Dysnatremia among runners in a half marathon performed under warm and humid conditions

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ABSTRACT

Background Dysnatremia has been associated with sports activity, especially long-distance running and endurance sports. High fluid intake is associated with hyponatremia. This study aims to evaluate dysnatremia and risk factors in half-marathon runners under warm and humid environmental conditions.

Methods A cross-sectional study was performed among randomly selected runners in the 2017 Cali half marathon. Runners on diuretic therapy or with a known history of kidney disease were excluded. Participants went through a 2-day assessment. Previous medical history, training history, body mass index and running history were determined in the first assessment. Symptoms of dysnatremia and level of fluid consumption during the race were registered during the second assessment and post-run blood sampling for serum [Na⁺] was also undertaken.

Results 130 runners were included in the study. The complete 2-day assessment was performed on 81 participants (62%) that were included in the final analysis. No cases of hyponatremia were found; instead, there were six cases of asymptomatic hypernatremia (7.4%). This hypernatremia had a statistically significant association with lower frequency ($p=0.01$) and volume of fluid intake during the race (water: $p=0.02$, Gatorade: $p=0.04$).

Conclusion Hyponatremia has been associated with high fluid intake in races performed under cool weather, such as the Boston Marathon during spring. In contrast, hypernatremia was found in a half marathon in warm and humid weather, which was associated with lower volume and frequency of fluid intake, suggesting that under warm and humid conditions, a median fluid intake of 900 mL during the race could prevent this event.

What are the new findings

- ▶ Lower fluid intake is associated with hypernatremia in runners of a half marathon in warm and humid weather.
- ▶ 7.4% was the incidence of hypernatremia during the race.
- ▶ A median fluid intake of 900 mL protects against hypernatremia in this type of race.

How might it impact on clinical practice in the near future

- ▶ Runners could prevent dysnatremia when running a half marathon.
- ▶ Fluid intake may vary depending on the length and weather conditions of the race.
- ▶ Runners could have a recommended range of fluid intake during a race.

volume, transport across the cell membrane, electric potential and cell signalling. The normal range for blood sodium is between 135 and 145 milliequivalents per litre (mEq/L).¹ Dysnatremias are values that fall outside this range (either hyponatremia or hypernatremia) and either can cause cellular dysfunction and systemic symptoms.³

Under optimal functioning, renal and hormonal systems maintain the plasma osmolality within tight limits, reflecting the physiological importance of osmolality regulation for cell volume and function, as previously mentioned.³ Exercise represents a situation of stress that can lead to electrolyte imbalance and the body has mechanisms to defend itself when faced to this, such as the ability to redistribute water and electrolytes within its fluid compartments, providing a reservoir to minimise the effects of water deficit or electrolyte imbalances,⁴⁻⁷ and the hormonal secretion of antidiuretic hormone (ADH), which regulates the secretion and reabsorption of electrolytes, and stimulates the thirst centre to ensure an adequate fluid

INTRODUCTION

An adequate fluid and electrolyte balance is of great importance for metabolic regulation, as water and electrolytes provide the medium for physiological reactions and determine the maintenance of both an adequate blood volume and integrity of the cardiovascular system as a whole.¹⁻³

Sodium is one of the most important electrolytes involved in the homeostasis of the human body: as the major extracellular cation, it mediates the regulation of cell

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intake during exercise.⁸ These mechanisms can, however, fail; for athletes, high-endurance competitions represent a higher risk for such failures.^{9–11}

In athletic competitions, acute hyponatremia and dehydration can present as a result of water loss through sweat associated with low or insufficient fluid intake.^{9 10 12} This is a state of hyperosmolality, hence it induces water movement from cells into the extracellular compartment, which is especially important for the central nervous system as it may cause cell shrinkage, leading to symptoms such as nausea, vomiting, confusion, seizures, muscle weakness, muscle twitching and even death. Although it is uncommon for hyponatremia to progress to serious complications in such settings,¹³ it has occasionally been associated with collapse.^{10 14 15} On the other hand, exercise-associated hyponatremia is usually the result of excessive water intake.^{16–19} In most cases, it presents with no symptoms or mild symptoms of weakness, dizziness, nausea and vomiting, but in cases involving a major drop in serum sodium levels, there is higher risk of a fast inflow of water into the cells leading to oedema which, in the central nervous system, is manifested as altered mental status, seizures and even death.^{3 10 20}

