An Aggregate Urine Analysis Tool to Detect Acute Dehydration

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Purpose: Urine sampling has previously been evaluated for detecting dehydration in young male athletes. The present study investigated whether urine analysis can serve as a measure of dehydration in men and women of a wide age span. Methods: Urine sampling and body weight measurement were undertaken before and after recreational physical exercise (median time: 90 min) in 57 volunteers age 17–69 years (mean age: 42). Urine analysis included urine color, osmolality, specific gravity, and creatinine. Results: The volunteers’ body weight decreased 1.1% (mean) while they exercised. There were strong correlations between all 4 urinary markers of dehydration ($r = .73–.84$, $p < .001$). Researchers constructed a composite dehydration index graded from 1 to 6 based on these markers. This index changed from 2.70 before exercising to 3.55 after exercising, which corresponded to dehydration of 1.0% as given by a preliminary reference curve based on 7 previous studies in athletes. Men were slightly dehydrated at baseline (mean: 1.9%) compared with women (mean: 0.7%; $p < .001$), though age had no influence on the results. A final reference curve that considered both the present results and the 7 previous studies was constructed in which exercise-induced weight loss ($x$) was predicted by the exponential equation $x = 0.20$ dehydration index$^{1.86}$. Conclusion: Urine sampling can be used to estimate weight loss due to dehydration in adults up to age 70. A robust dehydration index based on four indicators reduces the influence of confounders.

Keywords: urine color, osmolality, creatinine, specific gravity

Studies in sport medicine have evaluated urine sampling as a means of quantifying dehydration (Armstrong et al., 1998). Urinary changes can be mainly attributed to increased concentrations of metabolic waste substances from the stimulation of the kidneys to conserve water. End products from the metabolism of erythrocytes and muscle are excreted at a relatively constant rate throughout the day, and higher urinary concentrations of these products may indicate renal fluid retention in response to dehydration. With the loss of body water caused by physical activity, the urine color gradually darkens, the osmolality and the creatinine concentration increase, and the specific gravity of the urine becomes higher (Oppliger et al., 2005). Studies have been performed only on male athletes in their early twenties, which makes it difficult to apply the results uncritically to other age groups.

This study evaluates the use of urinary indicators as measures of dehydration with the hope of making urine sampling useful for routine testing in larger groups of athletes, as well as nonathletes spanning a wide age range. To overcome the problem of occasional misleading measurements, the study introduces a dehydration index based on the following four markers of dehydration: Urine color reflects the concentration of waste products from the breakdown of erythrocytes. Creatinine is a remnant from the metabolism of muscle. Specific gravity and osmolality are measures of the weight and the number of dissolved solutes in the urine, respectively.

The logic of using a composite index is that several urinary markers of dehydration are unlikely to be erroneous at the same time; therefore, the dehydration index would be a more robust and valid measure of dehydration than any one of the four components. The decrease in body weight during physical exercise was used as the reference standard. We hypothesized that the aggregate urine analysis tool would uniformly detect urinary changes attributable to acute body mass loss during exercise in men and women over a wide age span.

Methods

Subjects

Fifty-seven volunteers (mean age: 42 years, range: 17–69), composed of 28 men and 29 women, participated in this prospective observational study between September 2010 and May 2011. Once a week, the volunteers were involved in physical activities arranged by local sports clubs in southern Stockholm. The activities were
tennis (n = 27), cross-country running (n = 20), and Thai boxing (n = 10).

The volunteers received written and oral information about the study and gave their verbal consent to participate. Recruitment was based on a self-declaration that ensured each subject was in good health, ingested no daily medication, and accepted the terms of the study, which included examinations just before and immediately following a recreational physical activity that involved some degree of sweating. The activity was undertaken at various times of the day: cross-country running between 6 and 8 p.m., tennis between 9 a.m. and 1 p.m. or, in a few cases, between 6 and 8 p.m., and Thai boxing between 5 and 8 p.m. All volunteers were instructed to eat and drink normally and, for ethical reasons, were not forbidden to drink during the exercise.

The ethics committee of Stockholm (permit 2010/1128-31/2) approved the study, which was in accordance with the standards of the Declaration of Helsinki.

