Application of Non-invasive Methods in Assessment of Hydration Status following Habitual Training in Male Collegiate Soccer Players

大学男子サッカー選手における日常トレーニング後の非侵襲的メソッドを用いた体内水和状態の評価

YASUDA, Nobuo
Department of Health Science
International Pacific University, Okayama, Japan
安田　従生

OE, Akihiro
Department of Physical Education
International Pacific University, Okayama, Japan
大江　明宏

KAWAI, Yojiro
Department of Health Science
International Pacific University, Okayama, Japan
河合洋二郎

IIDE, Kazuhide
Department of Health Science
International Pacific University, Okayama, Japan
飯出　一秀

MATSUMURA, Tomohiro
Department of Health Science
International Pacific University, Okayama, Japan
松村　智弘

Abstract：

The purpose of this study was to determine the effects of habitual soccer training on hydration status in male collegiate players based on two types of non-invasive methods. Fifteen male collegiate soccer players (age: 19.5 ± 1.4 year, height: 173.2 ± 5.9 cm; body weight: 67.0 ± 7.6 kg; BMI: 22.6 ± 1.8 kg/m^2, body fat: 11.6 ± 3.6 %) served as the subjects. The soccer training consisted of routine ball handling, shooting, other specialized skill training and games. Spot urine was collected within 10 minutes before (Pre) and after (Post) each training session over three consecutive days (Day 1, Day 3, and Day 5). For analysis of hydration status, urine specific gravity (Usg) and osmolality (Uosm) were determined with a handheld refractometer and osmometer, respectively. Each training session lasted approximately 3 hours. A two-way analysis of variances (ANOVA) showed significant main effects for time before and after the soccer training session, but no difference across days in Usg (g/mL) or Uosm (mOsm/kg H_2O). Moreover, linear regression analysis of the present data demonstrated a significant correlation between Usg and Uosm. These findings indicate that non-invasive measurements of Uosm as well as Usg could be applicable to the field settings with regard to hydration status over three consecutive days of soccer training.

Keywords： exercise intensity, intermittent exercise, aldosterone, urine osmolality, urine specific gravity

本研究は，大学男子サッカー選手における日常トレーニング後の体内水和状態を２種類の非侵襲的メソッドを用いて検討することを目的とした。被検者は，環太平洋大学体育会に所属する男子サッカー部員15名であった（age: 19.5 ± 1.4 year, height: 173.2 ± 5.9 cm; body weight: 67.0 ± 7.6 kg; BMI: 22.6 ± 1.8 kg/m^2, body fat: 11.6 ± 3.6 %）。サッカートレーニングはボールハンドリング，シューティング，その他の技術練習及びゲームから構成された。それらの練習は，約３時間に及んだ。サッカートレーニング前後で，脱水症状の指標となる尿比重値と尿浸透圧値を測定した。二元配置分散分析により，サッカートレーニング後で，尿比重値及び尿浸透圧値は有意に増加することが判明したが，練

習日間による差はみられなかった。また，尿比重値と尿浸透圧値との間に，有意な相関が認められた。これらの結果から，尿比重値だけでなく尿浸透圧値も間欠的運動が長時間続くサッカーのようなトレーニング形態で，体内水和状態を評価する指標として応用することが可能であることが示唆された。

INTRODUCTION

Attempts to assess hydration status have been conducted in a variety of situations for a number of years. According to Grant and Kubo (1975), tests open to use in a clinical setting can be categorized into three categories: (i) laboratory tests, (ii) objective and noninvasive measurements and (iii) subjective observations. Laboratory tests include measures of serum osmolality and sodium concentration, blood urea nitrogen, haematocrit and urine osmolality. The objective and noninvasive measurements are based on body mass, intake and output measurements, stool number and consistency, including 'vital signs' such as temperature, heart rate and respiratory rate. The subjective observations are skin turgor, thirst and mucous membrane moisture.

Under conditions of progressive hypertonic dehydration, urine shows acute changes in volume, colour, specific gravity (Usg), osmolality (Uosm) and conductance. Under normal conditions, urine volume averages 1.5-2.5 L/day and is characterized by Usg ≦1.020 g/mL, Uosm <500 mOsm/kg H_2O and a pale to light yellow (straw) colour (Strasinger, 1994). In order to maintain plasma volume and intercellular water immediately effecting urinary volume and its physiological characteristics, water conservation mechanisms are initiated in the kidneys at the onset of exercise (Oppliger and Bartok, 2002). Especially, measurement of urinary markers of dehydration is considered to be inexpensive and requires minimal expertise from the technician. Furthermore, some of these methods are easily used by athletes (Oppliger and Bartok, 2002).

