Validation Testing Demonstrates Efficacy of a 7-Day Fluid Record to Estimate Daily Water Intake in Adult Men and Women When Compared with Total Body Water Turnover Measurement


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Abstract

Background: Mean daily water intake from fluids (WATER-FL) has proven to be difficult to measure because of a range of nonvalidated data collection techniques. Few questionnaires have been validated to estimate WATER-FL against self-reported diaries or urine hydration markers, which may limit their objectivity.

Objectives: The goals of this investigation were 1) to assess the validity of a 7-d fluid record (7dFLR) to measure WATER-FL (WATER-FL-7dFLR) through comparison with WATER-FL as calculated by measuring deuterium oxide (D2O) disappearance (WATER-FL-D2O), and 2) to evaluate the reliability of the 7dFLR in measuring WATER-FL.

Methods: Participants [n = 96; 51% female; mean ± SD age: 41 ± 14 y; mean ± SD body mass index (in kg/m²): 26.2 ± 5.1] completed body water turnover analysis over 3 consecutive weeks. They completed the 7dFLR and food diaries during weeks 2 and 4 of the observation. The records were entered into nutritional software to determine the water content of all foods and fluids consumed. WATER-FL-D2O was calculated from water turnover (via the D2O dilution method), minus water from food and metabolic water. The agreement between the 2 methods of determining WATER-FL were compared according to a Bland-Altman plot at week 2. The test-retest reliability of 7dFLR between weeks 2 and 4 was assessed via intraclass correlation (ICC).

Results: The mean ± SD difference between WATER-FL-7dFLR and WATER-FL-D2O was −131 ± 845 mL/d. In addition, no bias was observed (71.94 = 0.484; R² = 0.006; P = 0.488). When comparing WATER-FL-7dFLR from weeks 2 and 4, no significant difference (mean ± SD difference: 71 ± 75 mL/d; 71.94 = 0.954; P = 0.343) and an ICC of 0.85 (95% CI: 0.77, 0.90) was observed.

Conclusions: The main findings of this study were that the use of the 7dFLR is an effective and reliable method to estimate WATER-FL in adults. This style of questionnaire may be extremely helpful for collecting water intake data for large-scale epidemiologic studies. J Nutr 2017;147:2001–7.

Keywords: deuterium oxide, water turnover, dietary assessment, hydration, fluid intake, diet record, water, Liq.in7, 7-day record

Introduction

The USDA categorizes DRIs for specific nutrients based on the quantity and quality of available evidence (1). For nutrients such as calcium and vitamin A, large sample–based and consistent observational research allow estimated average requirements (EARs) to be determined on which an RDA can be based (2).

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When sufficient data are not relevant to the reduction of disease risk, or when needs within the population vary greatly, such as in the case of daily preformed water intake (WATER-pref), an EAR cannot be specified, and instead an adequate intake (AI) is assigned (3). Because the AI is partially based on water intake data, it is important that the methodologies behind the collection of these data be accurate, reliable, and consistent within and between populations. Further, improved methodologies for collecting water intake data could progress recommendations from an AI toward an EAR and thus an RDA.

Evidence exists that systematic errors may confound measurement of mean daily WATER-pref at the population level. For example, within 12 European countries, 10 different methods were used to measure WATER-pref in the population (4). These values ranged from a low of 941 mL/d in Italian women, collected through the use of a 3-d food diary, to a high of 2659 mL/d in German men, collected through the use of a beverage dietary history. Separately, within a single country (France), mean WATER-pref has been measured at a range of 1200–1800 mL/d (5). Small differences between and within countries are expected because of climate, activity level, culture, or normal sampling variability. However, the large differences demonstrated have been partially attributed to inconsistencies between measurement techniques (6).

Most previous WATER-pref measurement techniques have relied on participants’ self-report through the use of FFQs, food recalls, or food diaries (7–9). However, WATER-pref consumption differs from food consumption because ~20% of mean daily water intake is from solid foods (WATER-food) consumed during meals and ~80% is from fluids (WATER-FL; i.e., in beverages or drinks including plain water) consumed during and between meals (3). While we can assume that WATER-food is accurately captured by tools that have been validated for solid food intake, it is unclear whether WATER-FL is accurately captured by these same tools. Therefore, there is value in creating a separate diary specific to capturing the volume of WATER-FL consumed each day.