Measurements

Measurements were performed just before and after the volunteers exercised and included an assessment of thirst intensity on a visual analog scale (VAS), voiding, and weighing in underwear without shoes. Voiding was always done before weighing.

The VAS has previously been used to assess thirst in patients with cancer (Morita et al., 2001), heart failure (Holst et al., 2003; Waldrèus et al., 2011), and renal failure (Wirth & Folstein, 1982). The volunteers marked an “X” on a 100-mm line to grade their thirst intensity from none (0 mm) to worst possible (100 mm).

The change in body weight during exercise was considered the most valuable reference method and was therefore used (Maughan et al., 2007). Weighing was performed to the nearest 10 g via the same electronic balance. After testing several methods of handling each urine marker) had the same weight, which makes it possible to exclude extreme outliers without disturbing the balance. After testing several methods of handling outliers, we found that an apparent outlier typically raised the SD to >1.0 when the mean value of the four markers was calculated. The individual scores were then reviewed, and any single outlier was omitted, after which the dehydration index was recalculated. If the SD was <1.0, the new value was accepted; if the SD was still >1.0, the index was discarded as a failure.

Statistics

For practical reasons, the project ended when one sports season in the participating sports clubs was finished. The results are presented as medians (range) due to the occurrence of skewed distributions, or as the mean ± SD. Changes were examined with ANOVA or the Wilcoxon matched-pair test, and differences between groups were assessed with the Mann-Whitney U test if distributions were skewed. Simple linear regression analysis was used to evaluate correlations. p < .05 was considered statistically significant.
Results

Effects of Exercise

During the exercise, the volunteers’ body weight decreased 0.80 ± 0.41 kg (range –0.05 to 1.75) or 1.1 ± 0.5% (range –0.08 to 2.47). Ten volunteers drank water (median: 150 ml, range: 50–700) while exercising, which lasted for 90 (35–120) min.

Exercise tripled the thirst intensity (Table 1). At baseline, the younger subjects reported more intense thirst. Although the thirst score was 32 (0–69) mm for the 25 volunteers who were younger than 40 years, the scores started at 18 (0–63) mm for those 40 years or older (p < .03; Mann-Whitney’s test). There were no statistically significant differences between younger and older volunteers regarding subsequent changes in thirst (Wilcoxon’s test) and body weight (ANOVA).

All volunteers voided before the exercise, but two were unable to deliver the second urine sample. Regarding the others, thirst, urine color, specific gravity, and creatinine showed significantly higher values after physical exercise. The urine sodium concentration decreased, but the potassium concentration and the osmolality did not change significantly (Table 1).

No age-dependent differences in urine color, specific gravity, osmolality, and creatinine were found when dichotomizing the volunteers for age using (in turn) 40, 50, and 60 years as the cutoff point between young and old. Urine osmolality was 10–15% lower among the “old,” but this difference never reached statistical significance.

Correlations and Algorithm for Dehydration

The results of the urine analysis obtained before and after exercise were pooled to outline the overall correlations among the four markers of dehydration (Figure 1). The pooled pre- and postexercise data on osmolality, creatinine, and urine color were then calibrated to the specific gravity to form dehydration scores (Table 2). The mean value of these scores was called the dehydration index. One index was calculated for each urine sample. However, 15 of the dehydration indexes had to be recalculated due to single outliers that raised the SD for the mean value of the four markers to > 1.0. The outliers appeared to be randomly distributed regarding sex, type of marker, and whether the outlier had a higher or lower score than the other markers. After the recalculation, the SD remained > 1.0 in one of them. This dehydration index was discarded, but in the subsequent presentation, the other 14 were used for which SD < 1.0.

Dehydration Index

The overall dehydration index, after the correction for outliers, was 2.70 ± 1.39 before the volunteers exercised and 3.55 ± 1.33 immediately after (p < .001). Two volunteers who could not void after exercising initially had unusually high dehydration indexes (3.6 and 5.0, respectively). However, these two volunteers were excluded from the study due to the lack of postexercise urine data. Men were slightly dehydrated before the exercise compared with women (p < .001). No statistically significant age-dependent differences in the dehydration index were found when dichotomizing the volunteers for age using (in turn) 40, 50, and 60 years as the cutoff point between young and old (Table 3).

