The Validity of Multifrequency Bioelectrical Impedance Measures to Detect Changes in the Hydration Status of Wrestlers During Acute Dehydration and Rehydration

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Abstract

Utter, AC, McAnulty, SR, Riha, BF, Pratt, BF, and Grose, JM. The validity of multifrequency bioelectrical impedance measures to detect changes in the hydration status of wrestlers during acute dehydration and rehydration. *J Strength Cond Res* 26(1): 9–15, 2012—The objective of this study was to examine the validity of multifrequency direct segmental bioelectrical impedance analysis (DSM-BIA) measures to detect changes in the hydration status of wrestlers after they underwent 3% acute dehydration and a 2-hour rehydration period. Fifty-six National Collegiate Athletic Association wrestlers: (mean $\pm$ *SEM*); age 19.5 $\pm$ 0.2 years, height 1.73 $\pm$ 0.01 m, and body mass (BM) 82.5 $\pm$ 2.3 kg were tested in euhydrated, dehydrated (-3.5%), and 2-hour rehydration conditions using DSM-BIA to detect the changes in hydration status. The hydration status was quantified by measuring the changes in plasma osmolality (P_{osm}), urine osmolality (U_{osm}), urine specific gravity (U_{sg}), BM, and weighted segmental impedance at frequencies of 5, 20, 50, 100, and 500 kHz. Weighted segmental impedance significantly increased after a 3.5% reduction in the body weight for all the 5 frequencies evaluated, but it did not return to baseline at 2-hour rehydration. P_{osm} (303 $\pm$ 0.6 mOsm·L^{-1}), U_{osm} (617 $\pm$ 47 mOsm·L^{-1}), and U_{sg} (1.017 $\pm$ 0.001) all significantly increased at postdehydration and returned to baseline at 2-hour rehydration. Estimations of extracellular water were significantly different throughout the trial, but there were no significant changes in the estimations of the total body water or intracellular water. The results of this study demonstrate the potential use of DSM-BIA as a field measure to assess the hydration status of wrestlers for the purpose of minimal weight certification before the competitive season. When employing DSM-BIA to assess the hydration status, the results indicated that the changes in weighted segmental impedance at the frequencies evaluated (5, 20, 50, 100, and 500 kHz) are sensitive to acute changes in dehydration but lag behind changes in the standard physiological (plasma and urinary) markers of hydration status after a 2-hour rehydration period.

Key Words wrestling, athletes, euhydration, plasma osmolality

Introduction

Every year, countless athletes die or are injured because of the effects of severe dehydration. In 2010, The National Center for Catastrophic Sports Injuries reported 21 deaths among college and high football players caused by heat stroke over the past 6 years, and 9 of those deaths took place in 2008 and 2009 alone (19). The American College of Sports Medicine (1) and the National Athletic Trainer's Association (9) have summarized the physiologic, medical, and performance considerations associated with dehydration. Proper hydration and fluid balance can have a significant impact on the health and performance of athletes (1,9). In almost any sport, athletes undergoing dehydration may not only experience lost training time and performance decrements, but they may also suffer from dehydration-related injuries such as fatigue, cramps, heat exhaustion, and heat stroke (21). Powell and Barber-Foss's 2-year surveillance study of 39,032 player seasons of 5 major high school sports (boys' or girls' basketball, soccer, baseball, and softball) found that of the 8,988 injuries reported, dehydration resulted in lost game or practice time for almost 90 athletes, or about 1% (26).

Physiological processes including but not limited to impaired temperature regulation, biochemical reactions, circulatory function, and metabolism illustrate the importance of maintaining total body water (TBW). The loss of water from the kidneys, lungs, and skin coupled with the use of water from liquids and foods keep the TBW balance in a constant state of fluctuation (2). Throughout the day, the body can usually regulate the daily body water balance by way of the kidneys, which will produce more or less urine in response to changes in body fluid volumes (29). However, excess stress from exercise and the environment can

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jeopardize an individual's fluid balance homeostasis, physical performance, and overall health (24).

