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Evaluation of hydration status by urine, body mass variation and plasma parameters during an official half-marathon

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ABSTRACT

BACKGROUND: The aim of this study was to verify the agreement of urine, body mass variations and plasma parameters to determine the hydration status of 14 male runners (29±4 years and 54.3±5.5 mLO_2/kg/min) in an official 21.1 km road race.
METHODS: The mean dry-bulb temperature and air relative humidity during the road race were 25.1±2.1 °C and 54.7±2.2%, respectively. The volume of water ingested by the runners was monitored using marked volumetric plastic bottles provided at the hydration stations located at 0, 2.5, 5.0, 7.5, 10.5, 14.0, 16.0 and 18.5 km from the starting line. Hydration status was assessed using urine specific gravity (U_{SG}), urine osmolality (U_{OSM}) and plasma osmolality (P_{OSM}). Furthermore, body mass variation (ΔBM) was assessed by comparing body mass (BM) immediately prior and after the race. Total sweat was estimated by ΔBM, added water volume ingested and deducted blood volume collected. The sweat rate was calculated through total sweat and total exercise time.
RESULTS: The mean water intake was 0.82±0.40 L, and the mean sweat rate and total sweating were 1440.11±182.13 mL/h and 2.67±0.23 L. After the race, the BM reduced by 1.7±0.4 kg. The ΔBM was -2.41±0.47%, and the plasma volume variation was -9.79±4.6% between pre- and post-running measurements. Despite the P_{OSM} increased post-race compared to pre-race, the U_{OSM} and U_{SG} did not change. No significant correlations were found between P_{OSM} variation with U_{OSM} variation (r=-0.08; P=0.71), U_{SG} variation (r=-0.11; P=0.78) or ΔBM (r=0.09; P=0.77).
CONCLUSIONS: In conclusion, this study shows that both ΔBM and ΔP_{OSM} indicated a hypohydration state after exercise even though the ΔBM did not correlate significantly with ΔP_{OSM}. These results demonstrate that ΔBM is a practical method and can be sufficiently sensitive to evaluate the hydration state, but it should be utilized with caution.

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In recent years, the number of athletes who participate in long-term running competitions has increased considerably,[1] and several events are held in a warm environment that can be a health risk in extreme cases.[2, 3] Several biological mechanisms can be affected [3, 4] as a result of the heat produced by the muscles and the increased ambient temperature that reduces the body's heat dissipation gradient. This increases the skin blood flow and the sweat rate in an attempt to allow heat dissipation to the environment. The increased sweat rate during prolonged exercise could lead to dehydration and increases the cardiovascular and thermoregulation stress [5, 6] and impairs aerobic performance.[3]

The reduced total body water caused by exercise-in-

duced dehydration increases plasma osmolality (P_{OSM}) and decreases plasma volume.[7] However, despite the published consensus on the importance of hydration for performance,[3, 4, 7] it is unclear which way is more effective to maintain hydration status after training or competition.

Body water content and P_{OSM} are the most efficient methods for hydration status estimates [8, 9] because they are related to thirst sensation [10] and arginine vasopressin hormone secretion.[11, 12] However, while P_{OSM} is the gold standard for evaluating hydration status [2, 8, 9, 13] it is not a practical measure for monitoring daily hydration status due the difficulties in obtaining blood samples during official competitive events and daily.[8] Therefore, other variables such as urine analyses and body mass variations (ΔBM) are often used to estimate hydration status.[14]

While some papers evaluated hydration status in official or simulated half-marathon competitions by analyzing urine, blood parameters and ΔBM [15-17] these papers do not compare hydration status evaluated by a gold standard with a more practical and field method. These metrics can be used daily by coaches and athletes to monitor hydration. This is a critical point because some methods can result in contradictory information [18] and lead to an inaccurate evaluation of hydration status. To the best of our knowledge, the efficiency of different methods analyzing the runners' hydration status has never been compared during an official road race. Therefore, the aim of this study was to verify the agreement of urine parameters and ΔBM with a plasma parameter (P_{OSM}) to determine hydration status in moderately trained runners after an official half-marathon competition.

