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Fluid Balance During and After an Ironman Triathlon

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Objective: To record weight changes, fluid intake and changes in serum sodium concentration in ultradistance triathletes.

Design: Descriptive research.

Setting: Ironman triathlon (3.8 km swim, 180 km cycle, 42.2 km run). Air temperature at 1200 h was 21°C, (relative humidity 91%). Water temperature was 20.7°C.

Participants: 18 triathletes.

Interventions: None.

Main Outcome Measures: Subjects were weighed and had blood drawn for serum sodium concentration [Na], hemoglobin, and hematocrit, pre-race, post-race, and at 0800 h on the morning following the race ("recovery"); subjects were also weighed at transitions. Fluid intake during the race was estimated by athlete recall.

Results: Median weight change during the race = −2.5 kg ($p < 0.0006$). Subjects lost weight during recovery (median = −1.0 kg) ($p < 0.03$). Median hourly fluid intake = 716 ml/h (range 421–970). Fluid intakes were higher on the bike than on the run (median 889 versus 632 ml/h, $p = 0.03$). Median calculated fluid losses cycling were 808 ml/h and running were 1,021 ml/h. No significant difference existed between pre-race and post-race [Na] (median 140 versus 138 mmol/L) or between post-race and recovery [Na] (median 138 versus 137 mmol/L). Plasma volume increased during the race, median + 10.8% ($p = 0.0005$). There was an inverse relationship between change in [Na] pre-race to post-race and relative weight change ($r = -0.68$, $p = 0.0029$). Five subjects developed hyponatremia ([Na] 128–133 mmol/L).

Conclusions: Athletes lose 2.5 kg of weight during an ultradistance triathlon, most likely from sources other than fluid loss. Fluid intakes during this event are more modest than that recommended for shorter duration exercise. Plasma volume increases during the ultradistance triathlon. Subjects who developed hyponatremia had evidence of fluid overload despite modest fluid intakes.

Key Words: Ultradistance—Hyponatremia—Triathlete—Dehydration.

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INTRODUCTION

"Ironman" ultradistance triathlons involving a 3.8 km swim, a 180 km cycle, and a 42.2 km marathon run have increased greatly in popularity in the last 15 years. Despite the popularity of these events, there has been little field research to measure the fluid intake of triathletes during these events. Speedy et al.[1] reported the estimated fluid intakes of four athletes who developed hyponatremia during an Ironman triathlon. These intakes ranged between 6.2–16 L. These authors have also reported a mean weight loss, considered a measure of hydration status, of 2.1 kg or a 2.9% loss of body weight among healthy finishers in the 1996 New Zealand Ironman triathlon.[1]

Although there are well-established guidelines for appropriate fluid intakes for shorter athletic events,[2] to the best of our knowledge there has been only one report on the actual fluid intakes of athletes in an ultradistance triathlon: Applegate et al.[3] reported a high rate of fluid ingestion (1.5 L/h) at the Hawaiian Ironman. There has only been one study investigating how weight changes relate to actual hydration status in these ultradistance events.[4] The paucity of such data make it difficult to provide athletes with firm recommendations on what is an appropriate fluid intake for these ultradistance triathlons, in which athletes are often exercising at a low intensity but for 12 or more hours. Indeed, ultradistance athletes need to be cognizant not only of the risks of dehydration if they drink too little, but must also avoid overdrinking as fluid overload is the likely etiology of symptomatic exercise-induced hyponatremia, a common complication of ultradistance triathlons.[1,5–7,8,9]

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Accordingly, the aim of this study was to measure weight changes, fluid intake, and changes in serum sodium concentration in 19 triathletes competing in the 1997 New Zealand Ironman triathlon, a large international ultradistance event.

METHODS

Twelve male and 7 female athletes were studied prospectively to determine their fluid intake during the 1997 New Zealand Ironman triathlon. This triathlon involves a swim of 3.8 km, a cycle of 180 km, and a run of 42.2 km. Ambient air temperature at 1200 h was 21°C, with a relative humidity of 91%. Water temperature was 20.7°C.

