Total body water volumes for adult males and females estimated from simple anthropometric measurements[1]

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ABSTRACT Individual total body water volumes for 458 adult males and 265 adult females obtained from dilution studies, together with their height, weight, and age have been selected from the literature. These values were used to derive total body water prediction equations for adults of any age. The equations that gave the best fit were for males:

$$\underset{\text{(liters)}}{\text{total body water}} = 2.447 - 0.09516 \underset{\text{(yr)}}{A} + 0.1074 \underset{\text{(cm)}}{\text{height}} + 0.3362 \underset{\text{(kg)}}{\text{weight}}$$

(SD: 3.76, r^2: 70.4%)

and for females:

$$\underset{\text{(liters)}}{\text{total body water}} = -2.097 + 0.1069 \underset{\text{(cm)}}{\text{height}} + 0.2466 \underset{\text{(kg)}}{\text{weight}}$$

(SD: 3.60, r^2: 73.6%)

Numerous other linear regression equations to predict total body water from anthropometric measurements have been reported in the literature. Most apply only to restricted age groups. These, and the equations from the present study were tested on completely independent data. In all cases the equations from the present study gave the best overall results, though for women one equation designed for a specific age group, gave for that age group a marginally better fit. *Am. J. Clin. Nutr.* 33: 27–39, 1980.

Knowledge of the total amount of water in the body (TBW) is basic to a full description of human body composition. If TBW values are available, estimates can be made of various body fractions including lean body mass (LBM), fat mass, and total body solids. With studies on human subjects, TBW is usually estimated by dilution methods using known amounts of diluents such as deuterium or tritium oxide or antipyrine, which diffuse freely through all body compartments with no permeability barrier. Although dilution methods are the most accurate available, the expertise, equipment, and time required to determine body water is often out of proportion to the precision of the data required for particular purposes. For rapid approximate estimates of TBW, simple anthropometric measurements can be used to give data of surprising accuracy.

Most TBW prediction equations using anthropometric data as variables (1–10) have been based on measurements from small samples and often limited to a restricted age group. It is generally accepted that these equations apply only to populations similar to those from which the basic information was obtained. Their general applicability cannot be assumed without an independent test on a different population sample (11).

The present study was initiated to test the possibility that reliable TBW prediction equations applicable to any Western population could be derived from simple anthro-

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pometric measurements for use over the whole adult life span. It was proposed to compare such equations with published TBW prediction equations using the same basic data.

Many studies have been reported giving TBW measurements for groups of people in North America, Europe, and Australia. Some of these studies gave basic data that could be used to obtain the regression equations in this study. Values from very lean to grossly obese subjects were used with the percentage of obese individuals in the sample approximating the percentage of obese people in Western populations. Values for Asians were not included because of their smaller frame size and lighter weight.

Materials and methods

Selection of data

Individual adult TBW volumes, obtained by dilution methods, were collected from those reports in the literature where age, sex, height, and weight of the subjects were recorded (1-3, 8, 12-37). For this study, an adult was considered to be a person age 17 years or older. While most of the individuals were healthy volunteers, some were patients hospitalized for minor disorders with no clinical evidence of edema or conditions that might affect normal water metabolism. Data were not included for some patients whose water metabolism was claimed to be normal but who had conditions that may have affected their degree of hydration. Duplicate data in different papers by the same authors were not used. In some studies (18, 21, 24) heights were not given but they could be recalculated from surface area figures using the DuBois equation (38) if weights were reported. Where TBW was given as a weight (kilograms), this was converted to the volume at 37 C using 0.9933 as the density of water at this temperature (17, 22, 25, 31).

Data were finally selected for 458 men and 265 women from 30 different studies. A computer print-out of the raw data is available on request from the authors. For the male subjects, deuterium or tritium-labeled water was used to estimate TBW for 269 individuals, antipyrine for 144, N-acetyl-4-amino antipyrine for 35, and urea for 10. For females, the corresponding numbers were, for deuterium or tritium-labeled water, 127; antipyrine, 114; N-acetyl-4-amino antipyrine, 13; and urea, 11. Where more than one TBW measurement was reported for an individual estimated with different diluents, the volume from using deuterium or tritium-labeled water was taken preferentially and, as a second choice, volumes obtained with antipyrine (23, 24, 33).

In one study, correction had been made for the over-estimation of total body water by deuterium or tritium-labeled water (30). Here the uncorrected data were used.

In cases where TBW values were not published as such but had been used to estimate other body characteristics such as lean body mass or fat mass, the original TBW values were determined by back-calculation from the equations used in that particular study (3, 20, 28).

