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Revisiting indices of hydration state during progressive dehydration to a 7% water deficit

Abstract

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REVISITING INDICES OF HYDRATION STATE DURING PROGRESSIVE DEHYDRATION TO A 7% WATER DEFICIT.

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INTRODUCTION

From a clinical perspective, hydration state is typically evaluated from changes in the osmolality (concentration) of blood. The assumption of this measurement is that altered intra- and extracellular body-fluid volumes will be reflected within the blood, since water freely moves across cellular membranes and capillary walls, as dictated by osmotic gradients. Thus, a loss of body fluid through sweating is eventually borne equally by all body-fluid compartments (Maw *et al.*, 1998), and one could therefore expect changes in plasma osmolality to be related to body-water deficits. Since humans also regulate the volume and osmolality of the intravascular fluid compartment, and since both of these regulatory mechanisms involve the modulation of renal function, then one could anticipate that the electrolyte composition and flow of urine, and therefore its osmolality, specific gravity and colour, would also reflect body-water deficits. Indeed, the change in urine colour has become the most widely practised method for assessing hydration state in the field (Armstrong *et al.*, 1994), although a gold standard for evaluating hydration state does not exist (Shirreffs, 2000).

Since the current laboratory recently completed a series of experiments involving progressive dehydration, including 12 trials to a 3% water deficit and 24 trials to a water deficit of 7% (Machado-Moreira *et al.*, 2009; Peoples *et al.*, 2009; Taylor *et al.*, 2009a, 2009b), an opportunity became available in which the inter-relationship of these different hydration indices could be evaluated under controlled laboratory conditions, and across a wide range of controlled and known hydration states. In this paper, four indices of hydration state are evaluated across 36 trials in which subjects were progressively dehydrated. The validity and sensitivity of the saliva osmolality method has been reported in a parallel communication (Taylor *et al.*, 2009b). Herein are described subsequent modifications to serum and urine osmolality, urine specific gravity and urine colour, and how changes in these variables reflect sequential reductions in hydration state, as reflected by changes in body mass.

METHODS

Twelve physically active men performed intermittent cycling in hot-humid conditions: 35.6°C (± 0.4) and 56.0% humidity (± 1.0). Each participated in three trials wearing only shorts and running shoes: 7% dehydration, 3% dehydration with partial rehydration, and 7% repeated dehydration. All tests were conducted at approximately the same time of day for each person, using fully-hydrated subjects. For the day preceding each trial, subjects were provided with 30 mL.kg⁻¹ of isotonic drink, to be consumed between 0600 h and 1800 h. For the night prior to each trial, subjects were instructed to drink 15 mL.kg⁻¹ of additional water before retiring, in the morning they were required to drink 500 mL of fluid (in any form) with breakfast, and on presentation, they drank a supplementary water volume (10 mL.kg⁻¹). Accordingly, every subject presented with a urine specific gravity <1.021. Since the objective of this project was to

gradually dehydrate subjects to both a 3% and a 7% water deficit using intermittent exercise in the heat, the controlled-hyperthermia (isothermal clamping) technique was used to elevate and clamp core temperature at ~38.5°C. An isotonic mouth rinse and drink (50 mL (trials 1 and 3) or 60% of the previous mass loss (partial rehydration trial)), and food (banana and biscuit: total mass: 90 g) were provided after reaching each of these targets.

Dehydration targets were determined from changes in body mass, with blood and urine samples collected to evaluate hydration state. Blood samples were obtained at baseline, at each 1% dehydration target and during recovery. Samples were taken from an indwelling cannula (regularly flushed with saline) positioned in a superficial forearm vein, and collected into serum vacutainers (Starstedt Aktiengesellschaft and Company, Numbrecht, Germany). Following separation, serum samples were centrifuged at 1,500 g for 15 min and transferred to Eppendorf tubes. Urine specimens were obtained at baseline, 3% and 7% dehydration, and following recovery. Urine specific gravity was measured from fresh specimens (Clinical Refractometer, Model 140, Shibuya Optical, Tokyo, Japan), and these samples were also evaluated for colour (Armstrong *et al.*, 1994). All serum and urine samples were then frozen (-80°C). Osmolalities were measured using a freezing-point osmometer (Model 3250 Advanced Osmometer, Advanced Instruments Inc., Norwood, MA, U.S.A.) after completing the entire experiment.

RESULTS AND DISCUSSION

During the 7% trials, the current subjects, who had an average pre-experimental body mass of 76.18 kg (SD 9.09), lost 5.28 kg (SD 0.54), and this represented a mean mass reduction of 6.93%. The lower than expected mass change resulted from five trial terminations (out of 24) at the 6% target, due to heat exhaustion or muscle cramps. Baseline measures of serum osmolality averaged 286.1 mOsmol.kg⁻¹ H₂O (SD 4.2, coefficient of variation (CV) 1.8%), and the corresponding values for urine osmolality were 250.6 mOsmol.kg⁻¹ H₂O (SD 177.5, CV 61.6%), urine specific gravity 1.006 (SD 0.006, CV 0.4%) and urine colour 1.4 (SD 0.64, CV 33.4%).

Each of the four hydration indices tracked changes in body mass. However, due to the inherent variability within some of these indices, there was a considerable range in the reliability with which one may be able to predict changes in hydration state. This variability is illustrated within Table 1, and in Figures 1 and 2.

Table 1: Peak values for each dehydration index averaged across the two 7% trials.