Subjects were recruited by examining all entry forms for the race. Athletes who lived in Auckland City, where the race was held, and who estimated their race time to be between 10.5 and 14 hours were invited to participate in this study. Subjects gave their informed consent, and ethical approval for the study was obtained from the North Health Ethics Committee. All subjects were healthy, with no significant medical illnesses, as expected in competitors in this arduous event.

One to 1.5 hours prior to the start of the race, subjects had 20 ml of blood drawn by venipuncture and assayed for serum sodium concentration, hemoglobin (Hb), and hematocrit (Hct). This procedure was repeated upon completion of the race, and at 0800 h on the morning after the race (approximately 12 hours after completing the race). All venipunctures were performed in the sitting position. Assay for serum sodium concentration was carried out on the day after the race with Hitachi 747 or 737 analyzers (Boehringer Mannheim, Mannheim, Germany), using standard methods and the manufacturer's reagents, on serum that had been collected into silicone-gel separator tubes and stored at 4°C after centrifugation within 1 hour of collection. Plasma sodium assays on any subjects needing medical care post-race were performed on-site using a Nova Ion Selective Electrode analyzer (Waltham, MA, U.S.A.) on lithium–heparin anticoagulated samples. A calibration difference of 2 mmol/L was detected between the on-site Nova Ion Selective Electrode and the Hitachi analyzers in both this study and in a much larger study ($n = 373$)[1] performed using the same analyzers in the same race. The results from the Hitachi analyzers were therefore scaled down by 2 mmol/L to ensure comparability with the specimens analyzed on-site. Routine hematological assays for Hb and Hct were carried out on the day after the race with Technicon H1, H2, or H3 analyzers (Technicon Corporation, Tarrytown, NY, U.S.A.) on EDTA-anticoagulated samples that had been stored at 4°C. The laboratory performing the analyses was accredited for medical testing to ISO9001 by International Accreditation New Zealand. Plasma volume changes were calculated using the formula derived from the Dill and Costill's equation.[10,11]

All subjects were weighed approximately 1 hour prior to the race, at the swim–bike transition, at the bike–run transition, immediately after finishing the race, and at 0800 h on the morning after the race. Subjects were weighed in minimal clothing and without shoes or bicycle helmets. Weights were measured on calibrated Seca scales (Seca, Hamburg, Germany) placed on a hard level surface.

Food and drink were freely available at support stations every 12 km on the cycle course and every 1.8 km on the run. Fluid choices included water, Coca-Cola, and a sports drink (Powerade) containing 8% carbohydrate and 10 mmol/L of sodium. Athletes were instructed prior to the race to keep a careful mental note of how much fluid and which fluid they were consuming during the race, expressed in terms of number of drink bottles on the cycle and cups of fluid on the run. Athletes were questioned while they were racing to determine their fluid intakes. Interviewers ran or cycled with the athletes for a short distance to obtain this information, and also questioned the athletes at the transitions. Interviews took place at the swim–cycle transition, at 100 km on the cycle course, the cycle–run transition, at three points on the run course (6.2 km, 19.9 km, and 34.7 km), and immediately after finishing the race.

Drink cups at the run support stations were of two sizes (predominantly 355 ml, with a few 250 mL cups also used). Also used were 750 mL cycle bottles. The drink cups and cycle bottles were filled by race support station staff, and the volumes with which they were filled were not measured. It was retrospectively estimated by the athletes (by interview within 3 days of the race) that the drink cups on the run were half filled (to contain approximately 175 mL of fluid) and that the cycle bottles were filled to contain approximately 700 mL of fluid.

Fluid losses (total of sweat, urine, and respiratory) during the cycle and run splits were calculated by subtracting weight change from fluid intake during these sections of the race. Rates of fluid loss were calculated by dividing total fluid loss by the time taken to complete each leg of the race. Weight of intake of solid nutrients and weight changes from any fecal loss were not included in these calculations. Weight loss from use of metabolic fuel was likewise disregarded for these calculations.

