

Water turnover in 458 US adults 40 to 79 years of age.

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ABSTRACT

Despite recent interest in water intake, there are few data available on water metabolism in adults. To determine the average and range of usual water intake, urine output and total body water, we administered deuterium oxide to 458 noninstitutionalised 40-79 y/o adults living in temperate climates. Urine was collected in a subset of individuals (n=280) to measure 24hr urine production using para-aminobenzoic acid (PABA) to insure complete collection. Preformed water intake was calculated from isotopic turnover and corrected for metabolic water and insensible water absorption from humidity. Preformed water intake, which is water from beverages and food moisture, averaged 3.0 L/d in men (range: 1.4-7.7L/d) and 2.5 L/d in women (range: 1.2-4.6L/d). Preformed water intake was lower in 70-79y/o men (2.8 L/d) than in 40-49 y/o men and was lower in 70-79 y/o women (2.3 L/d) than 40-49 and 50-59 y/o women. Urine production averaged 2.2 L/d in men (range: 0.6-4.9 L/d) and 2.2 L/d in women (0.9-6.0 L/d). There were no age-related differences in women but the 60-69 y/o men had significantly higher urine output than the 40-49 and 50-59 y/o men. Only the 70-79 y/o group included sufficient Blacks for a racial analysis. Blacks in this age group showed significantly lower preformed water intakes than the Whites. Whites had significantly higher water turnover rates than Blacks as well. Multivariate regression indicated that age, weight, height and BMI explained less than 12% of the gender specific variance in water input or urine output yet repeat measures indicated that within individual coefficient of variation was 8% for preformed water intake (n=22) and 9% for 24hr urine production (n=222). These results demonstrate that water turnover is highly variable among individuals and that little of the variance is explained by anthropometric parameters.

Key words: water intake, 24hr urine, preformed water; insensible water.

INTRODUCTION

Recommendations for consumption of water and nonalcoholic beverages have recently been questioned (20). The interest in this issue is widespread because water is among the most important nutrients for the maintenance of life. The body uses water for transporting nutrients and wastes, lubrication, temperature regulation and tissue structure maintenance. In addition, plentiful fluid consumption may be protective against diverse medical conditions, including kidney stones (26), constipation (5), colorectal cancer, premalignant adenomatous polyps (35) and bladder cancer (23).

Water deprivation results in life threatening dehydration within a few days. Loss of body water exceeding 5% of body weight leads to decreased endurance culminating in heat exhaustion (20; 25). Older versus younger individuals have been shown to have a higher risk of developing dehydration than younger adults which may be attributed to decreased total body water with age (33), impaired renal fluid conservation (6), and physiological hypodipsia (11).

Despite the physiologic importance of water to life, little is known about water intake and excretion patterns in free-living individuals, because fluid intake, particularly from noncaloric, nonalcoholic, and noncaffeinated beverages is poorly documented. The 1977-1978 National Food Consumption Survey (NFCS) (2) is one of the few sources of information on water intake, but these data are limited by unaccounted water found in foods and the use of a single 24hr dietary recall (15; 20). Moreover, non-quantitative intake from water fountains and the likelihood that many people consume fluids with little thought leads to underreporting (19).

An alternative approach that does not depend on self-reported intake is the use of hydrogen labeled water turnover, a method used by comparative animal physiologists to

objectively measure water turnover in wild animals for decades (24). The procedure begins with a bolus administration of isotopically labeled water, such as non-radioactive deuterium oxide. Within two to three hours, this tracer equilibrates with body water and provides a measure of the volume of the total body water pool (32). The labeled water is then excreted from the body through all routes of water loss and, is diluted by unlabeled water through all routes of input. The time course of labeled water dilution provides a measure of water turnover (input and output) per unit time (12; 24).

We combined data from 2 studies in healthy, free-living, US adults across a broad age range in which deuterium labeled water was administered to measure total energy expenditure (TEE) using the doubly labeled water (DLW) technique (32). In one of these studies, two 24h urines were collected from many of these same participants using para-aminobenzoic acid (PABA) to confirm completeness. These data are among the first objective assessment of water turnover in US adults, and provide documentation of both the average and range of water input and urine production.

METHODS

To evaluate the water requirements of normal adults, we combined two data sets for which we measured water influx and efflux. The first was the Health, Aging and Body Composition (Health ABC) study conducted between July 1998 and August 2000 in Memphis, TN and Pittsburgh, PA. The main objective of Health ABC was to establish relationships between the changes in body composition and the development of early disabilities and mortality in the elderly. The second was the Observing Protein and Energy Nutrition (OPEN) study, which took place in Rockville, MD between August 1999 and March 2000. The main objective of the OPEN study was to assess the structure of dietary measurement error associated with food frequency questionnaires and 24-hour dietary recalls in middle-aged adults. The experimental protocols for Health ABC and OPEN have been previously described (9; 34). Data were combined from these two studies.

Participants

To be eligible in the Health ABC study, elderly persons had to be free of difficulties with activities of daily living and lower-extremity functional limitations, defined as difficulty walking one-quarter mile or climbing 10 steps without resting. Participants were recruited from a random sample of white Medicare beneficiaries, and all age-eligible black community residents in designated zip codes in and around Pittsburgh, PA and Memphis, TN. The Health ABC study involved 3075 participants aged 70 to 79 years stratified by race (Black, White) and gender. Of these, a sub-group of 323 individuals, with the same race and gender stratification, participated

in an energy expenditure study published elsewhere and thus were eligible for inclusion in the current analysis of water metabolism (9). Of the 323 participants, data from 40 were excluded, including 9 who did not have usable isotopic data, 16 who did not have different physical characteristics and 15 who were over 79 years old. Of the remaining 283 participants, 145 were White and 138 were Black. Because the Health ABC study included far more Blacks than the OPEN study and because Health ABC study included only one age group (70-79 y/o's), age related data analysis focused on White participants only.