Estimating Dehydration From the Dehydration Index

Figure 2 shows a preliminary reference curve for the relationship between dehydration and loss of body weight based on the data reported in the seven previous studies in which specific gravity was reported with a measured

<table>
<thead>
<tr>
<th>Variable</th>
<th>Start</th>
<th>End</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body weight (kg)</td>
<td>72.87 ± 14.54</td>
<td>72.07 ± 14.35</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>Thirst (VAS mm)</td>
<td>21 (0–69)</td>
<td>60 (22–86)</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>Urine analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>volume (ml)</td>
<td>95 (0–1,000)</td>
<td>70 (0–255)</td>
<td>p &lt; .05</td>
</tr>
<tr>
<td>specific gravity</td>
<td>1.014 ± 0.028</td>
<td>1.018 ± 0.007</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>osmolality (mOsmol/kg)</td>
<td>599 (156–1,171)</td>
<td>642 (133–1,009)</td>
<td>NS</td>
</tr>
<tr>
<td>creatinine (mmol/L)</td>
<td>7.0 (3.1–12.6)</td>
<td>11.7 (6.8–21.2)</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>color (shade)</td>
<td>2.3 ± 0.9</td>
<td>3.1 ± 1.0</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>sodium (mmol/L)</td>
<td>79 (20–256)</td>
<td>74 (10–207)</td>
<td>p &lt; .001</td>
</tr>
<tr>
<td>potassium (mmol/L)</td>
<td>61 (9–132)</td>
<td>63 (11–157)</td>
<td>NS</td>
</tr>
</tbody>
</table>

Note. Data presented as M ± SD, analyzed with the paired t test, or median (range), analyzed with the Wilcoxon matched-pair test.
deficit in body fluid volume (Armstrong et al., 1994; Armstrong et al., 1998; Casa et al., 2000; Francesconi et al., 1987; Harvey et al., 2008; Oppliger et al., 2005; Popowski et al., 2001).

The pre- and postexercise data on the dehydration index are projected onto this preliminary reference curve in Figure 3, where the thick lines connect the dehydration index before and after exercise for all volunteers (top), for men and women (middle), and for those aged 40 years or younger (bottom).

The theoretical loss of body weight inferred from Figure 3 was compared with the measured decrease in body weight shown in Table 3. The researchers then modified the preliminary constructed reference curve based on minor discrepancies between the predicted and measured weight losses and arrived at the composite, final reference curve shown in Figure 4. In the event that the decrease in body weight differed from that predicted by the equation for the regression line in Figure 2, the following occurred: The measured decrease in body weight was applied by extending or reducing the x-axis difference between the dehydration indexes obtained before and after exercise, and the mean of the two was accepted as a true value.

The final reference curve shown in Figure 4 implies that exercise-induced weight loss (in percent of the body weight) can be predicted as 0.20 dehydration index\(^{1.86}\). This final reference curve and the equation are thus based on previous data from male athletes (Figure 2) and the new data for all ages and both sexes (Figure 3).

**Exploratory Analyses**

Urine osmolality correlated more strongly with the other markers of dehydration than did the sodium concentration (simple regression analysis).
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Ten volunteers gave 14 urine samples with erythrocytes. Half had faint traces of 10 cells/μl, four had 50 cells/μl, and three had 250 cells/μl. The last were all women aged 18, 20, and 34 years (i.e., of menstruating age). The urine color did not appear as an outlier in any of the subsequent calculations of the dehydration index (Table 3), but the color tended to be slightly darker than in samples without erythrocytes (3.6 vs. 3.0; Mann-Whitney’s test p = .17).

### Discussion

This study shows that dehydration amounting to only 1% of body weight across a large age span is followed by slightly darker urine, higher specific gravity of the urine, and a higher urinary creatinine concentration (Table 1). In contrast, urine osmolality did not change significantly in response to exercise, although this marker correlated statistically with the other three markers of dehydration. Overall, the intercorrelations between the four markers suggest that osmolality increases most at an early stage and creatinine increases most at a later stage of the dehydration process (Figure 1).