Statistical Analysis

Differences were tested by means of nonparametric tests, using the sign test for paired comparisons. Nonparametric analysis was used because of the small sample size and the nonnormal distribution of the outcome. Correlations between weight changes and serum sodium concentrations and change in serum sodium concentrations were calculated using Pearson's correlation coefficient.

RESULTS

One subject (male) failed to finish the race, withdrawing after finishing the cycle, with dizziness, vomiting, and mild hyponatremia ([Na] = 134 mmol/L), and was not included in the analysis, thus leaving 18 athletes available for analysis. Their median age was 35 years (range 23–49), and weight was 67 kg (range 57.5–93.5).

Subjects completed the race with a median race finishing time of 12.3 hours (range 10.9–15.3). The median time from race finish to post-race venipuncture was 13.5 minutes (range 7–32). Sixteen subjects lost weight during the race, the median weight change over the entire race was −2.5 kg (−4 to +1.5), which equates to a relative loss body weight of −3.5% (−6.1 to +2.5), this change being statistically significant ($p < 0.0006$).

Weight changes were measured after the swim, bike, and run sections, and at 0800 h the following morning ("recovery"). Full data on weight were not available on two subjects.

Subjects sustained median weight losses of −1.0 kg (range −2.0 to +0.5) during the swim ($p = 0.3$) and −2.0 kg (−3.5 to +1.5) during the run ($p < 0.0002$). However there was a significant median weight gain of +0.5 kg (−1.0 to +3.0) during the cycle ($p = 0.03$). Subjects also lost weight during recovery, with a significant median weight loss from race finish to the following morning of −1.0 kg (−4.5 to +1.0) ($p < 0.03$). As a result, all athletes lost weight over the period from before the race start to recovery the following morning (median = −2.8 kg, range −1.5 to −5).

Fluid intakes of subjects over the race are shown in Table 1. Median hourly fluid intake over the whole race was 716 ml/h (range 421–970). The median intakes of water and Powerade were 275 ml/h (0–567) and 271 ml/h (0–618), respectively. Median hourly fluid intakes were significantly higher on the bike 889 ml/h (601–1,310) than on the run 632 ml/h (238–1,129) ($p = 0.0327$). Median calculated fluid losses during cycling were 808 ml/h (range 469–1,083) and during running were median = 1,021 ml/h (range 404–1,801).

There were no significant differences between pre-race and post-race serum sodium concentrations (median = 140 mmol/L versus 138 mmol/L) ($p = 0.12$), or between post-race and recovery serum sodium concentrations (median = 138 mmol/L versus 137 mmol/L) ($p = 0.17$). However there was a significant difference between pre-race and recovery serum sodium concentrations (median = 140 mmol/L versus 137 mmol/L) ($p = 0.03$).

Full data for hematocrits and hemoglobins were not available on three subjects. There was a significant increase in plasma volume over the race (median = +10.8%, $p = 0.0005$). As a result there was a significant fall in hematocrit during the race (median = −2.5%, range −7 to 1, $p = 0.009$), and a significant fall in hemoglobin during the race (median = −7 g/L, range −18 to 1, $p = 0.014$). However there was only a minimal change in plasma volume during the recovery period (median = −1.1%, range −12.4 to 14.2, p = NS).

Five subjects (one male and four females) developed hyponatremia with post-race serum sodium concentrations between 128–133 mmol/L. Two of these subjects (one male and one female) sought medical attention. The median pre-race weight of these five athletes was 67 kg and they had a median weight loss during the race of 0.5 kg, or 0.7%. Median fluid intake for these athletes was 714 ml/h (range 421–766). However they had a high fluid intake on the cycle (median = 913 ml/h; range 631–1,207). Median fluid intake over the race was water = 4,630 ml, Powerade = 3,325ml, Coke = 50 ml.

