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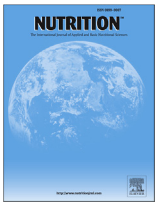

Applied nutritional investigation

An empirical method to determine inadequacy of dietary water

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ABSTRACT

Objectives: The physiological regulation of total body water and fluid concentrations is complex and dynamic. The human daily water requirement varies because of differences in body size, dietary solute load, exercise, and activities. Although chronically concentrated urine increases the risk of renal diseases, an empirical method to determine inadequate daily water consumption has not been described for any demographic group; instead, statistical analyses are applied to estimate nutritional guidelines (i.e., adequate intake). This investigation describes a novel empirical method to determine the 24-h total fluid intake (TFI; TFI = water + beverages + moisture in food) and 24-h urine volume, which correspond to inadequate 24-h water intake (defined as urine osmolality of 800 mOsm/kg; U800).
Methods: Healthy young women (mean ± standard deviation; age, 20 ± 2 y, mass, 60.8 ± 11.7 kg; n = 28) were observed for 7 consecutive days. A 24-h urine sample was analyzed for volume and osmolality. Diet records were analyzed to determine 24-h TFI.
Results: For these 28 healthy young women, the U800 corresponded to a TFI ≥2.4 L/d (≥39 mL/kg/d) and a urine volume ≥1.3 L/d.
Conclusions: The U800 method could be employed to empirically determine 24-h TFI and 24-h urine volumes that correspond to inadequate water intake in diverse demographic groups, residents of specific geographic regions, and individuals who consume specialized diets or experience large daily water turnover. Because laboratory expertise and instrumentation are required, this technique provides greatest value in research and clinical settings.
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Introduction

The human body cannot produce adequate metabolic water (250–350 mL/d) [1] to offset fluid losses from the kidneys, lungs, and skin (adult range, 1.1–3.1 L/d) [2]. The thirst drive does not stimulate drinking until water loss reaches 1% to 2% of body weight [3], and solid food provides only approximately 20% of daily total fluid intake [1]. Because of these diverse factors, as well as differences in body size and dietary intake, daily water requirement varies from person to person. Further complicating the matter, the 24-h fluid intake of adult women [1] ranges from 1.3 (lowest decile; n = 3091) to 6.1 (highest decile) L/d, suggesting that drinking behavior involves a sizeable volitional component. Despite the advanced technological capabilities that science employs today, a universal daily adequate water intake has not been defined precisely [3] for any demographic group (i.e., adults, children, pregnant women) because body water turnover is complex and dynamic [4–6]. The European Food Safety Authority (EFSA) [7] approached this problem by considering fundamental principles of urinary water and solute excretion. Specifically, EFSA determined adequate intakes (AI) for water (i.e., the AI meets or exceeds the needs of most healthy individuals in a specific life-stage and sex) by combining median water consumption data with a theoretical desirable urine osmolality [7]. This approach is justified, in part, by the fact that urine is the only avenue of fluid loss which is homeostatically regulated by the brain.

Although numerous indices of hydration status are utilized today (e.g., body weight change; plasma osmolality; and urine volume, color, specific gravity, and osmolality) [8], no single biomarker unequivocally represents human hydration status in all settings and in all persons [6,9]. However, a number of physiologists and dietitians have proposed that urine osmolality (U_{osm}) distinguishes mild dehydration from euhydration when it exceeds 800 mOsm/kg [10–15]. For example, in a population study of German children that analyzed urine collections (n = 718) excreted

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during a 24-h period, Manz and Wentz [16] statistically identified 830 mOsm/kg as the lower limit of dehydration. A complex statistical evaluation of hydration biomarkers [9], involving receiver operating curve analyses of sensitivity and specificity, identified 831 mOsm/kg as the criterion value for dehydration in adult men and women. Similarly, two recent publications involving healthy adults evaluated commonly used hydration biomarkers. In the first, a U_{osm} of 800 was categorized as mild dehydration [17]; in the second study, no man or woman (n = 71) who consumed more than 2 L water/d (range, 2–4 L/d) experienced a U_{osm} >800 mOsm/kg during 4 d of observations [18]. These publications independently support using a 24-h urine osmolality of approximately 800 mOsm/kg as the threshold that determines dehydration. Additional support for using urine osmolality as an index of inadequate water intake arises from studies of water homeostasis, in that thirst is sensed when plasma osmolality reaches 290 to 295 mOsm/kg; this tonicity corresponds to a urine osmolality of approximately 800 mOsm/kg [12,19], suggesting that the brain initiates thirst, in part, to avoid concentrating urine excessively.

Therefore, we propose that inadequate water consumption exists when urine osmolality exceeds 800 mOsm/kg in a 24-h sample (U800). Using U800 in the present investigation, we identify the 24-h total fluid intake (TFI; TFI = water + beverages + moisture in solid foods) and 24-h urine volume that represent the threshold of inadequate daily water consumption. Although more cumbersome than a spontaneous urine sample, a 24-h urine collection is advantageous because 1) it represents the sum of all behavioral (i.e., diet and exercise) and neuroendocrine responses that influence renal concentration or dilution throughout a day [5], and 2) it represents whole-body hydration status more accurately than spontaneous measurements made at a single point in time [5,18,20]. Furthermore, the large natural variance of 24-h urine osmolality (i.e., interindividual and intraindividual) is acknowledged and incorporated into the U800 technique.