The OPEN study involved 484 healthy participants aged 40 to 69 years (34). Among the 399 White participants in the OPEN study, 27 participants had unusable TEE and were excluded from the analysis. Of the 372 remaining participants, 59 participants either did not have 24 hour urines collected or their urines were deemed unusable due to incomplete PABA recoveries.

Together there were 458 White participants who had complete data and were included in the primary analysis, of which 145 participants were from the Health ABC study and 313 from the OPEN study. In addition, the 138 elderly Black participants (70-79 y/o) from the Health ABC study were included in a secondary analysis to examine race related differences in preformed water intake in the elderly population.

Protocol

In both the OPEN and Health ABC studies, TEE was measured using the DLW method according to protocols described elsewhere (9; 34). Briefly, participants made 2 visits approximately two-weeks apart. Prior to visit 1, participants fasted for 4hrs and in most instances overnight. Body mass was measured either in a clinic setting or in a hospital and baseline urine

samples were collected. Then, a dose of DLW was given orally to the participant. The dose provided approximately 1.9 g 10 atom% ^{18}O water and 0.12 g 99.9 atom% ^2H water per kg of estimated total body water (32). Urine collections were taken either at 2, 3 and 4hrs post dose (OPEN study) or 4 and 6hrs post dose (Health ABC study) to assess isotope equilibration in the body water. Plasma samples were collected at 4hrs post dose in participants above 60 years of age in the OPEN study and in all participants in the Health ABC study. The participants came back for visit 2 about fourteen days later and provided end dose urine specimens. Urine samples were stored in cryogenic stable tubes at -20°C before analysis by isotope ratio mass spectrometry.

All participants in the OPEN study were asked to collect two 24hr urines between visit 1 and 2. The urines were analyzed for urinary nitrogen, potassium and sodium. For 24hr urine collection, the participants were asked to take three PABA pills orally, one at each meal. The completeness of the 24hr urine collection was assessed using the amount of PABA excreted in urine as described by Bingham et al (8). When PABA recovery was greater than 85%, the subject's urine was considered complete. Recoveries less than 70% were removed from the analysis. When recoveries were between 70% and 85%, urine samples were considered usable after adjusting them to 93% recovery of PABA (n=51 of 935 24hr urines) (18). All samples in excess of 110% recovery by the colorimetric technique were analyzed by HPLC to distinguish between PABA and acetaminophen, a drug commonly taken by participants (n=123 of the 935 urines collected in the study).

Isotopic analysis

The isotopic analyses have been previously described for Health ABC as well as for OPEN (9; 36). Briefly, deuterium analyses were performed by chromium reduction according to Schoeller et al. (30) using a dual-inlet isotope ratio mass spectrometer (Delta Plus Mass Spectrometer, Finnigan MAT, San Jose, CA, USA). Oxygen-18 enrichments were measured by CO₂ equilibration on a Delta-S isotope ratio mass spectrometer (Finnigan MAT, San Jose, CA, USA) through a continuous flow inlet system developed in the laboratory (30). To protect against possible interference from post-void residual volume, plasma specimens were collected from the participants who were in their 7th and 8th decades of life. Urine analyses were used unless the enrichment differed by more than 2%, plasma enrichment was used for calculating TBW. Agreement was observed in 87% of participants.

Calculations

Total body water (TBW)

The isotopic dilution spaces (N) of deuterium and oxygen-18 were calculated according to Coward (10):

$$N \text{ (kg)} = (WA/1000a)(\delta_a - \delta_t) / (\delta_s - \delta_p);$$

Where *W* is g of water used to make a dilution of the dose water; *A* is g of dose water administered to the participant and *a* is g of dose water used in the dilution and; δ_a is isotopic abundance of the diluted dose water; δ_t is isotopic abundance of tap water used in dilution; δ_s is

isotopic abundance of post-dose specimen, δ_p is isotopic abundance of the pre-dose specimen; and isotopic abundances are measured in per mil units [δ ‰ = $(R/R_s - 1) \times 1000$, where R = Ratio of heavy to light hydrogen isotope in sample (R) and standard (R_s)]. The ratio of ^2H to ^{18}O dilution spaces averaged to 1.034 ± 0.018 .

TBW was calculated as an average of the deuterium dilution space (N_d) and the ^{18}O dilution space (N_o) after correcting for *in vivo* isotopic exchange using the equation (28) -

$$\text{TBW (kg)} = (N_o / 1.007 + N_d / 1.042) / 2$$

Total energy expenditure

The DLW derived carbon dioxide production ($r\text{CO}_2$) was calculated according to Schoeller et al (31):

$$r\text{CO}_2 \text{ (moles/d)} = 0.455 * \text{TBW} (1.007k_o - 1.041k_d),$$

where TBW is total body water in moles, and k_o and k_d are the oxygen and deuterium elimination rates per day, respectively. TEE was derived from the Wier's equation, assuming a respiratory quotient (RQ) of 0.86.

Water turnover

The water turnover (Kg/d) in the body was calculated from the deuterium dilution space and elimination rate (12):

$$r\text{H}_2\text{O} = N_d * k_d \text{ and}$$

$$k_d = [\ln (c_f - c_i)] / (t_f - t_i)$$

(N_d is the dilution space measured using deuterium and k_d is the fractional turnover rate of deuterium in the body water after equilibration) where c_f is the final abundance of deuterium in the urine, c_i is the initial abundance of deuterium in urine, t_f is the final time point and t_i is the

initial time point. In the calculation of water turnover, equality between the water influx and efflux was assumed.

