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Total body water reference values and prediction equations for adults

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Background. The clinical interpretation of total body water (TBW) necessitates the availability of timely comparative reference data. The prediction of TBW volume in renal disease is critical in order to prescribe and monitor the dose of dialysis in the determination of Kt/V. In clinical practice, urea distribution (V) is commonly predicted from anthropometric equations that are several decades old and for white patients only. This article presents new reference values and prediction equations for TBW from anthropometry for white and black adults.

Methods. The study sample included four data sets, two from Ohio and one each from New Mexico and New York, for a total of 604 white men, 128 black men, 772 white women, and 191 black women who were 18 to 90 years of age. The TBW concentration was measured by the deuterium or tritium oxide dilution method, and body composition was measured with a Lunar DXA machine. An all-possible-subsets of regression was used to predict TBW. The accuracy of the selected equations was confirmed by cross-validation.

Results. Blacks had larger TBW means than whites at all age groups. The 75th TBW percentile for whites approximated the TBW median for blacks at most ages. The white men and black men and women had the largest TBW means ever reported for healthy individuals. The race- and sex-specific TBW prediction equations included age, weight, and stature, with body mass index (BMI) substituted for weight in the white men. The root mean square errors (RMSEs) and standard errors for the individual (SEIs) ranged from approximately 3.8 to 5.0 L for the men and from 3.3 to 3.6 L for the women. In both men and women, high values of TBW were associated with high levels of total body fat (TBF) and fat-free mass (FFM).

Conclusion. TBW in these healthy adults is relatively stable through a large portion of adulthood. There are significant race and sex differences in TBW. These accurate and precise equations for TBW provide a useful tool for the clinical prediction of TBW in renal disease for white and black adults. These are the first TBW prediction equations that are specific for blacks.

Key words: renal insufficiency, volume, body weight, cross sectional data, kidney disease, dialysis.

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Water is the most abundant compound in the body and is an essential regulator of its internal environment [1, 2]. Mean values for total body water (TBW) are reported to range from about 38 to 46 L in white men compared with approximately 26 to 33 L in white women, with smaller values occurring at older ages in both sexes [3–8]. TBW values for other racial groups are few and are further limited by the small sizes of the samples studied [9, 10]. TBW is affected by numerous diseases, most especially renal insufficiency [11], where it occupies a central role. The clinical interpretation of TBW in persons with renal disease necessitates the availability of timely, comparative reference data from healthy individuals. At the same time, the prediction of TBW volume in renal disease is critical in order to prescribe and monitor treatment [12]. TBW reflects urea distribution (V) and is used in calculating the dose of dialysis (or assessing its performance) in the determination of Kt/V, where "K" is urea clearance and "t" is the duration of dialysis [13–15]. In routine clinical practice, V is commonly predicted in peritoneal dialysis from the anthropometric equations for TBW developed by Watson et al [16], Hume and Weyers [17], or estimated as a fixed percentage of body weight [15, 18]. Recently, the Watson equations have been criticized because of the nonrepresentative nature of the sample used in their development [3]. Most TBW data and TBW prediction equations are several decades old. Their reported age relationships may reflect cohort effects rather than underlying biological differences, and they are for whites only.

This article presents new reference values together with new prediction equations for TBW in healthy white and black adults 18 to 90 years of age. These findings are from an assembled set of cross sectional data for TBW collected recently in Ohio, New Mexico, and New York. The availability of these TBW reference values together with accurate and precise TBW prediction equations for white and black adults should provide a set of useful and timely tools for the clinical evaluation of TBW volume in persons with renal disease and those undergoing dialysis.

METHODS

Samples

The study sample was assembled using four data sets. Two data sets were from the Division of Human Biology (Department of Community Health, Wright State University School of Medicine, Dayton, Ohio, USA); one set was from the New Mexico Aging Process Study (Clinical Nutrition Program, Center for Population Health, University of New Mexico School of Medicine, Albuquerque, New Mexico), and one set was from the Body Composition Laboratory (St. Luke's-Roosevelt Hospital, Columbia University College of Physicians and Surgeons, New York, NY, USA). This collaborative research effort was necessary in order to assemble a large sample of measured TBW data for normal white and black adults over as broad an age range as possible. These healthy free-living individuals were cohorts of volunteers not selected because of the presence of any disease or body composition criteria. They were not participating in any clinical trials or undergoing treatment for obesity. The institutional review board of the corresponding university at each study site approved all research procedures.