TBW volumes vary slightly with the diluent used for the determinations, e.g., deuterium and tritium-labeled water give an over-estimate of 1 to 4%, attributed to an exchange of deuterium or tritium atoms in the water molecule with hydrogen atoms in organic body constituents (7, 16, 21, 30, 39). Determination of TBW by either antipyrine or urea give similar results, normally about 1 to 3% lower than the volumes obtained with isotopically-labeled water (24, 33, 40, 41). When N-acetyl-4-amino antipyrine is used as the diluent, the volumes are slightly lower again than the antipyrine and urea results (41).

The experimental errors in estimating TBW using different diluents are considered to be about ±1 to 3% for deuterium or tritium-labeled water (7, 9, 21, 39) and ±3 to 6% for antipyrine, urea and N-acetyl-4-amino antipyrine (17, 20, 34, 39). Although the methods show these differences in accuracy, they are all satisfactory as an absolute measure of TBW since the degree of hydration for individuals may vary from day to day by ±6.5% about their mean TBW volume (7, 39).

Analysis of the data that had been selected was carried out using the computer package Minitab II produced by the Pennsylvania State University in 1976.

Description of the sample

The range, mean, and SD for the subjects, grouped into males and females of age, height, weight, and TBW, and TBW and body fat expressed as percentages of body weight, are given in Table 1. Also included in Table 1 are the percentages of subjects with relative weights in four ranges.

Mean values of height, weight, the obesity index weight/height^2, TBW and the ratio of TBW and body fat to weight along with the SD and range of the latter, are given in Table 2 for males and females in decades for subjects age 20 and over. In general, height, the absolute volume of water in the body and the fraction of the body that is water, decrease with age, the fraction of the body that is fat increases with age, while weight increases to a maximum in middle age and then decreases (4, 5, 18, 39, 41, 55, 56).

These same trends are seen in the collected data in Table 2. For females the trends are slight for both the TBW volume and the fraction of water in the body. TBW shows no obvious decrease until the seventh decade but it is possible that the effect of cyclical hormonal changes on water balance (42) masks such a trend in younger women, especially as most studies have not confined estimations to that phase of the menstrual cycle where water balance is least likely to be affected (1, 3, 8, 12, 15, 17, 18, 20-22, 24, 25, 28, 33, 34). Others have noted this minimal change in TBW with age in females (10, 43), including Moore et al. (4) who found no significant trend with age in women over 30.

Fat is the body constituent subject to greatest variation in adult life. This is reflected in the very wide range of values for body fat seen among subjects in each decade. The few males in the 80 to 89 age group and females in the 70 to 89 age group probably account for the observed decrease in body fat in these groups. Otherwise the mean percentages of body fat for each decade are very similar to those measured in the large studies of Durnin and Womersley (55) and Novak (56).

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TABLE 1
Description of sample

	Males (458 subjects)		Females (265 subjects)	
	Range	Mean ± SD	Range	Mean ± SD
Age (yr)	17–86	39 ± 16	17–84	38 ± 16
Ht (cm)	132–201	173 ± 10	124–181	160 ± 9
Wt (kg)	36.4–148.3	72.2 ± 14.2	31.4–186.4	69.1 ± 23.2
TBW (liter)	23.5–66.2	41.6 ± 6.9	14.4–71.7	32.1 ± 7.0
TBW/wt (%)	38.5–73.5	58.3 ± 6.7	27.4–70.9	48.5 ± 8.6
Body fat/wt[a] (%)	0.6–47.3	20.2 ± 9.2	2.9–62.5	33.6 ± 11.7
Relative wt[b] (%)				
<100%	36		32	
100–119%	47		28	
120–139%	12		11	
≥140%	6		29	

[a] Body fat was calculated from TBW using the standard equations

$$\text{LBM (kg)} = \frac{\text{TBW (kg)}}{0.73}$$

$$\text{body fat (kg)} = \text{wt (kg} - \text{LBM (kg)}$$

and the results expressed as a percentage of body weight (53).

[b] $$\text{Relative weight} = \frac{\text{actual body weight}}{\text{standard body weight}}$$

for that height. Standard body weights for males and females were taken from the weight for height tables Reference 57.

