

Exercise-associated hyponatremia: A review

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Abstract

This paper reviews the extensive literature on hyponatremia, a common and potentially serious complication of ultra-distance exercise. Fluid overload is the likely aetiology. Fluid intakes are typically high in athletes who develop hyponatremia, although hyponatremia can occur with relatively modest fluid intakes. The development of fluid overload and hyponatremia in the presence of a modest fluid intake raises the possibility that athletes with this condition may have an impaired renal capacity to excrete a fluid load. The bulk of evidence favours fluid retention in the extracellular space (dilutional hyponatremia) rather than fluid remaining unabsorbed in the intestine. Female gender is an important risk factor for the development of hyponatremia. Management and prevention of exercise-associated hyponatremia are discussed. **See Commentary, page 5.**

Key words: *exercise, hyponatremia, sodium, triathlete, triathlon.*

Introduction

Since its first description in 1985 by Noakes *et al.*,¹ hyponatremia has increasingly been recognized as a common and potentially serious complication of ultra-distance exercise.^{2–20} The incidence of exercise-associated hyponatremia has been reported to be as high as 18% in race finishers in the New Zealand¹⁴ and 29% in the Hawaiian Ironman triathlons.^{5,21} Exercise-associated hyponatremia has, therefore, become the commonest medical complication of ultra-distance exercise.

There is a wide range in the severity of symptoms caused by exercise-associated hyponatremia. The condition can be asymptomatic, usually defined as an athlete with hyponatremia who does not present for medical care

at the end of these races. Speedy *et al.*¹⁴ reported that only 31% of athletes with biochemically diagnosed hyponatremia in the New Zealand Ironman triathlon presented for medical care. Similar figures (44% and 31%) have been reported at the Hawaiian Ironman triathlon.^{5,9} Speedy *et al.*¹⁴ have also reported that 15% of the asymptomatic race finishers who did not seek medical care were hyponatremic, although only 1.5% had a plasma sodium concentration below 130 mmol/L. It is not known whether athletes with so-called 'asymptomatic' hyponatremia do not experience symptoms, or whether the symptoms are so mild that they do not prompt the athlete to seek medical care. In a case study of two athletes with asymptomatic hyponatremia,¹³ both athletes did admit, on specific enquiry after the race, to some symptoms,

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although they were not severe enough to cause the athletes to seek medical care.

However, symptoms of hyponatremia have been reported to include non-specific symptoms such as malaise, nausea, light-headedness and fatigue. More specific symptoms, which correlate with presumed cerebral oedema include confusion, headache, in-coordination, seizures, coma and even death.^{1–3,6,7,14,16,17,20,22–26} The non-specific symptoms of mild hyponatremia are common to other conditions seen following ultra-distance exercise including exercise-associated collapse, exhaustion and exercise-related gastrointestinal disturbances. The most useful symptom for the diagnosis and clinical management of this condition is an alteration in mental status,^{16,27} which is presumed to indicate a degree of developing cerebral oedema.

In the only report comparing symptom differences between athletes with asymptomatic or symptomatic hyponatremia, Speedy *et al.*¹⁴ reported that all hyponatremic athletes with plasma sodium concentrations below 125 mmol/L were symptomatic, whereas the majority of athletes with plasma sodium concentrations between 130 and 134 mmol/L were asymptomatic. Indeed, only 1.5% of the asymptomatic race finishers who did not seek medical care were found to have a plasma sodium concentration lower than 130 mmol/L. This suggests that mild hyponatremia (130–134 mmol/L) is often asymptomatic whereas more severe hyponatremia (< 130 mmol/L) is usually symptomatic.

The incidence of symptomatic hyponatremia among athletes seeking medical care at the New Zealand Ironman has been recorded as high as 23%.¹⁴ Holtzhausen *et al.*²⁸ reported that 8% of 56 km ultra-marathoners who were treated for exercise-associated collapse were hyponatremic. Laird²⁹ has reported that 5% of athletes seeking medical care at the Hawaiian Ironman are hyponatremic. Exercise-associated hyponatremia, both symptomatic and asymptomatic is, therefore, a common and potentially serious complication of ultra-distance exercise.