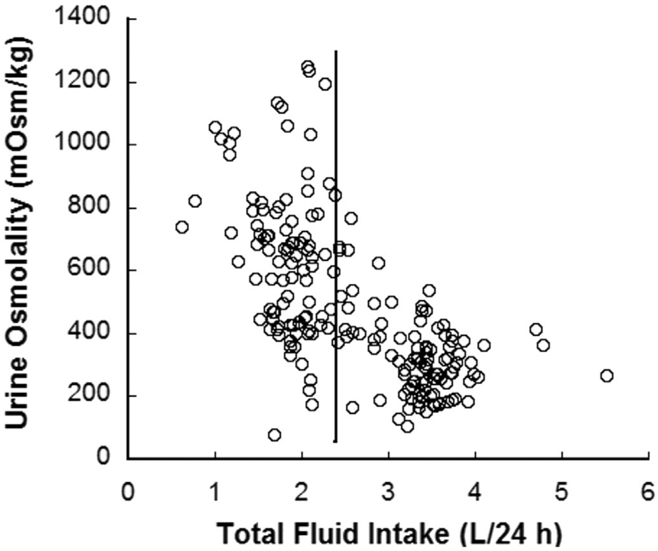

Fig. 1. Determination of U800 for 24-h total fluid intake (L/d; n = 195).

Methods

The data provided in this manuscript were collected according to the guidelines described in the Declaration of Helsinki, and all procedures involving human subjects were approved by the University of Connecticut Institutional Review Board for human studies. Written informed consent was obtained from all subjects. This retrospective analysis stems from a larger research study, organized in our laboratory [21], which involved measurements and analyses other than TFI and urinalysis. Figures 1–3 have not appeared in any previous publication.

All subjects were college-aged females who had used oral contraceptives for at least 2 mo before enrolling. Eighty subjects qualified to participate in this investigation; of these, 28 volunteered to continue testing and were selected because they were either high volume drinkers (HIGH, n = 14; top tertile; TFI, 2.0-4.0 L d^{-1}) or low volume drinkers (LOW, n = 14; bottom tertile; ≤1.2 L/d). Exclusionary criteria included use of tobacco or nicotine; history of a disease or illness that alters normal fluid-electrolyte balance; fainting or becoming nauseous upon viewing needles or blood; being outside the age range of 19 to 34 y; not taking oral contraceptives for at least 90 d before enrollment; medication (other than oral contraceptives) that alter normal fluid–electrolyte balance, plasma osmolality, or urinary osmolality; diagnosis of type 1 or type 2 diabetes; reported caffeine intake >500 mg per day; engaging in >7 h moderate aerobic endurance training per week; or unwilling to abstain from alcohol during and the 2 d preceding this study.

Fluid and food consumption were recorded across 6 consecutive days. On the morning of day 1, participants were instructed how to properly keep a 1-d diet record and to maintain their regular diet over the next 5 d (days 1–5). Participants returned to the laboratory each morning (days 2–6) between 0530 and 0800 h to review the previous day's diet record with a counselor. Daily TFI was calculated by adding beverage volume, water volume, plus moisture content analysis of solid foods (Nutritionist Pro, Axxya Systems, Stafford TX).

The data of HIGH and LOW were combined, to demonstrate the U800 method presented in this manuscript. These women reported to the laboratory between 05.30 and 08.00 h each day. Within each subject, arrival time did not differ more than 1 h throughout the course of observations. Day 1 was standardized for each participant to occur on the first day that she consumed the first placebo pill of her contraceptive pill pack. This was done to reduce the variance of day-to-day fluctuations in total body water due to reproductive hormone changes across the menstrual cycle. On 7 consecutive days, 24-h urine output was collected and analyzed for four variables: total volume by mass (Ohaus, Ranger, Parsippany, NJ); urine osmolality by freezing point depression osmometry (U_{osm}; Advanced Instruments Inc., Model 3320, Norwood MA); urine color, using a previously published color chart [22]; and urine specific gravity with a hand-held refractometer (Atago, A300 CL, Tokyo, Japan).

Because indisputable thresholds for biological variables rarely exist, the U800 was determined in the present investigation, via data spreadsheet or graphs, as the minimum 24-h TFI or minimum 24-h urine volume that maintained U_{osm} below 800 mOsm/kg for all individuals in the test group (i.e., avoiding high urine concentration, reducing the risk of urolithiasis, and delaying the decline of renal function with age) [10–15,18,23,24].

Results

Average personal characteristics for the 28 female participants were as follows: age, 20 ± 2 y; mass, 60.8 ± 11.7 kg; and height 164 ± 9 cm. Figures 1–3 depict relationships between

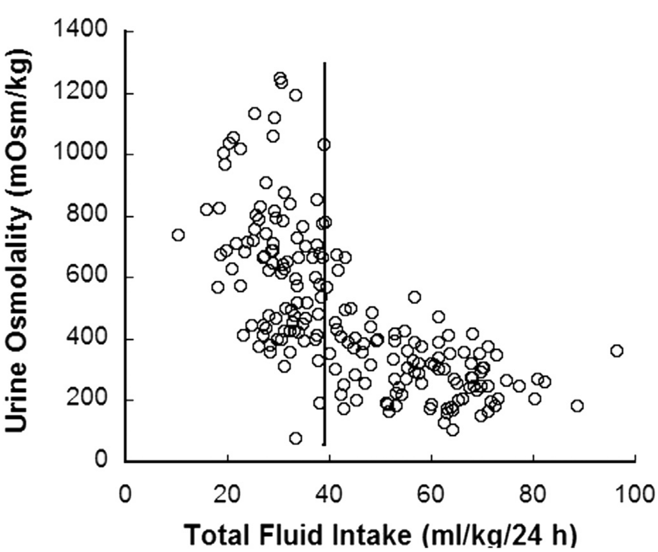

Fig. 2. Determination of U800 for 24-h total fluid intake, expressed relative to body weight (mL/kg/d; n = 195).

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