Ideally, all diet-related variables would be measured without relying on self-report (e.g., doubly labeled water analysis for energy expenditure). However, the funding and time required for biomarker-derived dietary measurement is prohibitive for large population sampling. For example, the cost of doubly labeled water used to measure energy expenditure is nearly $1000/subject, not including the analytical costs (10). Therefore, self-report questionnaires are vital to the collection of diet-related data. However, to minimize and understand the inaccuracies in any self-reported nutritional data collection tool (11–14), the tool should first be verified against an objective measurement within a smaller population, and on 2 separate occasions within the same population, in order to ensure validity and reliability, respectively (15, 16).

Water turnover can be measured (and thus water intake calculated) by D₂O administration (17–19), but this technique has yet to be used to validate a self-report tool designed to measure WATER-FL (7–9, 20). Therefore, the purpose of this investigation was to assess the validity (via D₂O administration) and reliability (via repeated completion) of a 7-d fluid record (7dFLR) designed to specifically measure WATER-FL among a sample of free-living, healthy male and female participants.

Methods

Subjects. Before voluntary participation, all individuals provided informed consent that they understood all risks and benefits associated with the study procedures. All procedures adhered to the tenets of the Declaration of Helsinki and were reviewed and approved by the institutional review board and biosafety committee of the University of Arkansas (protocol no. 14–03–555). Participants received monetary compensation in line with expected time requirements and normal payment for unskilled labor (21). Payment was prorated if participants chose to stop involvement at any time. Participation took place over 4 consecutive weeks and involved calculating mean daily water turnover (WTO) using the D₂O dilution method (described below) and hard-copy records of all dietary intake to estimate WATER-food and WATER-FL, and to estimate mean metabolic water formed daily in the body (WATER-net). WTO was measured over the first 3 wk as part of a larger experiment. Participants completed the 7dFLR at weeks 2 and 4 of the observation (Figure 1). The 7dFLR was validated at week 2, whereas reliability testing involved the comparison of 7dFLR data between weeks 2 and 4. A total of 262 men and women were screened for participation between May and December 2014. Potential participants were excluded if any of the following factors that could alter fluid balance or metabolic water calculations were present: 1) evidence of clinically relevant diseases, 2) pregnant or breastfeeding, 3) previous surgery on the digestive tract, 4) regular drug treatment within the past 15 d, 5) currently exercising >4 h/wk, or 6) in the process of attempting to gain or lose weight. Participants were recruited to reflect the age and sex distribution within the United States between the ages of 18 and 65 y (22). After screening, 103 participants were enrolled in the study. Investigators initially excluded the data from 2 participants because they failed to follow protocol instructions (e.g., did not meet with investigators during their assigned appointment time), and 5 other participants because of an incomplete food diary or 7dFLR during week 2. After validity analyses, investigators excluded from repeatability analyses the data from 16 additional participants because of an incomplete food diary or 7dFLR during week 4. Thus, 96 and 80 participants were included in the validation and repeatability analyses, respectively. Body weight was recorded at the beginning of the investigation when collecting demographic information, and during each laboratory visit during the observation period to ensure weight stability and thus, complete macronutrient utilization. Investigators recorded standing height with a wall-mounted stadiometer (model 7700, Seca). Body composition was measured with a DXA scanner (Lunar Prodigy, General Electric Healthcare).

