Accuracy of Urine Specific Gravity and Osmolality as Indicators of Hydration Status

Robert A. Oppliger, Scott A. Magnes, LeRoy A. Popowski, and Carl V. Gisolfi

To reduce the adverse consequences of exertion-related and acute intentional dehydration research has focused on monitoring hydration status. This investigation: 1) compared sensitivity of urine specific gravity (Usg), urine osmolality (Uosm) and a criterion measurement of hydration, plasma osmolality (Posm), at progressive stages of acute hypertonic dehydration and 2) using a medical decision model, determined whether Usg or Uosm accurately reflected hydration status compared to Posm among 51 subjects tested throughout the day. Incremental changes in Posm were observed as subjects dehydrated by 5% of body weight and rehydrated while Usg and Uosm showed delayed dehydration-related changes. Using the medical decision model, sensitivity and specificity were not significant at selected cut-offs for Usg and Uosm. At the most accurate cut-off values, 1.015 and 1.020 for Usg and 700 m osm/kg and 800 m osm/kg for Uosm only 65% of the athletes were correctly classified using Usg and 63% using Uosm. P osm, Usg, and Uosm appear sensitive to incremental changes in acute hypertonic dehydration, however, the misclassified outcomes for Usg and Uosm raise concerns. Research focused on elucidating the factors affecting accurate assessment of hydration status appears warranted.

Key Words: dehydration, euhydration, plasma osmolality, wrestling

Proper hydration plays a significant role in the performance of athletes (1, 7). At the extreme, acute dehydration is a significant health risk that might result in heat stroke and death. Over the past 5 y, the National Center for Sports Injuries (13) reports more than a dozen dehydration-related deaths associated with football. Similarly during a 5-wk span in 1997, 3 wrestlers died while using acute dehydration techniques to lose weight for a competition (8). Decrements in physical performance, primarily associated with cardiovascular function and thermoregulation have been documented by a number of investigators and summarized in recent position statements by the American College of Sports Medicine (ACSM)(1), ACSM Roundtable on Hydration and Physical Activity (RHPA)(7), and the National Athletic Trainers Association (NATA)(6). Acute dehydration as described here, which is the focus of
this investigation, refers more specifically to hypertonic dehydration (14). Blood hypernatremia, hyperosmolality, and reduced plasma volume characterize exercise-induced hypertonic dehydration.

In response to the potential health and safety risks associated with dehydration, the ACSM, RHPA, and NATA, as well as several investigators (3, 12, 14, 18), have recommended more careful monitoring of hydration status. Simple methods include diurnal weight change and monitoring urinary markers including color, specific gravity, osmolality, and conductance by medical support staff or the athletes themselves. This is emphasized among athletes who experience involuntary dehydration during practice and competition. Among athletes in weight-regulated sports (e.g., wrestling, boxing, martial arts, and lightweight crew) intentional dehydration occurs as a technique to gain a real or perceived competitive advantage. Both the National Collegiate Athletic Association (NCAA) and the National Federation of State High School Associations (NFSHSA) have instituted rule changes that require the assessment of hydration status among wrestlers prior to establishing the minimum weight for competition (19, 20). The purpose of these rules is to deter acute dehydration-related weight loss and its potential health risks as well as to promote competitive equity among the athletes.

Included with the recommendations for monitoring hydration status are threshold values that represent stages in acute dehydration from minimal to severe. The NATA, for example, associates a minimal dehydration (1% to 3% of weight) with “straw”-colored urine and urine specific gravity (U\text{sg}) of 1.010 to 1.020 (6). Both the NCAA and the NFSHSA have adopted this standard as a criterion for minimum weight regulations in wrestling (19, 20). When U\text{sg} exceeds 1.030, the NATA classifies the dehydration as severe and greater than 3% weight loss.

Research supporting the recommended thresholds is limited and there have been calls for more investigations focused on markers for hydration status (14). Armstrong et al. (2, 3, 4) has completed several investigations, including both laboratory and field data examining markers of hydration status. These investigations found a strong association (r = 0.97) between U\text{sg} and U\text{osm} and suggested that, for a euhydrated person, U\text{sg} should not exceed 1.030 and U\text{osm} should not exceed 1050 m\text{osm}/kg (3). Similarly, Shirreffs and Maughan (18) suggested a U\text{osm} > 716 m\text{osm}/kg in a first morning void reflected a state of hypohydration. Popowski et al. (15) monitored U\text{osm} and U\text{osm} progressively as subjects dehydrated from baseline to 5% body weight. At 5% dehydration, mean U\text{osm} was 1.021 while mean U\text{osm} was 643 m\text{osm}/kg. Francesconi et al. (11) observed indicators of hypohydration among military personnel on a 44-d field exercise. They observed a consistent pattern between P\text{osm}, U\text{osm}, and weight loss at each test day.

