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Original Article

Normal Values of Total Body Water in Healthy Korean Adults: Comparison with Data from Western Populations

Moon-Jae Kim, Seoung Woo Lee, and Joon Ho Song

Division of Nephrology and Hypertension, Department of Internal Medicine, Inha University College of Medicine, Inchon, Korea.

To find reference total body water (TBW) values in healthy Korean adults, we performed single frequency bioelectrical impedance analysis on 2942 healthy adults and compared these data with those of normal western adults. Males were found to have greater TBW than females. Conversely, females were found to have greater percent fat (pFat) than males. In both sexes, body weight (BW) and TBW were significantly lower in age groups of < 30, 50 - 59, ≥ 60 years than in the 40 - 49 years age group. pFats were significantly higher in age groups of 50 - 59 and ≥ 60 years than in the 40 - 49 years age group. pFats were similar among age groups of < 30, 30 - 39, and 40 - 49 in both sexes. In all age groups, pFats were significantly higher in females than in males. TBW was significantly correlated with BW, height (HT), fat mass, and body mass index (BMI) in both sexes. There was a significant correlation between TBW and age in males($r=-0.15$, $p=0.00$), but not in females ($r=-0.02$, $p=0.45$). On linear regression analysis, TBW values were independently associated with BW, HT and age in males and were independently associated with BW and BMI in females. In all age groups, Korean males and females had lower mean TBW than in Western populations. However, this difference was greater in males than in females. In summary, we represented the contemporary normal TBW data in healthy Korean adults. At present, there are no national reference data relating TBW in Korea. We hope the results of this study will be useful as the baseline data for the evaluation of hydration and nutritional status in healthy and ill adults, including end-stage renal disease (ESRD).

Key Words: Total body water, bioelectrical impedance analysis, body composition

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Reprint address: requests to Dr. Moon-Jae Kim, Kidney Center, Inha University Hospital, 7-206, 3-Ga, Sinhung-Dong, Jung-Gu, Inchon 400-103, Korea. Tel: 82-32-890-2538, Fax: 82-32-890-2534, E-mail: nhkimj@inha.ac.kr

INTRODUCTION

Water is the most abundant compound in the body. Numerous diseases, especially chronic renal failure (CRF), affect total body water (TBW), where it plays a central role.[1] For accurate clinical interpretation of TBW in persons with CRF, the availability of up to date comparative reference data from healthy individuals is a prerequisite. As the majority of TBW resides in the skeletal muscle, TBW may serve as a proxy for somatic protein stores.[2] Normal values for TBW have been reported for white races,[3-5] but those for other racial groups are few, and restricted by the small sample sizes studied.[6,7]

TBW is accurately measured by the deuterium (^2H_2O) or tritium(^3H_2O) oxide dilution method. However, isotope dilution methods require expensive machines and cannot be applied to large populations. Numerous investigators have shown that TBW can be accurately and reliably estimated by bioelectrical impedance analysis (BIA).[8,9] Therefore, BIA has the potential to replace isotope dilution methods.

In this study, we present reference TBW values in healthy Korean adults using BIA. The availability of these TBW reference values should provide a useful tool for the clinical evaluation of TBW volume in persons with CRF and end-stage renal disease(ESRD) undergoing dialysis.

MATERIALS AND METHODS

For this study 2942 healthy adults were selected from the 3581 visiting the Health Promotion

Center (HPC) at Inha University Hospital between May and October 2000. The exclusion criteria were as follows: < 18 years of age, serum creatinine > 1.4 mg/dl, positive urine protein, subjects who complaining of edema, with an amputation or diabetes mellitus, congestive heart failure, chronic liver disease, or subjects that had not undergone bioelectrical impedance analysis (BIA). After an 8-hour fast, the subjects were admitted to the HPC at 9 a.m. Subsequently, their heights (HT) and body weights (BW) were measured to the nearest 0.1cm and 0.1kg using a linear height scale and electronic weighing scale, respectively. The mean values of two measurements were used for data analysis. BIA (GIF-891DX, Gil Woo Trading Co., Seoul, Korea) were performed by well-trained nursing staff. An inner electrode was attached to the dorsal surface of the right wrist, an outer electrode placed on the dorsal surface of the third metacarpal bone, and a second pair of electrodes positioned on the anterior surface of the ipsilateral ankle and the dorsal surface of the third metatarsal bone. A single frequency low-amplitude imperceptible current (800 μA at 50kHz) was introduced via the electrodes on the hand and foot. Electrodes on the wrist and ankle detected the voltage drop. The procedure was performed in 5 minutes or less. TBW, fat and lean body masses were automatically calculated from BIA. Percent body fat (pFat) and lean body mass (LBM)(pLBM) were calculated by the ratio of fat mass or LBM to weight, and multiplying by 100. Body mass index (BMI) was calculated with the equation BW/HT^2 (Kg/m^2).

