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Knechtle, Beat; Kiouplidis, Konstantin; Knechtle, Patrizia; Kohler, Götz; Imoberdorf, Reinhard; Ballmer, Peter

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Research Article

DOES A MULTI-STAGE ULTRA-ENDURANCE RUN CAUSE DE- OR HYPER HYDRATION?

Beat Knechtle[1,2], Konstantin Kiouplidis[3], Patrizia Knechtle[1], Götz Kohler[4], Reinhard Imoberdorf[5], Peter Ballmer[5]

[1]Gesundheitszentrum St. Gallen, St. Gallen, Switzerland. [2]Department of General Practice, University of Zurich, Switzerland. [3]Zentrale Laboratorien, Kantonsspital Winterthur, Winterthur, Switzerland. [4]Radio-Oncology, University Hospital Basel, Basel, Switzerland. [5]Medizinische Klinik, Kantonsspital Winterthur, Winterthur, Switzerland

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ABSTRACT
We investigated the changes in body mass and parameters of both renal function and fluid metabolism in a case study in a female ultra-endurance runner during the longest multi-stage mountain ultra-marathon in Europe, the 'Swiss Jura Marathon' in 2008. The female ultra-runner performed the 7 stages with a total distance of 175 km, a total ascent of 5,000 m, and a total descent of 8,000 m within 23:11 h: min, finishing as second female runner. By the end of the race, body mass decreased by 0.3 kg, fat mass by 1.2 kg and skeletal muscle mass by 0.7 kg. Haemoglobin and haematocrit decreased by 4.5% and 7.5 %, respectively, and plasma volume increased by 10 %. Serum osmolality decreased by 3.3%. Parameters of myocellular damage increased substantially (CK + 630 %, LDH + 178 % and GOT + 181 %). Creatinine continuously increased in plasma (+ 23 %) and urine (+ 47 %). Creatinine clearance (– 18.7 %), glomerular filtration rate (– 19.4 %) and serum albumin (– 10.6 %) decreased. Urinary specific gravity decreased after each stage and was increased before each stage. Urinary osmolality decreased after each stage and was increased before each stage. The average daily fluid intake from stage 1 to stage 7 (during performance and rest) was 4.9 l per day. Total body water increased by 1.2 l by the end of the race. The potassium-to-sodium ratio in urine was increased after each stage. We assume that the increase in total body water was due to an increased activity in the renin-angiotensin-aldosterone-system as evidenced by the change in urinary electrolytes after the stages and an increased activity of vasopressin as evidenced by increase of urinary osmolality before the stages.

Key words: ultra-run, fluid intake, skeletal muscle damage, renal function

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Corresponding author. Facharzt FMH für Allgemeinmedizin. Gesundheitszentrum. Vadianstrasse 26. 9001 St. Gallen. Switzerland
Phone: +41 (0) 71 226 82 82 / Fax: +41 (0) 71 226 82 72
E-mail: beat.knechtle@hispeed.ch

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INTRODUCTION

Ultra-endurance races are of increasing popularity. Apart from the classic marathon run over 42.195 km, ultra-marathons as single or multi-day runs attract more and more athletes (Knechtle and Kohler, 2007; Knechtle, Duff, Schulze and Kohler, 2008b). Abundant literature is available about single ultra-distance running, but little is known about the effects of running hundreds or even thousands of kilometres within a few days or weeks on human body composition (Knechtle and Kohler, 2007; Knechtle et al., 2008b; Raschka, Plath, Cerull, Bernhard, Jung and Leitzmann, 1991; Raschka and Plath, 1992).

Marathon and ultra-marathon running is associated with different problems such as dehydration (Kao, Shyu, Yang, et al., 2008; Pastene, Germain, Allevard, Gharib and Lacour, 1996; Whiting, Maughan and Miller, 1984), loss in skeletal muscle mass (Höchli, Schneiter, Ferretti, et al., 1995; Knechtle and Kohler, 2007; Knechtle, Duff, Schulze and Kohler, 2008a; Knechtle, Salas, Andonie and Kohler, 2008d) and increase in total body water (Fellmann, Ritz, Ribeyre, Beaufrère, Delaître and Coudert, 1999; Knechtle et al., 2008b; Knechtle, Knechtle, Schück, Andonie and Kohler, 2008c; Knechtle, Wirth, Knechtle and Rosemann, 2009).