The present investigation evaluated the use of U\text{sg} and U\text{osm} as markers of dehydration. Of particular interest was the efficacy of the NATA, NCAA, and NFSHSA guideline of U\text{sg} < 1.020 as a marker for euhydration and the recommended cut-off for U\text{osm} suggested by Armstrong et al. (3) and Shirreffs and Maughan (18).

There were 2 parts to the investigation. Specifically, the purpose of the first part of this investigation was to evaluate the response of U\text{sg} and U\text{osm} to a change in hydration status over the range from euhydration to 5% of weight loss by dehydration. The protocol was completed in a controlled setting, and as a marker for the body’s hydration level plasma osmolality (P\text{osm}) was assessed and compared to changes in U\text{sg} and U\text{osm}.
Controlled laboratory studies are valuable in elucidating the dynamic changes occurring in $U_{sg}$, $U_{osm}$, and $P_{osm}$ during dehydration, and provide information sorely lacking in the literature. As investigations by Armstrong et al. (3), Francesconi et al. (11), and Shirreffs and Maughan (18) demonstrated, however, it is important to evaluate these techniques in a field setting. This is particularly true when applied to the enforcement of the new NCAA and NFHS wrestling weight management rules.

The purpose of the second part of this investigation was to evaluate the accuracy of $U_{sg}$ and $U_{osm}$ assessments of hydration status in the field against a criterion measure ($P_{osm}$). A medical decision model was employed to evaluate the outcomes (10). This model uses both a quantitative assessment of the “diagnostic test,” (e.g. the $U_{sg}$ cut-off), and a qualitative assessment of the potential health and economic implications for the diagnosis of the condition (i.e. dehydration). This type of evaluation would have significant implications toward application of the NCAA and NFHS rules and the determination of a valid cut-off value.

**Methods**

**Part 1**

**Subjects.** Physically fit male athletes ($N = 12$, mass $78.6 \pm 4.0$ kg, age $20.9 \pm 1.8$ y, mean $\pm$ standard deviation) able to endure exercise in the heat for a sufficient duration to achieve a weight loss equal to 5% of total body mass were invited to participate. The subjects completed a screening history and physical examination prior to initiating the protocol. Written informed consent was obtained in accordance with the University of Iowa Institutional Review Board.

**Protocol.** To insure adequate hydration, subjects were instructed to consume water frequently on the day preceding the study. Upon awakening on the day of the intervention, subjects were instructed to drink 250 mL of water before coming to the laboratory. On arrival, $U_{sg}$ was measured to insure the subjects were euhydrated at the beginning of the protocol. Subjects with a $U_{sg}$ greater than 1.015 were excluded from the study; 4 subjects did not meet the standard and were excluded. The remaining subjects, after voiding, had their nude body weight measured. The urine samples were used for determination of $U_{sg}$ and $U_{osm}$. Rectal temperature and heart rate (HR) measurements were assessed and a 10 mL blood sample was drawn from a superficial forearm vein to determine $P_{osm}$.

$P_{osm}$ and $U_{osm}$ were determined via freezing point depression with an osmometer (model 2430, Precision Systems, Inc., Natick, MA). $U_{sg}$ was determined using an Atago optical $U_{sg}$ refractometer (NSG Precision Cells, Inc., Farmingdale, NY) calibrated with deionized water. In Part 1 of the investigation, body mass ($\pm$ 50 g) was measured on a digital platform scale (model DS20 L, Ohaus Corp., Florham Park, NJ); rectal temperature by insertion of a rectal thermometer 10 cm beyond the sphincter, and HR via Polar Beat HR Monitor (Polar Electro Inc., Port Washington, NY).

The subjects dressed in shorts and shoes and entered an environmental chamber maintained at 43 °C and 20% relative humidity. HR and rectal temperature were monitored to ensure the safety of the subjects. HR did not exceed 180 beats/min and rectal temperature 39.5 °C. Subjects exercised on either a stationary cycle or...
treadmill and dehydrated by 1% of total body mass, determined by weight loss, in
approximately 0.5 h. At 1% dehydration, blood and urine samples were collected.
Samples were drawn after the subjects had achieved a 3% and 5% loss of body mass
by exercising in the heated chamber. Subjects needed approximately one additional
hour to reach 3% dehydration and another hour to finish the dehydration phase of
the protocol. Periodically after toweling off sweat, nude body weight was checked
to insure that they did not exceed the cut-offs.

After losing 5% of their body mass, a 60-min recovery began during which
subjects consumed chilled (~ 10 °C), distilled water equivalent to the amount of
weight lost; half within the first 30 min of recovery and the other half during the
final 30 min of recovery. Urine and blood samples were obtained after 30 and 60
min of recovery. Prior to leaving the lab, subjects were cleared by a physician and
encouraged to consume fluids liberally throughout the remainder of the day.