Aetiology

Despite the high incidence of hyponatremia following ultra-distance exercise, there is no consensus on its aetiology.³⁰ Two conflicting theories have been proposed. The first, proposed by Hiller,⁴ is that hyponatremia is caused by large water and salt losses in the sweat during prolonged exercise so that athletes with this condition are likely to be both dehydrated and sodium depleted. In contrast, the second theory proposes that athletes with hyponatremia are overhydrated without a substantial sodium deficit.¹

Salt depletion with dehydration

The salt depletion/dehydration theory for exercise-associated hyponatremia is based on two arguments. First, is the anecdotal clinical observation that approximately 70% of athletes treated for hyponatremia following the Hawaiian Ironman triathlon were considered to be dehydrated on unspecified clinical grounds.⁴ However, no weight measurements were made in those studies; thus, there is no published hard experimental evidence to support this hypothesis.

Second, estimates of water and sodium losses in sweat during exercise have suggested that athletes might incur large sodium deficits during ultra-distance exercise.⁴ However, such large estimates of salt loss have never actually been measured during an Ironman triathlon and may be erroneous. The only attempts to assess sodium losses during ultra-distance exercise are studies performed during recovery from exercise-associated hyponatremia in athletes competing in the 90 km Comrades ultra-marathon⁶ and the New Zealand Ironman triathlon.¹⁵ In both studies, the sodium deficits calculated in hyponatremic athletes were not large and were not different from those calculated in normonatremic controls. In a prospective study of two ultra-distance triathletes with exercise-associated hyponatremia, calculated sodium deficits during the recovery period were negligible.¹³

Fluid overload

The only published analysis of the relationship between hydration status and post-race serum sodium concentrations at the Hawaiian Ironman triathlon does not support the postulate that hyponatremia is associated with dehydration.⁹ Hyponatremic athletes lost significantly less weight than did normonatremic athletes and there was an inverse correlation between percentage change in body weight and post-race serum sodium concentration, indicating that dehydration causes hypernatremia, not hyponatremia.

The most important evidence supporting the theory that hyponatremia is caused by fluid overload is the relationship of post-race serum sodium concentrations to the changes in body weight that develop during the race. All published series reporting this relationship^{6,9,11,12,14,31} confirm an inverse correlation between post-race serum sodium concentrations and relative body weight changes after ultra-distance races. This relationship demonstrates that hyponatremia is associated with minimal weight change or indeed weight gain, that is fluid overload, whereas dehydration causes hypernatremia. This inverse relationship between post-race serum sodium concentration

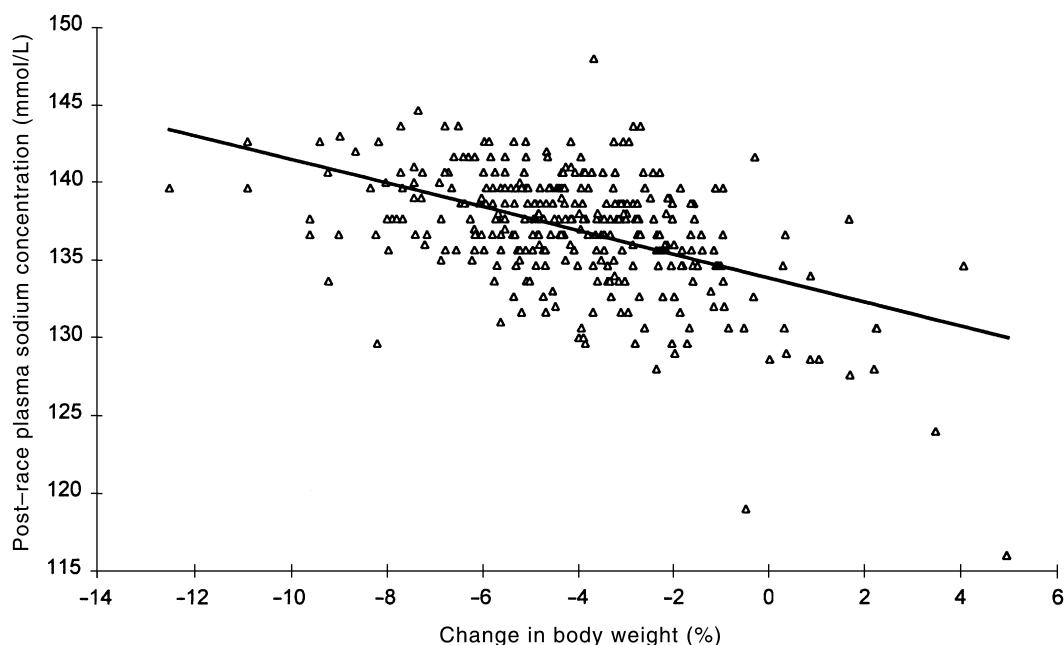


Figure 1. Inverse relationship between post-race plasma sodium concentration and percentage change in body weight in 330 ultradistance triathletes. Reproduced, with permission, from Speedy DB, Noakes TD, Rogers IR *et al.* Hyponatremia in ultradistance triathletes. *Med. Sci. Sport. Exerc.* 1999; **31**: 809–15.