TABLE 2
Values of subjects by age

	Ages in decades						
	20–29	30–39	40–49	50–59	60–69	70–79	80–89
Males							
No. of subjects[a]	171	93	59	68	33	23	3
Mean ht (cm)	176	175	172	170	165	163	164
Mean wt (kg)	72.0	78.0	72.9	71.9	65.7	62.0	60.9
Mean wt/ht^2 (kg/m^2)	23.1	25.4	24.6	24.8	24.2	23.8	23.0
Mean TBW (liter)	43.3	44.1	41.2	39.7	36.7	33.2	33.9
Mean TBW/wt (%)	60.5	57.8	57.0	56.4	56.5	54.0	56.3
Mean body fat/wt (%)	17.1	20.9	21.9	22.8	22.5	26.0	22.9
SD body fat/wt (%)	7.1	10.3	8.6	11.0	8.3	9.4	12.2
Range body fat/wt (%)	0.6–36.8	1.9–45.6	2.6–36.7	0.7–47.3	3.3–34.6	6.4–44.3	14.3–36.9
Females							
No. of subjects[a]	100	48	37	43	19	5	4
Mean ht (cm)	165	159	158	156	155	146	147
Mean wt (kg)	67.0	66.9	71.4	74.8	75.4	56.1	50.0
Mean wt/ht^2 (kg/m^2)	24.4	26.6	28.3	30.7	31.5	26.1	22.8
Mean TBW (liter)	32.2	31.4	32.1	33.2	32.6	25.8	23.9
Mean TBW/wt (%)	49.6	48.8	47.5	47.1	44.5	47.0	52.0
Mean body fat/wt (%)	32.0	33.1	34.9	35.4	39.0	35.7	28.8
SD body fat/wt (%)	10.0	12.7	12.8	14.0	9.2	8.3	19.1
Range body fat/wt (%)	2.9–57.7	5.3–62.5	4.7–57.0	6.7–57.8	20.1–57.6	22.0–44.4	14.4–56.7

[a] This analysis does not include values for subjects ages between 17 and 19.

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Results

The data for males and females were analyzed together and separately. Seven variables were considered. These were sex, age, height, weight, the diluent used for TBW estimation, e.g., tritium-labeled water, the state of health of the subject, i.e., a normal healthy individual or patient with a minor disorder, and the nationality of the subject. Each single variable and multiples of these variables were regressed against TBW. Prelimiary analysis showed that the contribution of the last three variables (the diluent used, the health and nationality of the subject) was negligible, in accounting for the total variance, when compared with that of the first four variables. In all subsequent calculations only these major variables, sex, age, height, and weight, were considered.

Rearrangement of the order of variables for both men and women made no difference to the coefficient of the variables in the regression equation and no real difference to the variance explained by each variable. More complicated equations were tried using polynomials up to the fifth power of the height, weight, and age variables, as well as the logarithm of age and mixed functions. None of these alternatives gave any significant improvement in fit. If the data used to obtain the regression equations were confined to that for subjects within ±20% of their standard weight for height, the SD of the actual from the predicted TBW was very close to the SD obtained when all the data was used. However, the total variance explained by the regression (r^2) was considerably less, especially for females, than when all the data were used (r^2: 61.8% for males and 36.3% for females) which was surprising as a more homogeneous population was expected to give an improved result.

The results of the linear regression of each major individual variable for each sex and the more important multiple regressions of these variables are summarized in Table 3.

Considering firstly the calculations based on the combined data for males and females, 79% of the total variance could be accounted for by the regression equation with four variables (including sex), improving by only 0.2% (to 79.2%) when all seven possible varibles were included. The SD of the actual TBW compared with the predicted value was slightly greater than when data for each sex were used separately. However, while this equation predicts TBW almost as well as the separate equations for males and females, it was preferred to avoid the use of sex as a "dummy" variable and work with the simpler equations.

For males, the linear regression information for each of the major variables with TBW (Table 3) shows that weight is the most important variable, by a considerable margin, followed by height, and then age. All of the variables were significant. It was decided that the best prediction equation was as follows:

$$\text{TBW} = 20.03 - 0.1183\ \text{A} + 0.3626\ \text{wt} \qquad (Ib)$$

(liters) (yr) (kg)

The following simpler form is almost as satisfactory:

$$\text{TBW} = 20.03 - 0.1183\ \text{A} + 0.3626\ \text{wt} \qquad (Ib)$$

(liter) (yr) (kg)

Considering the linear regressions of each of the variables with TBW for women, weight is again the most important variable followed by height while age makes a negligible contribution. In the multiple variable regression equations, the inclusion of age gave no improvement. The recommended linear regression equation to predict TBW for females is as follows:

$$\text{TBW} = -2.097 + 0.1069\ \text{ht} + 0.2466\ \text{wt} \qquad (Id)$$

(liters) (cm) (kg)

The following simpler equation is almost as satisfactory:

$$\text{TBW} = 14.46 + 0.2549\ \text{wt} \qquad (Ie)$$

(liters) (kg)

The validity of these equations was tested by applying them to completely independent data that had not been used in determining the equations. For males, the data published by Olsson and Saltin (44) were used. These authors had measured total body water in 19 Swedish students, ages 21 to 28, using tritium oxide. With equation (*Ia*), the correlation of actual with predicted volumes for TBW was

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TABLE 3
Linear regressions of TBW with single and multiple variables