Part 2

In this part of the study, blood and urine samples were collected from 51 subjects,
16 from a Division I wrestling program, 31 from a Division III wrestling program,
and 4 from physically active nonwrestlers. Because measurements were taken in the
field, we did not record descriptive characteristics for the subjects. Measurements
were taken at various times of the day including mid-morning (approximately 10
AM), prior to daily wrestling practices (approximately 2 to 3 PM), and following
practices (4 to 5 PM). Prior to each blood sample, subjects rested in a seated posi-
tion for 10 to 15 min. Activities prior to taking the blood sample varied widely and
ranged from being seated during an academic lecture to completing a wrestling
practice, although we did not collect a history of recent activity. $U_{sq}$ was assayed
at the time of the measurement. Urine samples and blood samples were packed in
ice for measurement of $U_{osm}$ and $P_{osm}$ at a later time. All assays were completed as
described in Part 1.

Statistical Analysis

For Part 1, a repeated-measures ANOVA design was used to test for significant
differences ($P < 0.05$) between measurement at the 6 stages, i.e. baseline, 1%,
3%, and 5% dehydration and 30 and 60 min rehydration. Follow-up tests were
applied where appropriate, with the significance adjusted for multiple comparisons.
Dependent variables included $P_{osm}$, $U_{sq}$, and $U_{osm}$. Data for Part 1 were analyzed
using SAS software (16).

The quantitative assessment using the medical decision model computes 2
values. Sensitivity (or true positives) is defined as the presence of the condition and
a positive diagnostic test for detecting the condition among a sample of subjects
known to have the condition. Specificity (or true negatives) is defined as an absence
of the condition and a negative diagnostic test for the condition among a sample of
subjects known to not have the condition. Ideally, in the medical decision model
the coefficient for both sensitivity and specificity will approach the perfect outcome
of 1.0 (100% correctly classified), but this rarely occurs (10).

For the present investigation, the “condition” is hydration status and pres-
ence of the condition would be dehydration (D+) as represented by a $P_{osm} > 290$
mosm/kg and absences of the condition euhydration (D-), $P_{\text{osm}} \leq 290 \text{ mosm/kg}$. The “diagnostic test” being evaluated is either $U_{\text{sg}}$ or $U_{\text{osm}}$ at a designated cut-off. For example, with the $U_{\text{sg}}$ cut-off at 1.020, a test value lower than 1.020 represents a negative test (T-) and a test greater than or equal to 1.020 a positive test (T+).

Table 1 illustrates the $2 \times 2$ contingency table created to compute sensitivity and specificity for a diagnostic test with the $U_{\text{sg}}$ cut-off for dehydration at $\geq 1.020$ for the 51 subjects in the present sample. True positives (TP, $U_{\text{sg}} \geq 1.020$ and $P_{\text{osm}} > 290 \text{ mosm/kg}$) are shown in the upper left box, true negatives (TN, $U_{\text{sg}} < 1.020$ and $P_{\text{osm}} \leq 290 \text{ mosm/kg}$) in the lower right box, false positives (FP, $U_{\text{sg}} \geq 1.020$ and $P_{\text{osm}} \leq 290 \text{ mosm/kg}$) in the upper right box, and false negatives (FN, $U_{\text{sg}} < 1.020$ and $P_{\text{osm}} > 290 \text{ mosm/kg}$) in the lower left box. A similar contingency table can be generated for each of the cut-offs tested in the present investigation. The number of subjects classified as euhydrated ($n = 16$) or dehydrated ($n = 35$) by $P_{\text{osm}}$ remains the same, but as the cut-off for the test changes, the values in each cell change. A $\chi^2$-square test ($P < 0.05$) can be applied to determine if the distribution in the contingency table is significantly different from the expected distribution.

The qualitative aspect of a medical decision-making model places a value judgment on the test outcome. Some of the factors that are considered include the health risk associated with not diagnosing the condition (e.g. death or severe disability), the acute effects on the subject, (e.g. psychological stress or physical discomfort in completing the test), and economic considerations, such as the cost to administer the diagnostic test.