The sample from the Division of Human Biology (DHB) consisted of a cross-sectional set of 334 white men, 20 black men, 354 white women, and 42 black women who were between 18 and 64 years of age [19, 20]. The sample from New Mexico consisted of another cross-sectional set of participants from the New Mexico Aging Process Study (NMAPS) and included 58 white men and 98 white women who were 60 to 94 years of age [21, 22]. The cross-sectional sample from St. Luke's-Roosevelt Hospital (St. Luke's) included 212 white men, 108 black men, 320 white women, and 149 black women who were 18 to 94 years of age. Combined, these data sets contained a total of 604 white men, 128 black men, 772 white women, and 191 black women. An individual's racial identification was self-determined.

Stature and weight were collected using standardized procedures at each study site [23]. Total body water was measured at the Ohio and New Mexico sites by the deuterium oxide (^2H_2O, 99.8%) dilution method and was corrected for natural abundance and isotope exchange [24]. The concentration of the natural abundance of deuterium and the deuterium dose in the saliva specimen samples (collected after 2 or 3 hours) was measured by deuterium nuclear magnetic resonance (NMR) spectroscopy. The TBW of the participants at St. Luke's Hospital was measured using tritium oxide (^3H_2O, 200 μCi). The concentration of ^3H_2O in plasma was measured by scintillating counting, and a nonaqueous phase correction was made [25]. These procedures have been reported in detail previously [26, 27].

Body composition estimates were made at each study site with Lunar DPX, DXA machines using 3.6z software. 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. 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 percentage body fat (%BF) were calculated as whole body fat tissue (g) or total body fat (TBF) divided by total tissue mass (g).

TBW reference values

The combined cross-sectional data were arranged into a format of seven, 10-year age groups by race and sex starting at 20 years of age. Those participants less than 20 or older than 90 years of age were grouped with the corresponding adjacent age group. Descriptive statistics, including means and standard deviations, were computed for TBW, weight, stature, and body mass index (BMI) for each participant along with concurrent measures of TBF, FFM, and %BF from DXA.

TBW prediction equations

Participants within each sex and race group were assigned randomly and equally to either a validation or a cross-validation group. The sex- and race-specific validation groups were used to develop the prediction equations, and the corresponding cross-validation groups were used to cross-validate the selected equations. An all-possible-subsets of regression analysis was performed using the validation group to predict TBW from weight, stature, BMI, and age. This procedure develops and evaluates equations that contain all the possible combinations of the independent variables, that is, $2^p + 1$ equations, when there are P potential independent variables [28]. The regression model with the lowest root mean square error (RMSE) and Mallow's Cp [29] was tentatively selected as the model for predicting TBW for a group.

The accuracy of the selected equation models from the validation groups was confirmed by applying them to the corresponding cross-validation groups. This accuracy was determined by a comparison of the RMSE with the corresponding pure error [28]. A final set of sex- and race-specific equations was then derived after merging