The decrease in skeletal muscle mass in long-distance running can be explained by the eccentric component in running (Fridén, 1984; Kuipers, Janssen, Bosman, Frederik and Geurten, 1989) and the consecutive damage to skeletal muscle (Fellmann, Sagnol, Bedu et al., 1988).

The increase in total body water could be due to several different mechanisms such as protein catabolism with consecutive development of hypoproteinemic oedema (Bircher, Enggist, Jehle and Knechtle, 2006; Lehmann, Huonker and Dimeo, 1995), increased synthesis of plasma proteins with an increase in plasma volume (Maughan, Whiting and Davidson, 1985; Mischler, Boirie, Gachon et al., 2003), retention of sodium due to increased activity of aldosterone (Fellmann, Bedu, Giry et al., 1989; Fellmann et al., 1999; Freund, Claybaugh, Dice and Hashiro, 1987; Melin, Eclache, Geelen et al., 1980; Milledge, Bryson, Catley et al., 1982), increase in plasma volume due to increased activity of vasopressin (Fellmann et al., 1989) and a consecutive increase in plasma volume (Neumayr, Pfister, Hoertnagl, Mitterbauer, Prokop and Joannidis, 2005), and/or impairment of renal function due to dehydration and rhabodmyolysis because of skeletal muscle damage (Gastmann, Dimeo, Huonker et al., 1998; Kim, Lee and Kim, 2007; Skenderi, Kavouras, Anastasiou, Yiannakouris and Matalas, 2006).

Regarding these findings, the question is whether there is a link between skeletal muscle damage, impairment of renal function and retention, respectively, and accumulation in total body water.

As disorders in fluid and electrolyte metabolism are rather frequently found in female endurance athletes (Speedy, Faris, Hamlin et al., 1997; Speedy, Noakes, Rogers et al., 1999), we focused our investigation on a female ultra-runner. In a recent case study in a female ultra-endurance runner in a multi-stage ultra-endurance run, a continuous accumulation of total body water has been found (Knechtle et al., 2008a).

The aim of the present case study was therefore to investigate whether skeletal muscle damage due to ultra-running could be responsible for the impairment of renal function, thus

leading to continuous accumulation of total body water. We investigated a female ultra-runner during a multi-stage ultra-endurance mountain-marathon with high ascents and deep descents and focused on skeletal muscle damage and changes in total body water and fluid metabolism.

MATERIALS AND METHODS

Athlete and race

The female ultra-runner (43 years, 57 kg body mass, 1.72 m body height) has been running for four years and has performed 2 marathons with a personal best time of 4:50 h: min. She participated in 2008 in the 'Swiss Jura Marathon', a multi-stage ultra-endurance run over 7 stages with a total distance of 175 km, with a total ascent of 5,000 m and a total descent of 8,000 m. The study was approved by the Institutional Review Board for use of Human subjects of the Canton of St. Gallen, Switzerland. The athlete was informed of the experimental risks and gave informed written consent. The 18th edition of the 'Swiss Jura Marathon' took place from 6 July to 12 July 2008. It is the longest mountain multi-stage ultra-endurance run in Europe, held in the mountains of the 'Jura' from Geneva to Basel. Table 1 represents the stages of the run with the ascents and the descents.

Table 1. *Stages and general weather conditions during the race*

Stage	Distance (km)	Ascent (m)	Descent (m)	Temperature at the start (° Celsius)	Temperature at the finish (° Celsius)	Weather	Time (h:min)
1	21	1'210	640	12	14	Rain	3:05
2	27	660	1'150	10	12	Clouds	3:47
3	26	850	1'380	8	12	Clouds	3:38
4	20	550	1'120	8	20	Sun	2:54
5	29	670	1'500	14	26	Sun	3:45
6	25	680	1'450	18	27	Sun	3:21
7	27	550	960	14	22	Clouds	2:39