One tool of particular value when evaluating a diagnostic test is a receiver operating characteristic (ROC) curve. ROC curves were adapted from radio

<table>
<thead>
<tr>
<th>Cut-off of 1.020</th>
<th>D+ Dehydrated $P_{\text{osm}} &gt; 290 \text{ mosm/kg}$</th>
<th>D- Euhydrated $P_{\text{osm}} \leq 290 \text{ mosm/kg}$</th>
<th>Total ($n$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T + U_{\text{sg}} \geq 1.020$</td>
<td>TP 80.0% ($n = 28$)</td>
<td>FP 68.8% ($n = 11$)</td>
<td>39</td>
</tr>
<tr>
<td>$T - U_{\text{sg}} &lt; 1.020$</td>
<td>FN 20.0% ($n = 5$)</td>
<td>TN 31.3% ($n = 7$)</td>
<td>12</td>
</tr>
<tr>
<td>Total ($n$)</td>
<td>35</td>
<td>16</td>
<td>51</td>
</tr>
</tbody>
</table>

Note. True condition is represented in column D+ (dehydrated, $P_{\text{osm}} > 290 \text{ mosm/kg}$) and D- (euhydrated, $P_{\text{osm}} \leq 290 \text{ mosm/kg}$); test outcomes T+ ($U_{\text{sg}} \geq 1.020$) and T- ($U_{\text{sg}} < 1.020$). Subjects correctly classified by the test are represented by the true positive (TP) and true negative (TN) cells ($N = 51$).
Indicators of Hydration Status

transmission technology. A plot is generated between the coefficient for the signal, i.e. the diagnostic test sensitivity or TP identified in Table 1 and the noise, FP. By including multiple diagnostic test cut-offs, the plot provides a visualization to better determine the optimal cut-off for use in the clinical setting. It still requires a qualitative evaluation as described above, however.

At each of the 4 cut-offs for $U_{sg}$ and $U_{osm}$, the $2 \times 2$ contingency table was analyzed using a $\chi$-square analysis with significance set at $P < 0.05$. In addition, a power coefficient for Type II error was computed using the method of Cohen (9). To compare the association between $U_{sg}$ and $U_{osm}$, a Pearson correlation was computed.

Results

Part 1

At the beginning of the protocol the subjects’ body mass was $78.6 \pm 4.0$ kg (mean ± standard deviation). During the dehydration protocol, weight loss equaled an average of $1.2 \pm 0.2\%$, $3.1 \pm 0.2\%$, and $5.1 \pm 0.2\%$. At the end of the dehydration protocol, the subjects’ body mass averaged $74.6 \pm 3.8$ kg and at the end of the 60-min rehydration period $77.9 \pm 3.9$ kg.

As shown in Figure 1, the $P_{osm}$ increased significantly through each stage of the protocol and peaked at 5% dehydration ($P < 0.006$ in Figure 1). $P_{osm}$ declined during the 2 stages of recovery and approached the upper range for euhydration, $291$ m osm /kg, by the end of 60 min of recovery, though $P_{osm}$ was still significantly elevated ($P < 0.006$ in Figure 1).

At 1% dehydration, $U_{sg}$ and $U_{osm}$ did not differ significantly from baseline (Figure 2). At 3% and 5% dehydration and after 30 and 60 min of recovery, both $U_{sg}$ and $U_{osm}$ remained significantly elevated from baseline ($P < 0.006$ in Figure 1).

Part 2

Twenty-seven subjects were tested in the morning or early afternoon prior to scheduled training sessions, while 24 subjects presented shortly after the training session. Mean (± standard deviation) $P_{osm}$ was $292.6 \pm 5.6$ mosm/kg, $U_{sg}$ 1.022 ± 0.006, and $U_{osm}$ 813.8 ± 221.4 mosm/kg. As reflected by the average $P_{osm}$, the subjects for this field study showed minimal dehydration. Using the $P_{osm}$ criterion for hydration of 290 mosm/kg, 16 of the 51 subjects presenting were euhydrated. The correlation between $U_{sg}$ and $U_{osm}$ was high, $r = 0.85$ ($P < 0.05$).

Four cut-off points for $U_{sg}$ were tested. As we illustrated with the contingency table (see Table 1) and as shown in Figure 2 (solid bar) for the 1.020 $U_{sg}$ cut-off, 31.3% of the euhydrated subjects, (TN) are correctly classified and 80.0% of the dehydrated subjects, (TP), are correctly classified. Other cut-offs for $U_{sg}$ were also tested (Figure 2). A stair-step effect is generated between sensitivity (TP) and specificity (TN) that reflects the contrast between the sensitivity and the specificity as the cut-off point for the test used in the medical decision model is increased. The greatest number of subjects ($n = 33$) was correctly classified as TP or TN at 1.015 and 1.020. (Using a $\chi$-square test, $P$ values ranged from $P = 0.20$ at $U_{sg} = 1.025$ to $P = 0.90$ at $U_{sg} = 1.015$.)
Four cut-offs for $U_{\text{osmol}}$ were selected as markers for dehydration. Based on previous research, the values 716 m osmol/kg (18) and 1050 m osmol/kg (2) were included as test cut-off points. Two intermittent values (800 m osmol/kg and 900 m osmol/kg) were added to create a range in the same manner as the $U_{\text{sg}}$ values. The $P_{\text{osmol}}$ criterion for euhydration was again 290 m osmol/kg. The results are shown in Figure 3. Only 9 subjects met the $U_{\text{osmol}}$ 716 m osmol/kg cut-off criteria and as a result the number of TNs...
Figure 2—Specificity, true negatives (euhydrated), and sensitivity, true positives (dehydrated), for 4 urine specific gravity values compared to plasma osmolality. No significant differences were observed in the contingency tables for each value ($\chi^2 > 0.05$).