The results of the four urine markers of dehydration were compared with the reference standard (body mass change) after they had been combined to create a dehydration index, a new aggregate urine-based measure of dehydration that is likely to be more robust than any individual marker. The dehydration index is calculated with the mean of the four individual markers after calibration in the urine specific gravity and a statistically justified elimination of outliers.

### Age and Gender

The dehydration index was only marginally affected by age, if at all. The difference between the measured and predicted weight loss from urine sampling averaged only 0.1–0.3%, regardless of whether calculations were based...
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Researchers expected a slightly greater overall measured weight loss over the predicted degree of dehydration, because physical activity increases energy use. Each gram of oxidized glucose generates 0.6 g of water, and the remainder is lost as expired CO₂ (Maughan et al., 2007). Further minor discrepancies were rectified by slightly modifying the steepness of the final reference curve for the relationship between the dehydration index and weight loss (Figure 4).

For ethical reasons, severe dehydration cannot be induced deliberately in the elderly. However, many of the volunteers—particularly the men—appeared to be slightly dehydrated before exercising, which agrees with previous findings by Stover et al. (2006). Therefore, this study supports the reference curve for the relationship

![Figure 3](image3.png)  
**Figure 3** — Urinary dehydration index as predictor of exercise-induced fluid loss. Data from the current study were plotted on the preliminary reference curve derived in Figure 2. The thick lines represent the rise in the dehydration index from before to after physical exercise, and the predicted weight loss is projected on the x-axis (arrows). Top: all volunteers. Middle: males versus females. Bottom: ≥ 40 years versus younger.

![Figure 4](image4.png)  
**Figure 4** — Final reference curve for the relationship between the dehydration index and dehydration, expressed as a loss of body weight. Top: Included data are those from Figure 2 (circles) and Figure 3 (squares). Weight loss (x) from the dehydration index (y) could be predicted mathematically as $x = 0.20 y^{1.86}$ ($r = .96$). Bottom: final reference curve with grids for copying and personal use.
between the dehydration index and weight loss of up to 3% (which corresponds with a dehydration index of 4); older data have to be relied upon for extrapolation to more pronounced weight losses. We speculate that these individuals do not habitually consume fluids to denote euhydration. Alternatively, the individuals practice self-initiated, short-term fasting to avoid urgency during physical activity.

**Previous Data on Male Athletes**

Regarding male athletes, data on urine color and urine specific gravity corresponding to dehydration indexes 1–3 represent degrees of normal hydration; 4–5 indicate moderate dehydration, and 6 and higher correspond to severe dehydration (Casa et al., 2000). A dehydration index of 5 corresponds to dehydration amounting to approximately 5%, which indicates a clear need for additional intake of fluid. The urine composition changes very little when dehydration progresses from 5% to 7% (Popowski et al., 2001), and with worse dehydration, anuria develops due to concomitant reduction of renal blood flow.

Some previous data from athletes differ from the relationships presented here. Armstrong et al. (1998) reported a change in urine color from 4 to 6 from progressive dehydration from 2.5% to 4%, which represents a steeper dehydration curve than the one shown in Figure 4. Moreover, urine specific gravity increased from 1.005 to 1.028 from dehydration of only 2.5%. However, several other studies (Armstrong et al., 1994; Armstrong et al., 2010; Stover et al., 2006) are in agreement with our diagram for calculating the dehydration index.

Plasma osmolality is probably more reliable than using a single urine marker for measuring severe dehydration (Cheuvront et al., 2010; Popowski et al., 2001) but lacks the simplicity and noninvasiveness offered by the urine testing.

**Dehydration Index and Reference Curve**

Using a composite index for dehydration based on several markers of renal fluid conservation has the benefit of reducing occasional variations in these markers caused by diet, disease, and medication. Urine color might darken from infection, liver disease, or intake of certain vegetables. A diet rich in salt raises urine osmolality, and creatinine excretion might increase after ingestion of large amounts of meat.

To obtain a robust measure of dehydration, researchers suggest that outliers be excluded. A method for quickly identifying outliers was also applied. Alternative algorithms for exclusion may certainly be used, but the SD for the mean of all four dehydration scores effectively identified indexes that are based on apparently inconsistent scores. By using this refinement procedure in calculating a dehydration index, we believe that urine could become a more acceptable tool for detecting dehydration in the future.