Estimation of water influxes

Water influx is accounted for by metabolic water, inspiratory water (moisture content of inhaled air) transcutaneous water intake (water absorbed by the skin) and preformed water, (which is the water consumed orally from beverages and water in the food). Those variables were calculated using the following formulae described in Fjeld et al (12):

1) Metabolic water. Metabolic water production was calculated from the average macronutrient content of the diet of a normal healthy American according to the equation (12):

$$\begin{aligned} \text{Metabolic water (L/day)} = & \text{TEE} * (1/10^5) [(\% \text{Fat} * 0.119) + (\% \text{Protein} * 0.103) \\ & + (\% \text{Carbohydrates} * 0.15) + (\% \text{Alcohol} * 0.168)] \end{aligned}$$

where TEE is in kcal/d and where %fat, %protein, and %carbohydrate are taken as 31%, 14%, 52% and 4%, respectively, based on the values obtained from 24hr dietary recall #1 from the OPEN study. The percentages do not total to 100% due to a rounding error. The amount of water produced per kcal of substrate oxidized as fat, protein, carbohydrates and alcohol is 0.119, 0.103, 0.15 and 0.168 grams, respectively.

2) Inspiratory water. Inspiratory water was calculated as:

$$\text{Inspiratory water intake (g/d)} = \text{respiratory volume} * \text{absolute humidity}/1000$$

Where respiratory volume is in L/d and absolute humidity is in mg/L assuming average relative humidities of 35% for the winter period and 65% for the summer period at 24°C. Respiratory

volume was calculated from the $r\text{CO}_2$ obtained from DLW assuming that 3.5% of inspired air is CO_2 .

3) Transcutaneous water. Transcutaneous water influx was then calculated as:

$$\text{Transcutaneous water intake (L/d)} = (0.18 * (\text{absolute humidity}/21.7) * \text{BSA} * 1.44$$

where 0.18 is the rate of transcutaneous absorption in g/m^2 of body surface area in an atmosphere saturated with water vapor (21.7 mg/L). BSA is the body surface area (m^2) estimated from the Dubois formula (12). A clothing factor of 50% was assumed, as clothing would decrease the rate of evaporation through skin.

4) Preformed water intake. The preformed water was calculated by the difference between water turnover ($r\text{H}_2\text{O}$) and the sum of all the above-calculated values (metabolic water intake, inspiratory water intake and transcutaneous water intake).

Estimation of water efflux

Water efflux includes urinary water, fecal moisture and insensible water loss i.e. water lost through expiration, transcutaneous and sweat losses. **Urinary losses** were averaged for two 24hr urine collections ($n=313$) from participants in the OPEN study only. The mean difference between the two 24hr urine collections was 34.9 ml in women and 40.6 ml in men. We assumed average **fecal moisture** of 72% ($\pm 2\%$) and fecal weight from literature for a normal healthy individual consuming a typical American diet (4; 29). **Insensible water loss** was calculated as

the sum of transcutaneous, expiratory and sweat water. ***Expiratory water loss*** was calculated using the same formula as for inspiratory water influx but assuming a relative humidity of 97% in the expired air (14). Respiratory volume or tidal volume was calculated from the CO₂ production rate measured assuming that 3.5% of tidal volume was comprised of CO₂.

Sweat loss was calculated as the difference between the water turnover and the sum of expired, transcutaneous, fecal and urinary water losses.

Statistical analysis

Regression analyses were used to determine the effect of anthropometric variables (height, weight, age and BMI) on the preformed water intake. Analysis of variance and post-hoc Fischer's protected least significant difference test were performed to determine the effect of age on the preformed water intake. Intra-individual variability was determined from the coefficient of variation between the two 24hr urine collections. Statistical analyses were performed using STATVIEW software version 5.0.1. Results are expressed as mean \pm SD. A p-value of ≤ 0.05 was considered significant.

RESULTS

The anthropometric characteristics of 458 participants from the Health ABC and the OPEN study are presented in **Table 1**.

Water influx

Percentile distributions of preformed water intake from 251 male and 207 female participants are shown in **Figure 1**. Individuals varied widely in their preformed water intake, ranging from 1.4 to 7.7 L/day (mean 3.0 ± 0.9) for men and from 1.2 to 4.6 L/day (mean 2.5 ± 0.7) for women.

Average estimated values for water influx components - metabolic water intake, inspired water intake, transcutaneous water intake and preformed water, calculated by difference, are shown in **Table 2**, by age group and gender. Water influx values range from 1.9 to 8.6 L/day (mean 3.6 ± 0.9) in men and from 1.6 to 5.2 L/day (mean 3.0 ± 0.7) in women.

Percentile distribution of preformed water intake categorized by decade of age is shown in **Figure 2**. In both men and women, preformed water intake did not differ significantly among age groups until the 8th decade of life. The 70-79 y/o men had significantly lower preformed water intake than the 40-49 y/o men ($p=0.005$) and the 70-79 y/o women had lower preformed water intake than the 40-49 and 50-59 y/o women ($p=0.003$ and 0.03 respectively). There were no other significant differences in preformed water intake by age and gender ($p>0.05$, not detailed).

Univariate regression analysis of preformed water intake by gender using weight, age, height, BMI and urine output as independent variables are shown in **Table 3**. Univariate analysis of urine output showed a correlation with an r^2 of 0.51 and 0.47 with preformed water intake in men and women, respectively. None of the other variables assessed had a very biologically

meaningful correlation with preformed water intake. Multiple regression analysis with the same independent variables explained 57% and 61% of the variance of preformed water in men and women, respectively.