In 1999, after the death of 3 collegiate wrestlers because of starvation and thermal dehydration during the 1997–1998 wrestling season (10), the National Collegiate Athletic Association (NCAA) adopted new regulations associated with weight loss to ensure the health and safety of wrestlers (11,23,30). The National Federation of State High School Association (NFHS) implemented a similar wrestling weight management rule starting in the 2006–2007 wrestling season (31). The goal of these rules was to impede the potential health risks of acute intentional dehydration-related weight loss while at the same time promote competitive equity between athletes. According to the NCAA and NFHS rules, wrestlers must have a urine specific gravity (U_{sg}) measurement of $\leq$1.020 and 1.025, respectively (11,28). However, the studies of Oppliger et al. (22) and Popowski et al. (25) have found that, although sensitive to changes in hydration status, U_{sg} lagged being plasma osmolality (P_{osm}) during rapid periods of fluid turnover. More recently, Bartok et al. (6) has reported poor correlations between weight loss by dehydration and U_{sg} in collegiate wrestlers. The lack of precision in U_{sg} coupled with the cost, invasiveness, and impracticality of blood measures such as P_{osm} merit the need for a simple, noninvasive field measure of hydration status.

Multifrequency bioelectrical impedance analysis (MFBIA) was initially developed to estimate TBW and subsequent total body fat with the potential ability to discriminate between intracellular water (ICW) and extracellular water (ECW) (14). These estimates are made by measuring the resistance and reactance of electrical current as they are presented to the body ranging in frequencies from 5 kHz to 1 MHz (7). Quiterio et al. (27) conducted a study of 118 adolescent athletes and concluded that MFBIA was a valid and nonbiased method for predicting TBW in a euhydrated state when compared with deuterium dilution. However, the sensitivity of MFBIA to detect moderate hypohydration diminishes with isotonic fluid loss (20). A recent study conducted by Higgins et al. (14) in young adults (15 female, 2 male) found that even small, acute changes in ECW during rehydration can accurately be measured using MFBIA when compared with a bromide dilution. However, it was reported that the magnitude of change in ECW impacted the accuracy of MFBIA with overestimations of ECW at a value <1 kg and underestimations at values >1 kg. To our knowledge, no studies to date have investigated the use of MFBIA, specifically direct segmental bioelectrical impedance analysis (DSM-BIA), employing 5 different frequencies to detect changes in the hydration status of wrestlers during periods of acute dehydration and rehydration.

The purpose of this study was to evaluate the validity of multifrequency DSM-BIA to detect changes in the hydration status of wrestlers after undergoing acute dehydration and a 2-hour rehydration period. Hydration status was quantified by measuring changes in P_{osm}, U_{sg}, U_{osm}, and body mass (BM). We hypothesized that DSM-BIA would be able to detect changes in the hydration status of collegiate wrestlers undergoing acute hypertonic dehydration. The potential use of DSM-BIA would have direct application toward the administration of the NCAA and NFHS hydration rules in the sport of wrestling and also other sports in which weight loss and dehydration associated health risks are prevalent.

Methods

Experimental Approach to the Problem

The specific aim of this study was to evaluate the utility of DSM-BIA to detect the changes in the hydration status of NCAA wrestlers after undergoing acute dehydration and a 2-hour rehydration period. Hydration status was quantified by measuring the changes in P_{osm}, U_{sg}, U_{osm}, and BM all of which are considered standard laboratory indices (1). The research experiment followed a repeated measures design in which the subjects served as their own controls. The subjects reported to the ASU Human Performance Laboratory once for orientation and later the same day for subsequent measurements of DSM-BIA, P_{osm}, U_{sg}, U_{osm}, and BM during the dehydration-rehydration trials.