A comment must be made on the construction of the dehydration index chart. In previous studies, one step on the urine color chart corresponded to a change in specific gravity of 0.005 (Armstrong et al., 1994; Armstrong et al., 1998; Casa et al., 2000). The color shade in our study increased more slowly; therefore, a simple weighting equation had to be applied (see the bottom of Table 2) to calibrate the color to the specific gravity. The discrepancy is probably because urine color depends on subjective judgment. Variability due to the quality of the color printer is also an issue that, since 2011, can be reduced by purchasing the original color chart via a website (http://hydrationcheck.com). However, the urine color should be compared with the other markers of dehydration, and their intercorrelation should possibly be calibrated when setting up the method described here.

Data on the correlation between the change in body weight during exercise and urine specific gravity were also collected from other studies to support the construction of a reference curve. The final curve (Figure 4) contains old and new data. The fact that the old data are the urine specific gravity and the new data are the dehydration index should not matter much, as the former is the basis for the latter. Figure 4 shows that young male athletes and volunteers of both sexes over a wide age span participating in recreational physical exercise can be placed on the same exponential curve for the relationship between body weight loss and urine indices of dehydration.

Because the dehydration index is a mean value, the reference curve is potentially useful even when data consist of fewer than four markers—although the risk of having outliers is slightly higher. For example, the osmolality of euhydrated morning urine in a warm climate averaged 627 mOsmol/kg (= dehydration score 4), and the osmolality was 924 mOsmol/kg (= dehydration score 5) after a body mass loss of 1.85% (Shirreffs & Maughan, 1998). This decrease in body weight is well predicted by Figure 4.

**Limitations and Perspectives**

Limitations of the current study include the small weight losses; therefore, future studies should validate the dehydration index with greater mass loss. Volunteers were tested at various times of the day; however, the time of day does not seem to be important when measuring urine specific gravity (Stover et al., 2006).

Food and water intake were not controlled; therefore, the volunteers were not in a controlled euhydrated state but rather were slightly hypohydrated when they began exercising. Researchers had to rely on previous work (Figure 2) to find the starting point for estimates of dehydration-induced weight loss based on spot urine sampling (Figure 3).

Mild spontaneous admixture of the urine with erythrocytes seemed to have only a marginal effect on urine color, but hemorrhage from menstruation or recent catheterization might invalidate urine color as an index of dehydration. Moreover, glucose should be included in the chart of tests. Uncontrolled diabetes causes osmotic diuresis that results in dehydration from the excretion of...
diluted instead of concentrated urine. That clinical situation is extremely unlikely in the volunteers studied here.

Dehydration is believed to be common in hospital patients. Evaluations using urine sampling in that setting require further evaluation by fluid restriction in those affected by cardiovascular and renal disease. However, unpublished data from the researchers’ hospital show that a dehydration index of 4 or higher occurs in 30% of the patients scheduled for repair of a traumatic hip fracture. Moreover, in 256 patients admitted to acute geriatric care, 26% showed a dehydration index of 4 or more, and 8% reached the maximum score. These data may reflect that the elderly are prone to become dehydrated due to impairment of the thirst sensation (Farrell et al., 2008), which was also apparent before the exercise in the current study. The capacity to concentrate the urine declines with age, but this factor was hardly noticeable in the current study.

Conclusions

Loss of 1% of body weight through exercise in volunteers between 17 and 69 years of age induced fluid retention detectable with urine sampling in men and women. Researchers constructed a reference curve correlating the mean of four urine markers of dehydration (the dehydration index) and the loss of body weight by exercise-induced hypertonic hypovolemia. The final reference curve, which was based on the present results and on seven previous studies in athletes (among them, Armstrong et al., 1994; Armstrong et al., 1998; Casa et al., 2000; Harvey et al., 2008; Oppliger et al., 2005), implies that the exercise-induced weight loss (x, in percent of body weight) can be predicted with the exponential equation

\[ x = 0.20 \text{ dehydration index}^{1.86} \]

Urine sampling can be used to assess dehydration in healthy adults over a large age span when no reference body weight is available. The most apparent use is in women and men who lose fluid from acute exercise.

Acknowledgments

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References