Physical characteristics of the 70-79 y/o Black and White participants are presented in **Table 4**. Among all the 70-79 year olds, preformed water intake was significantly lower in Blacks than Whites in both men and women ($p < 0.05$). Whites had significantly higher water turnover rates than the Blacks as well ($p = 0.01$). Gender differences among Blacks in this limited group were similar to Whites with respect to their weight, height, BMI, and TBW.

Body composition data were available for only the 70-79 years old participants. To ascertain if these elderly Black and White participants were subjected to chronic, hyperosmotic dehydration secondary to low water intake, we divided the elderly cohort into quintiles of preformed water intake and compared it with the hydration of fat free mass (FFM) (measured using dual X-ray absorptiometry (DXA)) among 70-79 year olds. The hydration of FFM (TBW/FFM) did not differ between quintiles of preformed water intake. Although the difference was not significant, the hydration of the lowest quintile of water intake averaged 0.3% greater than the highest quintile, with a group standard deviation of 0.4%. As water intake was calculated from our primary measures, the above was not adjusted for body size, so we performed the identical analysis using fractional water turnover (k_2) as the dependent variable. Again there was no effect of water turnover on hydration status in the eighth decade of life.

Water efflux

Average calculated values for water efflux and its components are shown in **Table 5** by age and gender. Fecal losses were artifactually equal in all the participants (0.07 L/d) because we used

the same assumptions of fecal weight and moisture content (4; 29). Insensible water losses (transcutaneous, expiratory and sweat losses), calculated by difference, were highly variable among age groups. The 60-69 y/o men showed significantly lower insensible water losses compared to the 40–49 and 50-59 y/o men ($p < 0.0001$ and 0.006 respectively) and the 60-69 y/o women showed significantly lower insensible water losses than the 40-49 y/o women ($p = 0.004$).

Distributions of urine volume in 134 women and 180 men, from the OPEN data, are shown in **Figure 3**. The urine output in men was 0.62 – 4.94 L/d (mean 2.18 ± 0.94) and in women was 0.91 – 4.87 L/d (mean 2.19 ± 0.75).

Intra-individual variability of the 24hr urine output was calculated using two 24hr urine collections from a subset of 90 women and 133 men from the OPEN study. The mean difference between the two 24hr urine collections was 34.9 ml in women and 40.6 ml in men ($p < 0.001$). Urine output did not vary significantly with age among women ($p > 0.05$), but the 60-69 y/o men had significantly higher urine output than the 40-49 and 50-59 y/o men as seen in **Figure 4** ($p = 0.04$ and 0.02 respectively).

DISCUSSION

This is an unusually large set of objective data on water intake and urine production for US adults. Data on water turnover has proven to be elusive in the past because objective and accurate measures of water intake and urine production were lacking. Virtually no large population data are available regarding individual consumption of drinking water in the United States since the 1977-78 NFCS data (2) and these data are based on self-report as against the objective data presented here. Our analysis showed that preformed water intake varied from as low as 1.2 L/d to as high as 7.7 L/d among 458 individuals 40 to 79 years old. There was a 15 ± 5 ml decrease in preformed water intake with every decade increase in age among both men and women. The decrease, however, was small and thus only discernable because of the large sample size. Interestingly, the preformed water intake in these individuals did not show a major change when the values were adjusted for their FFM indicating that in this large sample older subjects are not prone to any greater risk of chronic low water intake than younger subjects. Similarly, the 24hr urinary output values did not show any age related differences in women. The 24hr urinary outputs of 40-49 y/o and 50-59 y/o men, however, were significantly lower than the 60-69 y/o men.

Even though there were statistically significant age effects on water turnover and preformed water intake, the differences between the age groups were small, and thus the age independent mean values for water intake in adults between the ages of 40 and 79 years can be compared with the National Research Council daily recommendations for water intake (1). For this comparison, water input was expressed in milliliters per kcal of energy expended. The water input per kcal of energy expended in the current study was 1.1 ml/kcal/d in men ($TEE = 2746 \pm$

488 Kcal/d) and 1.2 ml/ kcal/d in women (TEE = 2138 ± 392 Kcal/d), which is slightly higher than the National Research Council's recommendation of 1 ml/kcal of energy expended (3). Many (38%) of our participants, however, had water intakes that were lower than recommended. Despite this, hyperosmotic dehydration was not observed. Unfortunately, our primary study design was not directed towards the determination of water requirements, and hence we do not have data on health indicators such as urine osmolality, stone formation, or urinary tract infection rates, all of which are good predictors of hyperosmotic conditions and dehydration (13). These observations therefore do not directly refute the NRC recommendation.

It has often been recommended that individuals consume at least eight-8oz glasses of water each day (≈ 1.9 L/d) (37), however, it is not clear what data formed the basis for this recommendation. Our data indicates that it is not based on an averaged actual intake. If an intake of 64oz of water were combined with the typical water content of food (≈ 1 L/d) (1) and individuals drank no other beverages, intake would be about ≈ 3 L/d or 1.2 ml/kcal/d (as for our participants). If they drank other beverages in addition to the 64oz of water, intake would be even greater. Preformed water intake at or above this level was observed in only 36% of our participants. Therefore, it is clear from these data that the recommendation that individuals consume eight-8 oz glasses of water daily is not consistent with observed water intakes in these healthy adults living in the US.

Our findings indicate that preformed water intake and urinary output were highly variable among individuals. Regression analysis of preformed water with urinary output and anthropometric variables (age, weight, BMI and height), showed that only 4-8% of the variability was explained by anthropometric variables. Thus, it is likely that individual behavior and not the physiologic differences we investigated account for most of these large interindividual

variations. In addition, we found that urine output accounted for 66% of the total water efflux, rather than the 50% assumed in the past (1). This percentage, however, is likely to be dependent on preformed water intake and ambient conditions.