Subjects

The subjects ($N = 56$) were male interscholastic wrestlers from 2 North Carolina universities: Appalachian State (Boone, NC, USA) and Gardner Webb (Boiling Springs, NC, USA) both of which compete at the NCAA Division I level. The athletes ranged in age from 18 to 23 years, height 1.59 to 1.93 m, BM 55.5 to 103.6 kg with a (mean ± *SEM*) percent body fat 16.2 ± 1.0 and average duration of wrestling experience was 8.2 ± 0.4 years. Both teams were tested in September and October, which is considered preseason from a training status perspective. The subjects were representative of all 10 collegiate weight categories. Written informed consent was obtained from all the subjects before they were allowed to participate in the study, and all the experimental procedures were approved by the Institutional Review Board for investigations involving human subjects.

Testing Schedule

All the assessments were performed in the Human Performance Laboratory. The laboratory temperature ranged from 24 to 30°C, with a relative humidity of 20–40% for all testing. Upon arrival in the laboratory, BM, height, body composition (skinfolds), U_{sg}, U_{osm}, P_{osm}, and MFBIA (InBody 230 and 520) measures were obtained. All the subjects were tested during the same time of the day between 3:00 and 7:00 PM. All BM measurements were taken on a calibrated digital scale when the subjects wore minimal clothing (i.e., shorts). The skinfold measures were made with a Lange skinfold calipers at 3 sites: triceps, subscapular, and abdomen. Body density (D_b) was determined from the 3 skinfold measures using the prediction equation $D_b = [1.0982 - (\text{sum skinfolds}) \times 0.000815] + [(\text{sum skinfolds})^2 \times 0.00000084]$ validated by Lohman (16). Percent body fat was determined from D_b using the Brozek equation

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(8). The U_{sg} measurements were determined by an Atago optical refractometer (NSG Precision Cells Inc., Farmingdale, NY, USA), and all the subjects were required and considered to be adequately hydrated before testing based upon a $U_{sg} \leq 1.020$ g·ml^{-1}. U_{osm} and P_{osm} were determined via freezing point depression in triplicate using an osmometer (Model 3250, Advanced Instruments, Inc., Norwood, MA, USA) calibrated to the manufacturer's specification.

The subjects were then instructed to decrease their BM by 3% through this standard wrestling regimen. A 3% decrease in BM was chosen because this represents the typical amount of dehydration that occurs in the sport of wrestling in the 24-hour period before competition (23). Controlled acute dehydration was achieved during a 2-hour standard wrestling practice regime that normally occurs during the competitive season. The wrestling practice regime consisted of a combination of calisthenics exercises, active technical drilling, and live wrestling scenarios. We have employed this dehydration paradigm in previous published studies (32). Upon completion of successful dehydration, the subjects rested for a 30-minute stabilization period. After which additional measures of BM, MFBIA, U_{sg}, and P_{som} were obtained (postdehydration). The subjects then underwent a 2-hour rehydration period in which they were instructed to drink a carbohydrate-electrolyte solution (6%, or 60 g·L^{-1}) (Gatorade®, Barrington, IL, USA), which was chilled before consumption with an estimated temperature of 10–15°C. All the subjects consumed the same flavor of Gatorade throughout the rehydration trial. The carbohydrate-electrolyte beverage contained 20 mmol/L of sodium and 3.2 mmol/L of potassium. Research assistants provided all beverages to the subjects. During the first 20 minutes of their rehydration period, the subjects consumed a beverage equal to one-half of their BM loss. Within 20–40 minutes of the start of the 2-hour rehydration period, the subjects consumed a second volume of beverage to replace the remaining 50% of their BM loss. Additional measures of BM, U_{sg}, $P_{som,}U_{osm}$, and MFBIA measures were obtained at the 60- and 120-minute mark of the rehydration period.