Materials and methods

Fourteen healthy male runners (29±4 years, 71.0±11.6 kg, 12.0±4.2% of body fat, and 54.3±5.5 $mLO_2/kg/min$ of maximum oxygen consumption [$\dot{V}O_{2max}$]) volunteered to participate in this study. All participants reported regular participation in road races, and none of them used any kind of medication, smoked, or presented signs of acute or chronic diseases. After an explanation of experimental risks and procedures, all participants signed an informed consent form. Ethics approval was granted by the University's Human Research Ethics Committee (nº 379/10); all rules established by the National Health Council were respected.

Three days before the experimental protocol, all subjects underwent a physical screening for sample characterization. Body mass (BM) (kg) was assessed using a digital scale (Filizola®, Brazil), and the skinfolds were measured using a skinfold caliper (Lange, Beta Technology, Seko Dosing Systems Corp., Tullytown, PA, USA) for estimation of the body fat percentage.[19] A progressive intensity exercise test until exhaustion was performed on a treadmill (Quinton Med-Track ST65, Mortara Instrument, Milwaukee, WI, USA) to determine $\dot{V}O_{2max}$.[20] Ventilatory variables were measured breath-by-breath and analyzed every 30 seconds with a gas analyzer (BIOPAC System, Goleta, CA, USA) previously calibrated before each test. The $\dot{V}O_{2max}$ was considered as the highest oxygen uptake recorded.

The experimental setting consisted of running an official outdoor half-marathon competition (21.1 km; start at 8:00 a.m.). Before and after the competition, blood and urine samples were collected, and the BM was measured to compare hydration state and to estimate exercise dehydration. The subjects were identified with a colored bracelet to follow them during the experiment. They were advised not to perform any strenuous exercise nor ingest alcoholic beverages and to keep their regular food ingestion (dinner and breakfast) and liquid intake from 48 hours prior to the experiment.

Pre-race data collection was conducted 1 hour prior to the beginning race near the starting line. Participants were instructed to empty their bladder in a disposable container. The urine specific gravity (U_{SG}) was assessed using a portable refractometer (Uridens Inlab, São Paulo, Brazil) and a sample of urine was stored in two 1.5-mL tubes and frozen at -20 °C for later determination of urinary osmolality (U_{OSM}).[21] The BM was measured while the subjects wore only shorts and blood samples were collected through a venous puncture at the antecubital fossa (Flashback 25×8, BD Vacutainer™, Becton, Dickinson and Co., Franklin Lakes, NJ, USA) using a 4.0-mL vacuum tube containing lithium heparin (Vacuette®, Greiner Bio-One, Kremsmünster, Austria).

Pre and post samples of venous blood (4 mL) were collected in a seated position inside a tent located near the start/finish line. Runners sat 15-20 minutes prior to blood collection to stabilize the plasma volume.[22] Blood samples were immediately centrifuged for 15 minutes at 3500 rpm (Combate, CELM, São Caetano do Sul, Brazil) to obtain plasma samples, which were stored in

1.5-mL plastic tubes at -20 °C for further P_{OSM} study by freezing point (5004 Micro-Osmette™, Precision Systems Inc., Natick, MA, USA).[21] All blood and plasma analyses were performed in triplicate.

The ΔBM was calculated through the difference between pre and post BM and minus the urine excreted. Total sweat was estimated over the difference between pre and post BM added water volume ingested and deducted blood volume collected. To calculate the sweating rate the total sweat was divided by the time taken to complete the race [23] according to the following equations:

$$\text{Total sweat (L)} = (BM_{pre} - BM_{post}) + \text{water} - (\text{urine} + \text{blood})$$

$$\text{Sweat rate (L·min)} = \text{total sweat / time to complete race}$$

where BM_{pre} is the body mass before race, BM_{post} is the body mass after race, "water" is the water mass ingested, "blood" is the blood mass collected and "time to complete race" is the total time of exercise expressed in minutes.