It is unlikely that the large variability results from measurement error. The methods used herein to measure preformed water intake and urine output are more accurate than methods used in previous research. The urine collection employed PABA recovery to confirm complete collections and thus reduced errors associated with incomplete collections. The intake data is derived not from self-report, but from the deuterium technique and this has been validated for accuracy in animal models and humans (10, 23, 31).

An important caveat is that the deuterium method does not directly measure water intake. Preformed water intake constitutes only 80-85% of water turnover volume. Because of this, we corrected water turnover values for metabolic water, inspired water and transcutaneous water, which are estimated to constitute 16-18% of water influx volume. The assumptions made in these calculations are not perfectly accurate, but even if our assumption were in error by 25% for these minor routes of water metabolism, the relative error in preformed water intake would be less than 5%. As such, the accuracy of our estimates of preformed water intake is probably very high.

Our urine output data should also be considered accurate. Normally, 24hr urine collections are prone to error due to incomplete collection; however, we reduced this error by employing PABA as a tracer for complete collection (7; 8; 17; 18). The average PABA recovery was 103 ± 14 % for the data reported herein indicating little mean collection error.

Perhaps the greatest limitation in our methods was the use of DXA to assess %hydration of FFM. Dual-energy X-ray absorptiometry (DXA) is a widely used method for measurement of

body composition in humans (16). There is, however, a limit in the use of DXA in estimating the hydration of FFM. Changes in fluid balance in the body cause a small systematic and predictable error in DXA soft tissue composition analysis and can result in a misassessment of dehydration in the body. In a validation study by Lukaski et al (21), Sprague – Dawley rats were exposed to a variety of dietary stressors and changes in body composition were measured using DXA, decrease body mass and hydration status. DXA underestimated the body mass and FFM by 3% and significantly overestimated the fat mass, the greatest errors occurring in treatment groups in which body mass was diminished and body hydration was decreased (21). In addition, %hydration of FFM is, by its very nature, an insensitive measure of dehydration. A decrease in the TBW by 2% of body weight in a person with 20% body fat will result in a 2.5% decrease in FFM and a 3.4% decrease in TBW. The combined effect is a decrease in FFM hydration of only 1%. Whether this amount of decrease in hydration is detectable by DXA and TBW in humans is questionable. Also, DXA is known to be sensitive to changes in electrolytes. If a hyperosmotic condition exists, as in thermal dehydration where there is an increased loss of fluids relative to electrolytes, the changes in x-ray absorptions can lead to an overestimation of FFM by DXA (27) thereby masking the hydration status differences among age groups. The potential impact of this confounder cannot be ascertained in our data set.

Other limitations of this study include the fact that the participants were selected from only three geographic areas (suburban Washington DC, Pittsburgh, PA, and Memphis, TN) and that most were studied in fall or winter. Thus our data are limited both geographically and seasonally. Individuals living in hot climates would be expected to have increased sweat losses, decreased urine loss and/or increased preformed water intake. Thus, the data presented here hold only for adults doing low to moderate exercise with little exposure to extremes of temperature

and humidity. Racial differences were reported only in the elderly 70- 79 year olds due to non-availability of data in the younger age groups. Differences could not be explained by body size, but we did not investigate other causes. These differences could be due to cultural differences with regard to fluid intake or differences in socioeconomic status. The above however are purely speculations and further studies need to be done to identify the racial effect on fluid intake.

One of our aims for this analysis was to test whether the elderly had low intakes of water that might predispose them to chronic dehydration. We found that on average the oldest group of individuals had a preformed water intake that was 98% of that of the younger group of individuals when expressed per kcal of energy expended. Although our methods had limited sensitivity, we did not find any evidence of dehydration in the 70-79 y/o group, despite the majority of the individuals having intakes less than the commonly used suggestion of eight-8 oz glasses of water each day. Furthermore, recommendations to increase fluid intake to eight-8oz glasses of water in the elderly may not be prudent because the elderly have an elevated risk of overhydration due to an attenuated osmoregulatory mechanism (22). Instead, it may be better to concentrate on recommendations for increasing fluid intake during periods of acute thermal stress (11).

This is a large set of objective data on water intake and urine production in adults using methods to assess preformed water input and urine production that are more accurate than those used to assess these parameters in the past. We found no evidence of chronic hyper-osmotic dehydration among the elderly with lower than average preformed water intake although the sensitivity of DXA to small changes in hydration is limited. Furthermore, these data do not address the observation that elderly individuals are more prone to dehydration under acute stresses of reduced fluid intake and excessive fluid losses (11). Although our findings are not be

applicable to all climates and regions, these data provide the largest sample to date for preformed water intake from beverages and foods and urinary output for adults between 40 and 79 years.

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Legends for figures

Figure 1: Panel shows distribution of preformed water intake from 251 men and 207 women participants.

Figure 2: the percentile preformed water distribution are shown for each age group within genders. The 90th, 75th, 25th and 10th percentiles are indicated by the upper error bar, the roof of the box, the bottom of the box and the lower error bar respectively. The median is indicated by the horizontal line dividing the box. Age groups with the same superscripts differ significantly within genders ($p < 0.05$).

Figure 3: Panel shows the distribution of urine volume with 133 women and 180 men of 40 – 69 y/o. The urine output (mean \pm SD) of the men varied between 0.62 – 4.94 L/d (2.18 ± 0.94) and that of women varied between 0.91 – 4.87 L/d (2.19 ± 0.75).