Measurement of Uosm has recently been an extensively studied parameter as a possible hydration status marker. In studies of fluid restriction, Uosm has increased to values greater than 900 mOsm/kg H_2O for the first urine test of the day taken by individuals dehydrated by approximately 2% of their body mass, as determined by body mass changes (Shirreffs and Maughan, 1998). Armstrong et al. (1994) have determined that measurement of Uosm can be used interchangeably with Usg, opening this as another potential marker (Shirreffs, 2003).

In the later stages of a soccer game, dehydration has often been suggested as a factor responsible for the development of fatigue (Maughan and Leiper, 1994; Reilly, 1997). This is a credible observation as even moderate dehydration appears to be associated with negative endurance-based exercise responses both in a controlled laboratory environment (Montain and Coyle, 1992; Saunders et al., 2005) and also in more soccer-specific field conditions (Edwards et al., 2007). However, it remains to be clarified whether game-induced dehydration is a cause of fatigue, or merely a single characteristic outcome of exercise controlled by a complex metabolic system (Lambert et al., 2005; Edwards and Noakes, 2009). Taken together, the purpose of this study was to assess hydration status following habitual soccer training based on two non-invasive methods (Usg and Uosm).

METHODS

Subjects

Fifteen healthy male collegiate soccer players completed this study. The physiological characteristics of the subjects are demonstrated in Table 1. All subjects had no major medical problems at the time of the study. The experimental procedures were approved by the ethics committee of International Pacific University. Each subject provided their written consent before participating in this study.

Overall protocols

Before each experiment, no strenuous exercise was undertaken by the subjects. All training sessions

Table 1. Physical characteristics of the subjects (N=15)

Variable	Mean±SD
Age (years)	19.5±1.4
Height (cm)	173.2±5.9
Body mass (kg)	67.03±7.6
BMI (kg/ m^2)	22.6±1.8
Body fat (%)	11.6±3.6
Body surface area (m^2)	1.799±0.121

All data are mean±SD.

began in the midafternoon and the subjects were allowed to drink water *ad libitum* during each training session over three consecutive days (Day 1, Day 3, and Day 5). Each training session lasted approximately 3 hours. Soccer training consisted of routine ball handling, shooting and other specialized drills. Spot urine was collected within 10 minutes before (Pre) and after (Post) soccer training sessions. Borg's ratings of perceived exertions were also measured before and after all training sessions. During all experimental days, the wet-bulb globe temperature (WBGT) was measured with a WBGT-203A system (Kyoto Electronics Manufacturing Co., LTD., Kyoto, Japan) as the WBGT provides an index for comparing environmental heat stress across training sessions (Daanen et al., 2011).

Quantification of Hydration Status

In order to test hydration status during soccer training, Uosm was quantified with an osmometer. Moreover, Usg was assessed using a handheld refractometer. Distilled water was used to calibrate the refractometer before each use (Sherwood, 1999). While the instrument was in a horizontal position, a small drop of urine was placed on the prism, and the cover plate was placed over it. The scale seen in the eyepiece was focused, and the specific gravity was determined.

Statistical Analysis

A two-way ANOVA with repeated measures was performed for each dependent variable. When an overall difference was identified, a Tukey Post Hoc test was used to detect the specific difference using STATISTICA version 5.0 for Windows. Statistical significance was assessed at $p<0.05$. All data were expressed as mean ± SD.

RESULTS

During each exercise training session, the WBGT ranged from 17.5℃ to 19.5℃, and the thermal stress was classified as "moderate risk" represented by a WBGT of 18℃~23℃ (Daanen et al., 2011). No significant differences were observed in water intake between training sessions. A total volume of water intake *ad libitum* ranged from 750 to 1,050 mL/3h during each training. The length of daily training over three consecutive days is shown in Figure 1.