Table 1. Means and standard deviations in ten-year age groups by race and sex

		Age groups													
		20–29 years		30–39 years		40–49 years		50–59 years		60–69 years		70–79 years		80–89 years	
	Units	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
White men	*N*	137		98		101		87		74		59		48	
TBW	*liter*	45.6[a]	7.9	47.5	7.3	45.7[a]	6.7	46.9	7.4	44.8	6.46	44.1	5.2	42.5	4.9
Weight	*kg*	76.2	13.8	82.3	16.3	82.2	11.7	85.2	13.7	85.3	14.9	75.8	11.9	74.2	10.5
Stature	*cm*	179.2	7.5	178.0	7.3	178.9	8.1	176.8	7.3	175.4	6.7	173.9	6.7	171.7	6.2
BMI	*kg/m²*	23.7	3.9	25.9	4.8	25.7	3.3	27.3	4.1	27.7	4.8	25.0	3.3	25.1	3.1
TBF	*kg*	13.1	7.8	19.4	10.1	20.4	8.3	22.8	8.2	23.4	8.8	20.8	8.0	21.2	8.2
FFM	*kg*	62.7	8.5	62.9	8.8	61.7[a]	7.4	62.5	8.5	60.6	7.0	54.9[a]	5.9	52.5	5.4
%BF	%	16.5	7.7	22.6	7.7	24.3	7.8	26.2	6.6	27.1	6.8	26.7[a]	6.9	28.1	7.9
Black men	*N*	21		20		26		19		19		23			
TBW	*liter*	50.9	7.6	50.7	8.8	50.8	8.0	46.9	7.0	46.4	5.5	44.2	5.4		
Weight	*kg*	78.4	12.3	83.4	16.4	86.8	14.6	82.9	18.1	82.3	14.2	77.0	11.6		
Stature	*cm*	179.1	7.3	175.6	8.3	177.8	6.8	173.1	5.5	172.6	4.9	172.3	7.0		
BMI	*kg/m²*	24.4	3.1	27.0	4.5	27.4	3.7	27.6	5.8	27.6	4.2	25.9	3.2		
TBF	*kg*	13.3	6.4	19.7	9.8	21.5	6.6	20.7	9.9	21.8	9.8	18.5	7.5		
FFM	*kg*	65.1	9.1	63.6	9.4	65.2	9.2	62.2	9.9	60.5	6.5	58.4	7.2		
%BF	%	16.5	6.2	22.8	7.8	24.4	4.8	23.7	7.9	25.4	8.1	23.6	6.4		
White women	*N*	124		130		104		135		117		91		71	
TBW	*liter*	32.0[a]	5.0	33.2[a]	4.5	33.0[a]	5.6	32.9[a]	4.8	31.4[a]	4.9	30.9[a]	4.3	30.2	3.9
Weight	*kg*	62.4[a]	12.4	63.6[a]	13.7	68.5[a]	15.5	71.7[a]	15.4	67.0[a]	11.8	60.9[a]	11.3	59.5	9.0
Stature	*cm*	166.0	7.0	164.7	6.0	165.0	5.5	164.8	5.4	161.6	5.7	158.5	6.4	156.2	6.3
BMI	*kg/m²*	22.6[a]	4.2	23.4[a]	4.8	25.2[a]	5.5	26.5[a]	6.0	25.7[a]	4.8	24.2[a]	3.9	24.4	3.4
TBF	*kg*	18.4	8.8	19.9[a]	9.3	24.8[a]	10.9	28.3[a]	11.8	26.5[a]	9.2	23.8[a]	8.9	23.5	7.5
FFM	*kg*	44.1	6.2	43.1	5.3	43.5[a]	6.6	43.2[a]	6.2	40.2[a]	4.7	37.1[a]	4.3	35.9	3.3
%BF	%	28.5[a]	8.8	30.4[a]	8.2	35.0[a]	8.9	38.2[a]	9.1	38.7	7.9	38.0	7.8	38.8	7.4
Black women	*N*	15		27		33		41		44		30			
TBW	*liter*	39.1	8.3	36.6	5.3	37.8	5.0	38.7	6.4	34.1	4.9	32.9	4.3		
Weight	*kg*	77.5	26.2	74.2	14.7	79.8	16.2	85.5	18.1	75.3	14.5	70.9	14.7		
Stature	*cm*	164.3	6.0	165.8	5.3	164.9	5.9	163.7	6.7	161.1	6.3	157.1	6.1		
BMI	*kg/m²*	28.6	9.2	27.0	5.1	29.3	5.1	32.0	7.0	29.0	4.9	28.7	5.5		
TBF	*kg*	29.8	20.4	28.8	12.1	32.6	10.6	38.6	11.1	31.1	10.4	28.9	11.3		
FFM	*kg*	47.5	9.0	45.3	5.7	46.0	6.1	47.5	7.9	44.4	7.3	42.0	5.1		
%BF	%	35.4	12.7	37.5	9.7	40.7	6.7	44.3	5.2	40.3	8.7	39.4	8.2		

Abbreviations are: TBW, total body water; BMI, body mass index; TBF, total body fat; FFM, free fat mass; %BF, percent body fat.
[a] Significant race difference, $P < 0.05$

the corresponding sex- and ethnic-specific validation and cross-validation groups together so as to increase the available sample size in each sex and race group.

