Kidney International, Vol. 56 (1999), pp. 244–252

Total body water data for white adults 18 to 64 years of age: The Fels Longitudinal Study

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Background. Total body water (TBW) volume is reported to decrease with age, but much of the published data are 20 to almost 50 years old and are cross-sectional. Proper interpretation of clinical levels of TBW and trends with age necessitates the availability of current longitudinal data from healthy individuals.

Methods. Mixed longitudinal data for TBW of 274 white men and 292 white women (18 to 64 years of age) in the Fels Longitudinal Study were collected on a regular schedule over a recent eight-year period. The concentration of deuterium was measured by deuterium nuclear magnetic resonance spectroscopy. Body composition estimates were made with dual-energy x-ray absorptiometry, and random effect models were used to determine the patterns of change over time with and without covariates.

Results. The mean TBW data for the Fels men are either similar to or approximately 2 to as much as 6 liters greater than that reported by most other investigators 20 to 50 years ago. For Fels women, the mean TBW ranges from approximately 2 to as much as 5 liters less than that reported previously. These comparisons with much earlier studies reflect cohort effects and the secular changes in overall body size that have occurred during the past 60 to 70 years. These findings are reinforced by the fact that some early data sets included individuals born almost 140 years ago. After adjusting for the covariate effects of total body fat (TBF) and fat-free mass (FFM) with age, there were no significant age or age-squared effects on TBW in the men. In the women, after adjusting for the covariate associations of TBF and FFM with age, there was a small, but significant, negative linear association of TBW with age. In the men and women, the mean ratio of TBW to weight declined with age as a function of an increase in body fatness and more so for the men than the women.

Conclusion. The findings from these mixed longitudinal data indicate that TBW volume, on average, maintains a reasonable degree of stability in men and women through a large portion of adulthood. These TBW data are recommended as current reference data for healthy adults.

Key words: intracellular water, extracellular water, body weight, fat, obesity.

Received for publication November 6, 1998
and in revised form January 29, 1999
Accepted for publication February 10, 1999

Water is the major chemical component of the body and the essential medium of the body's internal environment [1–3]. Approximately 65% of total body water (TBW) is intracellular (ICW) with an 35% extracellular water (ECW) in the proverbial 70 kg person. TBW volume in a healthy, weight (WT)-stable adult reportedly fluctuates approximately ±5% daily because of ongoing physiological processes and the consumption of food and drink [1]. Differences in climate, salt intake, level of physical activity, and cultural habits are additional factors that affect the interindividual variance of levels of TBW, along with numerous pharmacological agents, most commonly caffeine [4, 5]. TBW volume is further affected by disease, especially renal insufficiency, along with diabetes, liver disease, cancer, and heart disease [6]. The proper interpretation of clinical levels of TBW as a function of disease necessitates the availability of timely corresponding comparative data from healthy individuals [7, 8].

Healthy adult men, on average, consistently have larger amounts of TBW than women as a function of their larger size and muscle mass [9, 10]. Mean values for TBW have been reported to range from approximately 35 to 45 liters in men and approximately 25 to 33 liters in women, depending on age [9–14]. The level of TBW reportedly starts to decrease around middle age in men and women and is rapid in women after approximately 60 years of age [3, 15, 16]. The average decline between 20 and 80 years of age is reported to be about 4 liters in men and 6 liters in women [9–11, 14, 17, 18]. A decline in TBW with age could be due to a reduction in the volume of ICW or the body cell mass and/or a fall in the volume of ECW [3, 16]. The latter is thought to occur with the aging process by some investigators [19, 20] but not others [11, 15].

Total body water comprises approximately 50 to 60% of adult body WT with a range from 45 to 75% [19, 21, 22]. The breadth of this range is due to sex and age differences and levels of leanness or fatness; that is, if there is more muscle, then there is proportionately more water, or if there is more fat, then there is proportionately less water [23, 24]. The ratio of TBW to weight (TBW/weight) also decreases in adults with age [19]. This decrease is a function of either a decline in TBW volume with aging or as a gain in weight and fatness that also occurs with increased age in many adults today [10, 14, 19, 25]. Body fatness is considered the most important factor, except for disease, in describing TBW content among individuals at any point in life [6]. However, the extent to which variations in levels of fatness among individuals affects TBW has not been presented. The effect of the level of fatness on the change in TBW with age is an important factor in interpreting the clinical management of TBW [16].