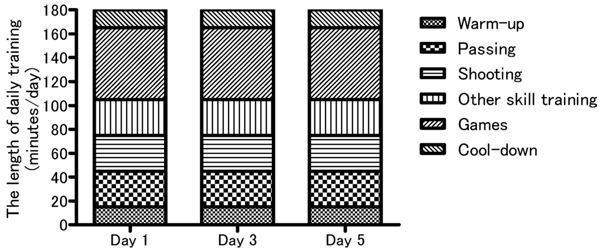

Figure 1. The length of daily training over three consecutive days

In terms of Usg (g/mL) and Uosm (mOsm/kg H_2O), a two-way analysis of variances (ANOVA) showed significant main effects for time (Figure 2A and 2B) before and after the soccer training session, whereas no significant main effects for day or interactions were observed (Figure 2A and 2B). The results of RPE also demonstrated a similar pattern (Figure 3). Moreover, linear regression analysis of the present data represented a significant correlation between Usg and Uosm (Figure 4).

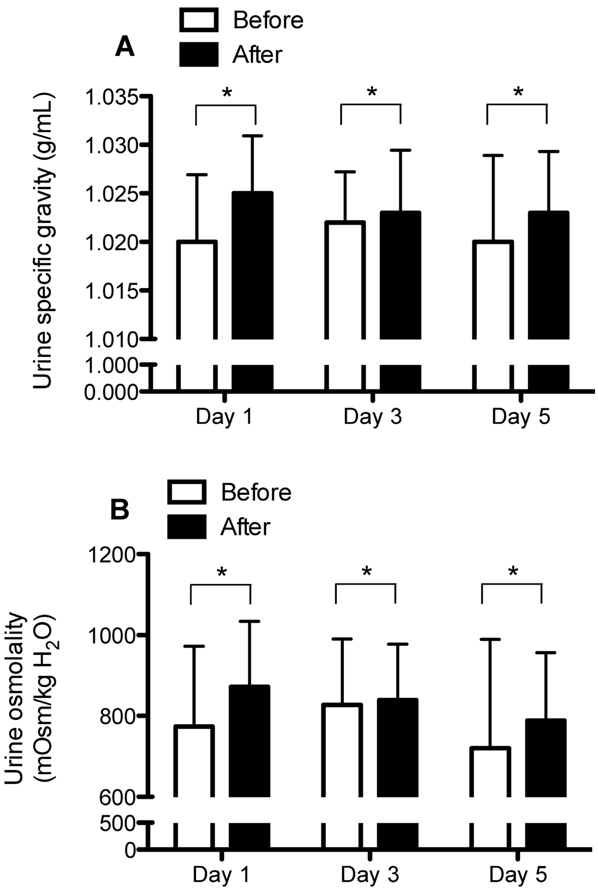

Figure 2. (A) Urine specific gravity (Usg) and (B) urine osmolality (Uosm) before and after soccer training over three consecutive days (*a main effect for time, p<0.05).

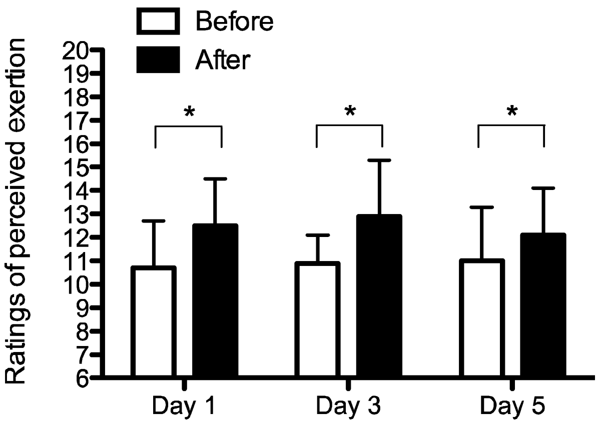

Figure 3. Ratings of perceived exertion (RPE) before and after soccer training over three consecutive days (*a main effect for time, p<0.05).

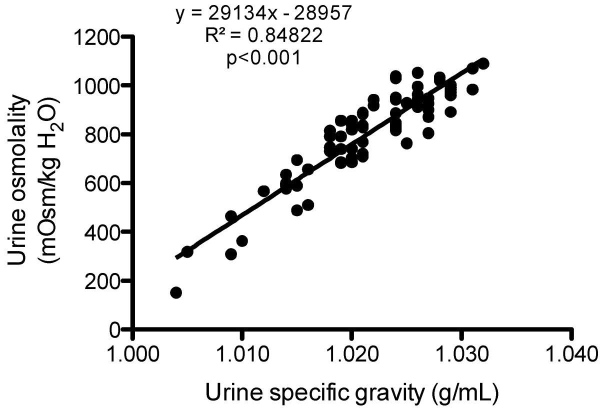

Figure 4. (A) Urine specific gravity (Usg) and (B) urine osmolality (Uosm) before and after soccer training over three consecutive days (*a main effect for time, p<0.05).