and relative body-weight change in the largest series yet reported is shown (Fig. 1).¹⁴

To date, there have been 57 case reports of exercise-associated hyponatremia in the medical literature (Table 1). Weight changes during the activity have been recorded in 14 of these subjects. Weight gain was reported in 10 of these 14 cases with minimal weight losses in the other four athletes. These case reports further support the postulate that symptomatic hyponatremia is associated with fluid overload.

The relationship of mild hyponatremia (serum sodium concentration 130–134 mmol/L) to fluid status is not as clearly defined. The only report examining this relationship (Fig. 1) shows that there is a wide range of weight changes in athletes with mild hyponatremia, raising the possibility that although fluid overload is associated with severe hyponatremia, other aetiological mechanisms may contribute to mild hyponatremia.¹⁴ It is possible that sodium losses may play a role in the development of mild hyponatremia despite the failure of present studies to show significant sodium losses in these athletes.

Despite the clear association between fluid overload and hyponatremia, the cause of the fluid overload is still uncertain. Fluid overload can result either from an excessive fluid intake with fluid accumulation in a physiological third space, such as the intestinal lumen with

subsequent sodium movement into that fluid, or from impaired renal excretion of a fluid load.

The only published reports of fluid intake in association with exercise-associated hyponatremia are the case reports presented (Table 1). Fluid intake has been estimated retrospectively in 25 of these athletes. The mean fluid intake of the athletes presented is 1.2 L/h (Table 1). This mean rate of fluid intake is higher than that generally recommended for ultra-distance exercise (500–1000 mL/h).³⁵ It is interesting that of the nine athletes who developed hyponatremia with fluid intakes less than 1 L/h, eight were female. There are two possible explanations for this. Standard recommendations for fluid intake may be too high for female athletes who have a smaller body weight and who may exercise at lower absolute work rates and, hence, lower sweat rates.³⁶ Females are known to be at significantly increased risk for the development of symptomatic hyponatremia,¹⁴ although the reasons for this are still unclear.

A prospective study on fluid intakes in athletes in the New Zealand Ironman triathlon³¹ reported a median fluid intake of 716 mL/h with a range of 421–970 mL/h. The fluid intakes described in the case reports are clearly excessive in most cases (Table 1). In the prospective study of fluid intake at the New Zealand Ironman triathlon,³¹ five subjects (one male, four female), developed

Table 1. Reported cases of exercise-associated hyponatremia (adapted from Noakes TD, 1995²³)