This article reports the status of TBW in normal adults and its relationship to increasing age and levels of body fatness. Most reported reference values for TBW are now several, if not many decades old, but their results are generally accepted and are still widely quoted. It is reasonable to consider how this earlier TBW literature compares with more current data. Also, the reported age and sex trends in TBW are from analyses of cross-sectional data. Such analyses cannot demonstrate an effect of age because of the independence of each subject and potential cohort effects. In order to demonstrate a real change with age requires the validity that comes from a longitudinal study of individuals followed over time [3]. This article looks at a set of mixed longitudinal data for TBW in white adults 18 to 64 years of age collected on a regular schedule over a recent eight-year period. These data allow the determination of patterns of intraindividual and interindividual changes in TBW relative to concurrent measures of body composition through the use of improved statistical models. This study also examines the relationship between levels of fatness and TBW. In light of the increased prevalence of obesity in the U.S. population over the past several decades [26], this increased fatness among adults and its effects on TBW values need to be considered. A better understanding of the status of TBW in normal adults living today should provide a useful comparison for clinical interpretations of TBW in cases of disease.

METHODS

This study sample included 274 Caucasian men and 292 Caucasian women between 18 and 64 years of age. These healthy participants were observed at regularly scheduled visits as long-term participants in the Fels Longitudinal Study [27] between 1989 and 1996. The Fels Longitudinal Study is an ongoing study of the growth, development, body composition, and aging of white persons born between 1929 and the present, approximately 75% of whom live in Ohio or contiguous states. Scheduled visits for participants were at two- to five-year intervals. In this mixed serial data set, there were one to four visits per participant, with a maximum of six years of follow-up. This produced a total of 504 visits for the men and 553 visits for the women. All procedures were approved by the Institutional Review Board of Wright State University (Dayton, OH, USA).

Stature and weight were collected according to standardized procedures at each visit [28]. To measure TBW, each participant provided a baseline saliva sample to determine the natural abundance of deuterium and then received 15 g of deuterium oxide (D_2O, 99.8%) in 150 cm^3 of water. A second saliva sample was taken at least two hours after the deuterium dose. The concentration of the deuterium dose in the specimen samples was measured by deuterium nuclear magnetic resonance (NMR) spectroscopy and was corrected for natural abundance and isotope exchange [29]. These procedures have been reported in detail previously [30].

Body composition estimates were made with dual energy x-ray absorptiometry (DXA) using a Lunar DPX™ machine with version 3.6z software (Lunar Radiation Corp., Madison, WI, USA). Fat-free mass (FFM) in kilograms was calculated as the sum of whole body lean tissue (g) and whole body bone mineral mass (g) divided by 1000. The total tissue mass (g) for the whole body was calculated as the sum of the total soft tissue and bone mineral mass values. Body composition values for the percentage of body fat (%BF) were calculated as whole body fat tissue (g) or the total body fat (TBF) divided by total tissue mass (g).

Statistical methods

Cross-sectional analysis. This set of mixed serial data was arranged into a cross-sectional format of five, 10-year age groups starting at 20 years of age in order to compare it with existing published data. An individual participant's data were represented only once within each age group, but it could be represented in two adjacent age groups. Descriptive statistics, including means and standard deviation, were computed for stature, weight, body mass index (BMI), and TBW for each participant. These calculations were also conducted for those participants who had concurrent measures of FFM, TBF, and %BF from DXA.

Longitudinal analysis. Using the complete mixed longitudinal data set, means and standard deviations for TBW and TBW/WT were computed for age groups separated into two-year intervals from 18 through 64 years of age for men and women separately. The means and one SD were plotted by the midpoint of the age intervals

Table 1. Means and standard deviations for 10-year age groups using one observation per participant in each age group