Statistical analysis

Data are expressed as mean ± SD. TBWs were arranged into 5, 10-year age groups for both sexes (< 30, 30 - 39, 40 - 49, 50 - 59, ≥ 60 years of age). Employing the TBWs of the age group 40 - 49 years as reference, the other age groups were compared with ANOVA. Independent t-tests were used to compare the data between males and females in each age group. Linear regression analyses were performed to evaluate independent variables having an affect on TBW. We also compared these data with those of normal Western population (Chumlea et al.,[3,10] Watson et al.,[4] and Hume and Weyers[5]). A p value of less than 0.05 was considered as statistically significant.

RESULTS

Normal Korean TBW data

Means and standard deviations for TBW and other relevant variables are presented in 10-year age groups, by sex, in Table 1. Males had significantly larger HT, BW, TBW, pTBW, LBM and pLBM than females, except for fat and pFat in all age groups. In both sexes, BW and TBW were significantly lower in age groups of < 30, 50 - 59, ≥ 60 years than that of 40 - 49 years. In males, HT, BW, LBM and TBW were decreased for the age groups ≥ 50. However, fat mass remained unchanged regardless of age, resulting in higher pFat values for the age groups ≥ 50. In females, HT, BW, LBM and TBW were also decreased for the age groups > 50. BMIs were significantly higher in males compared to females until the age of < 60 years. Fat was similar between males and females in age groups of < 30 and 30 - 39. However, fat was significantly larger in females than in males after the age 40. Females had significantly larger pFat than males in the same age groups. pFats were significantly higher in the age groups 50 - 59 and ≥ 60 years than those in the 40 - 49 years age group in both sexes. pFats were similar among age groups of < 30, 30 - 39, and 40-49 in both sexes. In all age groups, pFats were significantly higher in females than in males.

Sex-specific plots of the 25th, 50th, and 75th percentiles for TBW data are presented in Fig. 1. TBWs were highest in age groups 40 - 49 and 50-59 years compared to other age groups. There was a trend(reversed U-shape) in the changes of TBW according to age groups in females. In males, TBW seemed to be similar in age groups of < 30, 30 - 39, and 40 - 49 years, although the age group < 30 years had lower TBW than those in the age group 40 - 49 years.

Correlation between TBW and other variables

TBW was positively correlated with BW (r= 0.861, 0.843), HT (r=0.613, 0.622), fat (r=0.379,

Table 1. Total Body Water and Other Body Composition Data in 10-Year Age Groups by Sex