Age (years)	Sex	Event	Duration (h : min)	Sodium (mmol/L)	Symptoms	Estimated total fluid intake (L)	Estimated rate fluid intake (L/h)	Weight change (kg)	Treatment	Reference no.
46	F	90 km run	± 7 : 00*	115	Seizure, pulmonary oedema.	6	0.9	?	IV normal saline.	1
37	M	90 km run	10 : 10	118	Muscle fasciculation.	12	1.2	?	IV normal saline + 5% dextrose.	1
20	M	90 km run	± 9 : 00	124	Seizure.	10	1.1	?	IV normal saline.	1
29	F	148 km triathlon	9 : 56	125	Pulmonary oedema.	8	0.8	+ 4.5	IV normal saline + diuretic.	1
24	M	100 km run	8 : 36	123	Seizure, respiratory arrest.	20	2.4	?	IV normal saline.	3
45	M	80 km run	10 : 36	118	Disorientation, mental confusion.	24	2.3	?	IV hypertonic 5% saline.	3
28	F	90 km run	± 7 : 00	112	Seizure, imminent cerebral coning.	13	1.9	?	Mannitol, frusemide, IV hypertonic 5% saline.	8
21	M	42 km run	5 : 30	123	Disorientation, pulmonary oedema.	?	?	?	Frusemide/saline.	24
56	M	90 km run	10 : 48	113	Seizure, respiratory arrest, pulmonary oedema, coma.	20	1.8	?		6,7
35	M	90 km run	10 : 10	122	Seizure, vomiting, confusion.	17	1.6	?		6,7
37	M	90 km run	9 : 37	113	Seizure, vomiting, confusion.	17	1.7	?		6,7
42	M	90 km run	7 : 45	124	Vomiting, pulmonary oedema.	10	1.3	?		6,7
38	F	90 km run	10 : 58	127	Weakness, incoordination, nausea.	11	1.0	?		6,7
35	F	90 km run	10 : 38	124	Weakness, incoordination, nausea.	10	1.0	?		6,7
41	F	90 km run	7 : 30	128	Weakness, incoordination, nausea.	6	0.8	?		6,7
50	F	90 km run	9 : 58	128	Weakness, incoordination, nausea.	10	1.0	?		6,7
21	M	Lab study	7 : 00	122	Nausea, malaise.	10.3	1.5	+ 4.0	Hypertonic (5%) IV saline then fluid restriction.	32
57	M	88.5 km run*	?	111	Dizziness, dysarthria, loss of consciousness, anisocoria.	6.3	?	?	Hypertonic (3%) IV saline, furosemide, mannitol, hyperventilation.	18
15	F	Hike ?distance	?	117	Malaise, headache, loss of consciousness, seizures.	'Large quantity'	?	?	Hypertonic IV saline.	33
19	M	Hike ?distance	?	115	Agitation, confusion, seizure.	'Large quantity'	?	?	Fluid deprivation.	33
19	F	20 km march	6 : 00	123	Fatigue, nausea, vertigo, confusion, agitation.	6.0	1.0	?	Hypertonic IV saline.	33
14	F	Hike ?distance	?	121	Vomiting, weakness, confusion, agitation.	> 6.0	?	?	Hypertonic IV saline.	33
18	F	8 km march	?	120	Headache, vomiting, agitation, seizures.	?	?	?	?	33

Table 1. continued

Age (years)	Sex	Event	Duration (h : min)	Sodium (mmol/L)	Symptoms	Estimated total fluid intake (L)	Estimated rate fluid intake (L/h)	Weight change (kg)	Treatment	Reference no.
18	M	March ?distance	?	116	Agitation, confusion, loss of consciousness.	'Large quantity'	?	?	Water deprivation.	33
12	M	'Few km'		117	Vomiting, stupor, seizures.	> 2.0	?	?	Hypertonic IV saline.	33
42	F	8 km hike/run	?	123	Exhaustion, nausea, weakness, ataxia.	6.0	?	?	IV normal saline and IV ringers.	22
29	F	Day-long hike	?	126	Diarrhoea, muscle cramps, vomiting, post-exercise diuresis.	?	?	?	1 L IV ringers, oral electrolyte drink.	22
49	F	Hike	2 days	107	Exhaustion, nausea, dizziness, ataxia, loss of consciousness.	?	?	?	Hypertonic IV saline.	22
51	F	Hike	1 day	108	Headache, dizziness, nausea, vomiting, diarrhoea, seizures, post-exercise diuresis.	'Large quantity'	?	?	IV normal saline.	22
57	M	88.5 km run*	?	111	Confusion, dysarthria, seizure, anisocoria.	12.0	?	+ 2.0	Hypertonic (3%) IV saline, 2 furosemide, mannitol.	2
30	M	226 km triathlon	10 : 54	130	Malaise.	16.0	1.5	+ 2.5	Observation only.	12
30	F	226 km triathlon	13 : 18	131	Did not seek medical care, but light headed.	9.8	0.7	+ 0.5	Nil.	13
39	F	226 km triathlon	12 : 00	130	Did not seek medical care but skin felt 'tight'.	9.2	0.8	+ 1.5	Nil.	13
37	M	42.2 km marathon	?	119	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
37	F	42.2 km marathon	?	120	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
44	F	42.2 km marathon	?	121	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
29	M	42.2 km marathon	?	127	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
31	F	42.2 km marathon	?	125	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
46	F	42.2 km marathon	?	120	Pulmonary and cerebral oedema; died.	?	?	?		25
32	F	42.2 km marathon	?	117	Pulmonary and cerebral oedema.	?	?	?	Hypertonic saline.	25
27	F	226 km triathlon	?	118	Confusion, seizures, diarrhoea.	'Large amounts of water'/4–6 L fluid post-race	?	?	Hypertonic saline.	26
29	M	226 km triathlon	?	120	Collapse, confusion.	'Large amounts of water'	?	?	Hypertonic saline.	26
50	F	16 km hike	?	117	Seizure, vomiting.	?	?	?	Hypertonic saline.	34

