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MEASURES OF BODY FAT AND RELATED FACTORS IN NORMAL ADULTS—II

A SIMPLE CLINICAL METHOD TO ESTIMATE BODY FAT AND LEAN BODY MASS

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A VALID and simple anthropometric method to estimate body fat and lean body mass can enhance the clinician's armamentarium. By use of such a method in an epidemiological study of chronic diseases associated with overweight, obesity (excess body fat) can be distinguished from overweight (body weight greater than a standard weight for height and sex). This paper presents the development of regression equations which estimate body fat and lean body mass in adults. Equations are based on anthropometry and laboratory measures of body fat by the total body water–body density technique in healthy adults; the methods are described in detail in the preceding paper [1]. Potassium-40 (K^{40}) and cesium-137 (Cs^{137}) were measured in an Argonne-type whole body counter. Calculations of body composition from results of total body water–body density and K^{40} counting are correlated and discussed. The measurements made in this study have been utilized to compare body composition as estimated by several anthropometric equations developed on other population groups.

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STUDY POPULATION

Altogether 2301 healthy* volunteer subjects were measured by anthropometric methods as already described [1]. Of these, 2053 were classifiable in five arbitrary race–sex–age categories as follows:

I. Caucasian males, 25–34 years old.
II. Caucasian males, 35–44 years old.
III. Caucasian females, 25–34 years old.
IV. Caucasian females, 35–44 years old.
V. Negro males, 25–44 years old.

Hereafter each subject category is designated by the corresponding Roman numeral.

From each of these five categories a sample was randomly selected for laboratory measurements (Table 1). Work classifications of the subjects in the sample were varied and included professional and business occupations, students, housewives, firemen, policemen and laborers.

TABLE 1. NUMBER OF SUBJECTS

Category	Race	Sex	Age (yr)	Measurements		
				Anthropometric	Laboratory	
					TBW and body density	K^{40} and Cs^{137}
	Total	Male and female	25–44	2053	167	80
I	Caucasian	Male	25–34	478	35	23
II	Caucasian	Male	35–44	416	34	25
III	Caucasian	Female	25–34	379	33	12
IV	Caucasian	Female	35–44	438	31	16
V	Negro	Male	25–44	342	34	4

Note: TBW = Total body water.

Inability to obtain subjects in significant number and the limited time available precluded laboratory study of subjects from other race–sex–age categories. The anthropometric data for the 248 subjects thereby eliminated, i.e., Negro females, Orientals and subjects of other races, are the subject of a subsequent report [2].

By random selection within the five categories 172 subjects were chosen but 5 refused to cooperate, leaving 167 subjects who had laboratory studies of body density and total body water. Of these, 80 were studied by whole-body K^{40} and Cs^{137} counting techniques, 68 of whom also had body density and total body water determinations. These and an additional randomly selected sample, approximating 25 per cent of all subjects, were interviewed for a 24-hr recall of diet and of physical activity. The results of the interview as well as of the Cs^{137} data are reported separately [3, 4]. Somatotype was determined for over one hundred of the total of 2053 subjects [5].

*Healthy was defined as free of known disease, acute or chronic, upon statement of the subject, and having had no treatment by a physician for any illness during the three months prior to entry in the study. Any person with obvious physical deformity or loss of limb was excluded. In addition, pregnancy or suspected pregnancy eliminated any woman from the study.

METHODS

Anthropometric measurements, described in detail in the preceding paper [1] for easy reproducibility by the clinician, consisted of height, weight, seven circumferences, two limb lengths, five diameters and four skinfold thicknesses. Time required to make all measurements on one subject averaged about 3 minutes.

Laboratory measurements, as previously described [1], consisted of total body water (TBW) after an oral tracer dose of tritium, specific gravity by the helium dilution technique and whole-body counting of K^{40}. Body fat was calculated from the combined results of the first two of the above measurements [6]. Lean body mass (LBM) was obtained by difference: body weight minus body fat = LBM. Lean body weight ($LBW^{K\text{-}40}$) was calculated from K^{40} counts per minute by conversion to grams K (counts/min divided by efficiency factor, 1.09) and to K m-equiv by use of the formula:

$$LBW^{K\text{-}40}\,(\text{kg}) = \frac{\text{measured total K (m-equiv)}}{68.1}\ [7].$$

The percentage standard weight for each subject was determined as the proportion of his body weight to the median weight by height for sex as presented in Table 80 of the report of HATHAWAY and FOARD [8]. Median weights for heights not given in the tables were extrapolated.