Variables used	Regression equation	T ratio each variable	SD	Percentage total variance in body water explained by the regression r^2% (adjusted for DF)
Equations for males				
Age (A)	48.10 − 0.1672 A	8.96 (A)	6.39	14.8
Ht	24.83 + 0.3837 ht	13.36 (ht)	5.87	28.0
Wt	13.96 + 0.3829 wt	27.14 (wt)	4.28	61.7
Ht and wt	−12.86 + 0.1757 ht + 0.3331 wt	8.13 (ht), 22.90 (wt)	4.01	66.5
Age and wt[a]	20.03 − 0.1183 A + 0.3626 wt	10.38 (A), 28.22 (wt)	3.86	68.9
A, ht, and wt[a]	2.447 − 0.09516 A + 0.1074 ht + 0.3362 wt	7.86 (A), 4.87 (ht), 24.60 (wt)	3.76	70.4
Equations for females				
Age (A)	33.36 − 0.03355 A	1.24 (A)	7.00	0.2
Ht	−3.301 + 0.2209 ht	5.09 (ht)	6.70	8.6
Wt[a]	14.46 + 0.2549 wt	25.89 (wt)	3.72	71.7
Ht and wt[a]	−2.097 + 0.1069 ht + 0.2466 wt	4.51 (ht), 25.50 (wt)	3.60	73.6
A, ht, and wt	2.135 − 0.02556 A + 0.08551 ht + 0.2491 wt	1.60 (A), 3.15 (ht), 25.51 (wt)	3.58	63.8
Equations for males and females as a single group				
A, ht, and wt	−34.50 + 0.0159 A + 0.323 ht + 0.265 wt	1.35 (A), 18.90 (ht), 26.07 (wt)	4.72	68.1
Sex,[b] A, ht, and wt[a]	11.29 − 7.262 sex − 0.07408 A + 0.1158 ht + 0.2837 wt	19.80 (sex), 7.50 (A), 6.71 (ht), 34.36 (wt)	3.81	79.0
Diluent,[b] health,[b] Nationality,[b] sex, A, ht, and wt	13.86 − 0.3597 diluent − 0.2087 health − 0.3497 nationality − 7.376 sex − 0.06735 A + 0.1106 ht + 0.2824 wt	2.52 (diluent), 0.56 (health), 1.39 (nationality), 20.02 (sex), 6.03 (A), 6.37 (ht), 33.07 (wt)	3.80	79.2

[a] Equations recommended for use in the prediction of TBW. [b] The coding used for these variables was: sex (males: 1, females: 2), diluent used for TBW determination (deuterium: 1, tritium: 2, antipyrine: 3, NAAP: 4, urea: 5), health (normal healthy subject: 1, patient with minor disorder: 2) and nationality (European: 1, North American: 2, Oceanian: 3).

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TABLE 4
TBW prediction equations using anthropometric measurements

Reference	Equation reference	Equation	Sex to which equation applies	Age group to which equation applies	Sample size from which equation is derived
Present study	*Ia*	2.447 − 0.09516 A + 0.1074 ht + 0.3362 wt	M	17–86	458
	b	20.03 − 0.1183 A + 0.3626 wt	M	17–86	458
	c	11.29 − 7.262 Sex − 0.07408 A + 0.1158 ht + 0.2837 wt	M + F	17–86	723
	d	−2.097 + 0.1069 ht + 0.2466 wt	F	17–84	265
	e	14.46 + 0.2549 wt	F	17–84	265
Ljunggren et al. 1957 (1, 2)	*IIa*	53.0 ht − 55.2	M + F	20–47	31
	b	0.212 wt + 18.7	F	20–54	33
Edwards and Whyte 1962 (3)	*IIIa*	Desirable wt (DW) = 2.26 ht^2 − 1400	M	14–76	15
	b	0.73 (wt − {0.66 wt − 0.60 DW + 13.0})			
	c	$0.73\ (wt - \{0.18\ [\frac{wt}{ht^2} \times 10^5] - 23.2\})$	M + F	14–76	31
Moore et al. 1963 (4)	*IVa*	$\frac{TBW}{wt} \cdot 100 = 79.45 - 0.2389\ wt - 0.1477\ A$	M	15–90	132
	b	13.26 + 0.404 wt	M	16–30	63
	c	11.03 + 0.397 wt	M	31–60	56
	d	12.02 + 0.343 wt	M	61–90	13
	e	$\frac{TBW}{wt} \cdot 100 = 69.81 - 0.259\ wt - 0.1158\ A$	F	15–90	88
	f	11.63 + 0.318 wt	F	16–30	54
	g	8.84 + 0.331 wt	F	31–90	34
Udekwu et al. 1963 (5)	*Va*	25.05 + 0.24 wt	M	21–30	10
	b	5.71 + 0.50 wt	M	31–40	10
	c	10.69 + 0.41 wt	M	41–50	10
	d	12.85 + 0.39 wt	M	51–60	10
	e	18.80 + 0.27 wt	M	61–70	10
	f	18.49 + 0.24 wt	M	71–80	10
	g	20.57 + 0.15 wt	M	81+	10
	h	7.37 + 0.42 wt	F	21–30	10
	i	11.97 + 0.29 wt	F	31–40	10
	j	11.29 + 0.30 wt	F	41–50	10
	k	23.63 + 0.13 wt	F	51–60	10
	l	11.97 + 0.261 wt	F	61–70	10
	m	3.26 + 0.39 wt	F	71–80	10
	n	8.83 + 0.30 wt	F	81+	
Behnke 1963 (29)	*VIa*	0.72 (0.204 ht^2)	M		
	b	0.72 (0.18 ht^2)	F		