Table 1. continued

Age (years)	Sex	Event	Duration (h : min)	Sodium (mmol/L)	Symptoms	Estimated total fluid intake (L)	Estimated rate fluid intake (L/h)	Weight change (kg)	Treatment	Reference no.
64	F	14 km hike	?	109	Seizure, vomiting, diarrhoea.	'Large amounts of water'	?	?	Hypertonic saline.	34
19	F	24 km hike	?	117	Dizzy, vomiting, disoriented.	10.5	?	?	Normal saline with KCl.	34
21	F	Hike	Full day hiking	127	Headache, dizzy, seizure, vomiting.	5.0	?	?	Normal saline.	34
52	F	29 km hike	?	124	Dizzy, nausea, chest pain, lethargic.	?	?	?	Normal saline.	34
45	F	16 km hike	?	127	Dizzy, nausea, anxious, disoriented.	8.5	?	?	Fluid restriction; salty snacks.	34
23	M	29 km hike	14 : 00	122	Dizzy, vomiting, disoriented, comabative.	6.0	0.43	?	Normal saline with KCl.	34
35	M	226 km triathlon	14 : 03	116	Collapse, seizures.	23.0	1.6	+ 3.2	Hypertonic IV saline.	17
30	F	226 km triathlon*	13 : 50**	130	Dizziness, malaise, altered mental status, cramps, headache, bloating.**	?	?	+ 0.2	Fluid restriction.	15
47	F	226 km triathlon*	13 : 18**	119	Dizziness, nausea/vomiting, malaise, altered mental status, cramps.**	8.0**	0.6**	− 0.3	Fluid restriction.	15
31	F	226 km triathlon*	12 : 29**	124	Dizziness, nausea/vomiting, malaise, altered mental status.**	?	?	+ 2.2	IV normal saline.	15
33	M	226 km triathlon*	12 : 25**	128	Dizziness, nausea/vomiting.**	?	?	− 1.3	IV normal saline.	15
36	F	226 km triathlon*	11 : 59**	128	Nausea/vomiting.**	5.5**	0.5**	− 1.3	Fluid restriction.	15
37	M	226 km triathlon*	11 : 00**	134	Dizziness, cramps.**	?	?	− 2.3	Fluid restriction.	15
44	F	226 km triathlon*	12 : 15**	129	Dizziness, nausea/vomiting, malaise, bloating.**	8.7**	0.7**	+ 0.2	Fluid restriction.	15

*Completed only this distance, did not finish the event.

**D Speedy, pers. comm., 1999.

IV, Intravenous; KCl, potassium chloride.

hyponatremia but the median fluid intake for these hyponatremic athletes was only 714 mL/h (range 421–766 mL/h). Hyponatremia, although usually associated with a high fluid intake can, therefore, develop with what is thought to be an appropriately modest fluid intake.

In summary, the published evidence largely supports the alternative theory of fluid overload as the cause of symptomatic exercise-associated hyponatremia. However, it is also clear that most cases of asymptomatic hyponatremia occur in athletes who are modestly dehydrated during exercise (Fig. 1), indicating that other factors are also present.

Impaired renal function and hormonal influences

The development of fluid overload in exercise-associated hyponatremia in the presence of a modest fluid intake raises the possibility that athletes with this condition may have, or may develop during exercise, an impaired renal capacity to excrete a fluid load. Irving *et al.*⁶ reported that the renal response of ultramarathon runners recovering from exercise-induced hyponatremia was normal. They concluded that it was unlikely that exercise-induced renal damage caused an inability to excrete the excess fluid during the race.