There was a significant inverse correlation between post-race serum sodium concentration and relative body weight change ($r = -0.76$, $p = 0.0003$), with subjects with the higher serum sodium concentrations losing the most weight, and those with hyponatremia losing only minimal weight or gaining weight (Figure 1). There was a similar inverse relationship between the change in serum sodium concentration pre-race to post-race and the relative weight change ($r = -0.68$, $p = 0.0029$): a lowering of serum sodium concentration was associated with the least weight loss or weight gain (Figure 2).

DISCUSSION

The first important finding of our study is that despite high rates of fluid intake, athletes sustained a median weight loss during the race of 2.5 kg. We have reported a similar weight loss (2.9 kg) in athletes not seeking medical care in the same race.[9] Similar weight losses have been reported following other ultradistance events, including other ultradistance triathlons,[1,12] ultradistance running races,[13] and ultradistance multisport events.[4,14]

The data presented here support the postulate of Rogers et al.[4] that at least 2 kg of weight loss during an ultradistance triathlon is due to factors other than pure fluid loss. This weight loss includes loss of fat and glycogen, and the metabolic water stored with glycogen. This conclusion is supported by the following findings in this study: First, it is unlikely that subjects in this study were dehydrated at the finish of the race as their plasma volume was expanded and their serum sodium concentrations had not increased during the race. Second, subjects lost further weight (1 kg) in the 11–14 hours after they finished the race despite ingesting food and fluids, suggesting that they may even have had a mild fluid surplus at the finish of the race. Indeed it is interesting that post-race serum sodium concentrations were in the normal range of 138–140 mmol/L only in subjects who finished the race with a weight loss of 3–4%, equal to 2.0–2.7 kg (Figures 1 and 2). In contrast, athletes who finished the race at the same body weight at which they

TABLE 1. *Fluid intakes of 18 subjects during the Ironman triathlon*

	Total intake (ml)	Water intake (ml)	Powerade intake (ml)	Coca-Cola intake (ml)	Other fluid intake (ml)
Median	9,205	3,383	3,250	180	525
Range	4,975–11,370	0–6,885	0–7,800	0–1,305	0–5,600

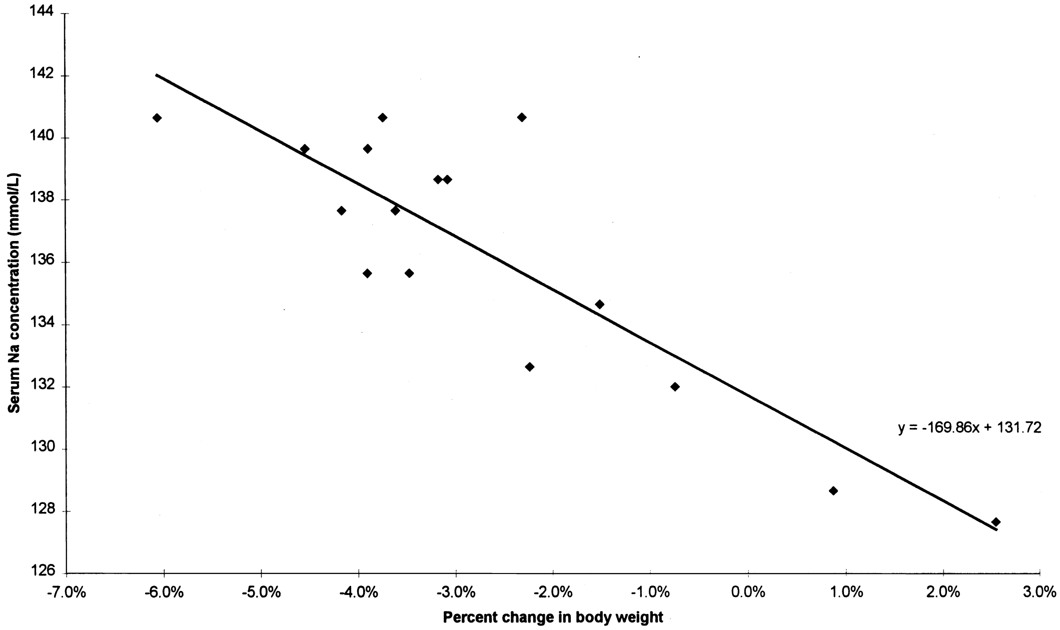

FIG. 1. Post-race serum sodium concentration versus percent weight change ($r = -0.87$).