DISCUSSION

The main finding of this study was that a significant correlation between Usg and Uosm were found after soccer training. This would demonstrate that one measurement at a sampling period is probably sufficient. Furthermore, high correlation between Usg and Uosm was in line with Armstrong et al. (1994), Popwski et al. (2001), and Stuempfle and Drury (2003).

Of all urinary analyzing methods, Uosm is considered the standard for measuring the total solute concentration of urine in a research or laboratory setting (Chadha et al., 2000), yet Usg and urine color have been regarded as suitable methods of measuring urine concentration in the clinical or field setting (Casa et al., 2000). This investigation revealed a strong correlation between Usg and Uosm. Although Usg is a valid and clinically accepted measurement of hydration status, plasma volume analysis remains a more accurate measure. Another limitation was that hydration status during testing was not static. Testing did occur in a thermoneutral environment, but the involved tasks may have induced trivial fluid losses through the sweat mechanism. Furthermore, the exercise task and conditions were not totally comparable with those encountered in many athletic settings (Patel et al., 2007).

Although, in the present study, most subjects resulted in moderate dehydration, a degree of hypohydration above 1.020 g/mL may be common in athletes of all ages (Casa and Yeargin, 2005). While the inclination to drink fluids has been linked to the degree of hydration (Maresh et al., 2004), it is possible that a fully hydrated state might not exist without a conscious effort to consume fluids on a regular basis. In this regard, an alternative argument explaining higher Usg and Uosm values might be that some individuals who routinely experience acute dehydration due to their daily training routine might adjust their homeostatic tolerance to a higher level by increasing their plasma osmolality (Posm), (Popowski et al., 2001). Such an adjustment could reset the thirst mechanism to a higher level, thus reducing the amount of fluid taken in after exercise. This adjustment might also be reflected in urine output, although Armstrong et al. (1994, 2005) have indicated that Posm may not reflect urine variables very well. Although the possible mechanism for re-adjusting Posm and its effects on USG are uncertain at present (Smith et al., 2006), this phenomenon bares further investigation.

Exercise intensity was estimated at the basis of RPE in this study, although it was not directly measured (e.g. monitoring heart rate) in the players due to difficulty to set up work rate, work duration, or work-to-rest ratios. Moreover, there was the limitation of assessing Usg via a spot urine sample. The first morning void or the void after a 12-hour fast has been well established as the recommended time to assess urine specific gravity (Aoyagi et al., 1997; Armstrong, 2005). In the present study, spot urine samples were chosen to assess Usg and Uosm before practice for several reasons: (i) It was more convenient for the coaches and athletes, (ii) It provided the coaches and athletes with a general idea of prepractice hydration status, and (iii) It offered some basis for comparisons for practitioners who may only have the opportunity to assess spot urine samples before team practices (Volpe et al., 2009).

In conclusion, non-invasive measurements of urine osmolality as well as urine specific gravity could be applicable to the field settings with regard to hydration status over three consecutive days of soccer training. These findings of the present study may provide unique insight into selected physiological and perceptual responses related to fluid balance and thermal strain in male collegiate soccer players. Such insight may also help to establish more specific and effective guidelines and strategies for improving the safety of players during soccer training (Bergeron et al., 2006).

ACKNOWLEDGEMENT

We are grateful to Dr. Christian Burrows for their productive comments in this manuscript. We would also like to thank our research participants for their commitment to the study.

REFERENCES

Aoyagi Y, McLellan TM, Shephard RJ. (1997). Interactions of physical training and heat acclimation: the thermophysiology of exercising in a hot climate. *Sports Med*, 23: 173-210.

Armstrong LE. (2005). Hydration assessment techniques. *Nutr Rev*, 63: S40-S54.

Armstrong LE, Maresh CM, Castellani JW, Bergeron MF, Kenefick RW, LaGasse KE, Riebe D. (1994). Urinary indices of hydration status. *Int J Sport Nutr*, 4, 265-279.

Armstrong LE, Pumerantz AC, Roti MW, Judelson DA, Watson G, Dias JC, Sokmen B, Casa DJ, Maresh CM, Lieberman H, Kellogg M. (2005). Fluid, electrolyte, and renal indices of hydration during 11 days of controlled caffeine consumption. *Int J Sport Nutr Exerc Metab*, 15: 252-265.

Bergeron MF, Waller JL, Marinik EL. (2006). Voluntary fluid intake and core temperature responses in adolescent tennis players: sports beverage versus water. *Br J Sports Med*, 40: 406-410.