Measurements and calculations

Body mass, percent total body water and urinary parameters were determined before and after each stage. Venous blood samples and anthropometric measurements were performed before the start of the race and after stages 1, 3, 5 and 7. Skeletal muscle mass and percent body fat was calculated using anthropometric measurements. Percent total body water was determined using bioelectrical impedance analysis. Body mass was measured using the bioelectrical impedance analysis balance Tanita BC-545 (Tanita Corporation of America, Arlington Heights, IL, USA) to the nearest 0.1 kg. Skeletal muscle mass was calculated using the anthropometric method according to Lee, Wang, Heo, Ross, Janssen and Heymsfield (2000). Percentage of body fat was calculated using the anthropometric method following Ball, Swan and Desimone (2004). Percent total body water was measured using Tanita BC-545. Impedance measurements were performed with the athlete standing in an upright position, barefoot in running wear, on foot-electrodes on the platform of the instrument, with the legs

and thighs apart, and the arms without contact to the torso. The runner stood on the 4 foot-electrodes: 2 oval and 2 heel shaped electrodes, and gripped the 2 palm-and-thumb electrodes in order to yield 2 thumb and 2 palm electrodes. Since body weight and skeletal muscle mass are expressed in kg, fat mass was calculated in kg from body mass and percent body fat. Total body water was calculated from body weight and percent total body water. Venous blood samples were drawn after venipuncture of an antecubital vein, two Sarstedt S-Monovettes (serum gel, 7.5 ml) for chemical and one Sarstedt S-Monovette (lithium heparine, 2.7 ml) (Sarstedt, Nümbrecht, Germany) for haematological analysis were drawn. One Sarstedt monovette for urine (10 ml) was filled. Monovettes for serum were centrifuged at 3,000 g for 10 min at 4° C. Serum was collected and stored on ice. Blood and urinary samples were transported immediately after collection to the laboratory and analysed within 6 hours. In the venous blood samples, haemoglobin, haematocrit, creatinine, urea, sodium, potassium, plasma osmolality, creatine-kinase, lactic dehydrogenase (LDH), glutamate oxalacetate transaminase (GOT) and albumin were measured. In the urinary samples, creatinine, urea, sodium, potassium, urinary specific gravity and urinary osmolality were determined. Haemoglobin and haematocrit were determined using ADVIA® 120 (Siemens Healthcare Diagnostics, Deerfield, IL, USA). In the serum samples, creatinine, urea, sodium, potassium, creatine-kinase, LDH, GOT and albumin were measured using COBAS INTEGRA® 800 (Roche, Germany). Osmolality of plasma and urine was determined using Fiske® Modell 210 Mikro-Osmometer (IG Instrumenten-Gesellschaft AG, Zurich, Switzerland). Urinary specific gravity was analysed using Clinitek Atlas® Automated Urine Chemistry Analyzer (Siemens Healthcare Diagnostics, Deerfield, IL, USA). Creatinine and urea were measured using COBAS INTEGRA® 800. Electrolytes in the urinary samples were determined using ISE IL 943 Flame Photometer (GMI, Inc., Minnesota, USA). The change in plasma volume was calculated according to Dill and Costill (1974). The creatinine clearance was calculated using the method of Cockroft and Gault (1976) and the glomerular filtration rate was calculated according to Levey, Bosch, Lewis, Greene, Rogers and Roth (1999). The runner recorded fluid intake during the stages and during rest.

RESULTS

The athlete finished the 175 km within 23:11 h: min as the second female runner. By the end of the race, body mass was decreased by 0.3 kg, fat mass by 1.2 kg and skeletal muscle mass by 0.7 kg (Figure 1). Haemoglobin and haematocrit were reduced by 4.5 % and 7.5 %, respectively, and plasma volume increased by 10 % by the end of the race (Figure 2). Serum osmolality decreased by 3.3 %.