started, had serum sodium concentrations of about 132 mmol/l (Figure 1), indicating a state of fluid overload relative to the extracellular sodium content.[6]

We know of no accurate data that directly identify the source of this weight loss during an ultradistance race; however, a calculated estimate of the weight loss that might be expected is given below based on certain assumptions: An athlete with a VO_{2max} = 4.5L/min, exercising at 62% of VO_{2max} for 12 hours, expends 40,000 kJ of energy. The only published estimate of energy consumption in an Ironman race suggests an intake of 21,714 kJ,[14] leaving 18,286 kJ of energy to come from body stores. Assuming a respiratory quotient of 0.85, the energy will come equally from fat and carbohydrate: each gram of fat provides 35 kJ of energy, therefore 260 g of fat is used; each gram of carbohydrate provides 17 kJ, therefore 535 g of carbohydrate is used; each gram of glycogen has 2.7 g water stored with it, therefore weight loss from water stored with glycogen is 1,444 g. Total weight loss from metabolic fuel used during the race (fat and carbohydrate) plus water stored with glycogen therefore equals 2,239 g (260 + 535 + 1,444 g). The weight of solid food consumed during the race is assumed to equal the weight of fecal matter eliminated during the same

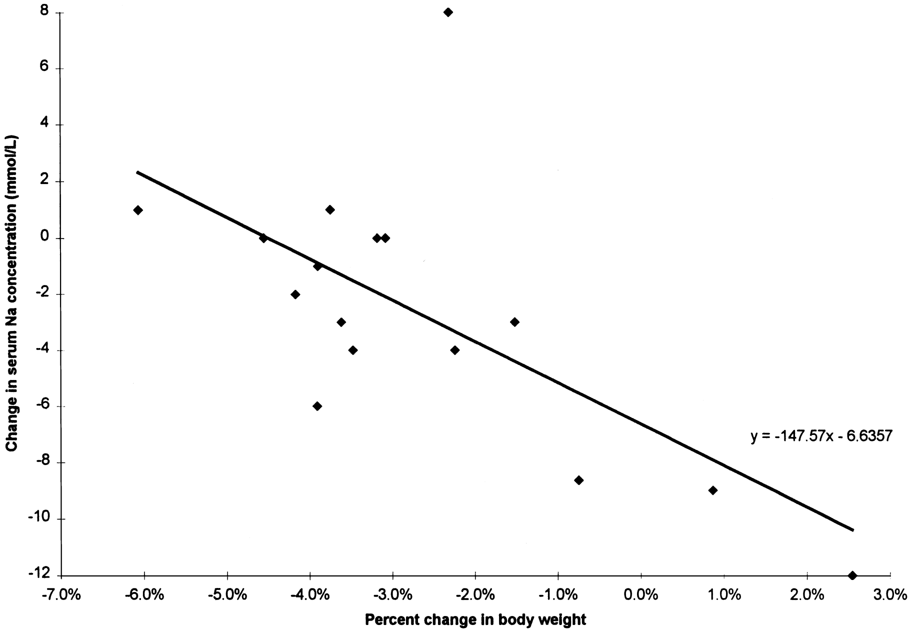

FIG. 2. Change in serum sodium concentration during race versus percent weight change ($r = -0.66$)

period in the above calculation. These calculations are speculative because of the assumptions that are made, but are given to present a model to explain the source of weight loss during ultradistance exercise. The calculated weight loss described above is consistent with the measured weight loss in this study and in other investigations of ultradistance exercise.[1,4,9,12,13,15]