Casa DJ, Armstrong LE, Hillman SK, Montain SJ, Reiff RV, Rich BS, Roberts WO, Stone JA. (2000). National athletic trainers' association position statement: fluid replacement for athletes. *J Athl Train*, 35: 212-224.

Casa DJ, Yeargin SW. (2005). Avoiding dehydration among young athletes. *ACSM's Health and Fitness Journal*, 9: 20-23.

Chadha V, Garg U, Alon US. (2001). Measurement of urinary concentration: a critical appraisal of methodologies. *Pediatr Nephrol*, 16: 374-382.

Daanen HA, Jonkman AG, Layden JD, Linnane DM, Weller AS. (2011). Optimising the acquisition and retention of heat acclimation. *Int J Sports Med*, 32: 822-828.

Edwards AM, Mann ME, Marfell-Jones MJ, Rankin DM, Noakes TD, Shillington DP. (2007). Influence of moderate dehydration on soccer performance: physiological responses to 45 min of outdoor match-play and the immediate subsequent performance of sport-specific and mental concentration tests. *Br J Sports Med*, 41: 385-391.

Edwards AM, Noakes TD. (2009). Dehydration: cause of fatigue or sign of pacing in elite soccer? *Sports Med*, 39: 1-13.

Grant MM, Kubo WM. (1975). Assessing a patient's hydration status. *Am J Nurs*, 75: 1307-1311.

Lambert EV, St Clair Gibson A, Noakes TD. (2005). Complex systems model of fatigue: integrative homoeostatic control of peripheral physiological systems during exercise in humans. *Br J Sports Med*, 39: 52-62.

Maresh CM, Gabaree-Boulant CL, Armstrong LE, Judelson DA, Hoffman JR, Castellani JW, Kenefick RW, Bergeron MF, Casa DJ. (2004). Effect of hydration status on thirst, drinking, and related hormonal responses during low-intensity exercise in the heat. *J Appl Physiol*, 97: 39-44.

Maughan RJ, Leiper JB. (1994). Fluid replacement requirements in soccer. *J Sports Sci*, 12: S29-S34.

Montain SJ, Coyle EF. (1992). Influence of graded dehydration on hyperthermia and cardiovascular drift during exercise. *J Appl Physiol*, 73: 1340-1350.

Oppliger RA, Bartok C. (2002). Hydration testing of athletes. *Sports Med*, 32: 959-971.

Patel AV, Mihalik JP, Notebaert AJ, Guskiewicz KM, Prentice WE. (2007). Neuropsychological performance, postural stability, and symptoms after dehydration. *J Athl Train*, 42: 66-75.

Popowski LA, Oppliger RA, Patrick Lambert G, Johnson RF, Kim Johnson A, Gisolf CV. (2001). Blood and urinary measures of hydration status during progressive acute dehydration. *Med Sci Sports Exerc*, 33: 747-753.

Reilly T. Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *J Sports Sci*. 1997 Jun; 15 (3): 257-63.

Saunders AG, Dugas JP, Tucker R, Lambert MI, Noakes TD. (2005). The effects of different air velocities on heat storage and body temperature in humans cycling in a hot, humid environment. *Acta Physiol Scand*, 183: 241-255.

Sherwood RJ. (1999). Measurement of specific gravity as a surrogate for urinary flow rate - a singular study. *Appl Occup Environ Hyg*, 14 : 696-700.

Shirreffs SM. (2003). Markers of hydration status. *Eur J Clin Nutr*, 57 Suppl 2: S6-S9.

Shirreffs SM, Maughan RJ. (1998): Urine osmolality and conductivity as indices of hydration status in athletes in the heat. *Med Sci Sport Exerc*, 30: 1598-1902.

Smith AE, Roberts BS, Koch A, Mayhew J. (2006). Within-day and between-day variations in urine specific gravity and osmolality measurements. *Mo J health, Physical Education, Recreation and Dance*, 16: 38-46.

Strasinger SK. (1994). Urinalysis and body fluids. Philadelphia (PA): FA Davis Company.

Stuempfle KJ, Drury DG. (2003). Comparison of 3 Methods to Assess Urine Specific Gravity in Collegiate Wrestlers. *J Athl Train*, 38: 315-319.

Volpe SL, Poule KA, Bland EG. (2009). Estimation of prepractice hydration status of National Collegiate Athletic Association Division I athletes. *J Athl Train*, 44: 624-629.