to 4 mL/kg per hour if needed.[56] Serum and urine electrolytes should be closely monitored during treatment. Hypertonic saline infusion can be stopped once neurological signs and symptoms resolve.[56]

Again, intravenous isotonic saline administration is contraindicated because of potential fluid overload exacerbation and hyponatremia.[1] Hypertonic saline resolves neurological manifestations by rapidly reversing cerebral edema through shifting of the osmotic gradient.[52] Plasma volume expansion associated with hypertonic saline administration also may suppress nonosmotically stimulated AVP, which helps normalize serum [Na^+].[52]

Prevention

Because fluid consumption in excess of urinary and sweat losses is the primary cause of EAH, it follows that athletes should avoid fluid overconsumption before, during, and after exercise.[1] Athletes are likely to drink excessively because of behavioral factors. Athletes overhydrate because they fear dehydrating and the suspected performance and health consequences. The prevailing view is that hypohydration (water deficit $>$ 2% bodyweight loss) compromises performance in temperate and hot environments,[20,57] although this view has been challenged.[57] It is unlikely that hypohydration compromises performance in cold temperatures.[20,58] Athletes also fear potential health consequences of hypohydration, particularly heat illness in hot environments, and hypothermia and frostbite in cold environments.[59] Although the widespread view is that hypohydration increases the risk of heat illness,[20] this view has been questioned.[60] Studies have shown that hypohydration does not increase hypothermia[61] or frostbite.[62] For winter athletes, it is unlikely that hypohydration decreases performance[20,58] or increases injury risk related to the cold.[61,62] In contrast, hyperhydration and EAH risk is significant and potentially life-threatening.[13]

Universal fluid replacement guidelines are not possible because sweat rate and maximal kidney excretory rate vary considerably among individuals and depend on exercise intensity and environmental conditions.[1,20,21] The ACSM recommends a customized fluid replacement program to prevent excessive hypohydration ($>$ 2% bodyweight loss) with measurement of pre- and post-exercise bodyweight to estimate sweat losses.[20] The Statement of the Second International Exercise-Associated Hyponatremia Development Conference and the IMMDA[21] recommend drinking to thirst (ad libitum) combined with monitoring pre- and post-exercise weight. Drinking to thirst is the body's dynamic fluid calculator and will protect athletes from the hazards of both hyperhydration and hypohydration by providing real-time feedback on plasma osmolality. Monitoring pre- and post-exercise weight is a static fluid calculator that provides an estimate of fluid losses. Athletes can use a static fluid calculator to estimate their fluid needs, but should always defer to physiological cues to increase (thirst) or decrease (bloating, weight gain) drinking.

The consumption of electrolyte-containing sports drinks cannot prevent EAH development in athletes who drink excessively.[1,63] All such drinks are markedly hypotonic to plasma (Gatorade®, [Na^+] 20 mmol/L vs normal serum, [Na^+] 140 mmol/L). Drinking this hypotonic fluid (like water) will decrease serum [Na^+].[63] Sports drinks may decrease the rate of decline in serum [Na^+],[19,64,65] but nonetheless, EAH will occur in athletes who drink excessively.[1,63,66] Additionally, if AVP is inappropriately elevated, even moderate consumption of electrolyte-containing sports drinks (or water) can result in EAH.[33,34] Currently, no evidence demonstrates that sodium ingestion prevents EAH or decreases EAH risk.

Sodium supplementation was not necessary to prevent EAH in Ironman triathlons[67,68] and may be harmful.[69]

Summary

Exercise-associated hyponatremia is a well-recognized and potentially serious complication of endurance exercise. Exercise-associated hyponatremia is a dilutional hyponatremia caused by overhydration and inappropriate AVP secretion. The major risk factor for EAH is excessive drinking. Serious signs and symptoms can develop from cerebral and pulmonary edema, including alteration of mental status, respiratory distress, seizures, coma, and death. Recognizing EAH signs and symptoms early and rapid measurement of serum [Na^+] are critical. Athletes with severe neurological signs and symptoms should be treated quickly with hypertonic saline. In contrast, administration of isotonic saline is contraindicated because fluid overload exacerbation. Exercise-associated hyponatremia can be prevented by educating athletes on how to avoid overhydration before, during, and after exercise.

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Conflict of Interest Statement

Kristin J. Stuempfle, PhD, ATC, FACSM discloses no conflicts of interest.

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