Variables	Units	Age groups: 20–29 years	30–39 years	40–49 years	50–59 years	60+ years
Men						
N		90	57	72	57	30
TBW	liters	41.90 ± 6.69	43.30 ± 6.13	43.94 ± 6.26	43.83 ± 6.99	42.87 ± 5.97
Weight	kgs	74.54 ± 13.00	81.41 ± 13.85	84.39 ± 11.88	86.42 ± 13.93	93.06 ± 15.37
Stature	cm	179.5 ± 7.20	179.8 ± 7.80	181.8 ± 8.61	177.7 ± 5.84	177.2 ± 6.03
BMI	kg/m^2	23.08 ± 3.60	24.18 ± 4.01	25.57 ± 3.37	27.33 ± 4.09	29.78 ± 5.68
*N**		69	39	57	40	24
TBF	kgs	14.90 ± 6.87	22.12 ± 7.29	22.90 ± 8.75	25.30 ± 9.40	28.08 ± 9.34
FFM	kgs	59.44 ± 7.74	60.30 ± 8.24	60.93 ± 7.25	60.33 ± 7.05	60.22 ± 4.76
PBF	%	19.50 ± 7.24	25.49 ± 6.60	26.80 ± 8.07	28.76 ± 8.09	31.19 ± 7.00
Women						
N		85	80	88	69	29
TBW	liters	30.70 ± 4.91	31.00 ± 4.54	30.72 ± 5.17	29.99 ± 4.15	27.80 ± 3.56
Weight	kgs	65.31 ± 14.83	67.13 ± 13.02	69.68 ± 16.27	70.29 ± 13.14	64.87 ± 11.72
Stature	cm	166.2 ± 7.00	166.1 ± 5.94	165.4 ± 5.75	165.5 ± 5.58	163.2 ± 6.65
BMI	kg/m^2	23.62 ± 5.16	24.28 ± 4.30	25.46 ± 5.69	25.65 ± 4.46	24.35 ± 4.26
*N**		59	62	65	61	27
TBF	kgs	23.34 ± 11.49	25.00 ± 9.76	27.60 ± 11.22	29.52 ± 9.99	25.88 ± 8.77
FFM	kgs	42.20 ± 5.21	41.99 ± 5.48	41.67 ± 5.32	41.13 ± 5.04	38.26 ± 4.76
PBF	%	33.97 ± 9.23	36.23 ± 8.70	38.57 ± 8.18	40.76 ± 7.53	39.40 ± 7.70

*N** is the sample size for those with DXA data. Data are mean ± SD. Abbreviations are: TBW, total body water; BMI, body mass index; TBF, total body fat; FFM, fat-free mass; PBF, percent body fat.

for TBW and TBW/weight. In addition, the relationships with age in the sample were explored in these data. Random effect models were used to determine the patterns of change over time in TBW. The parameters in the models characterized individual differences. This type of statistical model analyzes the complete set of serial and cross-sectional data and handles the occurrence of missing values and measurements taken at varying time intervals. Missing values are estimated by maximum likelihood procedures assuming that the pattern of change for an individual follows a pattern similar to the group. Random effect models also allow for the inclusion of covariates such as sex and amount of body fat [31].

RESULTS

Descriptive data

Means and standard deviations for the variables are presented cross-sectionally in Table 1 for men and women by 10-year age groups. Within each age group, the men were significantly taller and heavier and had more TBW and FFM and less %BF than the women. At the youngest age group, the women had more TBF than the men, whereas the men had significantly larger BMIs than the women at the oldest two age groups. Mean TBW from one age group to the next ranged from approximately 42 to 44 liters in the men and 28 to 31 liters in the women.

Total body weight comparative data

We compared the mean TBW volumes of these Fels men and women to corresponding mean values selected from reports by other investigators as early as the 1950s. This was a visual comparison because statistical methods were not always appropriate (Table 2). In some instances, distribution statistics were not presented. In others, only tabular lists were presented, and for some, there were differences in methodology or age ranges that were not comparable. In Table 2, reported means for three studies cover a 20-year rather than a 10-year age range. In the youngest age group, the mean TBW value for Fels men tended to be several liters smaller than that reported by Cohn et al [11], Edelman et al [8], and Watson et al [32], but larger than those values reported by Norris, Lundy, and Shock [13], Lesser and Markofsky [10], or Steele et al [14]. For the 30 to 39 year age group, the mean TBW values of the Fels men were again smaller than those reported by Watson et al [32] and Edelman et al [8], but larger than those of the other investigators. At the remaining age groupings, the mean TBW values of the Fels men were several liters larger than means reported by all the other investigators, except for the 40- to 49- and 50- to 59-year groupings for the data of Cohn et al [11] and the 60- to 69-year grouping for the data of Baumgartner et al [33]. In comparisons among the women, the Fels women had mean TBW volumes consistently smaller than those reported by Watson et al [32], Cohn et al [11], and Baumgartner et al [33] at all age groups. These four data sets (Fels, Watson, Cohn, and Baumgartner) had mean TBW values consistently larger than those reported for 20-year age ranges by Edelman et al [8], Steele et al [14], and Lesser and Markofsky [10] at all comparable age groups or groupings except the oldest. At the youngest and most contempora-

Table 2. Reported mean values for total body water (TBW in liters) for white adults by age and sex