The relationship between different hydroelectrolytic imbalances and exercise has been assessed in several studies. Almond *et al.*²¹ found hyponatremia in 13% of the runners in the Boston Marathon, which was associated with a higher intake of liquids during the race.²¹ Severac *et al.*²² reported the case of a 42-year-old woman who developed severe hyponatremia (serum [Na⁺] of 123 mEq/L) after running an Ironman race. She had symptoms of cephalgia, nausea and confusion, which rapidly evolved into neurological deterioration and ventilatory failure; she did, however, respond well to an adequate sodium correction and fluid replenishment.²²

On the other hand, Au-Yeung *et al.*¹³ measured serum sodium levels in marathon runners in Hong Kong, finding a higher incidence of hyponatremia (12.9%) than hyponatremia (0.4%). Increased sodium levels were more prevalent in runners who had a lower fluid intake during the race and those with better physical training prior to the marathon. No symptomatic dysnatremia was found.¹³ Hew-Butler *et al.*²³ evaluated the presence of dysnatremia in the Comrades Marathon, finding hyponatremia in 45% of the runners.²³

For the half-marathon distance, there is a report of severe hyponatremia after running a half marathon.²⁴ There is also a study of Del Coso *et al.*²⁵ comparing serum sodium concentration values before and after the race. In this study, there was a similar increase in serum sodium for both marathoners (from 140.0±0.9 to 143.7±1.6 mmol/L, *p*<0.05) and half-marathoners (from 140.7±1.2 to 142.3±1.7 mmol/L, *p*<0.05) at the end of the race, with no statistically significant difference between both group of runners.²⁵

The purpose of this study is to assess the incidence of dysnatremia in half-marathon runners, and was carried out in a warm and humid city in South America located

1000 m above sea level, and to correlate these findings with possible risk factors such as body mass index (BMI), fluid consumption, gender, age and time taken to complete the race. The hypothesis is that fluid intake correlates with dysnatremia in half-marathon runners under these conditions.

MATERIALS AND METHODS

Study design and study population

A cross-sectional study was performed among runners in the Cali half marathon (28 May 2017). Eligible participants included men and women over the age of 18 who were going to run the half marathon (21K). Participants on diuretic therapy or with a known history of kidney disease were excluded.

The recruitment process was carried out randomly at the Race Kit Pickup site the day before, which was a mandatory stop for every runner. After receiving information and addressing any doubts the potential participants might have had, the eligible participants signed a written consent and completed a survey regarding demographic information, running experience and training information. Afterwards, they were evaluated by a physician who registered medical history, weight and height..

A tent was set up at the finish line, where participants were instructed to arrive as soon as completing the race for a physical examination and to assess the presence of any symptoms such as confusion, muscle weakness, spasms, cramps, headache, dyspnoea, dizziness, nausea and vomiting. Information about fluid consumption during the race was collected through a questionnaire. Hydration stations were distributed through the race every 3 km and included water and Gatorade supply. Volume capacity of cups used to distribute sport drink and water in hydration stations was measured previously, to help in the process of calculating with each participant their fluid intake during the race.

Participants were seated during this interview process and a blood sample was taken from capillary blood in their right index finger. These blood samples were collected within the first 20 min after finishing the race and were immediately processed by qualified health personnel from Fundación Valle del Lili, using i-STAT (Abbott) devices to measure serum sodium levels. These devices were previously calibrated with a reportable range between 100 and 180 mmol/L.

Attendance at the second assessment was encouraged by means of providing a comfortable space to rest, with a selection of beverages and fruits after completing the assessment. There was also an active search for the enrolled participants at the finish line by 10 different people, who showed them their way to the tent.

Independent variable

Dysnatremia was diagnosed when a serum sodium concentration outside the reference range of 135–145 mmol/L was found. Values below and above this range

were considered hyponatremia and hypernatremia, respectively.

Dependent variables

BMI, fluid consumption during the race, frequency of fluid consumption, age, gender, total time elapsed to complete the race and the presence of symptoms of dysnatremia, such as confusion, muscle weakness, spasms, cramps, headache, dyspnoea, dizziness, nausea and vomiting.

Statistical analysis

Stata V.12 was used for statistical analysis. Descriptive statistics were used to calculate the incidence of hypernatremia and to present the demographic characteristics of runners. During the analysis, t-tests, χ^2 and Fisher's exact test were used to evaluate the associations between other variables and hypernatremia, considering p values of ≤ 0.05 to be significant. Prior to the study, sample size calculations were made with a 5% alpha error and 80% power, giving an estimated sample size of 96 runners for an expected incidence of hyponatremia of 7%.