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Hume 1966 (6)	*VIIa*	0.73 (0.3281 wt + 0.3393 ht − 29.5336)	M	40–77	29
	b	0.73 (−43.2933 + 0.2957 wt + 0.4181 ht)	F	37–80	27
Seitchik 1967 (45)	*VIII*	7.4 + 0.36 wt	F	19–36	36
Olsson 1970 (7)	*IXa*	8.2 + 0.51 wt	M	20–71	32
	b	13.13 + 0.26 wt	F	34–87	15
Mellits and Cheek 1970 (51)	*Xa*	−21.993 + 0.406 wt + 0.209 ht	M	Up to 34 (ht ≥ 132.7 cm)	105
	b	−10.313 + 0.252 wt + 0.154 ht	F	Up to 31 (ht ≥ 110.8 cm)	45
Hume and Weyers 1971 (8)	*XIa*	−14.0129 + 0.1948 ht + 0.2968 wt	M	35–71	30
	b	−35.2701 + 0.3445 ht + 0.1838 wt	F	33–84	30
Delwaide and Crenier 1973 (9)	*XII*	0.72 (−1.976 + 0.907 wt)	M	Mean age 20	53
Forbes 1974 (52)	*XIII*	0.73 (1.03 × 10^{-5} ht^3)	M + F	18–55	430
Hankin et al. 1976 (10)	*XIVa*	23.7 + 0.65 wt − 0.1875 ht	F	19–68 normal	27
	b	−14.0 + 0.1636 wt + 0.2271 ht	F	14–59 obese	27

0.839 (r^2 70.4%, SD 1.94). For equation (*Ib*), the correlation was 0.828 (r^2 68.5%, SD 2.04). Using equation (*Ic*) (Table 4) with sex as a variable, the correlation was 0.835 (r^2 69.7%, SD 2.05). Equation (*Ib*) was also tested with the data reported by Hyde and Jones (40) for TBW estimated using urea in 16 English patients ages between 20 and 65. In this case the correlation of actual with predicted TBW volumes was 0.850 (r^2 72.2%, SD 3.05).

To test the equations for female subjects, the data reported by Seitchik (45) were used. TBW had been estimated, using the deuterium oxide dilution method, in a group of 36 normal North American woman, ages from 19 to 36 years. For equation (*Id*), the correlation of actual with predicted TBW was 0.789 (r^2 62.2%, SD 2.09) and for equation (*Ie*), 0.780 (r^2 60.8%, SD 2.09). In equation (*Ic*) incorporating sex as a variable, the correlation was 0.755 (r^2 57%, SD 2.14).

Nomograms for the prediction of TBW

Nomograms have been prepared to simplify the estimation of TBW from the equations derived in this study. Figure 1 gives a four variable nomogram for TBW in males calculated from equation (*Ia*). Here, if the age, height, and weight of a male subject is

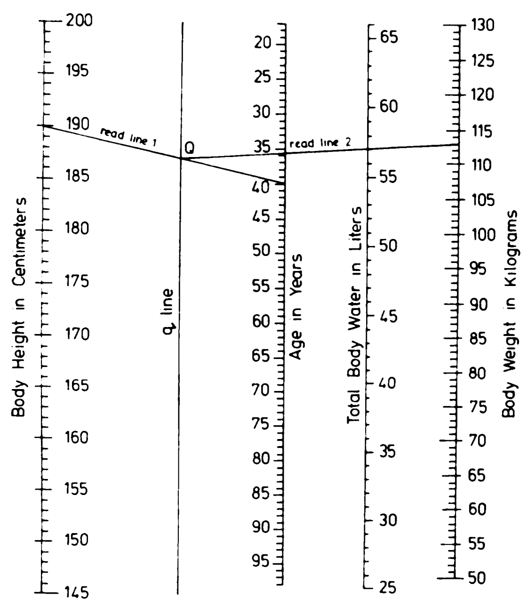

FIG. 1. Nomogram for the estimation of TBW in males.