It has been postulated that elevated plasma arginine vasopressin (AVP) levels may be responsible for the fluid retention in this condition.^{26,33} There has been one case report³² of an athlete developing hyponatremia with elevated plasma AVP concentrations. In contrast, the only prospective study to measure plasma AVP concentrations following ultra-distance exercise, found that these concentrations were not elevated in athletes with symptomatic hyponatremia.^{14,15} However, sampling for plasma AVP concentration was performed approximately 45 min post-race and may not have been an accurate reflection of plasma AVP concentrations during actual racing, as the half-life of plasma AVP is reported to be 24 min.³⁷ These normal post-race plasma AVP concentrations can also not explain why recovery from exercise-associated hyponatremia is so often delayed. The initial diuresis often occurs up to 2–4 h after the completion of exercise and restoration of fluid balance, taking 12 h or more in those with the most severe forms of hyponatremia.^{6,14,17} In summary, the available data do not support the postulate that inappropriately high plasma AVP concentrations are involved in the aetiology of hyponatremia.

Likewise, Speedy *et al.*¹⁵ have reported that post-exercise plasma aldosterone concentrations are no higher in hyponatremic athletes than in normonatremic

controls. Studies of renal function during ultra-distance exercise do not show any evidence for impaired renal function.³⁸

There are two possible reasons why the kidneys may be unable to excrete the excessive fluid load during exercise. Either the fluid is 'hidden' from the kidneys in some physiological third space, such as the intestinal lumen, or the rate of whole-body fluid accumulation may exceed the maximum capacity for urine production under those conditions. Lote has calculated that there is a limiting maximum rate of diuresis calculated to be 12–15 mL/min⁻¹ (720 mL/h⁻¹).³⁹

Thus, we speculate that this maximum rate of urine production may be reduced in some athletes during exercise, not because of renal ischaemia, but as a result of increased levels of circulating antidiuretic hormones, other than AVP. Under these conditions, fluid ingestion at rates faster than rates of fluid loss due to sweating and urine production, would also lead to a progressive fluid overload with hyponatremia.

Site of fluid accumulation in hyponatremia

It has been postulated that there may be an upper limit to the rate of intestinal fluid absorption. Thus, when an athlete ingests fluid at a rate exceeding this limit, the unabsorbed fluid would remain in the intestine, causing osmotic movement of sodium ions from the extracellular fluid into the intestinal lumen, resulting in hyponatremia.^{7,23,40} An early study by Irving *et al.*⁶ reported decreased post-exercise plasma volumes in hyponatremic ultramarathon runners compared with normonatremic controls. This is consistent with the hypothesis that fluid was retained in a physiological 'third space' (intestinal lumen), with the hyponatremia resulting from sodium moving from the extracellular space in order to equilibrate the sodium concentrations of the respective compartments. However, these findings were not replicated in the only other study that has evaluated fluid shifts during recovery from exercise-associated hyponatremia. Thus, Speedy *et al.*¹⁵ reported that hyponatremic Ironman triathletes had elevated plasma volumes, indicating that the excess fluid in these athletes was retained in the extracellular space. Because Speedy *et al.*¹⁵ studied athletes competing in the New Zealand Ironman triathlon and Irving *et al.*⁶ studied athletes in the Comrades 88 km ultra marathon, it is possible that there is a physiological difference in maximum rates of intestinal absorption in ultra-marathon running and ultra-distance triathlons. However, another study by Speedy *et al.*¹⁴ of 330 athletes competing in the New Zealand Ironman

triathlon has also shown a linear relationship between post-race plasma sodium concentrations and haematocrit. This confirms that exercise-associated hyponatremia, at least in ultra-distance triathletes, results from expansion of the extracellular space with dilution of the sodium content and is not due to a third-space effect, with loss of extracellular sodium into unabsorbed intestinal fluid. A prospective study of two athletes who developed hyponatremia in the same race¹³ also reported large increases in plasma volume during the race.

In summary, the evidence favours fluid retention in the extracellular space (dilutional hyponatremia), rather than fluid remaining unabsorbed in the intestine, as the cause of exercise-associated hyponatremia. This shows that the pathophysiological abnormality in exercise-associated hyponatremia is an inability of the kidneys to excrete fluid at high rates during prolonged exercise when rates of fluid ingestion are 750 mL or greater.

Role of female gender, slow running time and non-steroidal anti-inflammatory drugs

The most important risk factor for the development of hyponatremia is female gender as discussed above. Speedy *et al.*¹⁴ reported that 45% of female race finishers in the New Zealand Ironman triathlon developed hyponatremia compared with 14% of male race finishers. Investigators have also postulated that slower runners are more at risk of hyponatremia than faster runners.^{1,7,24} Noakes²³ has postulated that this is due to the increased opportunity for these athletes to drink excessive volumes due to their lower fluid requirements but increased opportunity to drink. The association of a slow running time with hyponatremia has been confirmed in the New Zealand Ironman triathlon¹⁴ in which running time was a significant variable in a multivariate analysis predicting the plasma sodium concentration. Non-steroidal anti-inflammatory drugs have also been postulated as a potential cause of exercise-associated hyponatremia,⁶ due to decreased renal prostaglandin production leading to a decline in glomerular filtration rate. However, the use of anti-inflammatory medications is widespread among endurance athletes, therefore any such relationship may be purely coincidental.