RESULTS

There were 2105 runners registered for the race. A total of 130 runners were included in the study and went through the first assessment. Eighty-one completed the post-run assessment, giving a 62% follow-up rate. Most participants were men (73%), with a mean age of 41.3 years (table 1). The weather during the race consisted of temperatures between 22 °C and -27 °C (72–80 °F) and a humidity of 76%–95%.

Table 1 shows the baseline characteristics of participants by gender, showing a trend towards male participants being older than female participants and showing statistically significant differences in the number of previous half marathons run, showing greater experience in such races in the female group.

Table 2 shows the baseline characteristics for the runners who completed the 2-day evaluation and runners who were not evaluated for a second time after finishing the race. Runners reporting at the finish line had more experience of running half marathons and had a slightly

Table 2 Comparing runners reporting and not reporting at finish line

Characteristic	Reporting at finish line n=8	Not reporting at finish line n=49	P values
Male sex (%)	72.8	73.5	0.55
Age, years (SD)	41.25 (12.47)	38.2 (10.7)	0.25
Body mass index (SD)	24.05 (2.36)	24.7 (3.1)	0.03
Previous half marathons, n (IQR)	4 (1–6)	3 (1–5)	<0.01
Years running, n (IQR)	4 (2–10)	4 (2–7)	0.62
Expected race time, min (IQR)	113 (105–130)	120 (120–135)	0.05

lower BMI. Otherwise, both groups were very similar to each other. When comparing the mean expected race time (116.3±18.5 min) with the real race time (120.0±19.5 min), results were very similar (p=0.22).

Table 3 shows the relationship between median serum sodium concentration and symptoms. There were no cases of symptomatic runners with dysnatremia. These symptoms were, however, associated with higher serum sodium concentrations, with no statistically significant differences. Nevertheless, since the frequency was very low, the strength of power for the association is limited.

At the end of the race, runners had a mean serum sodium concentration of 142.6±2.3 mmol/L. No cases of hyponatremia were found: instead, there were six cases of hypernatremia in this study (7.4%). Table 4 shows the association between hypernatremia, baseline characteristics and fluid intake during the race. Participants with hypernatremia had a statistically significant association with lower fluid volume intake (water: p=0.017, Gatorade: p=0.038) and lower frequency of fluid intake during the race (p=0.012). There was no association with gender, BMI, race time or age.

DISCUSSION

The results obtained in our study show how endurance sports can relate to different sodium disorders. Previous studies in runners have shown associations with both hypernatremia and hyponatremia in runners. Hyponatremia has been shown to be associated with

Table 1 Baseline characteristics of 2017 half-marathon runners in Cali, Colombia (n=81)

Sex distribution (%)	Men n=59 (72.8)	Women n=22 (27.2)	P values
Age, years (SD)	41.6 (12.5)	40.2 (12.7)	0.89
Body mass index (SD)	24.3 (2.4)	24 (2.4)	0.07
Previous half marathons, n (IQR)	3 (1–10)	4 (2–6)	0.05
Years running, n (IQR)	3 (2–11)	4.5 (3–8)	0.45
Expected race time, min (IQR)	110 (100–120)	125 (113–135)	0.13

Table 3 Relationship between serum sodium values and symptoms

Adverse events (n)	Serum sodium median (IQR)		P values
	Yes	No	
Nausea (1)	145	142 (141–144.5)	0.24
Confusion (2)	144.5 (143–146)	142 (141–145)	0.18
Dizziness (2)	144.5 (143–146)	142 (141–145)	0.18
Dyspnoea (1)	145	142 (141–144.5)	0.24

Table 4 Association of hypernatremia with age, gender, body mass index and fluid intake.

	Hypernatremia (n=6)	No hypernatremia (n=75)	P values
Age, years (SD)	46.7 (14.2)	40.8 (12.3)	0.33
Sex			
Male, n (%)	5 (8.5)	54 (91.5)	0.49
Female, n (%)	1 (4.5)	21 (95.4)	
Body mass index (SD)	22.8 (9)	24.1 (2.4)	0.13
Water intake, mL (IQR)	162.5 (0–700)	800 (600–1200)	0.02
Sport drink with electrolyte intake, mL (IQR)	30 (0–80)	80 (40–120)	0.04
Percentage of water loading in total fluid intake, % (IQR)	86.5 (0–100)	92 (87–95)	0.77
Race time, min (IQR)	103.5 (98–116)	119 (105–132)	0.06
Distance between fluid intake, km (IQR)	7.5 (3–21)	3 (3–4)	0.01

overhydration, a low level of training before the race and a longer time to finish the marathon.^{9 11 19}