During the race, water (temperature at 7±2 °C) was offered in bottles containing a previously defined volume 100 m past the official hydration checkpoints. This was the only fluid they received during the experiment. The runners were oriented to ingest water *ad libitum* without using it to wet themselves, and to return the bottles at another research checkpoint located 100 m further ahead. The hydration checkpoints were located at 0, 2.5, 5.0, 7.5, 10.5, 14.0, 16.0, and 18.5 km. Even though the participants did not want to drink water, they were instructed to get the bottle at each checkpoint to standardize the procedure. All bottles were identified per participant to measure the ingested water volume. At the end of the competition, post-race blood and urine samples were collected, and the BM was measured. All subjects were asked about bathroom use along competition. If any participant used the bathroom along the competition, then he would be excluded from the study (no volunteer was excluded). Exercise dehydration was estimated by absolute values and changes in U_{SG}, U_{OSM}, P_{OSM} and BM.[7]

Statistical analysis

All statistical analysis was conducted using the Sigma Plot v. 12.0 software package (Systat Software Inc., San Jose, CA, USA). The Ryan-Joiner test was used to verify the normality of the data. The paired Student's *t*-test was used to compare the results before and after the competition. The Pearson product-moment correlation was used to evaluate the correlation between variables. The level of significance was P≤0.05. All results are shown as means and standard deviations.

TABLE I.—*Plasma osmolality (P_{OSM}), body mass (BM), urinary osmolality (U_{OSM}) and urine specific gravity (U_{SG}) before and after the half-marathon.*

Parameters	Before	After
P_{OSM}, mOsm/kg	289±4	296±6*
BM, kg	75.8±8.0	74.1±7.9*
U_{OSM}, mOsm/kg	595±291	513±214
U_{SG}, g/mL	1019±9	1017±7

Values presented as mean±SD.
*Significant difference between before *vs*. after (P<0.01).

Results

All subjects completed the 21.1-km competition, and their mean race time was 111.9±9.5 minutes. The environmental conditions during the competition were 25.1±2.1 °C for dry bulb, 54.7±2.6% of relative humidity; the wind speed was 0.41±0.44 m/s. The mean water consumption was 0.82±0.4 L, and the mean sweat rate and total sweating were 1440.11±182.13 mL/h and 2.67±0.23 L, respectively. After the race, BM was reduced by 1.7±0.4 kg, ΔBM was -2.41±0.47% and plasma volume variation was -9.79±4.6% between pre- and post-running measurements. Despite the P_{OSM} that increased post-race compared to pre-race, the U_{OSM} and U_{SG} did not change (Table I).

No significant correlations were found between P_{OSM} variation with U_{OSM} variation (r=-0.08; P=0.71), U_{SG} variation (r=-0.11; P=0.78) or ΔBM (r=0.09; P=0.77).

Discussion

The main finding of the present study was that the ΔBM indicates that participants finished the official half-marathon competition with dehydration. Furthermore, participants showed a significant increase in P_{OSM} and a significant reduction in BM with mean values crossing the reference limits for hydration state: <290 mOsm/kg for P_{OSM} [7, 8, 24] and >2% reduction in BM.[7] However, some studies demonstrated that only a dehydration ≥4%

of body mass could impair physical performance during self-paced prolonged exercise.[25, 26]

The ΔBM of -2.41% observed in this study suggests a decrease in body water content sufficient to cause differences in P_{OSM} and plasma volume. However, Armstrong *et al.*[27] and Francesconi *et al.*[28] found no increases in P_{OSM} with a BM reduction of 1.85% [27] and 3%.[28] These conflicting results may be because there is no correlation responses of ΔBM and P_{OSM}.[27, 28]