RESULTS

TBW reference values

Means and standard deviations for TBW and the other relevant variables are presented in ten-year age groups by sex and race in Table 1. Within each age and sex group, the men were significantly taller and heavier and had more TBW and FFM than the women. The women had more TBF and %BF than the men. There was a trend for the black men to have larger means for TBW than the white men at all of the age groups, but these differences were significant ($P < 0.05$) at the 20 to 29 and 40 to 49 years age groups only. There was a similar trend for black men to have larger means for FFM than the white men, but these differences were statistically significant only at the 40 to 49 and the 70 to 79 years age groups. The black women had significantly larger means for TBW than the white women at all comparable age groups. The black women also had larger means for FFM, TBF, and %BF than the white women at most of the comparable age groups, and most of these were statistically significant. Sex- and race-specific plots of the 25th, 50th, and 75th percentiles for these TBW data are presented in Figures 1 and 2. In the men and the women, the 75th percentile for TBW for the whites approximated the median values for the blacks at most ages.

TBW comparative data

We compared the mean TBW volumes of these white and black men and women to corresponding mean values selected from available published reports by other investigators over the past 36 years (Table 2). This was a visual comparison only because in some instances, distribution statistics were not presented or only tabular lists were available. It should be noted that the present data for whites contains, in part, data presented in Table 2 for Fels from the DHB [3]. For the white and black men in the present study, the means for TBW are to our knowledge the largest ever reported at any age grouping for healthy individuals. Depending on the age and race

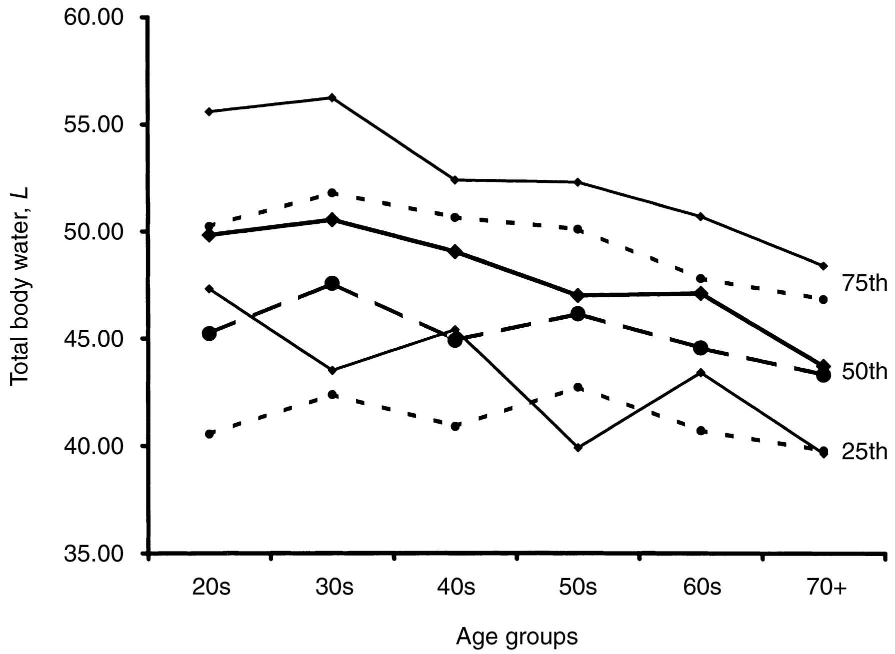

Fig. 1. Twenty-fifth, median, and 75th percentiles for total body water (TBW) for white (●) and black (◆) men at 10-year age intervals.