Incidence and risk factors

An incidence of hypernatremia of 7.4% was found and no cases of hyponatremia, which differs from the results found by Almond *et al*²¹ in the Boston Marathon, where hyponatremia was found at an incidence of 13%. These contrasting results could be attributed to weather differences, as the temperature and humidity registered the day of the half marathon of Cali were higher than those of a typical Boston spring, which can lead to greater dehydration in a shorter time. In addition, since the Boston marathon is longer, the intake of liquids is more prolonged, a situation that could lead to dilutional hyponatremia. Indeed, the hypernatremia found in our study was related to a lower fluid intake during the race.¹⁹

In the study conducted in Hong Kong by Au-Yeung *et al* (2010), hypernatremia was found in 12.9% of runners.¹¹ In this study, hypernatremia was found in those participants who had a lower intake of fluids during the race, whether it was water or sports drink containing electrolytes. In general, the total fluid intake for runners was much lower than that recorded in previous studies, possibly explaining why there were no cases of dilutional hyponatremia found as a consequence of the intake of large amounts of fluids.^{9 11 19}

These results are consistent with previous literature. Hypernatremia is more frequent than hyponatremia in runners, either in 21K, 42K or even 250K races,^{8 9 11} though there are no previous studies of this kind in a

warm and humid environment. However, Mohseni *et al*²⁶ measured serum sodium for runners of a half marathon before and after the race. Their study showed a decrease in half-marathon hyponatremic runners from 6.0% pre-race to 3.8% post-race, with an increase in the mean serum sodium from 137.9 (4.3) to 140.5 (3.8) mmol/L.²⁶ These results are in the same direction of our study, showing a mean increase in serum sodium concentration for runners.

In our study, the median intake of fluids (either pure water or sport beverages with electrolytes) for the group of runners without hypernatremia was 890 mL, suggesting that fluid intake during a half marathon, of around 900 mL, may be protective against hypernatremia.

Limitations

There are some limitations in this study. For instance, fluid consumption was calculated based on the number of hydration stations along the race, the serving size and the number of servings that runners could recall, making this data prone to some degree of inaccuracy. Since this limitation applies to all runners and is not exclusive to the group with hypernatremia, it is assumed that there might be no bias of the information in any certain direction. Another limitation was related to sample size calculations, which were made on the basis of aiming to find the incidence of hyponatremia and not hypernatremia. Nevertheless, the percentage of hypernatremia found was around 7%, which was the same value used for sample size calculations. Unfortunately, due to the loss of follow-up presented, the final sample was of only 81 runners, less than the 96 participants initially suggested as a sample size.

A higher follow-up rate would be desirable, but it represents a challenge due to the logistics required to guarantee assistance at the assessment after crossing the finish line, especially when it involves blood sampling; the participants usually want to go and rest as soon as possible after their effort. Nevertheless, taking into account these circumstances, a follow-up of 62% is considered a good result and is similar to the percentages obtained in other studies of this kind, such as the 64% follow-up for the Boston Marathon study. On the other hand, when comparing runners who completed the 2-day evaluation and runners lost to follow-up, both groups were very similar, having only slight differences in terms of experience and BMI. These variables showed no association with hypernatremia in the study and, therefore, this loss of follow-up is not considered to have significantly affected the outcome.

CONCLUSION

This study complements the one conducted in the 2002 Boston Marathon by Almond *et al*,²¹ which showed the presence of hyponatremia associated with a high intake of liquids in cold weather during spring. Our findings concur with the direction of the Boston Marathon results. This is a half marathon in the tropics, with warm

and humid conditions that led to hyponatremia in 7% of the runners, which in turn was associated with lower frequency and total liquid intake.

Dysnatremia is common in high-endurance activities, such as half and full marathons. Although usually mild, they can be severe and life threatening, and so it is important to aim at their prevention, mostly through recommendations regarding fluid intake and adequate training. Nevertheless, suggestions for the former preventative measure seem to need to take into consideration environmental factors. The results found in this study suggest that under warm and humid conditions, an average of 900 mL of fluid intake might be sufficient during a half marathon to ensure adequate sodium levels. More studies like these, with greater samples, are required to establish a better a hydration range, which, in turn, could lead to the development of guidelines and recommendations for runners and high-endurance athletes.

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