	Age, years				
	< 30	30 - 39	40 - 49	50 - 59	60 ≤
Male					
N	115	532	678	405	145
HT(cm)	172.7 ± 5.7*†	170.0 ± 6.0*	169.5 ± 5.8*	167.4 ± 5.7*†	167.2 ± 6.5*†
BW(Kg)	67.5 ± 10.8*†	69.3 ± 10.4*	69.1 ± 9.4*	66.9 ± 9.5*†	66.1 ± 10.2*†
BMI(Kg/m^2)	22.6 ± 3.2*†	24.0 ± 3.0*	24.0 ± 2.8*	23.8 ± 2.8*	23.6 ± 2.9
TBW(Litre)	38.5 ± 5.0*†	38.9 ± 5.0*	38.9 ± 4.9*	37.2 ± 4.7*†	36.1 ± 5.8*†
pTBW(%BW)	57.4 ± 4.1*	56.4 ± 4.0*	56.5 ± 3.7*	55.9 ± 4.4*	55.0 ± 6.1*†
LBM(Kg)	52.6 ± 6.8*	53.1 ± 6.8*	53.0 ± 6.6*	50.9 ± 6.3*†	49.4 ± 7.8*†
pLBM(%BW)	78.4 ± 5.5*	77.0 ± 5.5*	77.1 ± 5.0*	76.5 ± 5.8*	75.3 ± 8.2*†
Fat(Kg)	14.9 ± 5.6	16.3 ± 5.2	16.0 ± 4.7*	16.2 ± 5.2*	15.9 ± 4.9*
pFat(%BW)	21.6 ± 5.4*	21.1 ± 5.0*	22.9 ± 5.0*	23.6 ± 5.3*†	23.8 ± 5.0*†
Female					
N	101	279	314	245	128
HT(cm)	160.4 ± 4.7†	159.3 ± 5.7†	157.7 ± 6.3	155.5 ± 5.9†	153.1 ± 6.6†
BW(Kg)	52.9 ± 7.6†	56.8 ± 8.7	58.8 ± 9.2	59.1 ± 8.1†	56.8 ± 8.5†
BMI(Kg/m^2)	20.5 ± 2.7†	22.3 ± 3.0†	23.6 ± 3.0	24.4 ± 2.9†	24.2 ± 3.3
TBW(Litre)	27.5 ± 3.4†	29.4 ± 4.4	29.8 ± 4.7	29.3 ± 4.1†	27.7 ± 4.1†
pTBW(%BW)	52.3 ± 4.2†	52.0 ± 4.2†	50.9 ± 3.6	49.7 ± 3.7†	49.0 ± 4.5†
LBM(Kg)	37.5 ± 4.7†	40.1 ± 6.0	40.8 ± 6.4	39.8 ± 6.1	38.0 ± 5.7†
pLBM(%BW)	71.4 ± 5.8	71.0 ± 5.7†	69.6 ± 4.9	67.5 ± 6.2†	67.3 ± 8.2†
Fat(Kg)	15.0 ± 3.8†	16.7 ± 4.3†	18.0 ± 4.6	19.3 ± 4.7†	19.2 ± 5.4
pFat(%BW)	28.1 ± 4.2	29.2 ± 4.7	30.4 ± 4.9	32.2 ± 5.1†	33.0 ± 6.4†

N, number; HT, height; BW, body weight; BMI, body mass index; TBW, total body water; pTBW, percent TBW (TBW × 100/BW); pLBM, percent LBM (LBM × 100/BW); pFat, percent Fat (Fat × 100/BW).
*$p<0.05$, vs. female in each age group, †$p<0.05$, vs. age group of 40 - 49 years in each sex.

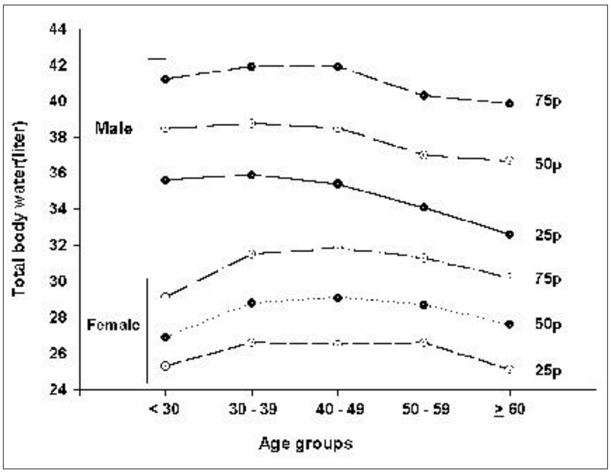

Fig. 1. Twenty-fifth, median, and 75th percentiles for total body water (TBW) for male and female at 10-year age intervals.

0.301) and BMI (r=0.664, 0.554) in both males and females. Age had a significant negative correlation with TBW (r=-0.15, p=0.000) in males, but no correlation with TBW (r=-0.023, p=0.454) in females. From the linear regression analyses, TBW values were independently associated with BW, HT and age in males, and with BW and BMI in females (Table 2).