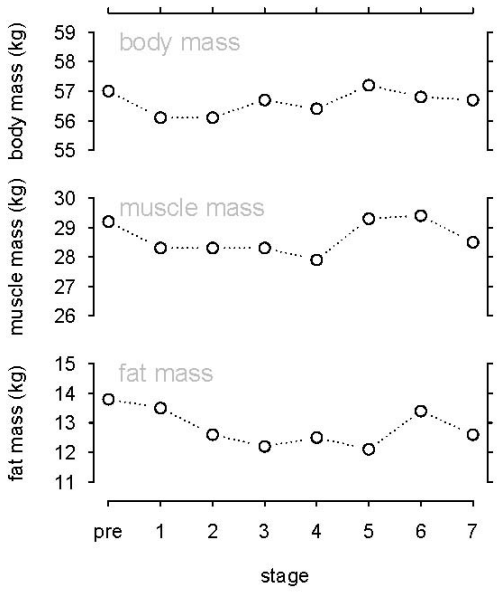

Figure 1. *Change in solid masses*

Table 2. *Fluid intake during and between the stages*

Time	Fluid (l)
During stage 1	2.2
Between stage 1 and 2	3.4
During stage 2	2.6
Between stage 2 and 3	2.2
During stage 3	1.8
Between stage 3 and 4	0.9
During stage 4	1.6
Between stage 4 and 5	3.4
During stage 5	2.4
Between stage 5 and 6	3.2
During stage 6	2.6
Between stage 6 and 7	3.3
During stage 7	2.6

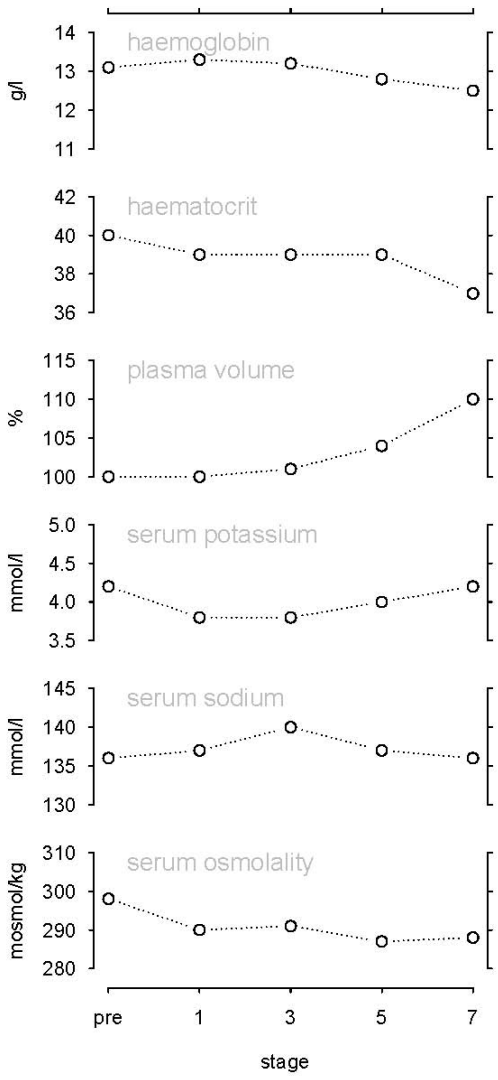

Figure 2. *Changes in haematologic and chemical parameters of fluid metabolism*

Parameters of myocellular damage increased substantially (CK + 630 %, LDH + 178 % und GOT +181 %) (Figure 3). Creatinine continuously increased in plasma (+ 23 %) (Figure 4) and urine (+ 47 %) (Figure 5). Both creatinine clearance (– 18.7 %) and glomerular filtration rate (– 19.4 %) decreased. Serum albumin decreased by 10.6 % (Figure 4). Body mass and urinary specific gravity decreased after each stage and was increased before each stage (Figure 6). Urinary osmolality decreased after each stage and was increased before each stage. The average daily fluid intake from stage 1 to stage 7 (during and after the stage) was 4.9 l per day (Table 2). Total body water was increased by 1.2 l and the potassium-to-sodium ratio in urine was increased after each stage (Figure 6).