Figure 3—Specificity, true negatives (euhydrated), and sensitivity, true positives (dehydrated), for 4 urine osmolality values compared to plasma osmolality. No significant differences were observed in the contingency tables for each value ($\chi^2 > 0.05$).
was small, three (18.8%). This resulted in a high percentage of the subjects (n = 43) being classified as dehydrated. Conversely, 46 of the subjects were below the criteria of 1050 mOsm/kg and a large number of the euhydrated subjects (93.8%) were correctly identified. The cut-off for Uosm of 800 mOsm/kg approximates the sample mean (813 mOsm/kg). The greatest number of subjects (n = 32) were correctly classified as TP or TN at 716 mOsm/kg and 800 mOsm/kg. (Using a χ-square test, P values ranged from P = 0.20 at Uosm = 800 mOsm/kg to P = 0.91 at Uosm = 716 mOsm/kg.)

Figure 4 illustrates the ROC curves for Usg and Uosm. The axes represent the number of subjects classified as either TP (y-axis) or FP (x-axis) as a decimal fraction of the total group. (The y-axis value at each data point corresponds to the TP values shown in Figure 2 and Figure 3 expressed as a decimal.) The solid diagonal line reflects the outcome that TP and FP are equally likely. None of the data points for either Usg or Uosm are significantly greater (χ-square test, P > 0.05) than equal likelihood, however, the values at Usg = 1.020 and Uosm = 800 mOsm/kg (third data point) show the greatest inflection. Power was computed for an effect size of 0.05, with n = 51 and P = 0.05. For each of the 8 values tested, power was low and did not exceed 0.35.

Discussion

Part 1

Table 2 compares Posm, Usg, and Uosm from the present study with seven different protocols presented in five refereed journal articles. With 1 exception (Shirreffs

![Figure 4 — Receiver operating characteristic (ROC) curves for 4 cut-off values of urine specific gravity and urine osmolality. (Axes are the relative probability of true positives and false positives expressed as a decimal fraction based on the outcomes for the 51 subjects.)](image-url)
Table 2  Plasma Osmolality, Urine Specific Gravity, and Urine Osmolality Among Subjects Undergoing Acute Hypertonic Dehydration

<table>
<thead>
<tr>
<th></th>
<th>Euhydrated</th>
<th></th>
<th>Dehydrated</th>
<th></th>
<th></th>
<th>Wt. Loss (%)</th>
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<tbody>
<tr>
<td></td>
<td>P&lt;sub&gt;osm&lt;/sub&gt;</td>
<td>U&lt;sub&gt;s&lt;/sub&gt;</td>
<td>U&lt;sub&gt;osm&lt;/sub&gt;</td>
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<td>U&lt;sub&gt;s&lt;/sub&gt;</td>
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<td></td>
<td>m&lt;sub&gt;osm/kg&lt;/sub&gt;</td>
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<td>m&lt;sub&gt;osm/kg&lt;/sub&gt;</td>
<td></td>
<td>m&lt;sub&gt;osm/kg&lt;/sub&gt;</td>
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</tr>
<tr>
<td>Armstrong et al. (3)</td>
<td>286 ± 3</td>
<td>1.013 ± 0.009</td>
<td>510 ± 332</td>
<td></td>
<td>293 ± 3</td>
<td>1.019 ± 0.008</td>
</tr>
<tr>
<td>Armstrong et al. (4)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>287 ± 6</td>
<td>1.016 ± 0.002</td>
<td>---</td>
<td></td>
<td>295 ± 7</td>
<td>1.028 ± 0.001</td>
</tr>
<tr>
<td>Armstrong et al. (4)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>287 ± 5</td>
<td>1.015 ± 0.002</td>
<td>---</td>
<td></td>
<td>296 ± 8</td>
<td>1.029 ± 0.001</td>
</tr>
<tr>
<td>Bartok et al. (5)</td>
<td>288 ± 4</td>
<td>1.015 ± 0.004</td>
<td>614 ± 192</td>
<td></td>
<td>298 ± 5</td>
<td>1.028 ± 0.004</td>
</tr>
<tr>
<td>Popowski et al. (15)</td>
<td>288 ± 4</td>
<td>1.009 ± 0.006</td>
<td>325 ± 218</td>
<td></td>
<td>300 ± 2</td>
<td>1.015 ± 0.009</td>
</tr>
<tr>
<td>Shirreffs &amp; Maughan (18)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>675 ± 232</td>
<td>1.008 ± 0.007</td>
<td>211 ± 195</td>
<td></td>
<td>627 ± 186</td>
<td>1.020 ± 0.009</td>
</tr>
<tr>
<td>Shirreffs &amp; Maughan (18)&lt;sup&gt;d&lt;/sup&gt;</td>
<td>924 ± 99</td>
<td>1.008 ± 0.007</td>
<td>211 ± 195</td>
<td></td>
<td>776 ± 258</td>
<td>1.020 ± 0.009</td>
</tr>
</tbody>
</table>