Comparison of TBW with Western data

Table 3 shows our mean TBW data, together with the reported normal TBW values of Western populations. In all age groups, Korean males and females had lower mean TBWs than their corresponding Western populations. This difference was largest between our data and that of Chumlea,[10] especially for males. In Western male populations, mean TBWs were increased with progression of age with Chumlea data,[10] which showed larger TBWs for all age groups than other reported data. However, mean TBWs were similar

Table 2. Linear Regression Coefficients(R) and Standard Errors for Predicting TBW According to Sex

Dependent variable: TBW				
Sex	Predictor Variables	Regression coefficient	SE	R^2
Male				
	Intercept	-14.079	1.750	0.776
	BW	0.382	0.007	
	HT	0.163	0.011	
	Age	-0.029	0.006	
Female				
	Intercept	8.923	0.447	0.796
	BW	0.649	0.013	
	BMI	-0.738	0.035	

TBW, total body water; BW, body weight; HT, height; BMI, body mass index; SE, standard error.

Table 3. Comparison of Mean Values of Total Body Water (TBW in Litres) for Adults by Age and Sex

Age groups	Kim 2001 TBW	Chumlea 2001 TBW	Fels 1999 TBW	Watson 1980 TBW	Hume 1971 TBW
Male					
< 30	38.5	45.6	41.9	43.3	
30 - 39	38.9	47.5	43.3	44.1	
40 - 49	38.9	45.7	43.9	41.2	46.2
50 - 59	37.2	46.9	43.8	39.7	39.9
60 ≤	36.1	44.8	42.9	36.7	35.3
Female					
< 30	27.5	32.0	30.7	32.2	
30 - 39	29.4	33.2	31.0	31.4	
40 - 49	29.8	33.0	30.7	32.1	30.9
50 - 59	29.3	32.9	30.0	33.2	30.2
60 ≤	27.7	31.4	27.8	32.6	39.8

between the data of Chumlea[10] and Watson[4] for Western female populations.

DISCUSSION

In this study, we represented the current normal TBW data for healthy Korean adults. The changes in TBW with age were similar to those of western populations for both sexes. BW and stature showed independently positive effects in both sexes. However, fat mass had negative effects on TBWs only in females. These results were different from the data of Chumlea et al.,[10] in which fat mass had a positive and age had a negative effect on TBW. From our data, Korean males had lower fat masses, or BMIs, than in the corresponding Western males. This difference may cause low significance of fat mass on TBW. From our data age was found to have a negative effect on TBW in males, but no effect in females. Furthermore, the independent effect of age was smaller than other variables in males. These results could be due to the relatively small number of subjects in the age groups > 50 years for females, compared to that of male subjects. There also seems to be higher percentages of fat mass in females than males. The percentage of fat mass showed almost linear elevation with increasing age in the females in our study. Chumlea et al.[10] also pointed out the relative low effect of age on TBW. They explained the associations of LBM and fat mass, with age, are so strong that much of the observed association of TBW and age is a function of the covariate associations between TBW, LBM and fat mass. There is no consistent view in the literature of the impact of obesity on TBW. Chumlea et al.[3] suggested that TBW is inherently related to the level of total body fat and fat free mass. Woodrow et al.[11] and Johansson et al.[12] concluded that the Watson formula[4] overestimated V, and this was more apparent with increasing obesity, in agreement with the result in the present study. In these reports, the decline in TBWs with ages seems to be due to an increase in body fatness and a decrease in LBM. The influence of body fatness on TBW is greater in females than in males. Female pFats were significantly higher than for males in all age groups. On the other hand, Wong et al.[13] found that the Watson formula underestimated TBW compared with the deuterium dilution method. This was emphasised in patients who were defined as obese, i.e., body fat/BW > 25% (men) or > 30% (women). They concluded that as body fat increases, deviations increase.