The Gubner index [9] was calculated by subtracting the waist circumference in inches from the height in inches.

The ponderal index was calculated by dividing height in inches by the cube root of the weight in pounds.

ANALYSIS OF DATA

All data were prepared for analysis by computer. Arithmetic means, standard deviations and ranges by subject category were obtained for all anthropometric measurements and indexes, body density, total body water, calculated kilograms of body fat and K^{40} counts per minute. Correlation matrices by subject category were computed for anthropometric measurements and kilograms body fat for those subjects who participated in the laboratory studies. Corresponding correlations for anthropometric measurements alone were computed for all subject categories in order to verify the representativeness of the laboratory sample.

Linear regressions of calculated body fat on the anthropometric measurements were determined for each of the five subject categories and for the following combined groups: all Caucasian males, all Caucasian females, Caucasian males and females aged 25–34 years, Caucasian males and females aged 35–44 years, all males, and all subjects.

For those subjects (n = 68) having both K^{40} and body fat measurements the calculated lean body weight from K^{40} counts/min ($LBW^{K\text{-}40}$) was correlated with lean body mass (LBM).

RESULTS OF ANTHROPOMETRIC AND LABORATORY MEASUREMENTS

Table 2 presents the means, standard deviations and ranges for the anthropometric measurements and indexes for 2053 subjects by category. There was a wide

TABLE 2. MEANS, STANDARD DEVIATIONS AND RANGES FOR ANTHROPOMETRIC MEASUREMENTS AND INDEXES FOR 2053 SUBJECTS MEASURED

Measurement	Category I (n=478)				Category II (n=416)				Category III (n=379)				Category IV (n=438)				Category V (n=342)			
	Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range	
Weight (lb)	169.2	24.2	114.6	275.5	172.8	23.7	123.8	250.6	129.4	19.8	90.8	237.6	133.2	22.5	79.8	299.6	174.1	28.8	110.8	291.8
Height (cm)	178.5	6.5	156.0	196.5	178.6	7.0	158.7	199.4	165.1	6.7	146.7	183.9	163.3	6.4	145.6	181.4	176.6	6.5	157.3	195.1
Biacromial diam. (cm)	40	3.0	34	46	40	1.9	35	47	36	2.0	29	43	35	1.8	16	40	41	2.1	35	50
A.P. chest diam. (cm)	17	3.3	13	22	17	2.3	14	55	15	1.6	10	24	16	1.6	12	20	17	2.6	13	29
Bi-iliac diam. (cm)	29	2.0	24	39	29	1.9	25	40	28	2.1	24	40	28	2.1	18	40	27	2.2	20	36
Chest circ. (cm)	97	7.4	76	119	100	6.8	84	128	84	5.8	64	120	86	6.1	72	112	98	9.2	79	128
Waist circ. (cm)	88	53.3	68	116	88	7.8	71	117	67	6.7	55	113	70	7.5	56	112	89	34.7	68	120
Iliac crest circ. (cm)	93	57.6	72	132	92	7.9	73	125	91	7.4	73	132	93	8.4	73	150	90	18.6	72	136
Arm circ. (cm)	32	3.1	24	43	33	2.6	26	42	27	2.7	20	40	28	3.2	16	43	35	3.2	26	44
Wrist circ. (cm)	18	2.6	15	20	18	0.9	15	20	15	0.8	12	18	15	0.8	13	18	18	1.0	15	20
Thigh circ. (cm)	53	4.0	43	69	53	3.7	42	68	49	4.6	32	74	50	5.0	38	84	55	4.6	42	74
Ankle circ. (cm)	22	1.4	18	27	22	1.6	19	40	21	1.5	17	26	21	1.5	16	25	22	1.5	18	28
Arm length (cm)	38	1.9	33	44	38	2.0	32	44	35	2.0	30	41	35	2.0	16	40	38	2.0	33	44
Thigh length (cm)	40	2.3	30	49	39	2.5	22	52	37	2.7	30	47	36	2.9	22	48	40	2.1	34	46
Arm skinfold (mm)	11	5.2	2	37	12	4.1	4	28	23	8.0	6	64	25	8.5	6	55	10	4.6	3	38
Scapula skinfold (mm)	12	4.7	6	38	13	4.6	6	32	16	7.7	7	58	19	9.7	6	65	14	5.8	5	36
Thorax skinfold (mm)	13	5.8	3	39	14	5.3	4	36	14	6.9	4	54	15	8.0	4	56	12	5.7	2	32
Abdomen skinfold (mm)	16	9.6	3	60	18	10.0	4	66	27	11.6	4	66	30	13.2	5	66	14	9.1	3	53
Average skinfold (mm)	13.2	5.6	4.0	40.8	14.2	5.1	4.8	39.2	19.8	6.8	6.2	55.5	22.3	8.8	6.0	59.5	12.5	5.6	3.8	32.2
A.P. iliac crest diam. (cm)	21	2.6	16	34	22	2.9	15	44	16	2.1	12	26	17	2.6	12	32	22	3.0	14	36
A.P. thigh diam. (cm)	16	1.5	13	21	16	1.4	12	22	14	1.5	10	22	14	2.1	10	36	17	1.7	12	22
Gubner index	37	3.5	25	46	36	3.8	21	47	38	3.3	23	45	37	3.7	21	45	35	3.9	21	45
Ponderal index	12.7	0.5	10.8	14.2	12.6	0.5	10.8	14.0	12.9	0.6	10.1	14.2	12.6	0.6	9.9	14.1	12.4	0.6	10.6	14.1
% standard wt.	106	12.9	80	169	109	13.4	80	167	103	14.1	77	197	108	17.3	78	233	112	16.1	77	179