Note: Armstrong et al. (4) completed 2 independent experiments in this investigation starting in either a euhydrated (<sup>a</sup>) or hypohydrated (<sup>b</sup>) state. Shirreffs & Maughan (18) completed 2 independent experiments in this investigation; <sup>c</sup> represents data from Part A of their investigation, and <sup>d</sup> represents data from Part B of their research.
and Maughan, 18, d), all the protocols measured subjects before and after an intervention that included acute hypertonic weight loss by dehydration. In all of the investigations, the weight loss was significant.

Among the euhydrated subjects in the 6 experiments, there was close agreement in the P(osm) that had a range of only 3 m(osm)/kg between the means. These outcomes are consistent with Senay’s (17) recommendation that a P(oosm) at or below 290 m(osm)/kg be used as a cut-off for euhydration.

Among the euhydrated subjects U(sg) and U(osm) showed greater variability. The mean U(sg) ranged from 1.008 in the present study to 1.016 (4) and the mean U(osm) ranged from 211 m(osm)/kg in the present study to 510 m(osm)/kg in the investigation by Armstrong et al. (3). This reflects the greater lability in these 2 variables that might be influenced by the recent ingestion of fluids and the time of day that the sample was measured. The present study is very similar to the Popowski, et al. investigation completed in our laboratory (15). The present investigation and that of Popowski, et al. (15) are consistent with the NATA guidelines for euhydration (U(sg) < 1.010), but the other studies cited suggest that this cut-off might be too low (3, 4, 5, 18).

The response to progressive dehydration and recovery, shown in Figure 1, is similar to the response observed by Popowski et al. (15) using a similar protocol. In both investigations, P(osm) showed a stair-step increase with progressive dehydration and a return toward euhydration during recovery. The lag in response to dehydration observed for both U(sg) and U(osm) could be attributed to the ingestion of 250 mL of water prior to initiating the protocol. As Popowski et al. (15) observed, the urinary parameters reflect the effect of the renal system’s effort to respond to acute changes in fluid balance. This might place the urine measures “out of step” with the control variables, in this case, P(osm).

The right side of Table 2 compares the outcome in the present study with the previous similar investigations that demonstrated significant dehydration. P(osm) increased by 7 m(osm)/kg to 12 m(osm)/kg and was greater than 295 m(osm)/kg among the 5 studies reporting weight loss of 3%. U(sg) and U(osm) showed more variability, but a U(sg) of 1.020 and U(osm) exceeding 500 m(osm)/kg appears to reflect body weight loss of 3% or more. The U(sg) outcome would be consistent with the NATA cut-off for minimal dehydration (6) and the recommendations from the RHPA (7).

A limitation of the present investigation is the relatively small sample size. When compared with a previous investigation from this laboratory (15) and others (3, 4, 5, 18), however, the present investigation found P(osm), U(sg), and U(osm) sensitive to changes in acute dehydration. Although it might be attributed to the experimental design, the response of both U(sg) and U(osm) were “out of step” with P(osm). The present investigation along with others (3, 4, 5, 15, 18) was consistent in demonstrating significant dehydration-related weight loss when U(sg) reached 1.020. This finding is consistent with the NATA guideline (6) and the RHPA (7) that associates dehydration with a U(sg) > 1.020.

Part 2

The purpose of the second portion of this investigation was to evaluate U(sg) and U(osm) as markers of hydration in a field setting. This protocol offered a departure from the laboratory setting and one in which we hoped to mimic conditions under which
wrestlers might present for the NCAA-regulated wrestling minimum-weight test. A history of the subjects’ prior activities and fluid consumption was not recorded. A novel aspect of this investigation was the use of a medical decision model to evaluate 4 cut-offs for dehydration using \( U_{osm} \) and \( U_{osm} \). By creating a ROC curve for each \( U_{osm} \) and \( U_{osm} \) cut-off, we were able to visualize the efficacy of the two “diagnostic” tests.