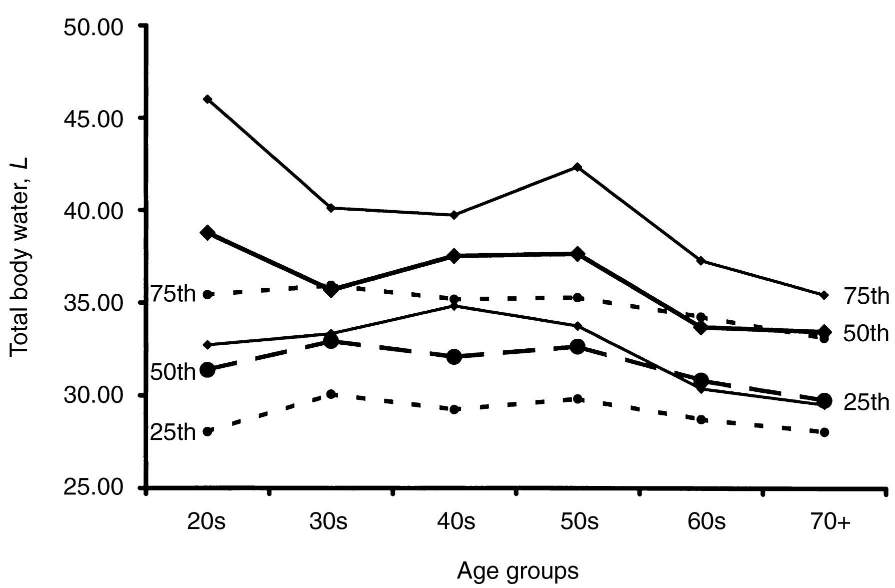

Fig. 2. Twenty-fifth, median, and 75th percentiles for total body water (TBW) for white (●) and black (◆) women at 10-year age intervals.

groupings, the present means for TBW in the men are anywhere from 2 to as much as 9 L larger than previously reported averages. In comparisons among the women, the present white women have mean TBW volumes similar to those reported by Watson et al [16] and Cohn et al [6] at all age groups, but larger than those reported for Fels women. The black women have TBW means that are from 2 to as much as 8 L greater than that of previously reported TBW means for white women.

TBW prediction equations

The TBW prediction equations developed in the sex- and race-specific validation groups had stature, weight, age, and BMI as the possible independent variables (Table 3). Weight had the highest correlation with TBW of all the independent variables for both whites and blacks. For white men, the addition of age and BMI into the equation increased the R^2 approximately 4 to 5% and reduced the RMSE about 0.2 L. For black men, the addition of age and stature increased the R^2 about 14% and reduced the RMSE by approximately 1 L. For white and black women, the addition of age and stature into the respective equations increased the R^2 approximately 6 to 7% and reduced the RMSE approximately 0.2 to 0.4 L. In these equations, the increase in the number of

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

Age	Present study													
	Whites		Blacks		Fels 1999		Watson 1980		Cohn 1980		Norris 1963		Hume 1971	
years	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW	*N*	TBW
Men														
20–29	137	45.6	21	50.9	90	41.9	171	43.3	24	46.9	4	39.4		
30–39	98	47.5	20	50.7	57	43.3	93	44.1	10	41.0	23	41.7		
40–49	101	45.7	26	50.8	72	43.9	59	41.2	10	44.7	35	41.6	5	46.2
50–59	87	46.9	19	46.9	57	43.8	68	39.7	10	45.2	30	39.9	16	39.9
60–69	74	44.8	19	46.4	30	42.9	33	36.7	10	41.0	26	41.7	7	35.3
70–79	59	44.1	23	44.2			23	33.2	9	40.3	21	38.6		
80–89	48	42.5									4	39.1		
Women														
20–29	124	32.0	15	39.1	85	30.7	100	32.2	10	32.2				
30–39	130	33.2	27	36.6	80	31.0	48	31.4	10	33.1				
40–49	104	33.0	33	37.8	88	30.7	37	32.1	10	31.5			9	30.9
50–59	135	32.9	41	38.7	69	30.0	43	33.2	10	32.0			12	30.2
60–69	117	31.4	44	34.1	29	27.8	19	32.6	14	28.5			5	39.8
70–79	91	30.9	30	32.9			5	25.8	8	26.6				
80–89	71	30.2												

Table 3. Prediction of TBW Models in the Validation Groups

Sex and race group	Predictor variables	R^2	RMSE	Cp
Men				
White	Weight	0.43	5.3	26.2
	Age, weight, BMI[a]	0.48	5.1	3.1
	Age, weight, stature, BMI	0.48	5.1	5.0
Black	Weight	0.63	4.9	35.7
	Age, weight, stature[a]	0.77	3.9	3.2
	Age, weight, stature, BMI	0.77	3.9	5.0
Women				
White	Weight	0.34	4.0	45.6
	Age, weight, stature[a]	0.41	3.7	3.2
	Age, weight, stature, BMI	0.41	3.8	5.0
Black	Weight	0.68	3.7	24.3
	Age, weight, stature[a]	0.75	3.3	3.2
	Age, weight, stature, BMI	0.75	3.3	5.0

Abbreviations are: BMI, body mass index; RMSE, root mean square error; Cp, Mallow's Cp value.
[a] Selected model

independent variables reduced the value of Mallow's Cp. The models with the highest R^2, smallest RMSE and Cp values, or the Cp value that was closest to the number of independent variables were selected [28]. These models included age, weight, and stature for white and black women and black men and age, weight, and BMI for the white men.