Gender	Fels 1999		Watson 1980		Cohn 1980		Norris 1963		Baumgartner 1995		Edelman 1952		Steele 1950		Lesser 1979	
years	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW
Men																
20–29 years	90	41.9	171	43.3	24	46.9	4	39.4			34	44.1	12	36.6	12	41.1
30–39 years	57	43.3	93	44.1	10	41.0	23	41.7								
40–49 years	72	43.9	59	41.2	10	44.7	35	41.6			10	43.8	22	33.4		
50–59 years	57	43.8	68	39.7	10	45.2	30	39.9								
60–69 years	30	42.9	33	36.7	10	41.0	26	41.7	17	43.0	6	38.1	14	29.5	10	38.1
70–79 years			23	33.2	9	40.3	21	38.6	78	42.4						
80–89 years							4	39.1	31	40.4						
Women																
20–29 years	85	30.7	100	32.2	10	32.2					18	29.4	18	28.0	10	31.9
30–39 years	80	31.0	48	31.4	10	33.1										
40–49 years	88	30.7	37	32.1	10	31.5					6	28.3	4	26.4		
50–59 years	69	30.0	43	33.2	10	32.0										
60–69 years	29	27.8	19	32.6	14	28.5			50	30.9	5	28.4	5	25.0	13	29.5
70–79 years			5	25.8	8	26.6			80	29.6						
80–89 years									51	28.2						

} = spans pairs of age ranges, for example, 20–29 and 30–39.

neous matches, the means for TBW in the Fels men and women were less than that reported by studies. At older age groups, the mean TBW in Fels men was larger than in earlier studies, but the mean TBW in Fels women was smaller than reported in earlier studies.

Total body water relationships with age

The data sets of the earlier cross-sectional studies except Cohn et al all demonstrate a sequential decline in mean TBW volumes with each older age group [11]. This age trend only appeared in the Fels men at the 60-to-69 year age group and in the men in the study of Cohn et al at the 60-to-69 and 70-to-79 year age groups [11]. This trend also appears across the 30 year age range in the data of Baumgartner et al, but these data start at age 60 years [33]. The mean TBW volumes of the Fels women showed a decline with age starting at the 50-to-59 year age group. The only decline for women with age noted by others started at the 60-to-69 year age group in the data of Cohn et al and Baumgartner et al and at the 70-to-79 year age group [11] in the data of Steele et al and Watson et al [14, 32].

To determine more clearly the relationship of TBW with age in these data, the means and one standard deviation for TBW at two-year age intervals from 18 to 64 years are presented for the men and women separately in Figure 1. To test for age-related changes in TBW, a random effects model was applied to these mixed longitudinal data without any adjustments for possible covariates (Table 3). TBW was not significantly associated with age or age squared (age^2) in the men from 18 to 64 years of age. However, in the women from 18 to 64 years of age, there was a significant ($P < 0.05$) linear (age) and curvilinear or quadratic relationship of TBW with age^2 (Table 3).

Further age relationships with stature, weight and levels of FFM, TBF and %BF also were determined with a random effect model (Table 3). Within these mixed serial data, there were significant, positive linear associations of age separately with weight, TBF, and %BF among the men and women. There were no significant relationships of age with stature in the men or in the women, but a negative relationship of FFM and age in the women was marginally significant ($P < 0.051$).

To clarify these age relationships further, a random effects model for TBW including age, age^2, and TBF and FFM as independent variables was analyzed (Tables 3 and 4). After taking into consideration the interrelationships of TBF, FFM, and age within the model, again there were no significant age or age^2 effects on TBW in the men. In the women, after adjusting for the covariate associations of TBF, FFM, and age, there remained a small but significant negative linear association of TBW with age, but no significant quadratic relationship independent of TBF and FFM (Table 4). In the women, higher values for both TBF and FFM were associated with increased levels of TBW. In the men, higher values for FFM but not TBF were associated with increased levels of TBW.

Total body water and body composition

Total body water/weight had a significant linear decline ($P < 0.05$) with age in both the men and women (Table 3), but the decrease was greater in the men than the women. In the men, the mean TBW/weight at an age declined from approximately 58% at age 18 years to approximately 46% at age 64 years (Fig. 2). In the women, the decline with age was not as steep as in the men, with the mean TBW/weight decreasing from 48% at age 18 years to approximately 43% at age 64 years.