Water intake from beverages: 7dFLR. Participants recorded all drinks, including plain water, into the 7dFLR, which investigators then used to calculate WATER-FL (WATER-FL-7dFLR). The record, called the Liq.In record (Supplemental Figure 1) and previously used in fluid-specific cross-sectional surveys (23, 24), consisted of a booklet with 7 separate pages for recording all drinks including plain water. Participants recorded high-water foods, such as soup broths or milk added to cereal, in the food diary, not in the 7dFLR. Investigators instructed participants to record the following information on a separate line each time they consumed a fluid: time, fluid category, type of container, and portion consumed. Participants were educated on how to classify each beverage into 1 of 39 fluid categories, which were listed on the facing page along with an identifying code number and descriptions when necessary, e.g., tap water, 1; packaged fruit juice containing a high percentage of juice, 21; diet or unsweetened iced coffee, 32; sports drinks (e.g., Isostar, Powerade), 28; spirits without mixer (e.g., vodka, cognac, whisky), 36. Type of container (e.g., cup or pre-packaged bottle) was also recorded with a code. Photos of typical fluid containers, their volume in milliliters and ounces, and their code were available in an appendix attached to each 7dFLR. After recording the fluid category and the container type, participants indicated the portion of the container consumed by checking 1 of the 5 check boxes corresponding to the following fractions: “all of it,” “about 3/4 of it,” “half of it,” “about 1/4 of it,” or “only a small amount of it.” After the first day of data collection, researchers asked the participants to review their 7dFLR from day 1 to check for understanding. At the end of weeks 2 and 4, participants returned the record to investigators. When investigators had questions regarding the entries (e.g., poor handwriting, unclear beverage classification), the particular entry was confirmed with the participant before 7dFLR analysis. For each 7dFLR, the aforementioned information was entered into a customized Excel spreadsheet (Microsoft Corp.) to calculate mean daily WATER-FL.

The calculation used the percentage water of the fluid type, determined with Nutritional Data System for Research (NDSR) software (Nutrition Coordinating Center, University of Minnesota, Minneapolis, Minnesota), the volume of the container, and the proportion consumed.
FIGURE 1 Urine D:H values in adults during the 3 wk of WTO measurement and values back-extrapolated to the time of ingestion (days 0, 7, and 14). Values are means ± SDs (n = 96). The background on day 0 is 152.1 ± 1.1 ppm. *Participants completed the 7dFLR and food diaries. Participants visited the laboratory on all days for which D:H values are shown (black circles) and on day 29. During laboratory visits, participants provided a spot urine sample, had body mass measured, and asked any questions they might have had regarding the recording of fluids or foods.

Water intake from foods and metabolic water. Participants recorded the type and amount of food consumed in the food diary (25, 26), which investigators then used to calculate WATER-food. Trained investigators performed the food diary entries into the NDSR software to calculate water content, macronutrient composition, and energy (kilocalories). All diet entry specialists were trained by the same head dietary consultant. A single investigator entered each participant’s full food diary from all 4 wk to avoid fluctuations in entry as a result of food selection. Following entry, all macronutrient and water intakes were checked extensively for outliers (e.g., grams of carbohydrate that were >2 SD from the mean). Each outlier was double-checked with the physical food diary and, if needed, with the participant. Last, a random selection of 10 handwritten food diaries were checked against the computer entries by the head dietary consultant, which confirmed that misentry frequency was minimal and acceptable.

The volume of WATER-met produced by macronutrient oxidation was calculated from total energy intake and percentage of energy from each macronutrient derived from the NDSR output (Equation 1) (27, 28). This assumes that total energy expenditure was equal to energy intake, which was confirmed in our sample through participant weight stability [e.g., a low CV (mean ± SD: 0.78% ± 0.32%) and a small weight change (mean ± SD: 0.07% ± 1.40%) over the 4 wk of observation].

\[
\text{WATER-met (L/d)} = \text{TEE} \times \left( \frac{1}{105} \right) \left[ \frac{\% \text{fat} \times 0.119}{1 + \frac{\% \text{protein} \times 0.103}{1 + \frac{\% \text{carbohydrates} \times 0.150}{1 + \frac{\% \text{alcohol} \times 0.168}{1}}}} \right]
\]

where TEE is the total energy expenditure.

Water intake from fluids: \(D_2O\) dilution. WATER-FL from \(D_2O\) dilution (WATER-FL-D\(_2O\)) was computed as the difference between WATER (measured with \(D_2O\) during week 2) and WATER-food + WATER-met. To calculate WATER, participants consumed 3 separate doses of \(D_2O\) (0.10, 0.05, and 0.08 mg/kg lean body mass; 99.9% deuterium; Cambridge Isotope Laboratories, Inc.) at the beginning of weeks 1, 2, and 3 (Figure 1). Each dose was measured into a sterile cup, then diluted with 100 mL bottled water, which the participant then quickly ingested. Two successive 100-mL volumes of bottled water were then poured into the cup and quickly ingested in order to rinse the cup and wash down the tracer. Participants provided urine samples immediately before the ingestion of each dose (days 0, 7, and 14) and at days 1, 8, 15, and 21 to evaluate the rate of disappearance (Figure 1). This sampling frequency was considered adequate (compared with daily samples) following a previous investigation in which the \(D_2O\) disappearance over a week-long period was found to be linear on the log scale (29). The ratio of deuterium to hydrogen (i.e., protium) in the urine (D:H) was measured by MS (Micromass IsoPrime dual inlet coupled with an Aquaprep system; Isoprime Ltd.) using the \(H_2\)-water equilibration method (30).