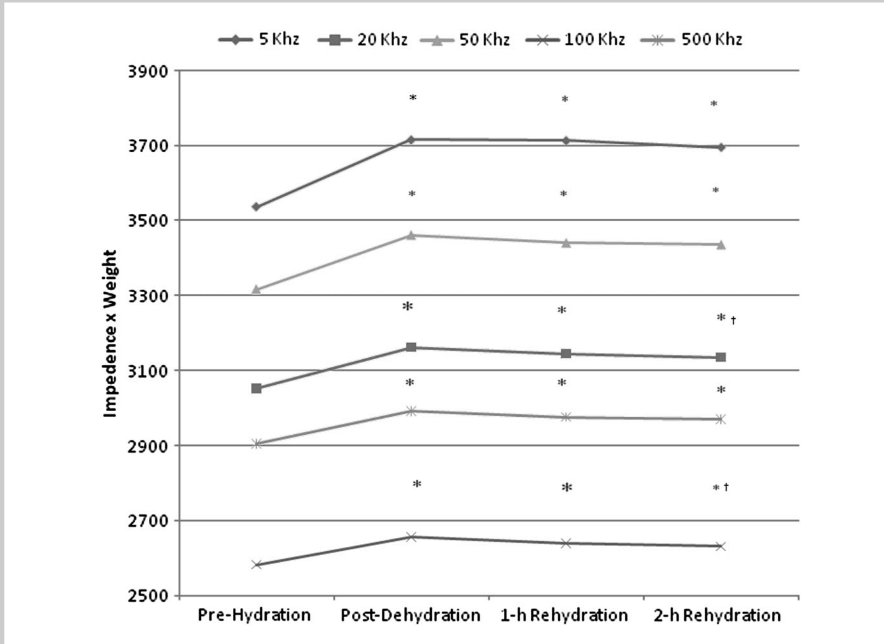

Figure 1. Weighted impedance measurements at 5 different frequencies at prehydration, postdehydration, and 1 hour, and 2 hour postrehydration. *Significantly different from predehydration, $p < 0.001$, †significantly different from postdehydration, $p < 0.001$.

Multifrequency Bioelectrical Impedance Analysis

The MFBIA measurements were made using the InBody 230 and 520 (Biospace Co., Los Angeles, CA, USA). The subjects were measured for MFBIA when they were standing erect. The InBody 230 body fat analyzer measures the direct segmental

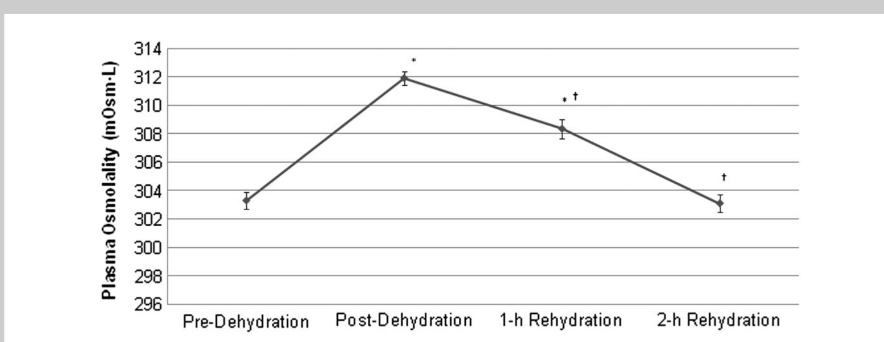

Figure 2. Plasma osmolality at prehydration, postdehydration, and 1 hour, and 2 hour postrehydration. *Significantly different from predehydration, $p < 0.001$, †significantly different from postdehydration, $p < 0.001$.