Ponderal index	12.7	0.5	10.8	14.2	12.6	0.5	10.8	14.0	12.9	0.6	10.1	14.2	12.6	0.6	9.9	14.1	12.4	0.6	10.6	14.1
% standard wt.	106	12.9	80	169	109	13.4	80	167	103	14.1	77	197	108	17.3	78	233	112	16.1	77	179

TABLE 3. MEANS, STANDARD DEVIATIONS AND RANGES OF ANTHROPOMETRIC MEASUREMENTS, INDEXES AND KILOGRAMS DETERMINED BODY FAT FOR LABORATORY SUBJECTS

Measurement	Category I (n=35)				Category II (n=34)				Category III (n=33)				Category IV (n=31)				Category V (n=34)			
	Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range		Mean	S.D.	Range	
Weight (lb)	168.3	30.3	128.6	267.4	171.4	20.7	129.8	229.9	133.0	26.2	97.8	237.6	139.1	29.1	104.0	240.0	174.9	34.5	115.3	288.6
Height (cm)	180.5	7.5	164.9	195.5	177.2	6.5	159.3	190.0	165.9	5.6	153.2	174.9	163.6	7.1	146.0	181.0	175.7	6.3	162.9	185.0
Biacromial diam. (cm)	40	2.5	35	45	40	1.8	35	44	36	1.9	33	40	35	1.5	32	38	41	2.4	32	44
A.P. chest diam. (cm)	16	1.8	14	22	17	1.6	14	22	16	1.9	13	24	16	1.5	12	20	17	2.9	13	29
Bi-iliac diam. (cm)	29	2.3	25	38	29	2.4	25	40	28	2.1	24	35	28	2.2	25	34	27	2.6	20	36
Chest circ. (cm)	96	7.5	76	113	100	7.5	84	120	85	7.9	64	120	87	8.0	77	109	97	8.8	79	128
Waist circ. (cm)	82	7.6	68	106	87	8.7	71	109	68	10.0	55	113	72	9.7	56	102	87	9.5	68	120
Iliac crest circ. (cm)	87	9.2	76	128	92	7.4	73	111	92	8.2	79	112	94	12.6	73	139	89	11.2	72	136
Arm circ. (cm)	32	3.1	24	40	33	2.3	26	38	27	3.0	20	37	28	4.1	24	42	35	3.4	26	42
Wrist circ. (cm)	17	1.1	16	20	18	0.7	15	19	15	0.9	14	18	15	0.7	13	16	18	1.1	15	20
Thigh circ. (cm)	53	4.6	43	67	53	2.6	42	61	50	5.0	42	63	52	6.0	44	75	55	4.7	42	67
Ankle circ. (cm)	22	1.6	18	27	22	1.1	19	25	21	1.6	19	25	21	1.4	16	25	22	1.8	18	25
Arm length (cm)	38	1.9	33	42	38	1.5	32	43	35	1.9	32	40	35	1.7	32	38	38	1.8	33	42
Thigh length (cm)	40	2.4	35	44	39	3.1	36	52	36	2.2	32	41	37	3.3	22	48	40	2.1	33	44
Arm skinfold (mm)	10	4.7	2	20	12	5.1	4	26	24	8.3	6	45	26	8.8	16	55	11	6.5	3	38
Scapula skinfold (mm)	11	4.1	6	24	14	5.2	6	28	18	10.4	7	58	20	12.0	7	55	15	6.0	6	28
Thorax skinfold (mm)	11	4.9	4	27	14	5.2	5	30	15	7.2	5	40	15	7.2	4	31	12	6.3	2	32
Abdomen skinfold (mm)	13	10.1	3	56	19	9.2	4	42	29	12.8	8	56	31	12.1	5	58	15	10.3	3	53
Average skinfold (mm)	11.0	5.2	4.0	31.0	14.8	4.9	4.8	26.5	20.9	8.9	8.2	46.5	22.9	9.2	11.0	48.8	13.3	6.5	3.8	32.2
Gubner index	38	3.7	25	45	36	4.5	21	43	38	3.9	23	42	36	4.2	21	42	35	3.6	21	44
Ponderal index	12.9	0.6	11.0	14.2	12.6	0.5	11.1	13.5	12.9	0.6	10.1	13.9	12.5	0.7	9.9	13.5	12.4	0.6	10.6	14.1
% standard wt.	104	15.7	80	164	109	13.4	80	152	105	18.4	85	175	113	22.6	88	203	112	18.2	77	173
Body fat (kg)	17.14	7.89	6.02	47.12	20.67	5.96	9.08	37.04	19.00	7.11	8.93	40.14	23.30	9.50	13.48	62.94	18.58	8.66	6.38	49.17
Lean body mass (kg)	59.35	8.29	49.07	83.41	57.30	6.40	46.20	69.41	41.18	6.85	31.43	69.79	39.92	5.06	32.47	52.98	61.00	10.08	41.30	82.19