These models were applied to their respective cross-validation samples, and the pure errors were calculated to determine their performance (Table 4). The pure error and the RMSE are conceptually similar but differ in value [28]. The closer the pure error is to its corresponding RMSE, the greater the confidence in the predicted TBW for an independent group and the greater the comparative accuracy of the equation when applied to other independent samples. The cross-validation pure errors were all smaller than their corresponding validation RMSEs except for the black women, where the pure error of 3.4 L was just slightly larger than the corresponding RMSE value (Table 4). These cross-validation results indicate that when these prediction models are applied to independent groups, the subsequent prediction errors should be similar to or smaller than the prediction errors for the groups from which the equations were developed. These results demonstrate the accuracy of developed equations when applied to an independent sample.

The sex-specific equations of Watson and of Hume and Weyers were also applied to the cross-validation data in order to determine their respective accuracy or pure errors and to compare them with the present equations (Table 4). The pure errors of the Watson equations when applied to the current men and women are much larger than their corresponding RMSEs, except for the white woman. The pure errors of the Hume and Weyers equations were even larger than those of the Watson equations when compared with their RMSE values.

The accuracy of prediction for the Watson and the Hume and Weyers equations compared with the present equations is larger for blacks than for whites. This race difference in predictive accuracy is expected since both the Watson and the Hume and Weyers equations were developed from samples of whites only. The Watson and the Hume and Weyers equations produced predicted results with larger errors in the present study samples than those of the newly developed prediction models and of the original samples used to develop these old equations. This indicates that the accuracy of the Watson and the Hume and Weyers equations is not as good as that of the present prediction equations. Furthermore, Watson and Hume and Weyers equations do not provide a standard error for the individual (SEI), and thus, it is

Table 4. Measures of performance of the selected models for total body water (TBW) in the validation and cross-validation groups, along with the performance of the equations of Watson and of Hume and Weyers

	Men						Women					
	Present equations		Watson equation		Hume & Weyers equation		Present equations		Watson equation		Hume & Weyers equation	
	RMSE	PE	RMSE	PE	RMSE	PE	RMSE	PE	RMSE	PE	RMSE	PE
Whites	5.1	4.9	3.8	5.4	2.1	5.1	3.7	3.5	3.6	3.7	1.8	3.8
Blacks	3.9	3.8		5.8		5.8	3.3	3.4		4.0		3.7

Abbreviations are: RMSE, root mean square error; PE, pure error.

Table 5. Regression coefficients and standard errors for final equations for predicting total body water (TBW) in sex- and race-specific groups

Sex and race group	Predictor variables	Regression coefficient	SE	R^2	RMSE	SEI
Men						
White	Intercept	23.04	1.30	0.50	5.0	5.0
	Age	−0.03	0.01			
	Weight	0.50	0.03			
	BMI	−0.62	0.11			
Black	Intercept	−18.37	9.66	0.75	3.8	3.8
	Age	−0.09	0.02			
	Weight	0.34	0.03			
	Stature	0.25	0.06			
Women						
White	Intercept	−10.50	3.64	0.46	3.6	3.6
	Age	−0.01	0.01			
	Weight	0.20	0.01			
	Stature	0.18	0.02			
Black	Intercept	−16.71	6.94	0.69	3.3	3.3
	Age	−0.05	0.02			
	Weight	0.22	0.02			
	Stature	0.24	0.04			

Abbreviations are: SE, standard error; RMSE, root mean square error; SEI, standard error for the individual; BMI, body mass index.

impossible to determine the predictive accuracy of these equations when they are applied to an individual.

At this point in the analysis, the corresponding sex- and race-specific validation and corresponding cross-validation groups were merged together, and final prediction equations were developed for each group based on the selected independent values. These final equations, including regression coefficients, standard errors of the coefficients, R^2, RMSE, and the SEI, are presented in Table 5. All estimates were significant in each sex- and race-specific group ($P < 0.05$). Included with the recommended final equations (Table 5) are the RMSEs and the SEI. The RMSE is used when the equation is applied to a group of individuals. Plus or minus twice the RMSE produces the approximate 95% confidence limits for the prediction of TBW for each sex and race group. For an independent group of individuals to which an equation is applied, there is a 95% chance that ± twice the RMSE will cover the true mean TBW of that group [28]. With the present equations, the 95% confidence limits range from 13 to almost 20 L depending on the race and sex group.