Figure 4: the percentile 24-hr urine output distribution are shown for each age group within genders. The 90th, 75th, 25th and 10th percentiles are indicated by the upper error bar, the roof of the box, the bottom of the box and the lower error bar respectively. The median is indicated by the horizontal line dividing the box. Age groups with the same superscripts differ significantly within genders ($p < 0.05$).

Table 1: Mean anthropometric and TBW values of 458 participants – 251 men and 207 women white participants.

Variables	Units	40-49 yr	50-59 yr	60-69 yr	70-79 yr
MEN					
n		66	58	56	71
Weight	kg	83 ± 13	90 ± 16	89 ± 16	83 ± 13
Height	cm	178 ± 7	177 ± 6	176 ± 7	174 ± 8
BMI	kg/m ²	26 ± 4	28.7 ± 5	29 ± 4	27 ± 4
TBW	kg	42 ± 5 ^a	43.5 ± 6 ^b	42 ± 6 ^c	39 ± 5 ^{abc}
WOMEN					
n		49	48	36	74
Weight	kg	75 ± 21	70 ± 15	72 ± 11	68 ± 14
Height	cm	164 ± 6	162 ± 7	164 ± 5	161 ± 6
BMI	kg/m ²	28 ± 8	27 ± 6	27 ± 4	27 ± 5
TBW	kg	33 ± 5 ^{abc}	30 ± 4 ^{ac}	30 ± 3 ^{bc}	28 ± 4 ^c

Values represent mean ± SD. Cells with the same superscript are significantly different within gender (p<0.05).

Table 2: Mean water turnover and influx values (mean \pm SD) in men and women by decade of age..

		Mean water turnover	Metabolic water	Inspired water	Trancutaneous water	Preformed water
	n	L/d	L/d	L/d	L/d	L/d ⁺
MEN						
40-49 yr	66	3.81 \pm 1.24	0.39 \pm 0.07	0.11 \pm 0.02	0.09 \pm 0.01	3.22 \pm 1.19
50-59 yr	58	3.63 \pm 0.89	0.38 \pm 0.06	0.11 \pm 0.02	0.10 \pm 0.01	3.03 \pm 0.85
60-69 yr	56	3.55 \pm 0.92	0.35 \pm 0.06	0.10 \pm 0.02	0.10 \pm 0.01	3.00 \pm 0.87
70-79 yr	71	3.35 \pm 0.78	0.33 \pm 0.05	0.13 \pm 0.05	0.13 \pm 0.04	2.75 \pm 0.77
WOMEN						
40-49 yr	49	3.26 \pm 0.78	0.33 \pm 0.06	0.10 \pm 0.02	0.08 \pm 0.01	2.75 \pm 0.75
50-59 yr	48	3.03 \pm 0.77	0.28 \pm 0.05	0.08 \pm 0.01	0.08 \pm 0.01	2.58 \pm 0.73
60-69 yr	36	2.87 \pm 0.66	0.28 \pm 0.04	0.08 \pm 0.01	0.08 \pm 0.01	2.42 \pm 0.65
70-79 yr	74	2.79 \pm 0.66	0.25 \pm 0.04	0.10 \pm 0.04	0.11 \pm 0.04	2.33 \pm 0.64

+ - Calculated by difference between water turnover and the sum of the other influx variables

Table 3: univariate regression analysis of preformed water intake

Predictive variable	R ²	intercept	coefficient	P value
Men				
Weight, kg	0.052	0.673	0.615	<0.0003
Age, yr	0.03	3.877	-0.015	0.0043
Height, cm	0.008	0.486	0.014	n. s.
BMI	0.032	1.868	0.041	0.0034
Urine output, n=164	0.512	0.032	0.693	<0.0001
Women				
Weight, kg	0.012	2.084	0.006	n. s.
Age, yr	0.071	3.481	-0.016	0.0001
Height, cm	0.014	-0.116	0.016	n. s.
BMI	0.004	2.173	0.012	n. s.
Urine output, n=116	0.465	0.349	0.709	<0.0001

Table 4: Mean anthropometric and TBW values by race and gender among participants 70-79 years.

Variable	Black		White		
	Men	Women	Men	Women	
n	72	66	71	74	
Average weight	kg	81.9 ± 14.3 ^a	73.8 ± 16.6 ^{ab}	82.7 ± 12.5 ^b	68.2 ± 13.9
Height	cm	174 ± 6.9 ^a	160 ± 6.5 ^{ab}	174 ± 7.8 ^b	161 ± 5.9
BMI	kg/m²	27.3 ± 4.5	28.7 ± 5.8	27.4 ± 4.3	26.5 ± 5.3
TBW	kg	40.8 ± 5.5 ^{ac}	30.5 ± 4.6 ^{ab}	39.4 ± 4.8 ^{bd}	28.1 ± 3.9 ^{cd}
rH ₂ O	L/d	3.07 ± 0.7 ^{ac}	2.56 ± 0.6 ^{ab}	3.35 ± 0.8 ^{bc}	2.79 ± 0.7
Preformed water	L/d	2.5 ± 0.6 ^{ac}	2.1 ± 0.6 ^{ab}	2.8 ± 0.8 ^{bc}	2.3 ± 0.6

Values represent mean ± SD. Cells with the same superscripts significantly differ between gender and race categories ($p < 0.05$).