Quantitatively, the results of Part 2 demonstrated high sensitivity (TP, dehydrated) but low specificity (TN, euhydrated) for detecting dehydration for both \( U_{osm} \) and \( U_{osm} \) (Figures 2 and 3) and were not statistically different from random outcomes \((P > 0.05)\). Typically in a medical decision model, the ROC curve takes the shape of a hyperbola with a steep ascent near the \( y \)-axis and an asymptotic plateau as the data points on the \( x \)-axis increase from zero. An optimal cut-off is typically associated with inflection point where the asymptotic plateau begins \((10)\). This outcome was not apparent, and contrasts with the controlled studies discussed in Part 1. As demonstrated by the ROC curve and the high Pearson correlation \((r = 0.85)\), \( U_{osm} \) and \( U_{osm} \) provide similar outcomes.

The qualitative evaluation of Part 2 needs to be considered and has significant application to the assessment. As identified in the ACSM Position Statement \((1)\), the NATA Position Statement \((6)\), and the RHPA \((7)\), there are sound physiological and medical reasons to detect and minimize dehydration. This is true for athletes who experience dehydration both volitionally and involuntarily. As illustrated by the deaths in football and wrestling, the risks associated with dehydration can be high and therefore offer a rationale for employing a test with high sensitivity. \( U_{osm} \) is attractive as a monitoring test because of its modest economic costs (using either refractometry or reagent strips), ease of administration, and convenience.

Other investigators \((3, 5, 11)\) have found a poor association between \( P_{osm} \) and urinary measures. For example, Francesconi et al. \((11)\) collected samples at 20-d intervals among subjects participating in a military field exercise. They found urinary parameters more sensitive to hypohydration than hematological parameters. Armstrong et al. \((3)\) measured subjects under conditions representing a variety of conditions including before and after rest in a neutral environment, exercise in the heat, and an outdoor tennis competition. The mean (+ standard deviation) \( U_{osm} \) reported for the investigations was \( 1.021 \pm 0.008 \) and \( U_{osm} \) \( 747 \pm 305 \text{ mosm/kg} \). Their results supported previous observations by Francesconi et al. and showed poor correlations between urinary parameters and \( P_{osm} \). More recently, Bartok et al. has shown poor associations between weight loss by dehydration and both \( U_{osm} \) and \( U_{osm} \) \((5)\).

The cut-off values for dehydration using \( U_{osm} \) suggested by Armstrong et al. \((3)\) were not consistent with the present outcomes. Armstrong et al. \((3)\) recommended a cut-off for euhydration of \( 1.029 \). The present sample had a mean and standard deviation for \( U_{osm} \) similar to that of Armstrong et al.’s data. With a higher cut-off \((\text{e.g. } 1.025 \text{ or } 1.030)\), fewer than 20 subjects (19 and 18, respectively) were correctly classified compared to the criterion, \( P_{osm} < 290 \text{ mosm/kg} \).

The cut-off values for \( U_{osm} \) were based on previous investigations by Armstrong et al. \((2)\) and Shirreffs and Maughan \((18)\). Included in the sample of subjects tested by Shirreffs and Maughan were 21 athletes competing in weight-category sports \((15 \text{ boxers and } 6 \text{ wrestlers})\) with \( U_{osm} \) values of \( 775 \pm 263 \text{ mosm/kg} \) and \( 777 \pm 254 \text{ mosm/kg} \), respectively, who were reducing their weight and preparing for
competition, a sample of eleven euhydrated and ten dehydrated subjects whose first void was sampled after a night’s rest and 5 subjects dehydrated by 2% and then rehydrated. Based on their evaluation, a cut-off for hydration was identified as 716 m\text{osm/kg}. In the present investigation, the U\text{osm} for only 9 subjects fell below Shirreffs and Maughan’s criterion. Using their criterion, 32 of the 51 subjects in the present sample were correctly classified.

Armstrong et al. (3) identified a U\text{osm} range from 442 m\text{osm/kg} to 1052 m\text{osm/kg} as euhydrated, i.e. the mean ± 1 standard deviation. The upper cut-off for Armstrong et al. corresponds closely with the present data, 1021 m\text{osm/kg} (mean + 1 standard deviation). Overall, 19 of the 51 subjects were correctly classified. As with the U\text{sg} cut-off, Armstrong et al.’s U\text{osm} cut-off appears too high for the present sample.

There are several weaknesses in Part 2 of this investigation. The primary weakness pertains to the absence of a recent history of the subject’s activities and fluid consumption, so the way the subject reached the Posm and urinary values was not known. As was demonstrated in Part 1, ingestion of fluids prior to being tested can lower the urinary parameters with minimal effect on Posm. Some subjects had just completed a vigorous training session but also might have consumed a large quantity of fluids during the training bout. This could increase the incidence of FN at any of the U\text{sg} or U\text{osm} cut-offs. As discussed above (3, 5, 11), there is an intricate relationship between P\text{osm}, U\text{sg}, and U\text{osm}. As indicated, however, it was the purpose of Part 2 of this investigation to evaluate the relationship between the urinary parameters and Posm with minimal historical information about the subjects.