The second contribution of our study is the description of fluid intakes in ultradistance triathletes. We acknowledge the potential limitations of athlete recall during a race in estimating fluid intake; however, a more accurate methodology would be extremely difficult in the "field" situation of an Ironman triathlon. We also acknowledge the potential limitations in estimation of fluid volume in the drink containers. To the best of our knowledge there have been only two previous descriptions of actual fluid intake in an ultradistance triathlon. Rogers et al. reported a mean fluid intake of 737 ml/h in athletes competing in a triathlon involving 21 km canoeing, 97 km cycling, and 42 km running[4]; Applegate[3] reported a very high rate of fluid ingestion at the Hawaiian Ironman (1.5 L/h). Fallon et al. recently reported a mean fluid intake of 540 ml/h in a 100 km ultramarathon running race.[16] The American College of Sports Medicine's position statement on fluid intake during exercise recommends a range of 600 to 1,200 ml/h.[2] While these recommendations may be appropriate for shorter distance races where the athletes compete at a high exercise intensity, they may not be appropriate either for ultradistance athletes competing at a lower intensity, or for smaller athletes whose metabolic and therefore sweat rates will be lower during exercise. Female ultradistance athletes in particular may have lower fluid requirements than "average" men due to lower sweat rates,[17] as they are usually smaller and take longer to finish these races, and have smaller fluid compartments. Indeed, Speedy et al.[9] have reported that women are at significantly greater risk of developing hyponatremia due to fluid overload[1,6–9,18,19] in ultradistance triathlons than are men. Furthermore, Noakes has postulated[13,20] that for the majority of noncompetitive ultradistance athletes, fluid intake during an ultradistance running event should be of the order of 500 ml/h, which approximates the *ad libitum* fluid intake of most athletes, as this will reduce the risk of developing symptomatic hyponatremia. Burke has recommended a fluid intake of 500–1,000 ml/h in ultradistance events.[21] The median fluid intake in our subjects of 716 ml/h is in keeping with these published recommendations, but would suggest that fluid intakes at the upper end of the range recommended by the American College of Sports Medicine position statement may be inappropriately high for ultradistance exercise.[2]

It is interesting that subjects in this study lost weight during the swim and the run sections but gained weight during the cycle. This would suggest that athletes may be drinking in excess of their fluid needs during the cycling section of an ultradistance triathlon. Indeed calculated fluid losses during the cycle were lower than during the run; however, the hourly intake on the cycle was significantly higher on the bike than during the run. The lower sweat rates during cycling may have resulted from the greater convective heat losses induced by the more rapid facing wind speeds generated in cycling than in running. It is not clear from our data whether an increased fluid intake during the cycle section is beneficial or detrimental. The athletes who developed hyponatremia in this study had a relatively high fluid intake on the cycle section, suggesting that this may have contributed to the development of their hyponatremia. Conversely, a higher fluid intake on the bike section may protect an athlete from subsequently becoming dehydrated on the run. The most likely explanation for the higher rates of fluid intake during cycling is the ready availability of fluids during the cycle (every 12 km), and the ease with which an athlete tolerates drinking when cycling as compared with running. Support stations at the New Zealand Ironman Triathlon provided a range of fluids including water, a sports drink (Powerade), and Coca-Cola. While there was a wide range of variability between subjects in what they chose to drink, Powerade and water were the most popular choices. To the best of our knowledge there are no other reports of what athletes choose to drink during an ultradistance triathlon.

The third and rather surprising finding of this study was that plasma volume increased by 10% during the ultradistance triathlon. Plasma volume is typically thought to decrease during intense exercise, due to dehydration and other factors.[16,22,23] Fallon et al. reported a mean decrease in plasma volume of 7.3% after a 100 km running race.[24] However there have been several other reports of an increased plasma volume during prolonged or ultradistance exercise[25–28] Gastmann et al.[28] have reported a mean plasma volume increase of 15.4% during an ultradistance triathlon of twice the length of an Ironman triathlon. They postulated that water movement from the intracellular to the extracellular space is favored during prolonged exercise by the decrease in such intracellular osmolytes as glycogen, proteins, and triglycerides.[28] They also suggest that the extent of the plasma volume increase may actually be overestimated by the Dill and Costill formula,[10] due to intravascular hemolysis.[28] Irving et al.[18] have reported the maintenance of plasma volume during a 56 km foot-race. They postulated that although plasma volume may decrease during the initial phases of exercise, fluid shifts in the latter phase of exercise (from influx of albumin and electrolytes into the intravascular compartment) maintain plasma volume.