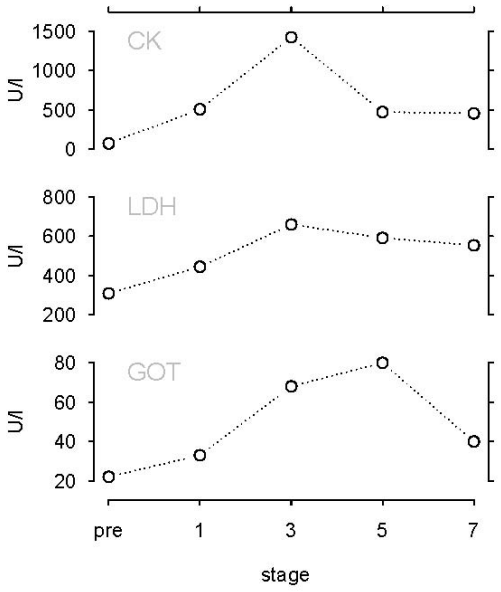

Figure 3. *Change in chemical parameters of skeletal muscle damage*

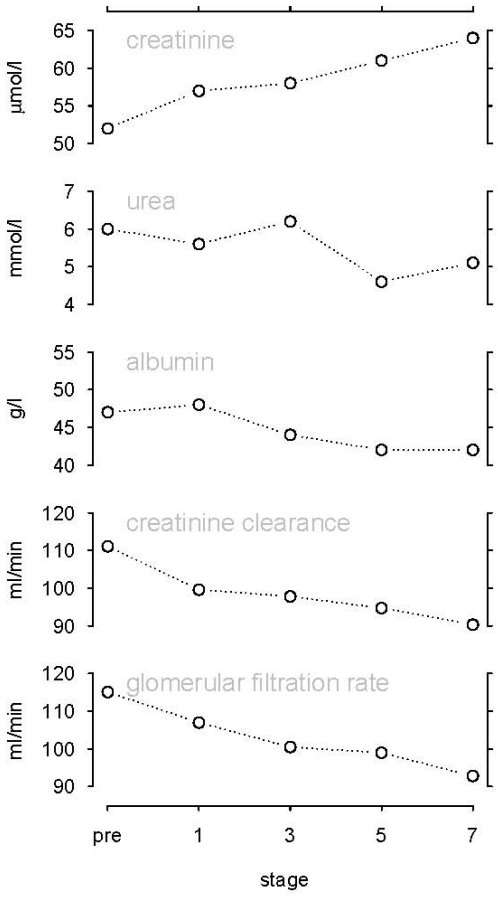

Figure 4: *Change in chemical parameters of renal function*

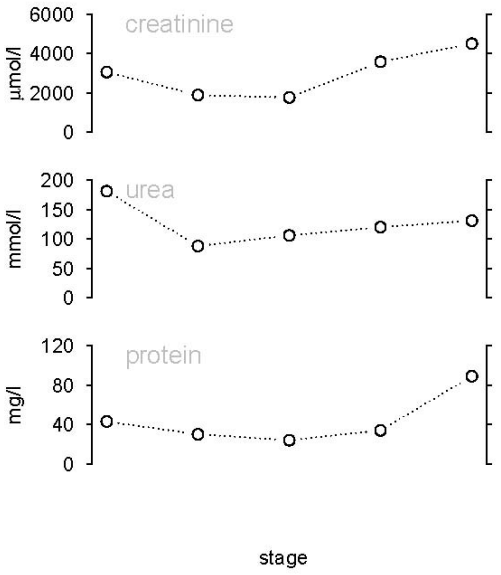

Figure 5. *Change in urinary parameters*

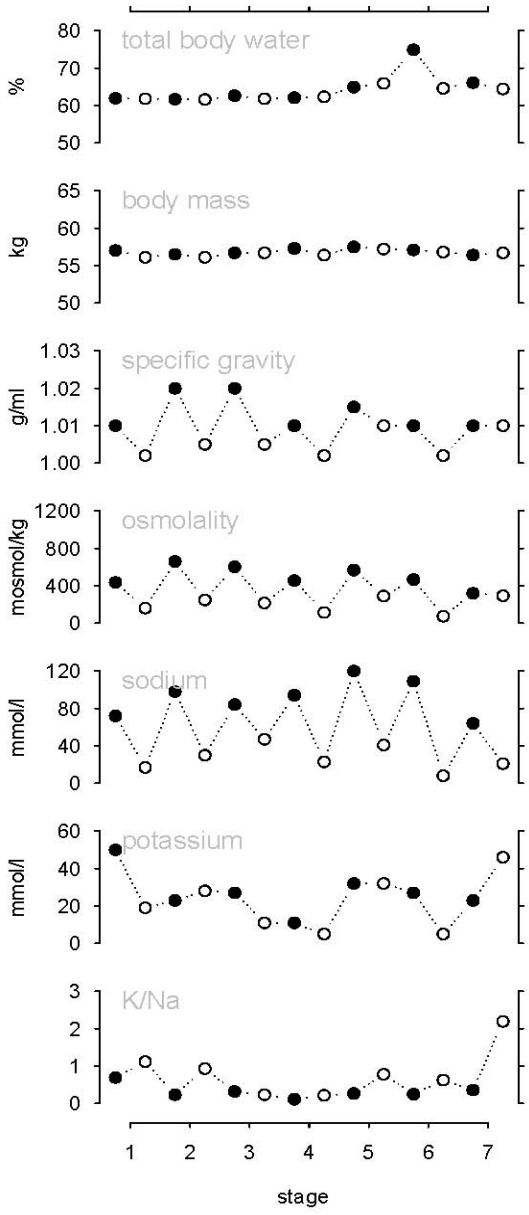

Figure 6. *Changes in body mass and urinary parameters of hydration status*

DISCUSSION

In this multi-stage ultra-endurance run, body mass, skeletal muscle mass and fat mass were reduced whereas total body water and plasma volume increased by the end of the race. The time course of body mass and urinary specific gravity indicates dehydration after each stage. The increase in urinary osmolality before each stage might be due to an increased activity of vasopressin (Fellmann et al., 1989) and the increased potassium-to-sodium ratio in urine after each stage reflects a contraction of the effective extra-cellular volume leading to a hyperreninemic hyperaldosteronemia.

Change in plasma volume due to hormonal changes?
A possible explanation for the increase in total body water could be an increase in plasma volume due to sodium retention as a consequence of increased activity of aldosterone (Milledge et al., 1982; Wade, Dressendorfer, O'Brien and Claybaugh, 1981). Transient expansion in plasma volume is commonly reported after endurance events (Fellmann et al., 1999; Maughan et al., 1985; Milledge et al., 1982).

Immediately after a 24-hour run, plasma volume was initially reduced, but started to increase after the race with a peak on day 2 (Fellmann et al., 1989).

As Wade et al. (1981) have demonstrated in a multi-stage ultra-endurance run, aldosterone excretion was continuously elevated although plasma sodium was reduced by the end of the race. The potassium-to-sodium ratio in urine was < 1 pre-race, and increased after stages 1, 2 and 7 to > 1 but returned to < 1 after each stage (Figure 6). We interpreted the decreases in urinary sodium as a reaction to the stimulation in the renin-angiotensin-aldosterone-system (RAAS). However, we were not able to measure RAAS which is a limitation of the study. The changes in urinary sodium and potassium suggest that more potassium than sodium was excreted during the performance, and the positive potassium-to-sodium ratio is suggestive for an increased aldosterone activity. The potassium-to-sodium ratio in urine > 1.0 reflects a contraction of the effective extra-cellular volume leading to a hyperreninemic hyperaldosteronemia. The potassium–to-sodium ratio in urine is a physiological reflexion of the potassium secretion in the distal tubulus and of sodium re-absorption an estimation of aldosterone activity in serum. The increase in urinary osmolality before each stage might indicate hypo-hydration, e.g. by relative fluid restriction or might be due to an increased activity of vasopressin (Fellmann et al., 1989).

The increase in total body water might also be explained by the endocrine situation in females. Our female runner was one week after her last period, therefore in the follicular phase and pre-ovulatory. In pre-ovulation, estrogen is elevated and with the start of the luteal phase, progesterone increases. The increase in progesterone is directly correlated with the increase in aldosterone which is also increased in the luteal phase (Szmuilowicz, Adler, Williams et al., 2006) and enhances absorption of sodium and chloride in the kidney. However, although the female hormones have an effect on water and electrolyte metabolism, the menstrual cycle shows no clear influence on fluid balance and concentration of electrolytes (Bisson, Dunster, O'Hare, Hampton and Penney, 1992). Since the competition was in her follicular phase and not in the luteal phase, progesterone was not increased and presumably the female hormones had no influence on fluid metabolism.