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known, an estimate of the TBW can be read from the nomogram. As an example, consider a 40-year-old male, of height 190 cm and weight 113 kg. If a straight line joining the height (190 cm) with age (40 yr) is drawn (read line: 1), the intersection of this line with the q line (point Q) forms the starting point for the second reading. If now a second straight line (read line: 2) joining Q to the weight of the subject (113 kg) is drawn, the intercept of this line with the TBW scale gives the TBW of that subject (in this case: 57 liters).

Figure 2 gives a simple three variable nomogram for the estimation of TBW in females calculated from equation (*Id*). If the height and weight of the subject are known, TBW can be predicted from the nomogram. The point where a straight line joining the height of a subject on the left-hand scale with weight on the right-hand scale, intersects the central scale, gives the predicted total body water.

Enlarged versions of both nomograms, from which TBW may be more easily read, are available on request from the authors.

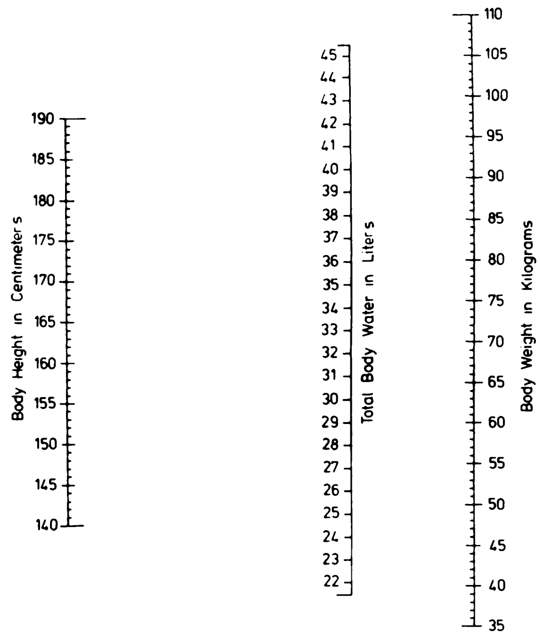

FIG. 2. Nomogram for the estimation of TBW in females.

Discussion

TBW estimates from density data

It was considered initially that estimates of TBW from both dilution and body density measurements could be used to provide the basic data in this study. However, when the volumes were compared for 90 men and women with whom both of these methods had been used (22, 23, 29, 31), the correlation of TBW measured by dilution with the estimates from density measurements (assuming the percentage of water in the LBM is 73%) was 0.895 with an SD of 3.12 using the formula of Brozek et al. (46) and 0.887, SD 3.24 using the formula of Siri (39). No correlation was found between the TBW measured by dilution and density, but the correlation between TBW expressed as a percentage of body weight and density was 0.859 (SD 3.89). In general, TBW calculated from density tended to be lower than the volume obtained by dilution measurements. The SE in the calculation of TBW from body density was at least double the largest error in values from dilution methods.

When the prediction equation (*Id*) was used to calculate TBW in 106 women for whom density, height, weight, and age were also available (47–50) and the values compared with TBW volumes calculated from their densities, the density calculation again tended to under-estimate TBW. The inclusion of these women for whom TBW had been calculated from density with those in whom TBW had been measured directly, resulted in a higher SD and lower correlation for the linear regression of TBW with height and weight (r 0.827, SD 3.70 against r 0.859, SD 3.60). If the regression of TBW with height and weight using the density data alone was considered, the correlation was considerably lower (0.773). Hence, because of the under-estimation of TBW when calculated from density, and the greater scatter in the resultant values, it was decided not to use density as an estimate of TBW.

Comparison of TBW prediction equations

A considerable number of linear regression equations to predict TBW from anthropometric measurements have been formulated and reported in the literature (1–10, 29, 45, 51, 52). Table 4 lists these equations with details of the sample size and age group from

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which the equations were derived and the sexes of individuals to which the equations apply. Most of the equations were derived from TBW measurements on small homogeneous samples, although a number were based on collected results from several authors. Some of the data used to derive the equations were also used in the present study.

It was considered of interest to compare the accuracy with which equations from the present and other studies predicted values for TBW. Such accuracy checks were carried out by applying each of the equations to the collected data used for this study and also to the data reported by Olsson and Saltin (44) (for males) and Seitchik (45) (for females). In addition, some equations that were derived to predict LBM were tested using, in reverse, the factor reported in the appropriate paper for the conversion of TBW to LBM, e.g., TBW = 0.73 LBM if the Pace and Rathbun (53) equation was used.

The SD and r for experimental compared with predicted TBW volumes and the percentage of total variance *not* accounted for by a particular equation ($1 - r^2$) are set out for males in Table 5 and females in Table 6. The equations were applied only to those subjects within the age and/or weight range used in deriving the equation being tested.