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impedance across both legs, arms, and the trunk via multiple frequencies of 20 and 100 kHz. The InBody 520 body fat analyzer measures direct segmental impedance in the same manner via frequencies of 5, 50, 500 kHz. The system's 8 electrodes are in the form of foot pads mounted on the surface of a platform scale and in handheld pads located in handles extending out from the machine's body. Each foot pad is divided into half so that the anterior and posterior portions form 2 separate electrodes. Each handle of the machine has 2 separate electrodes, 1 in contact with the thumb and the other in contact with the palm. These electrodes are connected to the current and voltage supply of the device. Impedance and BM are automatically measured, and the subject's height and age are manually entered into the system. The device is regulated by an internal microprocessor, which measures impedance from each body segment in a particular order and regulates the varying frequencies. Segmental impedance, TBW, ECW, ICW, and BM are all measured simultaneously when the subject's bare feet and palm and thumbs make pressure contact with the electrodes and digital scale. The palms, feet, and electrode surfaces were cleaned with a dry towel before all measurements. Weighted segmental impedance was calculated by using the segmental fat-free mass values and segmental impedance of the right arm, left arm, trunk, right leg, and left leg using the equations provided by the manufacturer.

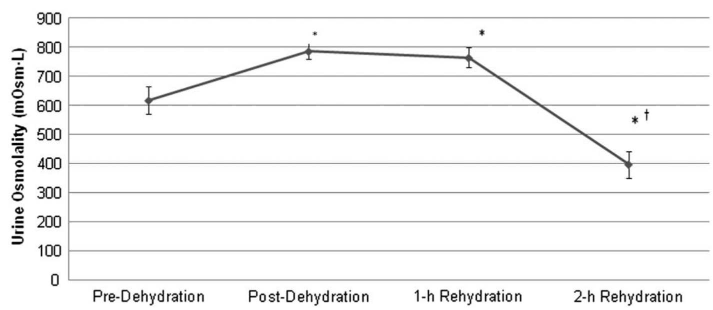

Figure 3. Urine osmolality at prehydration, postdehydration, and 1 hour, and 2 hour postrehydration. *Significantly different from predehydration, $p < 0.001$, †significantly different from postdehydration, $p < 0.001$.

Statistical Analyses

Values are expressed as mean ± *SEM.* Dependent variables were analyzed using a 1-way repeated measures analysis of variance. Significant main effects were evaluated with paired *t* tests using a Bonferroni adjustment, with statistical significance set at $p \leq 0.025$.

Results

The subjects dehydrated to achieve an average BM loss of 3.5 ± 0.16%. The BM changes (kilograms) throughout the study were as follows: Predehydration (baseline) = 82.4 ± 2.4, postdehydration = 79.5 ± 2.4 and 2-hour rehydration = 81.8 ± 2.4. For rehydration, the subjects were provided with beverage amounts equal to 100% of their BM loss. The subjects were able to regain 2.8 ± 0.14% of the BM loss during the 2-hour rehydration period. The ECW significantly decreased ($p < 0.001$) incrementally from predehydration (18.5 ± 0.4 kg) to 1-hour rehydration (18.2 ± 0.4 kg) but did not return to baseline at 2-hour rehydration (18.2 ± 0.4 kg). The TBW and ICW did not significantly change throughout the dehydration and rehydration trial.

For all 5 frequencies evaluated (5, 20, 50, 100, and 500 kHz), significant changes were reported ($p < 0.001$) throughout the dehydration and rehydration trial with significant increases found for weighted segmental impedance at the postdehydration time point (Figure 1). These increases in weighted segmental impedance started to decline but did not return to baseline at the 2-hour rehydration time. For both 20 and 100 kHz, the 2-hour weighted segmental impedance was significantly lower ($p < 0.001$) than the postdehydration value but still significantly higher than the predehydration value.