- ^a — significant difference between Black men and women
^b - significant difference between Black women and White men
^c - significant difference between Black men and White men
^d - significant difference between White men and women

Table 5: Mean water turnover and efflux values (mean \pm SD) by gender and age..

	n	Avg. water turnover L/d	Urine output L/d	Insensible loss L/d ⁺
MEN				
40-49 yr	66	3.81 \pm 1.24	2.09 \pm 0.96	1.61 \pm 0.79 ^a
50-59 yr	58	3.63 \pm 0.89	2.00 \pm 0.84	1.53 \pm 0.74 ^a
60-69 yr	56	3.56 \pm 0.92	2.45 \pm 1.01	1.00 \pm 0.67 ^b
WOMEN				
40-49 yr	49	3.26 \pm 0.78	2.05 \pm 0.70	1.11 \pm 0.68 ^a
50-59 yr	48	3.03 \pm 0.77	2.27 \pm 0.77	0.65 \pm 0.43
60-69 yr	36	2.87 \pm 0.66	2.27 \pm 0.78	0.49 \pm 0.54 ^b

+ - Calculated by difference between water turnover and the sum of the others efflux variables.

Age groups differing significantly within gender are indicated by different superscript.

Figure 1: Distribution of preformed water intake from 251 men and 207 women subjects.

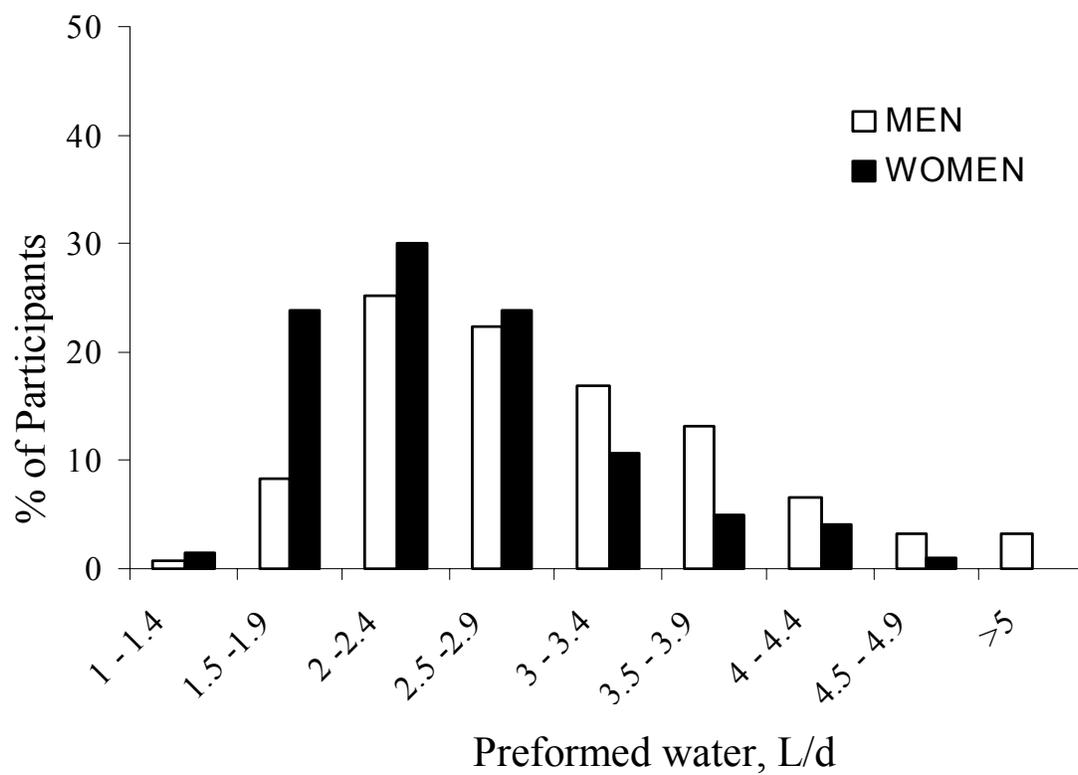
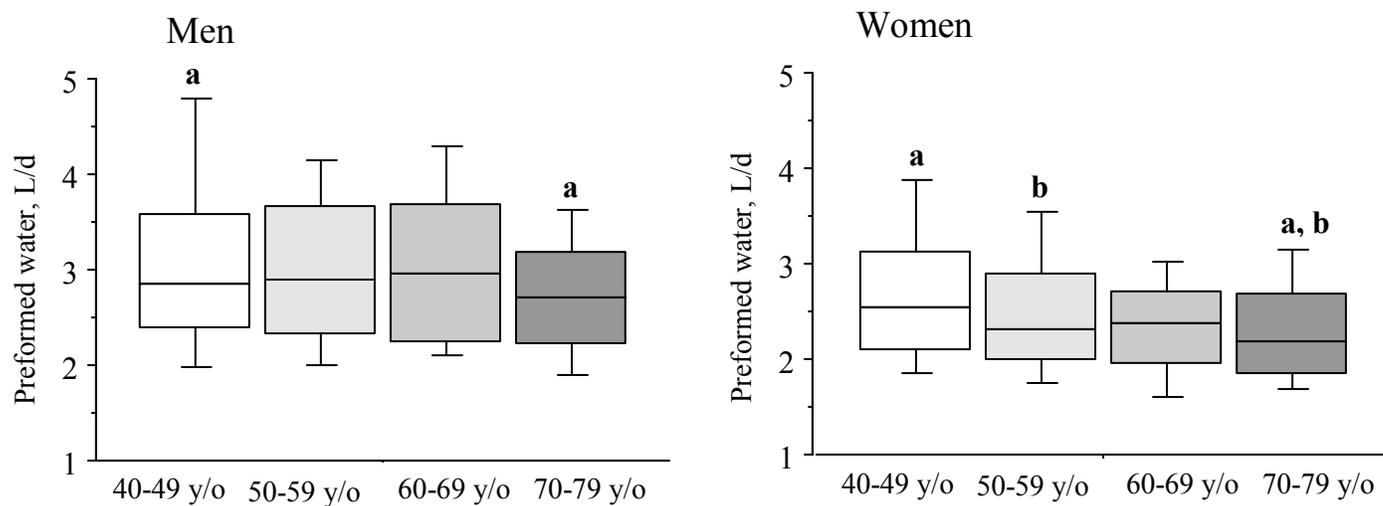


Figure 2: Percentile distribution of preformed water intake in 40 –79 y/o.