Three successive total body water (TBW) volumes were calculated from the dose of \(D_2O\) ingested and the corresponding increase in D:H, above the normal background D:H enrichment measured on day 0. Then the values were extrapolated backward to the time of ingestion from the rate of disappearance of \(D_2O\) from the body water pool over the subsequent week, through the use of the slope intercept method (17), as previously described (29).

No significant difference was observed in the fractional rate of \(D_2O\) disappearance from the body water pool (kd) or TBW, respectively, between weeks 1, 2, and 3: \(-0.0975 ± 0.0316\), \(-0.0971 ± 0.0299\), and \(-0.0971 ± 0.0285\); 38.2 ± 8.3, 38.5 ± 8.4, and 38.0 ± 8.2 L (means ± SDs). The mean TBW volume for each subject thus was used to compute WTO from kd at week 2 for questionnaire validation purposes. Investigators then subtracted WATER-food and WATER-met values from WTO to determine WATER-FL-D\(_2O\).

Statistical analyses. An appropriate sample size was calculated a priori based on 1) the 95% limits of agreement for the mean difference of the planned Bland-Altman analysis (31), and 2) identification of a difference based on a planned paired t test between means (32). For the Bland-Altman analysis, the 95% CI of the mean difference between measurements is equal to \(\pm [1.96 \cdot \frac{SD}{\sqrt{n}}]\) - \(\bar{d}\) where \(n\) is the sample size and \(\bar{d}\) is the SD of the differences between measurements. Because this type of comparison has not, to our knowledge, previously been completed, we determined that a 475 mL (i.e., two 8-ounce cups) was an acceptable margin of error between WATER-FL-7dFLR and WATER-FL-D\(_2O\). Thus, a sample size of 75 provides a 95% CI of ±186 mL. For the t test, a sample of 47 was necessary to identify a meaningful difference of 200 mL between measurements, assuming the same 475 mL SD of the differences, a power of 0.80, and \(\alpha = 0.05\). The Bland-Altman analysis drove the sample size selection above that of the t test.

All statistical analyses were completed with the use of JMP 12.1.0 software (SAS Institute Inc.). Characteristics are reported as means ± SDs. To assess differences in WATER-FL data between the 7dFLR and WATER-FL-D\(_2O\), we performed a paired t test. For all analyses, an appropriate sample size was calculated a priori using G*Power (33). The reliability of the 7dFLR was examined by the intraclass correlation coefficient (ICC).

Results

Table 1 displays the anthropometric and TBW means and SDs for the 96 participants included in the validation analyses.
divided into each of the age and sex groups that were used to recruit an appropriate sample. No significant differences for any variables were noted when mean demographics for the 80 participants included in the reliability assessment were compared against those of the full sample of 96 participants.

Table 2 displays the means and distributions from both methods used concurrently to measure WATER-FL. WATER-met and WATER-food accounted for 8% ± 3% and 21% ± 8% of WTO, respectively. WATER-FL-D₂O and WATER-FL-7dFLR comprised 71% ± 10% and 69% ± 20% of WTO.

Questionnaire validity. The volume of WATER-FL measured by WATER-FL-7dFLR and WATER-FL-D₂O were not significantly different (mean difference: −131 mL; t[95]; = −1.52; P = 0.132). The correlation coefficients between WATER-FL-7dFLR and WATER-FL-D₂O were 0.68 and 0.50, as determined by the Spearman ρ and Kendall τ, respectively (both P < 0.001). Bland-Altman plots displayed strong agreement between the WATER-FL data acquired through WATER-FL-7dFLR and WATER-FL-D₂O evaluation (Figure 2). The mean difference between WATER-FL-7dFLR and WATER-FL-D₂O was −131 ± 845 mL/d (95% CI: −1786, 1524 mL/d). No bias in the mean difference in the data between methods was observed over the range of mean WATER-FL (F[1,94] = 0.484; R² = 0.006; P = 0.488).