The P_{osm} significantly increased ($p < 0.001$) from prehydration (303.3 ± 0.6 mOsm·L^{-1}) to postdehydration (311.9 ± 0.5 mOsm·L^{-1}) followed by a significant decrease ($p < 0.001$)

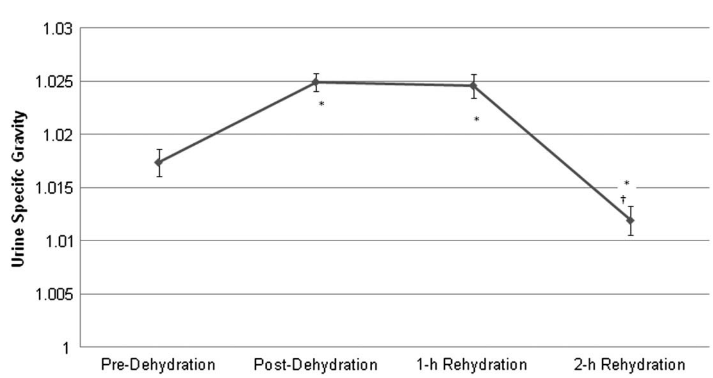

Figure 4. Urine specific gravity at prehydration, postdehydration, and 1 hour, and 2 hour postrehydration. *Significantly different from predehydration, $p < 0.001$, †significantly different from postdehydration, $p < 0.001$.

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at 1-hour rehydration and 2-hour rehydration when it returned below baseline values (303.1 ± 0.6 mOsm·L^{-1}) (Figure 2). U_{osm} also significantly increased ($p < 0.001$) from prehydration (617.0 ± 47.6 mOsm·L^{-1}) to postdehydration (786.5 ± 27.0 mOsm·L^{-1}) and returned to below baseline values at the 2-hour rehydration time point (396.3 ± 45.8 mOsm·L^{-1}) (Figure 3). Similar results were found with U_{sg}. U_{sg} significantly increased from prehydration (1.0174 ± 0.0010) to posthydration (1.0249 ± 0.0008) and then returned below baseline at the 2-hour time point (1.0 ± 0.001) (Figure 4).

Discussion

To our knowledge, this is the first study to investigate the use of multifrequency DSM-BIA at 5 different frequencies to detect changes in the hydration states of wrestlers during periods of acute dehydration and rehydration. The results from this study demonstrated a significant increase in weighted impedance during acute hypertonic dehydration in all 5 frequencies evaluated. However, weighted impedance failed to return to baseline after a 2-hour rehydration period. Significant changes were also found in P_{osm}, U_{sg}, U_{osm}, and BM during periods of dehydration and rehydration. Acute dehydration found in this study (BM change = −3.5 ± 0.16%) can compromise heat dissipation, cardiovascular function, and exercise performance (1,3). In sports such as wrestling, acute dehydration of 3% can reduce an athlete's predicted minimal competition weight as part of a weight certification program, putting the athlete at risk of an unhealthy and potentially dangerous weight loss (6,21). Therefore, any instrument used to assess whole-body hydration should be able to identify a minimum of a 3% reduction in TBW loss for the purposes of assessing minimal wrestling weight.

The decrease in ECW in a dehydrated state detected in this study is consistent with previous investigations that have evaluated the effects of changes in hydration status when employing MFBIA (14,27,28). However, Higgins et al. (14) recently reported that the magnitude of ECW loss affects the accuracy of MFBIA estimated changes in ECW. Although many studies have demonstrated the ability of MFBIA to accurately predict TBW (15,18,27), fewer studies have examined the ability of MFBIA to detect changes in TBW during altered states of acute hypertonic dehydration. O'Brien et al. (20) found MFBIA to accurately quantify dehydration when the subject is in a hypertonic state, but the resolution of this technique diminished with isotonic fluid loss. However, Gudivaka et al. in a study of 28 adults using MFBIA have shown improved accuracy and precision under diuretic-induced dehydration when compared with deuterium dilution and bromide (12). Waller et al. (33) have also found MFBIA to accurately track ECW, ICW, and TBW with hydration status in standard bred racehorses. Considering there were no direct measures of TBW in this study, when employing a Gold Standard technique such as isotope dilution, the reported significant changes in ECW and nonsignificant changes in TBW and ICW should be viewed with caution.