Management of exercise-related hyponatremia

The management of hyponatremia is dictated by the severity of the condition. Asymptomatic hyponatremia,

by definition,^{5,9,14} is not treated because these athletes do not present for medical care. As symptomatic hyponatremia is usually associated with fluid overload, appropriate management is close clinical observation with regular monitoring of serum sodium concentrations while awaiting a spontaneous diuresis of the retained fluid.¹⁶ Provided an athlete with symptomatic hyponatremia is clinically stable and without symptoms or signs of significant cerebral or pulmonary oedema, they can be managed usually in a well-equipped on-site medical facility.¹⁶ Such management normally requires several hours of observation.^{8–12} Speedy *et al.*¹⁶ have proposed that a specifically designated area for observation of such athletes should be provided. In particular, these athletes must not be given intravenous fluids because they are already fluid overloaded. Rather, they should have intravenous access with an intravenous cannula and Luer plug. It is not known whether oral salt supplementation speeds recovery. Some early reports at the Hawaiian Ironman triathlon⁴¹ described the treatment of this condition with 5% dextrose and normal saline. This approach has been criticized, because of the risk of compounding any fluid overload.¹⁶ Intravenous fluids should never be given to a collapsed ultra-distance athlete before an accurate diagnosis has been made because of the risk of harm from exacerbation of an unrecognized hyponatremia due to fluid overload.^{23,27,42}

As shown by Speedy *et al.*,¹⁴ there is a wide spectrum of hydration status associated with mild hyponatremia, although severe hyponatremia is usually associated with fluid overload (Fig. 1). Thus, there may be some athletes with mild hyponatremia who are also dehydrated. Judicious use of intravenous normal saline in these athletes might be considered but oral rehydration with salty solutions is safer. As the hydration status is the critical variable in the management of athletes with hyponatremia, and indeed in the management of all collapsed athletes following ultra-distance races, it has recently been recommended that all athletes competing in these events should be weighed prior to the race start and that this should be a compulsory requirement for race entrance.¹⁶ This can easily be done at race registration up to 48 h prior to the start of the race.^{12,14,27} If the athlete subsequently presents for medical care, a further measurement of weight can be included in the triage of the athlete and the result will guide appropriate management. A weight loss of 1.5–2.5 kg is to be expected in an ultradistance triathlon lasting approximately 12 h from sources other than fluid loss (i.e. loss of fat, glycogen and water associated with storage of glycogen).^{10,15,31} Thus, a weight loss of this magnitude in an ultradistance race

indicates neutral fluid balance. Conversely, no weight loss indicates a degree of fluid overload, and should raise suspicion of exercise-associated hyponatremia.

The exact role of hypertonic saline in the treatment of exercise-associated hyponatremia is unclear as the only published data on its use in the treatment of severe exercise-associated hyponatremia are case reports.^{3,8,18,25,32,33,43} Central nervous system manifestations of hyponatremia (mental confusion, convulsions and coma) require aggressive treatment, in both the emergency department and intensive care unit. Seizures and coma comprise a life-threatening emergency and these should be treated with hypertonic saline to create an osmolar gradient of 10–20 mmol/L to rapidly mobilize brain water.⁴⁴

We suggest the following protocol in the intensive care setting: 4-molar sodium chloride (4 mmol/mL), 50–60 mL can be injected into a large vein. This will raise the serum sodium concentration by approximately 7 mmol/L. Alternatively 3% saline (0.5 mmol/mL) can be used; however, a much larger quantity (400–500 mL) is required and, as more water is administered, the effect on serum sodium concentration will be less. The initial bolus must be followed by a continuous infusion of 3% saline. The amount of sodium chloride (NaCl) required can be calculated as:

$$\text{mmol NaCl} = 0.6 \times \text{weight (kg)} \times (\text{target [Na]} - \text{plasma [Na]})$$