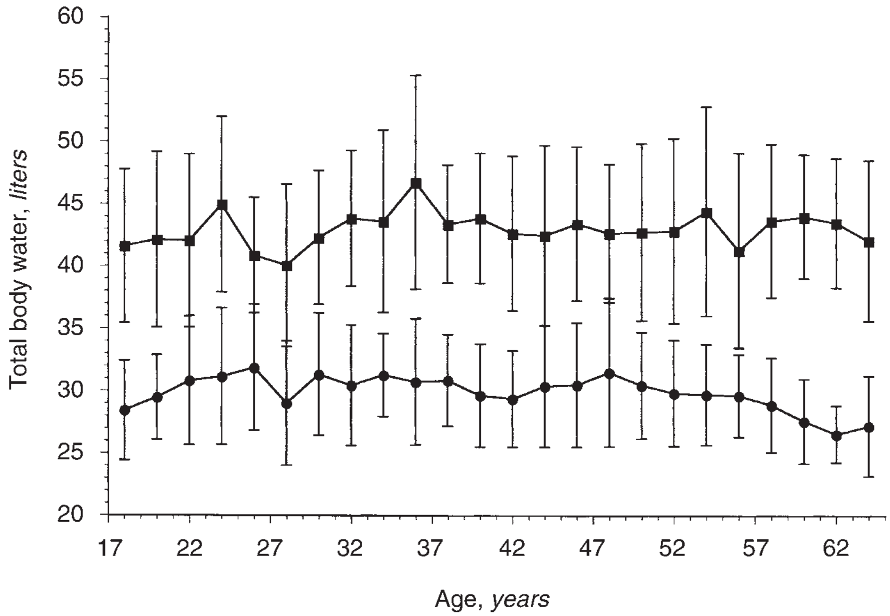

Fig. 1. Means and 1 SD for total body water (TBW) for males (■) and females (●) at two-year age intervals.

Table 3. Regressions of study variables on age using the random effects model

	Intercept	Age	Age^2
Men			
TBW *liter*	37.6	—	—
TBW/WT %	32.0	−0.22[a]	—
TBW/FFM %	70.0	—	—
Stature *cm*	179.9	—	—
Weight *kg*	63.0	0.49[a]	—
FFM *kg*	60.7	0.04	—
TBF *kg*	3.3	0.42[a]	—
%BF %	7.7	0.39[a]	—
Women			
TBW *liter*	22.5	0.46[a]	−0.01[a]
TBW/WT %	52.0	−0.15[a]	—
TBS/FFM %	72.0	—	—
Stature *cm*	165.9	—	—
Weight *kg*	54.1	0.35[a]	—
FFM *kg*	45.8	−0.051[a]	—
TBF *kg*	13.4	0.26[a]	—
%BF %	23.1	0.27[a]	—

Abbreviations are as in Table 1.
[a] $P < 0.05$

Because TBW did not change with age in the men, the decrease in TBW/weight in the men is due solely to an increase in weight over the age period. In the women, TBW decreased slowly with age, whereas weight increased with age. This small loss of TBW in the women implies a loss of FFM with age, which was marginally significant. However, an increase in weight in both the men and women signals an increase in fatness. To determine the extent to which the relationships of TBW and weight with age were associated with concurrent changes in body composition, the relationship of TBW to FFM, TBF, and %BF were explored. The percentage of TBW in FFM in both men and women (mean of approximately 0.68) did not change with age. This finding was not unexpected because there was little or no change with age in TBW or FFM in the men. In the women, because TBW and FFM were both declining slowly with age, then the ratio should remain relatively stable. These findings were confirmed with the random effects models, which showed no significant effects of age or age^2 on FFM for men and women.

In both the men and the women, TBF and %BF increased significantly with age. This increase in body fatness indicates that the decline in TBW/weight with age is, in great part, a function of an increase in body fatness and more so for the men than among the women. To clarify this relationship, a multiple regression of TBW/weight at an age on TBF and on %BF was conducted after removing associations with age among the variables. In the men and women, 40 to 45% and 44 to 56% of the variance, respectively, in TBW/weight was inversely related to the level of TBF or %BF, respectively; that is, the higher the level of fatness in an individual, the lower the TBW/weight. Thus, the interindividual variance in TBW/weight is, in large part, affected by the level of individual fatness rather than the level of TBW regardless of sex or age.

DISCUSSION

The volume of TBW in this study was measured *in vivo* by the dilution method using deuterium labeling and deuterium NMR [29]. Deuterium is the most commonly used solute, and its concentration can be quantitated accurately in body fluid specimens by mass spectrometry,

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