Our study showed that Korean adults had lower TBW than Western populations. With the data showing greatest difference when compared with that of Chumlea at al.[10] Mean TBWs in males were about 7 - 9kg lower and those in females about 3 - 5kg lower when compared with contemporary Western populations. These results were different from the data of Jiang et al.[6] In their study, TBWs between Chinese and American were not different (36.4 ± 1.0 vs. 39.0 ± 1.8kg in males: 25.4 ± 1.3 vs. 28.5 ± 0.9kg in females). They suggested that difference of body weight between Chinese and American was mainly due to the alteration in body fat and extracellular water. However, the number of subject was small and the range of ages was relatively narrow, and young (between 20 and 40 years), compared to our study. Also, American subjects seemed not to represent their age groups. Their mean TBWs were about 5 - 8kg lower in males and about 3 - 5kg lower in females, compared to mean TBW values of normal Western populations.[3-5,10]

We performed single frequency BIA for the measurement of TBW instead of the gold standard method. BIA is a method used to determine TBW and LBM (lean body mass), by measuring the impedance (Z) to the flow of a low-level electrical current (800 μA) introduced into the body of the subject at a fixed frequency. BIA prediction equations are based on the principle that body's resistance is inversely proportional to TBW and that LBM contains 73.4% water. These equations were derived from using hydrodensitometry and 2-component model reference measures employing a linear regression model.[14] Hydrodensitometry (underwater weighing) is traditionally considered to be the method of reference for body-composition assessment, and is considered to have excellent reliability and validity.[15] The BIA equipment (GIF-891DX) in this study, which was produced by Gil Woo Trading Co., Seoul, Korea, also used prediction equations derived from hydrodensitometry(developed by Selco, Yokohama, Japan), which has been validated for assessing human body composition.[16-19] Prediction of body composition, including TBW by BIA, is reliable and has been validated.[8,9,20-22]

BIA has limitations on the assessment of TBW. BIA estimates volume with several untrue assumptions relating the human body.[23] First, the human body is assumed to be a single cylindrical shape with a uniform length (l) and cross-sectional area (A), whereas the human body more closely approximates a series of cylinders. Second, it is assumed that the conducting material within a cylinder is homogeneous, which it is not. Finally, ρ is an assumed constant, but will vary depending on the microstructure, hydration status, and electrolyte concentration, of the tissue. Also, prediction equations were developed by regression equations using demographic, and BIA data, as independent variables, and with TBWs, fat masses or LBMs being measured by reference methods assuming them to be dependent variables in Western populations. Therefore, when applied to the other races, over- or underestimation may occur. In this study, a race-specific BIA equation, which was derived from the Japanese one, was installed in our BIA equipment, assuming Koreans and Japanese to be racially identical.

The accurate measurement of TBW is difficult, requiring isotopic dilution techniques, which is not easily applied to our clinical setting. However, any methods, even gold standard methods, for the assessment of body composition are based upon assumptions allowing for some inherent errors. Gold standard methods are expensive, laborious and hard to applied to large numbers of subjects, as in this study. BIA does have several advantages though; it is easy to use, rapid, non-invasive, inexpensive and applicable at the bedside. Furthermore, numerous investigators have shown that TBW can be accurately and reliably estimated by single frequency BIA[8,9,24] in normal healthy subjects. Therefore, several indirect methods of estimating TBW, with simple demographic and anthropometric data, are commonly employed by researchers and dialysis units, using one of the following: the Watson formula,[4] the Hume formula[5] or the Chertow formula.[25] However, these equations are largely based on subjects from Western populations. Our data suggest the need for race-specific TBW equations. This need is also supported by the report of Chumlea et al.[10] In their study, blacks had larger mean TBW than their white counterparts in North America. In other words, TBW prediction equations may under- or overestimate real TBWs when these are applied to other races. Lee et al.[26] and Borgonha et al.[27] reported that anthropometry-based equations overestimated the TBW in Koreans and Indians. Zillikens and Conway[28] also showed that TBWs were significantly underestimated in black subjects when using equations developed for Caucasians.

In summary, we represented the contemporary normal TBW data for healthy Korean adults. Our study also found that Asian adults, such as Koreans, had lower TBW than Western populations. At present, no national reference data are available for TBW in Koreans. The results of this study could be useful as baseline data for the evaluation of hydration and nutritional status in healthy adults and ill patients, including ESRD.

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