De- or hyper hydration during a multi-stage ultra-endurance run?
A decrease in body weight is thought to be a result of dehydration in marathon (Pastene et al., 1996; Whiting et al., 1984) and ultra-marathon (Kao et al., 2008) runners. The decrease in body weight is thought to be caused by dehydration and fluid loss (Cheuvront, Montain and Sawka, 2007; Kao et al., 2008; Pastene et al., 1996; Whiting et al., 1984). However, in recent field studies at multi-stage ultra-endurance races, a decrease in fat mass (Knechtle et al., 2008c) and skeletal muscle mass (Knechtle et al., 2008b) has been related in part to decrease in body mass.

During the past 20 years, many parameters have been developed to accurately assess hydration status in human subjects. Apart from a change in body weight, haematological and urinary parameters, bioelectrical impedance, skin-fold thickness, heart rate and blood pressure

are among these indices (Kavouras, 2002; Shireffs, 2003). Although there is no 'gold standard' for the correct assessment of hydration status, it appears that changes in body weight, along with urine osmolality, specific gravity of urine, conductivity and colour of urine are among the most widely used indices (Kavouras, 2002). The current evidence and opinions tend to favour urine indices, as the most promising marker available (Shireffs, 2003). Haematological measurements such as plasma osmolality, plasma sodium or haematocrit are not as sensitive in detecting mild hypo-hydration as selected urinary parameters are (Armstrong, Maresh, Castellani et al., 1994). Our athlete showed after each stage a decrease in body weight and increase in urinary specific gravity (Figure 6). According to the proposal of Kavouras (2002) our athlete was dehydrated after each stage, but rehydrated before each subsequent stage.
The present female athlete showed a continuous increase in plasma volume (Figure 2) during the race. Kaminsky and Paul (1991) found a significant relationship between fluid intake and change in plasma volume. Regarding the fluid intake of our athlete (Table 2), an excessive fluid intake leading to overload (Speedy et al., 1997; Speedy et al., 1999) thus leading to plasma volume expansion, can be excluded. The decrease in serum osmolality (Figure 2) and urinary osmolality after each stage in combination with the increase in total body water (Figure 6) might indicate hypotonic hyperhydration. This might be due to fluid overload, impaired renal function, lack of protein and/or an increased activity in vasopressin. In contrast to our finding, Wade et al. (1981) found in a 20-day 500-km race an elevation in osmolality. Osmolality is a primary regulator of the release of vasopressin. When osmolality decreases, the secretion of vasopressin will be reduced and consequently plasma volume will be reduced. This leads to an activation of the RAAS with an increased activity in aldosterone and reabsorption in sodium so that water retention occurs. We would therefore presume that our athlete was hyperhydrated rather than dehydrated after the race.

We would not support the hypothesis of hypoproteinemic oedema. The decrease in albumin is most probably due to hemodilution as evidenced by the decrease in haemoglobin and haematocrit. This may also lead to the change in the other serum measures. Furthermore, we assume that renal function was not impaired. Unfortunately, the intake of pain killers such as NSAID was not asked. NSAID can also disrupt fluid balance.

CONCLUSIONS

In one female ultra-runner during a multi-stage mountain ultra-endurance run, a decrease in body mass, skeletal muscle mass and fat muss occurred by the end of the race. After each stage, body mass was decreased and urinary specific gravity increased, indicating dehydration. Before the next stage, body mass and urinary specific gravity was restored. In addition, an increase in total body water and plasma volume could be detected by the end of the race. We assume that the continuous increase in total body water was due to an increased activity in the RAAS as evidenced by the change in urinary electrolytes after the stages and an increased activity of vasopressin as evidenced by increase of urinary osmolality before the stages. For future studies, the activity of the hormones aldosterone and vasopressin should be determined in a larger sample of ultra-runners during a multi-stage ultra-endurance run.

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