DISCUSSION

TBW reference values

At present, no national reference data are available for TBW. Our cross-sectional data set is, to our knowledge, the largest ever used to report TBW values from 18 to 90 years of age, and it was created with attention to sample, design, and methodological differences. At each study site, healthy free-living individuals were enrolled, and the measurement techniques were similar. The distributions of the BMI values for the sex and race subgroups in this total sample fell within the 5th and 95th percentiles for BMI for corresponding reference sex and race groups, as reported by the National Center for Health Statistics from the second National Health and Nutrition Examination Survey [30].

There were some significant differences between study sites in the mean values for the variables, but this is to be expected since the samples differed by age and race among the study sites. The significant intersite differences were between the blacks in New York and Ohio. The black men and women in Ohio were fatter, on average, than the blacks in New York, and the mean ages of the Ohio black men and women were older also. We recognize the existence of these differences, but the need for a large study sample spanning from young adulthood to old age necessitated combining the data from these three study sites in order to develop the prediction equations.

At all the age groupings, the means for TBW among the present data tend to be the largest ever reported for adults. The present findings indicate that, on average and at almost all age groups, the mean TBW in men and black women ranges from approximately 2 to as much as 9 L greater than that reported previously. The means for TBW in white women have not changed greatly in the last 30 or so years. These appreciable interstudy differences for men and black women are due, in part, to cohort effects that reflect the significant secular increase in overall body size and fatness that occurred during the 20th century [31]. Adult averages for stature, weight, and BMI increased with subsequent generations through much of the 20th century. Cohort differences persist in the present data also because of the broad age range used and the collaborative nature of the study.

To our knowledge, these are the first means for TBW reported for a large sample of black men and women. Shutte et al reported mean TBW for a small group of 15 young black men in 1984 [10], and more recently Aloia et al [32] presented TBW means for a sample of black women 20 to 70 years of age ($N = 72$). Means for TBW have also been reported for other ethnic/racial groups by Jiang et al for young to middle-aged Chinese adults ($N = 40$) in Beijing [9], by Borgonha et al for Indian men and women ($N = 30$) in Bangalore [33], and by Bartz et al for Indonesian men and women ($N = 42$) in Jakarta [34].

Total body water volume was measured by the dilution method using deuterium and tritium labeling [24, 27]. Deuterium and tritium are the most commonly used isotopes, and their concentration in body fluid specimens can be quantitated accurately by mass spectrometry, infrared spectrometry, or NMR [24]. Comparative studies with other isotopes have reported a high level of agreement in TBW volume estimates among subjects, isotopes used, specimens and laboratory methods, although some of these differences among methods can be approximately 2 to 3 L in individuals (abstract; Ma et al, *FASEB J* 12:A868, 1998) [8, 24, 35, 36]. These methodological differences could explain, in part, why the values for TBW are so much larger then those of previous findings by other contemporary investigators. However, these differences are within the range expected between comparisons of other criterion measures of body composition [26].

TBW prediction equations

This study presents new prediction equations for TBW from anthropometry for white adults and the first such equations for black adults. These equations were developed using data from healthy individuals, and the independent and dependent variables were collected using standard techniques. The heterogeneity of the conditions afflicting persons with renal or other chronic diseases will increase the errors of prediction when these equations are used clinically. Also because of the limited sample of black persons available to this study, caution should be taken in interpreting or applying these equations to other blacks. The equations for blacks will be somewhat less accurate than the equations for whites.

The final prediction equations were developed from a nonclinical sample, as were those of Watson et al [16]. The Watson equations were also developed by pooling numerous data sets from independent studies, some of which were many decades apart. The sample for the equations of Hume and Weyers [17] included clinical cases. Recently, Chertow et al developed prediction equations specific for hemodialysis patients, of whom approximately 50% were blacks [12]. In Chertow et al's sample, blacks also had larger TBW means than whites; however, there was no direct measure of TBW. The dependent values for TBW used by Chertow et al were estimated from a bioelectrical impedance prediction equation except for a small sample ($N = 33$) of hemodialysis patients in whom TBW was measured by the deuterium dilution method. Chertow et al cautioned that an underestimation of TBW can contribute to an overestimation of the prescribed dialysis dose. The present data yield the only available prediction equations that provide the SEI.