Comparing the results for males in Table 5, the equation (*Ia*) derived from the present study best fitted the total collected data, a finding that would have been expected. With the several equations that applied only to a restricted age group, and using SD of the predicted from measured TBW volumes as criteria for accuracy, only four equations, (*IVb*, *IVd*, *Ve*, *Xa*) gave a marginally better fit for the particular age group than the equation (*Ia*) from this study applied to all adult subjects. The greatest improvement found was from the test of the Moore equation (*IVb*) for 16 to 30 year olds, which resulted in an improvement of prediction of 1.2% (at the 95% level) representing only a minor difference. Accordingly, it was considered that no significant advantage was gained from the

TABLE 5
Comparison of the authors' TBW prediction equations with other prediction equations for males

Equation reference	Application to collected data				Application to Olsson and Saltin's data		
	No. of subjects in appropriate group	SD	r	$1 - r^2$	SD	r	$1 - r^2$
				%			%
Ia	458	3.76	0.840	29.4	1.95	0.839	29.6
b	458	3.86	0.831	30.9	2.04	0.828	31.5
c	458	3.84	0.840	29.4	2.05	0.835	30.3
IIa	312	5.55	0.508	74.2	2.92	0.523	46.2
IIIb	452	4.33	0.789	37.8	2.28	0.755	43.0
c	452	4.74	0.773	40.3	2.19	0.785	38.4
IVa	458	5.35	0.610	62.8	2.65	0.396	84.3
b	193	3.51	0.803	35.5	2.04	0.802	35.7
c	209	4.44	0.789	37.8		Not applicable	
d	56	3.56	0.805	35.2		Not applicable	
Va	177	4.02	0.801	35.8	2.38	0.802	35.7
b	85	5.38	0.750	43.8		Not applicable	
c	58	3.84	0.850	27.8		Not applicable	
d	66	4.31	0.781	39.0		Not applicable	
e	33	3.74	0.881	22.4		Not applicable	
f	22	3.86	0.583	66.0		Not applicable	
g		Insufficient data				Not applicable	
VIa	458	5.88	0.538	71.1	2.99	0.521	72.9
VIIa	181	4.56	0.783	38.7	2.10	0.785	38.4
IXa	428	4.43	0.787	38.1	2.02	0.802	35.7
Xa	231	3.68	0.812	34.1	1.95	0.818	33.1
XIa	205	4.25	0.813	33.9	2.00	0.811	34.2
XII[a]	193	4.32	0.803	35.5	2.20	0.802	35.7
XIII	372	6.25	0.499	75.1	3.56	0.520	73.0

[a] Applied to males between 17 and 30 years old.

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TABLE 6
Comparison of the authors' TBW prediction equations with other prediction equations for females

Equation reference	Application to collected data				Application to Seitchik's data		
	No. of subjects in appropriate group	SD	*r*	$1 - r^2$	SD	*r*	$1 - r^2$
				%			%
Id	265	3.60	0.859	26.2	2.09	0.790	37.6
e	265	3.72	0.847	28.2	2.18	0.780	39.2
c	265	3.77	0.855	26.9	2.14	0.755	43.0
IIa	176	6.09	0.278	92.3	2.96	0.434	81.2
b	207	3.73	0.857	26.6	2.27	0.775	39.9
IIIc	260	4.95	0.763	41.8	2.38	0.688	52.7
IVe	265	6.13	0.704	50.4	3.73	0.314	90.2
f	114	3.68	0.804	35.4	1.90	0.791	37.4
g	152	4.22	0.867	24.8	2.91	Insufficient data	
Vh	94	4.55	0.793	37.1	1.85	0.708	49.9
i	48	4.19	0.803	35.5	3.14	Insufficient data	
j	38	3.22	0.923	14.8	Not applicable		
k	41	6.49	0.870	24.3	Not applicable		
l	18	2.97	0.862	25.7	Not applicable		
m	Insufficient data				Not applicable		
n	Insufficient data				Not applicable		
VIb	265	6.85	0.306	90.6	2.93	0.438	80.8
VIIb	116	4.30	0.845	28.6	Not applicable		
VIII	139	4.25	0.824	32.1	Equation derived from this data		
IXb	137	3.90	0.875	23.5	Not applicable		
Xb	124	3.45	0.803	35.5	1.86	0.799	36.2
XIb	140	4.61	0.819	32.9	3.30	Insufficient data	
XIII	220	7.36	0.263	93.1	3.16	0.441	80.6
XIVa[a]	138	3.85	0.511	73.9	2.65	0.734	46.1
b[b]	85	4.25	0.803	35.5	Insufficient data		

[a] Normal subjects are arbitrarily defined as those with relative body weight between 0.8 and 1.2 of their standard weight. [b] Obese subjects were arbitrarily defined as those with relative body weight greater than 1.2 of their standard weight.