Parameter	Serum osmolality	Urine osmolality	Urine specific gravity	Urine colour
Mean	299.0	569.7	1.024	5.1
Standard deviation	1.6	75.5	0.003	0.5
Coefficient of variation	0.5%	13.3%	0.3%	9.5%
Base-to-peak change	32	1005	0.075	6

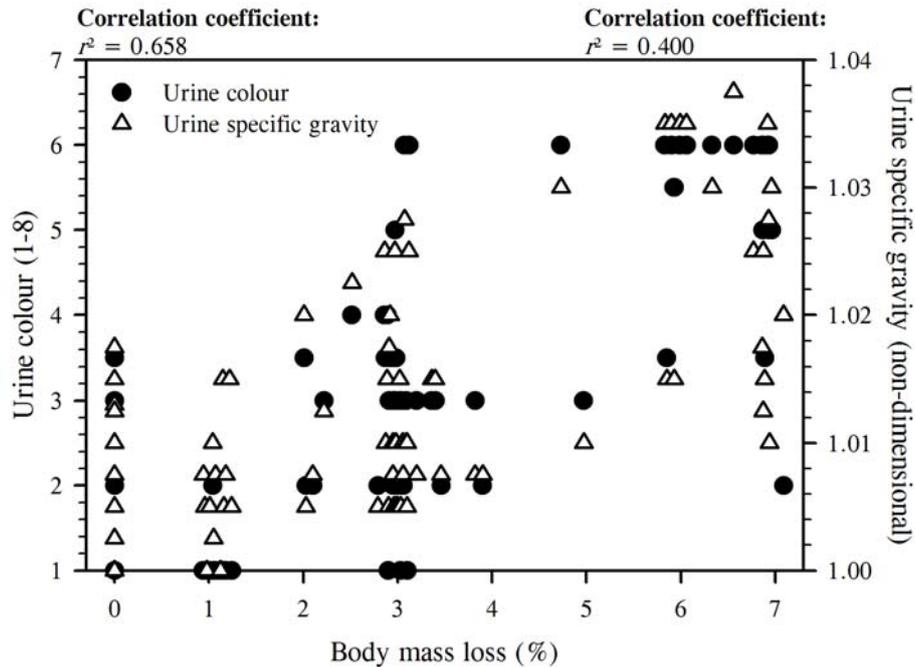


Figure 1: Changes in urine colour and urine specific gravity relative to decrements in body mass. Data are 132 and 135 points (respectively) for 12 subjects across one 3%, and two 7% dehydration trials.

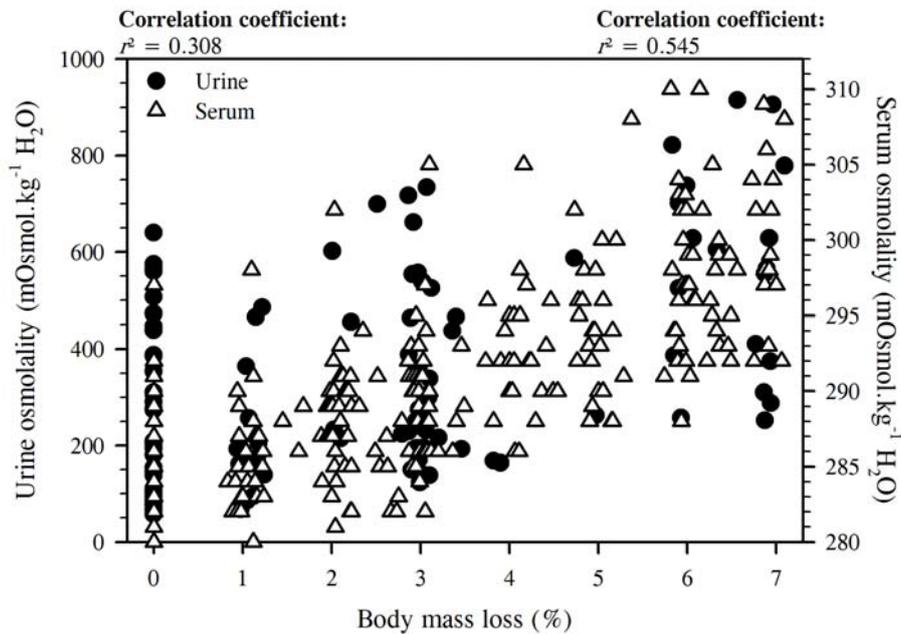


Figure 2: Changes in urine and serum osmolality relative to decrements in body mass. Data are 135 and 304 points (respectively) for 12 subjects across one 3%, and two 7% dehydration trials.

As dehydration progressed, the coefficients of variation for these indices became smaller (Table 1). However, at any given dehydration state, there still existed considerable inter-subject variation (Figures 1 and 2). For example, urine osmolality has been suggested to be the urinary index of choice within the laboratory (Shirreffs, 2000), yet across all three trials, the average minimal-maximal osmolality range across subjects was $488.1 \text{ mOsmol.kg}^{-1} \text{ H}_2\text{O}$, when derived using the 17 possible sampling points across the three trials. This value represents 86% of the peak value observed at a 7% water deficit. Urine colour was also quite variable, and this measure is sensitive to greater experimental error and to influences other than altered hydration state (*e.g.* diet and medication). Finally, serum osmolality had a mean minimal-maximal osmolality range of $14.7 \text{ mOsmol.kg}^{-1} \text{ H}_2\text{O}$ across the 26 sampling points. This represented just 5% of the peak observed at the 7% dehydration state. However, since plasma volume and osmolality are regulated, it is not necessarily correct to assume that osmolality will invariably reflect changes in whole-body hydration state.

CONCLUSIONS

It is concluded that, while some indices (*e.g.* urine osmolality) will certainly permit one to track serial changes in hydration state, single point determinations offer very little information pertaining the hydration of an individual without reference to some pre-experimental baseline.

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