The clinical importance of the recommended final equations in Table 5 appears in their application to a single individual. The SEI provides the distributions of the errors that can be expected in applying these equations to predict TBW for an individual. This indicates that the 95% confidence range for the estimated value of V in calculating Kt/V (if these equations are applied to persons with end-stage renal disease) is approximately ± 6 to 10 L, depending on the sex and race of the individual. The closer an individual's independent measurements are to their corresponding means of the group from which the equation was derived, the better the accuracy of the prediction. In the clinical use of these equations, the individual's value of predicted TBW and the SEI, along with the values for the independent measures, should be used in any decision to adjust a predicted TBW value.

Relationships with age and body composition

Much of the earlier cross-sectional data in the literature, except that of Cohn et al, demonstrate a sequential decline in mean TBW volumes with age [6]. In comparison with available reference data, these findings are most likely the result of the inclusion of data from numerous individuals who were born before the occurrence of the secular trend toward increasing body size and fatness during most of the 20th century. An age trend in declining mean TBW volumes appears in the present sample of white men starting with the 60- to 69-year-old age group and in the black men with the 50- to 59-year-old age group (Table 1). The mean TBW volumes of the present sample of white women show an increase between the 20- to 29- and 30- to 39-year-old age groups and a decline with age starting at the 50- to 59-year-old age group (Table 1). The decline for the black women also starts at the 50- to 59-year-old age group.

In each of the final prediction equations in Table 5, age was a significant variable with a negative coefficient. To test the significance of these possible age-related cohort differences in TBW, a separate model was applied to these data without any adjustments for possible covariates. TBW was not significantly associated with age or age squared (age^2) in the men. In the white women only, there was a significant ($P < 0.05$) linear (age) and curvilinear or quadratic relationship of TBW with age^2.

To clarify these age relationships further, another

Table 6. Model results of regression of age on total body water (TBW) with total body fat (TBF) and fat-free mass (FFM)

Race and sex	Intercept (SE)	Age (SE)	Age^2 (SE)	TBF (SE)	FFM (SE)
White men	7.16 (2.59)	−0.13 (0.07)	0.00 (0.00)	0.07[a] (0.03)	0.65[a] (0.03)
Black men	12.96 (5.18)	−0.39[a] (0.17)	0.00 (0.00)	0.06 (0.05)	0.72[a] (0.05)
White women	7.61 (2.02)	0.01 (0.06)	0.00 (0.00)	0.11[a] (0.02)	0.51[a] (0.04)
Black women	13.79 (3.58)	−0.22 (0.12)	0.00 (0.00)	0.12[a] (0.03)	0.57[a] (0.04)

[a] $P < 0.05$

model for TBW including age, age^2, TBF, and FFM as independent variables was analyzed (Table 6). After taking into consideration the interrelationships of TBF, FFM and age within this model, there were again no significant age or age^2 effects on TBW in the white men, but there was a significant negative age effect for the black men. In the women, after adjusting for the covariant associations of TBF, FFM and age, there was a small, positive linear association of TBW with age in the white women and a negative linear age effect in the black women, but these were not significant. There were also no significant, quadratic age relationships independent of TBF and FFM in women. In the white and black men, higher values for FFM were associated with increased levels of TBW, as were higher values for TBF in the white men. In the white and black women, high values for both TBF and FFM were consistently associated with high levels of TBW. The positive associations of TBW with TBF have been reported before [3, 11]. While age is a significant predictor of TBW, the independent relationship of TBW and age is in fact small. The associations of FFM and TBF with age are so strong that much of the observed association of TBW and age is a function of the covariate associations among TBW, FFM, and TBF. In separate serial analyses of TBW and age, there were no significant age effects independent of FFM and TBF [3].

Conclusions

Mean values for TBW and these new prediction equations are from a large assembled data set of U.S. adults. These are the first TBW prediction equations specific for black men and women from anthropometry. In the present cross-sectional findings, TBW, on average, is relatively stable through much of adulthood and well into old age. The increased prevalence of obesity among the U.S. population may have affected TBW levels in adults when compared with earlier findings, due to the positive association of TBW and TBF [37]. The increased prevalence of obesity among blacks may contribute to their larger means for TBW as compared with whites. The extent of this effect along with other changes in body composition should be considered in the clinical use of these data. We recommend these TBW data as current, limited reference data for healthy adults and the use of these new prediction equations for estimating TBW in end-stage renal disease.

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