In this study, P_{osm}, U_{osm}, and U_{sg} increased from predehydration to postdehydration and returned to below baseline at the 2-hour rehydration time period. Results from this study indicate that the significant increase in direct segmental weighted impedance when employing MFBIA at frequencies of 5, 20, 50, 100, and 500 kHz is sensitive to detect a 3.5% reduction in body weight as a result of acute hypertonic dehydration. However, direct segmental impedance lags behind changes in the standard physiological (plasma and urinary) markers of hydration status during a 2-hour rehydration period with a 6% carbohydrate-electrolyte solution. At present, the reason why segmental weighted impedance lags behind standard physiological markers of hydration status during the rehydration period is unclear. It has been suggested that exercise influences resistance by as much as 3% because of the effects of increased blood flow on skin and temperature, suggesting that tonicity may affect the accuracy of MFBIA (13). Our results are consistent with those of a recent study conducted by Higgins et al. (14) in which it was reported that MFBIA performs better when measuring changes in ECW during dehydration compared with during rehydration. Results of our investigation and those of Higgins et al. (14) implicate tonicity as a potential contributor to the increased error found during rehydration when employing MFBIA.

The results of this investigation are similar to those using similar protocols suggesting that P_{osm}, U_{sg}, and U_{osm}, are all sensitive to changes in acute hypertonic dehydration and rehydration in wrestlers (6,22,25,32). In these investigations, P_{osm} accurately tracked acute changes in the hydration status showing an increase with dehydration and a return toward euhydration during the recovery period. It has also been shown that ingestion of a carbohydrate-electrolyte beverage will return P_{osm} to baseline values after a 2- to 4-hour period after acute dehydration (17,32,34). However, many studies have found urinary measurements to be a poor indicator of hydration status when compared with P_{osm} (4,5,13,25). Popowski et al. (25) found U_{sg} and U_{osm} lagged behind P_{osm} in accurately identifying changes in acute dehydration and rehydration. This lag has been attributed to the kidney's regulation of antidiuretic hormone (ADH) during changes in hydration. During dehydration, P_{osm} increases to stimulate the release of ADH, reducing body water elimination and restoring P_{osm}; during rehydration, P_{osm} decreases to inhibit the release of ADH, increasing urination. U_{sg} and U_{osm} responded similarly in this study, thus suggesting P_{osm} to be a more sensitive indicator of hydration status. The results of the present investigation coupled with others (6,22,25,32) suggest that P_{osm}, U_{sg}, and U_{osm} are all sensitive to changes in acute hypertonic dehydration and rehydration in wrestlers.

The results of this study demonstrated a significant increase in direct segmental weighted impedance when employing MFBIA at frequencies of 5, 20, 50, 100, and 500 kHz during

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acute hypertonic dehydration. Direct segmental impedance lagged behind changes in the standard physiological markers of hydration status during a 2-hour rehydration period. The use of MFBIA may have a practical application, as an alternative method to U_{sg} for assessing hydration as part of a wrestling weight certification program. This study should be considered as a preliminary investigation into the utility of MFBIA to detect the changes in the hydration status of wrestlers and athletes in a field setting.

Practical Applications

Whether involuntary or intentional, the impaired physiological processes and other health risks that have been associated with dehydration justify the need for screening and detecting dehydration in athletic populations. As discussed in the sports of wrestling and football, the risks related to dehydration can be fatal, warranting the need for a simple, noninvasive field test of hydration. In contrast to U_{sg} and other field measures to assess hydration, MFBIA does not require a biological sample and provides quantitative data in a rapid, noninvasive manner. The use of MFBIA may eventually have practical application, as an alternative method to U_{sg}, in a wrestling weight certification program in which the athletes are required to have hydration assessed before the competitive season when establishing their minimal wrestling weight. Future research with MFBIA for the purpose of assessing the hydration status should be evaluated in combination with measures of TBW in both laboratory and field-based settings. In addition, future research establishing both reliability and validity with other wrestling and athletic populations is clearly warranted.

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