Cross-classification of WATER-FL revealed that 53% and 31% of participants were in either the identical or adjacent quartile of WATER-FL distributions, respectively, as measured by the 7dFLR and D₂O disappearance from TBW. In addition, this analysis showed a very low rate (1%) of extreme misclassification, that is, only 1 participant was in the highest quartile of the WATER-FL-D₂O distribution and in the lowest quartile of the WATER-FL-7dFLR distribution.

Questionnaire reliability. No significant difference was observed between WATER-FL-7dFLR (mean difference: 71 ± 75 mL/d; t[79] = 0.954; P = 0.343) when weeks 2 (2423 ± 1069 mL/d) and 4 (2495 ± 1156 mL/d) were compared for the 80 participants who completed all 4 wk of the observation. A moderate to strong linear relation existed between the 2 wk (R² = 0.677; F[1,78] = 163.562; P < 0.001) (Figure 3). The Cronbach α coefficient between the 2 measurements was 0.92 (P < 0.001), indicating high internal consistency. The ICC was 0.85 (95% CI: 0.77, 0.90), demonstrating good test-retest reliability of the 7dFLR.

Discussion

The main finding of this study is that the 7dFLR is a valid and reliable method to estimate the distribution of daily water intake from fluids within a sample of adult men and women from a region of the central United States around a university. Five separate statistical results support this finding: 1) Bland-Altman analysis demonstrating a mean difference of only 131 mL/d between WATER-FL-7dFLR and WATER-FL-D₂O, 2) no bias when using the 7dFLR over the full range of WATER-FL, 3) low rates of misclassification into extreme opposing WATER-FL quartiles when using the 7dFLR, 4) strong nonparametric correlations between WATER-FL-7dFLR and WATER-FL-D₂O, and 5) a high level of agreement between weeks 2 and 4 when using the 7dFLR, as shown by Cronbach α and ICC values.

The values obtained for D₂O-measured water intake variables are consistent with previous reports. In this investigation we determined a mean WTO of 3.65 L/d for a sample of men and women, among whom age and sex distributions are representative of the adult population in the United States. This value falls between the values of 3.81 and 3.26 L/d from Raman et al. (27), who studied groups of 40- to 49-y-old men and women, respectively. In addition, their calculations of WATER-pref equated to 3.22 and 2.75 L/d for the same groups of men and women. We can compare these values to the combination of

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Anthropometric measures and total body water of adult female and male participants (n = 96), by age group</th>
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<tbody>
<tr>
<td>Age range, y</td>
<td>Women</td>
</tr>
<tr>
<td></td>
<td>18–29</td>
</tr>
<tr>
<td>Participants, n</td>
<td>13</td>
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<tr>
<td>Height, m</td>
<td>1.66 ± 0.05</td>
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<tr>
<td>Weight, kg</td>
<td>70.0 ± 20.0</td>
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<tr>
<td>BMI, kg/m²</td>
<td>25.1 ± 7.1</td>
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<tr>
<td>Body fat, %</td>
<td>30.3 ± 9.7</td>
</tr>
<tr>
<td>TBW</td>
<td>liters</td>
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<td></td>
<td>%BM</td>
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1 Values are means ± SDs unless otherwise indicated. TBW, total body water; %BM, percentage of body mass.

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Water turnover and partitioning from the 7dFLR, food diary, and D₂O dilution in adult female and male participants (n = 96)</th>
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<tbody>
<tr>
<td></td>
<td>Food</td>
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<tr>
<td></td>
<td>diary</td>
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<tr>
<td>WTO</td>
<td>—</td>
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<tr>
<td>WATER-met</td>
<td>276 ± 71</td>
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<tr>
<td>WATER-pref</td>
<td>—</td>
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<tr>
<td>WATER-food</td>
<td>723 ± 275</td>
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<tr>
<td>WATER-FL</td>
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</tbody>
</table>

1 Values are mean ± SIs per day. D₂O, deuterium oxide; WATER-FL, mean daily water intake from fluids; WATER-met, mean daily water intake from fluids; WATER-pref, preformed water; WTO, mean daily water turnover; 7dFLR, 7-d fluid record.