inconvenience of using different equations for different age groups. The equation (*Ia*) from the present study, including age as a variable, gave the best overall results. This conclusion was further confirmed when the equations were tested with the independent data. Using the result of Olsson and Saltin (44), no equations were better than the equations from this study for predicting TBW; the standard deviation using the equation of Mellits and Cheek (*Xa*) gave the same level of accuracy while all of the other equations gave an inferior fit. Applicaton to the data of Hyde and Jones (40), which gave only age and weight with which to calculate TBW, was restricted to five equations (*IVa*, *IVc*, *Vc*, *IXa*, *XII*). The results were not included in Table 5 but again no equation gave a better prediction than the two parameter equation derived in this study (*Ib*) although the equation of Udekwu (*Vc*) for 41 to 50 year olds gave the same SD.

For females (Table 6), a comparison of the relevant equations gave similar results to those obtained for males. The two parameter equation derived in this study (*Id*) gave the best predicted TBW values over the entire adult age range when applied to the collected data. Of the equations for specific age groups, three (*Vj*, *Vl*, *Xb*) gave a slightly better fit with the best improvement in accuracy of prediction being 3.8% (at the 95% level) for 61 to 70 year olds using the equation of Udekwu (*Vl*). When the equations were applied to appropriate age groups in the data reported by Seitchik (45), three (*IVf*, *Vh*, *Xb*) gave slightly better predictions with the greatest improvement amounting to 1.6% for the equation of Udekwu applied to 21 to 30 year olds (*Vh*). Only the equation of Mellits and Cheek (*Xb*) for women up to 31 years of age consistently gave a small improvement in prediction of TBW for both sets of data (1.6% at the 95% level) when compared with the

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equation from this study (*Id*) tested with adult women of any age.

The data reported by Seitchik (45) was mainly for young women under the age of 21 and it might be expected that an equation derived specifically for this restricted age group would give more accurate predictions than the equations derived in this study for all age groups. However, the finding that the equation of Mellits and Cheek (*Xb*) gave only a minimal improvement over an equation derived for all adult ages, is consistent with a conclusion from the present study that age is not a significant variable in these prediction equations for females.

Bernier and Vidon (54) used the equations of Moore (*IVa*, *IVe*) to estimate the fraction of water in the body for males and females of different ages. These values formed the base from which their extensive body fluid and electrolyte tables were calculated. When these equations were applied to the collected data used in this study, the predicted TBW values were amongst the least accurate for all equations tested. (Males: *1*) collected data, SD 5.35, *r* 0.610, *2*) data of Olsson and Saltin (44), SD 2.65, *r* 0.396, *3*) data of Hyde and Jones (40), SD 4.53, *r* 0.665. Females: *1*) collected data, SD 6.13, *r* 0.704, *2*) data of Seitchik (45), SD 3.73, *r* 0.314). It is likely that the tables produced by Bernier and Vidon (54) would have contained more accurate information if they had used the equations published by Moore for different age groups with weight as the sole variable (*IVb*, *IVc*, *IVd*, *IVf*, *IVg*).

It is of interest that the poorest predictions of TBW for both males and females are those from equations derived with height as the only variable (*IIa*, *VIa*, *VIb*, *XIII*). Most of these equations were designed to predict LBM. Since LBM is proportional to TBW, it is reasonable to deduce that such equations are also poor predictors for LBM. This is not an unexpected conclusion when account is taken of the small percentage of the total variance explained by the height variable in the collected data for males and females when TBW is regressed against height (28% for males and 8.6% for females). Those equations derived to predict LBM that use weight or both weight and height as variables (*IIIb*, *IIIc*, *VIIa*, *VIIb*, *XII*) are much better predictors of TBW but none of these equations gives results as close to experimental measurements as the equations derived in this study or the other better prediction equations reported in the literature. As a corollary, it could be claimed that equations using age, height, and weight as variables that give good predictions of TBW will also give good predictions of LBM.

The effect of gross obesity

Extreme variation of body fat is the main factor affecting the accuracy of TBW prediction from equations of this type. The effect is much more pronounced in the grossly obese than in the very lean.

It has been estimated that adipose tissue contains from 10 to 30% water (4, 15, 25, 46). In the grossly obese a very large proportion of body weight is accounted for by this relatively anhydrous adipose tissue. Thus TBW prediction formulae derived from subjects with a wide range of body fatness will tend to overestimate TBW in the grossly obese. In this study, if gross obesity is said to be present when the percentage of fat in the body is 20% more than the mean value for that sex (i.e., >40% for males and >53% for females), then only six males and 10 females in a total of 723 subjects would come into this category. Because of the few subjects in this group the TBW prediction equations derived in this study may not produce as accurate results for males with body fat ≥40% and females with body fat ≥53%. There is a need for separate equations to be derived specifically for the grossly obese from data from different population groups.

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