However, post-race individual dehydration status analysis through P_{OSM} and ΔBM indicated that thirteen participants (93% of total sample) could be considered dehydrated regardless a lack of significant correlation between increases of P_{OSM} and ΔBM (r=0.27; P=0.36). Despite the dehydration state of participants after the race, this was not associated with any clinical disorder over and following race. Senay [29] observed a significant correlation between P_{OSM} and ΔBM during a progressive dehydration and rehydration protocol with a programmed water consumption throughout the rehydration phase. Unlike programmed water consumption, this study was performed in a real competition with an ad libitum water intake, and time range between the last water ingestion and BM evaluation was not standardized. Therefore, food and liquid ingestion, as well as intestinal food and fluid absorption may also represent a limitation to the hydration status estimates of ΔBM because water may have not yet been absorbed yet [30] and could only represent water loss in longer exercises (~5.8 hours).[18] Nevertheless, the ΔBM could be considered a practical and noninvasive technique to estimate the body water loss,[7] and the results of the present study suggest that ΔBM could be used with caution for evaluation of hydration status.

The urine variables (U_{SG} and U_{OSM}) did not show a similar state of dehydration appointed by P_{OSM} after race. During exercise, a reduced urine production and greater water reabsorption increases the urine concentration and redirects the blood flow from the kidneys to the active muscles.[4] However, even with a 2.41% reduction in BM we did not observe any significant alterations in U_{SG}. These results agree with the findings of Oppliger *et al.*[2] who showed that U_{SG} changed only after a reduction of at least 3% in BM.

Therefore, while suggestions that the analysis of urine concentration is a valid method to evaluate hydration status [27, 31, 32] and a U_{OSM} above 900 mOsm/kg and U_{SG} above 1020 g/mL are usually observed when BM reduction is ≥1.9%,[7, 32] the evaluation of the hydration status through urine variables has been questioned particularly after exercise.[9, 32] Moreover we did not find any significant correlation between ΔP_{OSM} and urine variables (ΔU_{SG} and ΔU_{OSM}).[33]

However, in this study the time range between the last water ingestion and urine collection was not standardized because the study encompassed a real competition. This may have influenced the U_{SG} and U_{OSM} results at the end of the exercise because the ingestion of a large volume of water can stimulate a higher urine production without replenishing the body water deficit.[9, 27] Shirreffs *et al.*[34] demonstrated that the intake of large volumes of hypotonic fluid resulted in greater urine volume before the dehydration status was reached. Therefore, urine variables may not respond efficiently to rapid changes in the hydration status.[9]

Additional interfering factors such as water generated from metabolism and breakdown of liver and muscle glycogen may influence the analysis of hydric balance through ΔBM. According to Noakes,[35] those sources can generate a considerable amount of water during long-term physical exercise. It is estimated that during a marathon, elite runners use approximately 400 g of carbohydrates.[36] Considering that approximately 3 g of water is generated by each gram of glycogen depleted, this process would result in the release of 1.2 L of water, which will be used in other biological mechanisms like sweating without altering P_{OSM}.[4] Moreover, food and liquid ingestion, as well as intestinal food and fluid absorption, may also limit the hydration status estimates using body mass variations.[30]

Limitations of the study

One of the limitations of this study was that we did not provide a standardized meal prior to the competition, and the fluid consumption was not recorded prior to the competition because the runners were instructed to follow their normal hydration pattern. Although the excreted urine before and after exercise was collected, it was not possible to evaluate the non-absorbed water volume or the rate of gastric emptying. This may influence BM because part of the water ingested is excreted in the feces or retained in the gastrointestinal tract,[4] which cannot reduce P_{OSM}.

Conclusions

In conclusion, this study shows that both ΔBM and ΔP_{OSM} indicated the hypohydration state after exercise even though the ΔBM did not significantly correlate with ΔP_{OSM}. The U_{SG} and U_{OSM}, on the other hand, did not represent the hydration status of runners immediately after a half-marathon race because these variables did not indicate the hypohydration state observed with P_{OSM}. These results demonstrate that ΔBM is a practical method and appears to be sufficiently sensitive to evaluate the hydration state but it should be utilized with caution.

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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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