2 Data were derived from the use of the D₂O dilution technique.

3 Data were derived from calculations using data from both the D₂O dilution technique and the food diary.

4 Data were derived from the use of the 7dFLR.
WATER-FL-D₂O plus WATER-food (3.37 L/d) in order to superficially confirm our WATER-FL-D₂O and WATER-food measurements. The knowledge that the current WATER-FL-D₂O and WATER-food measurements are in line with previous investigations enables appropriate validation of the 7dFLR, because it allows confidence in the “gold standard” to which it is being compared.

The 7dFLR technique used to measure WATER-FL displayed a very low mean difference (131 ± 845 mL/d) compared with the data collected with the D₂O measurement technique, which is similar to that shown by other questionnaires (129 ± 77 g) when compared against a food intake record (9). At the sample level, a volume error of 131 mL/d (~4 oz, or a half cup of water) would have little impact on the overall estimation of a population’s water intake distribution. However, when absolute accuracy of water intake measurement within a single individual is required (e.g., within a hospital setting where a patient’s fluid intake could affect treatment protocols), the 7dFLR would should not be recommended at this time. It is also important to point out that the 95% CI is large, in that WATER-FL-7dFLR could be either overestimated by 1524 mL/d or underestimated by −1786 mL/d. Previous questionnaires about water intake validated against simultaneous food records have displayed narrower limits of agreement (~±500 mL) for WATER-FL (8). The variation observed in this investigation may be due to inaccurate reporting of either foods that contain large amounts of water or beverages, or to variations in WTO. Although some argue that 7 d is optimal for nutrient recording (35), others suggest that participant recording fatigue can decrease accuracy after 3–4 d of consecutive recording (36). The slope intercept method of calculating and mathematically determining WTO is based on the measured rate of D₂O disappearance from the TBW pool (18). However, the relation between this calculated value and known water intake (i.e., in a laboratory or supervised setting) has yet to be established. By doing so, researchers could more thoroughly determine whether the large CI is due to inaccurate reporting, normal fluctuations in D₂O-measured water turnover, or—most likely—a combination of the 2 sources of error. If, however, D₂O measurement variation was the sole cause of the observed error, we would have expected a systematic under- or overcalculation, which was not seen.

A second strength of the 7dFLR is that we did not observe the typical underestimation observed with dietary self-reporting (37) (i.e., almost equal under- and overreporting). This finding can allow users of the 7dFLR to be confident that the mean values collected are representative of the sample and do not require any type of correction factor. In the future, it may be helpful to determine demographic characteristics that predict which individuals are likely to over- or underreport, and to implement further methodological steps to attenuate potential erroneous dietary recording. In addition, as shown by the high levels of agreement in the cross-classification analysis, the 7dFLR seems to be a useful tool to identify the high and low water intake extremes within a sample population. The 7dFLR seems to be best suited for observing the mean and distribution of WATER-FL within a population, but it may be less useful for precise identification of individuals’ WATER-FL.

The appropriateness of a measurement tool’s use in research also requires an assessment of the tool’s test-retest reliability. (That is, does the tool produce the same results if used on multiple occasions?) This evaluation is separate from that determining differences between WATER-FL-7dFLR and WATER-FL-D₂O in individual subjects. The current data provide support that the 7dFLR produces good reliability for WATER-FL, as evidenced by a Cronbach α coefficient between the 2 measurements of 0.92 and an ICC of 0.85 (based on the WATER-FL-7dFLR measurements from weeks 2 and 4). However, determining the true reliability of these measurements is difficult because fluid records were self-reported (i.e., it is impossible to collect water intake estimations with 2 diaries over the same time period), and normal fluctuations occur in free-living people’s dietary intake of water. It is possible that an individual consumed different volumes of water from one week to the next. This is not typical behavior, however, as humans have a very delicately tuned sense of thirst; this sense prevents significant dehydration from occurring as a result of underconsumption in healthy individuals residing in a stable climate (38, 39).
Fluctuation in water intake is more likely due to nonregulated drinking related to food intake or social surroundings. We did not see any indication of major fluctuations of WATER-FL within our population, as evidenced by stable TBW and kd values between weeks 1, 2, and 3. In addition, if a participant did consume an unusual amount of water on 1 d of either collection period, the impact was mitigated by the collection of 7 d of dietary intake during both periods. Although normal fluctuations can exist, the consistency of TBW and kd, combined with the systematic controls used to diminish the effects of nonregulated drinking, confirms the reliability of WATER-FL estimated by the 7dFLR.