Age groups with different superscripts differ significantly in their mean values within genders ($p < 0.05$).

Figure 3: Distribution of urine volume in 133 women and 180 men subjects.

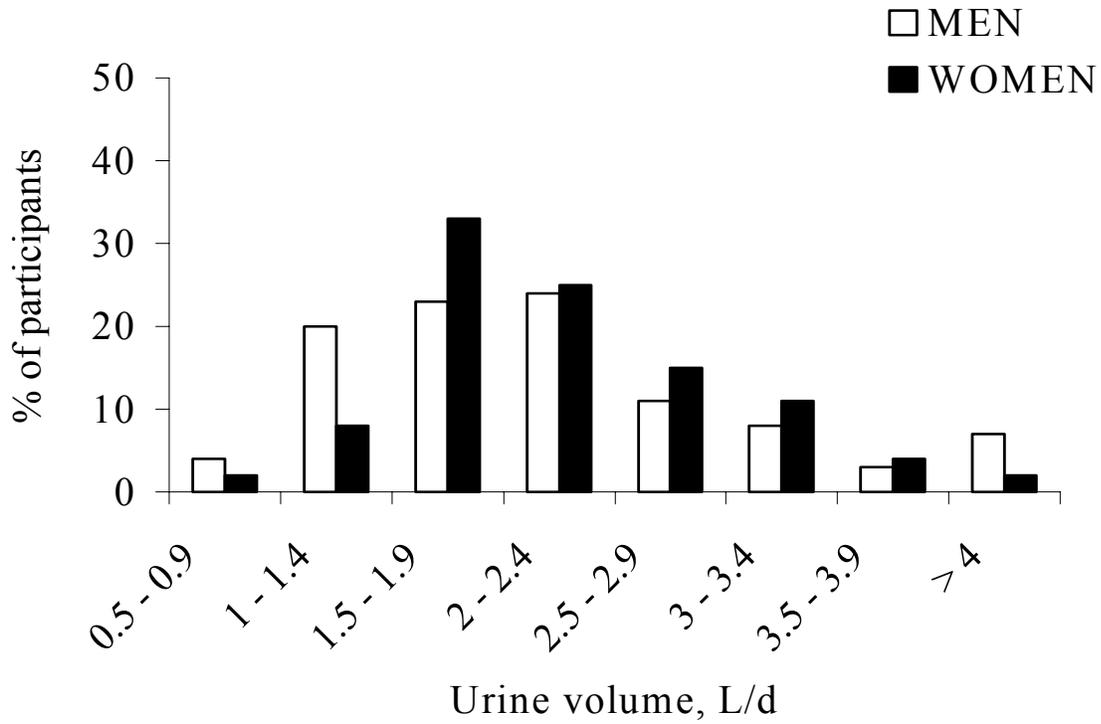
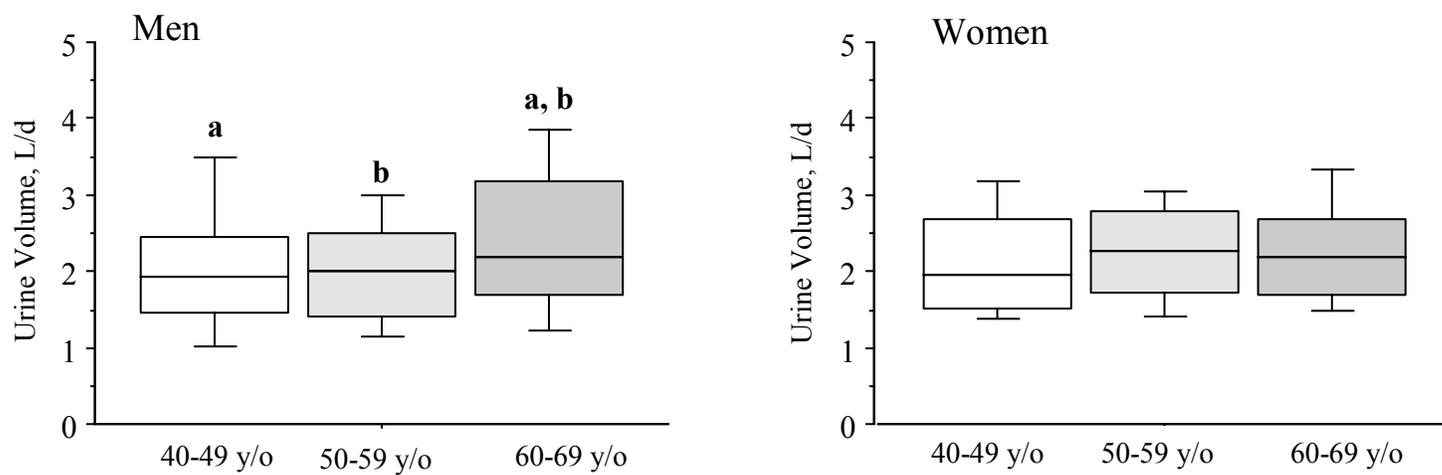


Figure 4: Percentile distribution of 24-hr urine volume in 40 –79 y/o.

Age groups with different superscripts differ significantly in their mean values within genders ($p < 0.05$).