The target value for the final serum sodium concentration is chosen as either an increase in serum sodium concentration of 20–25 mmol/L or an absolute value of 130 mmol/L, whichever is the lesser.⁴⁵ The amount of 3% NaCl infusion calculates as: 3% NaCl (mL) = 1000 × mmol NaCl/513. This should be infused at a rate calculated to increase the serum sodium concentration by 1–1.5 mmol/L per h (approximately 50 mmol/h in a 70 kg athlete). If fluid overload is of concern a loop diuretic (e.g. frusemide) may be given cautiously. Frequent measurements of serum sodium concentration are mandatory. The main danger of fast correction is the development of the rare neurological condition central pontine myelinolysis (CPM). Most reported cases of CPM are related to a too rapid correction of the serum sodium concentration (i.e. > 25 mmol/L in 48 h) or to a final serum sodium concentration higher than 130 mmol/L. Most cases of CPM also had more chronic hyponatremia and we are unaware of any athletes with exercise-associated hyponatremia who have developed this condition. Most experts believe that the risk of central nervous system damage due to severe hyponatremia greatly outweighs the risk of developing CPM.^{46–48}

Prevention of hyponatremia

The prevention of hyponatremia requires that athletes adopt an appropriate fluid replacement regimen during ultra-distance racing. In particular, they need to avoid over-drinking as fluid overload will cause symptomatic hyponatremia.^{1,3,6,7,23,32} Noakes *et al.*²³ have suggested that a fluid intake of 500 mL/h is appropriate for most non-competitive athletes during prolonged exercise. Burke³⁵ has suggested a fluid intake of between 500 mL/h and 1000 mL/h in ultra-distance events. These recommendations are lower than the American College of Sports Medicine's position statement that rates of fluid intake during exercise should be between 600 mL/h and 1200 mL/h.⁴⁹

The only published attempt at implementing a strategy for the specific prevention of hyponatremia by: (i) informing athletes of the appropriate fluid intake rates during prolonged exercise; and (ii) reducing the availability of fluids at support stations has recently been reported by Speedy *et al.*¹⁶ By introduction of these measures aimed at reducing the fluid intake of triathletes, they showed a reduction in the percentage of athletes treated for hyponatremia in the medical tent from 24% to 4%.¹⁶ The advice to prevent overhydration by curtailing fluid intake has been criticized⁴ but it needs to be emphasized that appropriate rates of fluid intake for ultra-distance exercise have not been established and the standard recommendations for fluid intake, including those of the American College of Sports Medicine, are based on data from shorter distance events.⁴⁹ To our knowledge, there have been only three studies of fluid intake during ultra-distance exercise: (i) Fallon *et al.*⁵⁰ reported a mean fluid intake of 540 mL/h in a 100 km ultra-marathon; (ii) Rogers *et al.*¹⁰ reported a mean fluid intake of 737 mL/h in an ultra-triathlon involving canoeing, cycling and running; and (iii) Speedy *et al.*³¹ reported a median fluid intake of 716 mL/h in an ironman triathlon. As already noted, some athletes still develop hyponatremia at modest fluid intakes^{12,14} and for slower athletes, or for those who are small or female, fluid intakes should be at the lower end of the recommended range. Nor is there any evidence that the mild dehydration found in athletes who follow these guidelines is detrimental to their health.⁵¹

The role of salt supplementation in the prevention of hyponatremia has yet to be determined. A recent laboratory study¹⁹ has shown that replacing sweat losses with a sports drink containing sodium may attenuate the fall in plasma sodium concentrations when compared to replacing sweat losses with water only. As already discussed, it is possible that sodium deficiency may play a role in some athletes who develop mild hyponatremia.

Until further evidence is obtained, it seems wise to counsel athletes to choose a sports drink that contains sodium as their replacement fluid during ultra-distance exercise, rather than water or a sodium-free soft drink.^{16,19} There are no published data on the benefits or risks of ingesting salt tablets during ultra-distance exercise.

Future directions

Symptomatic hyponatremia is caused by fluid overload, resulting from high rates of fluid intake with an inappropriate renal response causing fluid retention. Future research needs to investigate whether hyponatremic athletes have some intrinsic impairment of renal function preventing them from adequately excreting a fluid load. The role of possible sodium deficiency in athletes with mild hyponatremia who are also dehydrated warrants further investigation. Likewise, the role of sodium supplements during racing as a preventative strategy to maintain serum sodium concentration needs to be evaluated.

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