The fourth contribution of this study is an insight into the etiology of hyponatremia in the five athletes who developed this condition. The weight loss sustained by these athletes was minimal (median = −0.5 kg, range −3.5 to +1.5), and if a weight loss of approximately 2 kg is to be expected from the factors described above, then most of these athletes finished the race marginally overhydrated. Although the etiology of hyponatremia has been controversial, symptomatic hyponatremia is usually associated with fluid overload.[1,5,7–9] It is surprising however that the median fluid intake for these athletes was modest (714 ml/h), albeit their median intake during the cycle was high (913 ml/h). As the amount of Powerade consumed by hyponatremic athletes was similar to the group of athletes as a whole (median 3,325 ml versus 3,250ml), it is unlikely that fluid choices were involved in the etiology of the hyponatremia. This suggests that standard recommendations for fluid replacement[2,21] may be too high for some athletes competing in ultradistance events, especially smaller or female athletes.[13] Indeed four of these five hyponatremic athletes were female. We have shown previously[9] that female athletes are at significantly increased risk of exercise associated hyponatremia. The reasons for this are speculative, but include females' smaller size[20] and possible hormonal influences.[29] We have previously reported full details of two of these five hyponatremic athletes in a separate detailed case report.[8] The observation that fluid retention and hyponatremia developed in these five athletes who had modest overall fluid intakes during the race, suggests that the hyponatremia may be caused by a failure of the renal excretion of the fluid, and shows that even modest fluid intakes can produce hyponatremia.

Early descriptions of hyponatremia speculated that this condition occurred in association with dehydration, although there was no documented evidence to support this hypothesis.[30] However all the published correlations between serum sodium concentrations and relative weight change during exercise show an inverse relationship,[1,5,6,8,9,12,15] indicating that dehydration is associated with hypernatremia, and that hyponatremia is associated with minimal weight loss or actual weight gain. Our data are consistent with these observations. Our data also represent the first report of the relationship of change in serum sodium concentration to relative body weight change, again showing an inverse relationship, confirming that hyponatremia is associated with fluid overload and not dehydration.

The final contribution of this study is the finding that athletes had a significant weight loss (median 1.0 kg) during the first 12 hours of recovery after the race. There was no significant change in serum sodium concentration or plasma volume during this time, suggesting that the subjects were not dehydrated at the finish of the race despite a median 2.5 kg weight loss over the course of the race. The source of the weight loss during recovery needs further investigation. We speculate that it may reflect a persistently high metabolic rate in the immediate 12 hours after finishing an Ironman event, with increased oxidation of fat and glycogen.

CONCLUSIONS

Our data demonstrate that athletes lose approximately 2.5 kg of weight during an ultradistance triathlon, most likely from sources other than fluid loss (loss of fat, glycogen, and water stored with glycogen). Typical fluid intakes during an ultradistance triathlon are in the range of 400–1,000 ml/h, which is more modest than that recommended for exercise of shorter duration. The cycle section of the race is associated with the highest fluid intake and with weight gain, suggesting that athletes may drink too much on the cycle section, in part because they sweat less during cycling probably as a result of increased convective heat losses, yet are able to drink more. Plasma volume increases by approximately 10% during an ultradistance triathlon, the mechanism of which has yet to be determined. Lastly, the subjects who developed hyponatremia had evidence of fluid overload despite modest fluid intakes, suggesting both a failure of excretion of the fluid and that the fluid needs in some ultradistance athletes may be less than the current recommendations.

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