A second factor that could explain the large number of FP, (i.e. low specificity) is the validity of the cut-off for hydration (P\text{osm} < 290 m\text{osm/kg}). The cut-off for euhydration is subjective and might even include a range of P\text{osm} values. This has been a topic for discussion in the physiological literature (17). While strong evidence supports the P\text{osm} cut-off chosen, moving it up by 5 m\text{osm/kg} or 10 m\text{osm/kg} would alter the decision model outcomes. For example, increasing the cut-off for D+ to a P\text{osm} of 295 m\text{osm/kg} and using the T+ cut-off for U\text{osm} of 1.020, increases the specificity to 91.7% but decreases the sensitivity to 33.3% (\text{P} > 0.05).

Employing a more definitive criterion for D+, i.e. dehydration-related weight loss, alters the quantitative outcomes dramatically. For example, Bartok et al., (5) used weight loss as a criterion for dehydration (D+) and did not require the subjects to ingest fluids before losing weight. They measured U\text{sg} before and after dehydration in a group of 25 subjects. At the U\text{sg} cut-off (T+) of 1.015, specificity was 64% and sensitivity 100%; at 1.020, specificity was 96% and sensitivity 96%; and at 1.025, specificity was 100% and sensitivity 68%. These outcomes were all statistically significant and are consistent with the use of the 1.020 cut-off as the optimum value for detecting TP and TN subjects. Unfortunately, in a field setting, prior changes in weight cannot be determined at the time of the test.

A final weakness in Part 2 of the present investigation might be the relatively small sample size, making the probability of a Type II error high. Power for all the cut-offs tested was less than 0.35. Given the statistical effect size for the present investigation, data on approximately 150 subjects would have been required to generate a power coefficient of 0.75 (9). Alternatively, doubling the effect size would require a sample of 70 to 80 subjects. The sample size for the present investigation (n = 51), as in the investigations by Armstrong et al. (n = 45) and Shirreffs and Maughan (n = 47), was modest in size. The hypothetical outcomes illustrate
the need for using larger samples to more adequately test hypotheses in future field studies testing hydration status.

Part 2 in the present investigation was unique in applying a decision model to the field tests of hydration. Unlike a controlled laboratory study, in a field setting there is no prior information of the subject’s hydration status. The outcomes illustrate an issue of concern when applying cut-offs for $U_{sg}$ and $U_{osm}$ in a field setting. Optimal outcomes were observed at $U_{sg}$ of 1.015 and 1.020 and $U_{osm}$ of 700 m osm/kg and 800 m osm/kg but none were statistically significant. Limitations existed in the present investigation and as discussed quantitative outcomes must be considered in conjunction with qualitative evaluations. Clearly there is a need for more research with a similar experimental design to further evaluate these methods of assessing hydration.

**Conclusions and Practical Applications**

Four principal conclusions can be drawn from the present investigation. First, $P_{osm}$ is the best method for assessing hydration status and appears to be sensitive to small changes in hydration status. The use of this method in a field setting, however, lacks feasibility because of equipment needs, cost, technical assistance, athlete compliance with the blood sampling protocol, etc.

Second, $U_{sg}$ might offer a viable method for assessing hydration status. The present results from Part 1 coupled with the previous investigations (2, 3, 4, 5, 15) suggest that $U_{sg}$ is sensitive to change in acute hydration status. Taken together, they show significant weight loss associated with a $U_{sg}$ ≥ 1.020, and they are consistent with the recommended use of this cut-off as a marker for dehydration (6, 7, 19, 20). $U_{osm}$ and $U_{sg}$ appear to mimic each other, and because of the cost and technical requirements, $U_{osm}$ is preferred over $U_{osm}$.

Third, in a field setting (Part 2), our results provide evidence that other factors, not quantified by the present study, could adversely affect assessment of $U_{sg}$ and $U_{osm}$ and the accuracy of cut-offs as suggested by the NATA (6) and the NCAA Wrestling Weight Management Program (20). Considering the risks associated with dehydration, these factors must be determined as well as their influence on measurements for dehydration.

Finally, the results from Part 1 of the present study and our previous investigation (15) elucidate the dynamic changes in $P_{osm}$ and $U_{sg}$ and $U_{osm}$ during acute dehydration. The second part of this experiment and other studies (2, 4, 5, 6, 18), however, provide only limited data on how field measurements of $P_{osm}$ are related to $U_{osm}$. Sampling subjects under field conditions and including a history of activity and fluid consumption prior to taking the samples might indicate more accurately how these factors influence hydration status. Outcomes from investigations such as these could offer athletes insights into their hydration status and could be beneficial to coaches, medical staff, and athletes in developing procedures for training and competition to maintain adequate hydration.

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References

References