The proposed methodology for estimating WATER-FL intake with the 7dFLR advances the validation of other questionnaires designed to measure WATER-FL. The use of WATER-FL-D\textsubscript{2}O as the gold standard for comparison minimizes the amount of collinearity introduced, while also attempting to measure the same variable during the validation of the 7dFLR. Because our objective was to test the validity of a questionnaire specifically regarding the estimation of WATER-FL, rather than all water consumed daily, the standard to which the 7dFLR was compared subtracted WATER-food and WATER-met values derived from food diaries. Although this adds a small degree of self-report to both sides of the comparison, this method introduced the smallest possible amount of error, because WATER-food comprises roughly 20% of daily WATER-prefer, whereas WATER-FL comprises ~80% (3). On the contrary, previous WATER-FL questionnaire studies have compared the tool in question with simultaneously recorded food diaries or urinary markers of hydration (7–9). First, dual recording could artificially improve the precision of the questionnaire being validated. For example, an individual who recalls the consumption frequency of certain types of fluids would be more accurate if he or she were required to record all fluid intake during the week leading up to the administration of the questionnaire. In addition, if an individual mistakenly reports an extra 300 mL water on both the food diary and the questionnaire, the validation analysis would not detect any discrepancy. For this reason, others have made efforts to avoid dual recording by validating water questionnaires against urinary markers of water intake (7). Urine volume and urine concentration are directly related to habitual WATER-FL within a sample (41). However, individual factors such as caloric intake and physical activity could alter urine concentration independent of water intake. Therefore, direct comparison of questionnaire-derived WATER-FL to urinary variables for the purpose of validation is less than optimal. The current findings do not invalidate previous questionnaire validations, but provide support for estimating water intake via questionnaires. However, when ideal accuracy for population-based investigations is required, use of a daily beverage diary similar to the 7dFLR used in this investigation offers the ability to estimate water from fluids that has been compared against a direct measurement.

Our findings do not construe blanket validity for the 7dFLR, and limitations to its application still exist. Specifically, the validity testing to estimate WATER-FL described above pertains to the population of men and women in and around a major US university. Care was taken when designing this diary to produce maximum accuracy across many populations while reducing burden on the participant. For example, many pictures of beverage containers were included in the appendix so users were not required to know the absolute container volume or compute the volume when discrepancies between national units of measure (i.e., ounces compared with milliliters) existed. Also, the 7dFLR reduces the number of fluid options to 39, simplifying the process and minimizing the time required for recording. One final benefit of applying the 7dFLR over traditional food diaries (i.e., where all foods and fluids are recorded together) to estimate WATER-FL is that only fluids need to be recorded, further reducing the time required from participants in research studies. However, it has yet to be seen whether different fluid consumption practices outside of the United States influence the validity of the 7dFLR. Just as diet-based questionnaires require separate validation within different cultures, so too should the 7dFLR.

In conclusion, to our knowledge, this investigation represents the first time a fluid intake questionnaire has been tested against direct measurement of TBW turnover from D\textsubscript{2}O dilution. The findings of general acceptability at the sample level are important because evaluations of water intake within populations have resulted in a range of water recommendations in different countries, potentially due to differences in WATER-FL data collection techniques. The capacity of human physiology to respond to different levels of water intake is one of the defining processes that has enabled our existence. However, this ability may hinder the scientific community’s ability to determine optimal water intake guidelines. As the research surrounding water intake norms expands, a picture of potential consequences to low water intake has arisen (43) and requires further epidemiological and intervention-based research. The consistent application of WATER-FL questionnaires with high validity in longitudinal and large-scale cross-sectional investigations enables the comparison of data between research groups, with the understanding that the distributions shown are consistent with actual WATER-FL. Eventually, the use of methods that have data available to represent their validity and reliability could lead to the establishment of an RDA for water in North America and consensus among other countries. The goal of validating a specific method to determine WATER-FL is to begin a cohesion of WATER-FL data collection so that scientists draw appropriate comparisons and interpretations across and between research studies that seek to evaluate water intake.

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**References**