TABLE 4. CORRELATION COEFFICIENTS OF ANTHROPOMETRIC MEASUREMENTS WITH KILOGRAMS OF BODY FAT

Measurement	White males		White females		Negro males	All white males	All white females	All young white	All mature white	All males	All white	All groups
Age (yr)	25–34	35–44	25–34	35–44	25–44	25–44	25–44	25–34	35–44	25–44	25–44	25–44
Weight	0.852	0.747	0.874	0.957	0.820	0.805	0.912	0.662	0.642	0.806	0.648	0.644
Height	0.193	−0.109	0.194	0.151	0.357	0.034	0.115	0.046	−0.086	0.145	−0.047	0.002
Biacromial diam.	0.538	0.311	0.409	0.355	0.529	0.424	0.278	0.267	0.040	0.458	0.126	0.158
A.P. chest diam.	0.729	0.491	0.539	0.508	0.300	0.649	0.513	0.583	0.381	0.461	0.504	0.409
Bi-iliac diam.	0.629	0.228	0.644	0.737	0.565	0.464	0.672	0.613	0.441	0.487	0.524	0.535
Chest circ.	0.762	0.847	0.724	0.860	0.846	0.801	0.792	0.527	0.537	0.819	0.545	0.575
Waist circ.	0.894	0.851	0.837	0.883	0.873	0.865	0.855	0.583	0.545	0.860	0.580	0.576
Iliac crest circ.	0.913	0.815	0.854	0.938	0.882	0.884	0.897	0.881	0.902	0.883	0.893	0.891
Arm circ.	0.733	0.749	0.884	0.843	0.668	0.743	0.864	0.517	0.557	0.672	0.550	0.489
Wrist circ.	0.613	0.469	0.376	0.234	0.532	0.573	0.309	0.235	0.010	0.553	0.140	0.165
Thigh circ.	0.858	0.515	0.876	0.920	0.758	0.744	0.908	0.769	0.782	0.734	0.781	0.740
Ankle circ.	0.743	0.288	0.601	0.316	0.712	0.551	0.447	0.573	0.230	0.613	0.407	0.480
Arm length	0.182	0.166	0.206	0.233	0.468	0.151	0.194	0.074	0.033	0.265	0.041	0.087
Thigh length	0.175	0.049	0.067	−0.028	0.278	0.067	0.055	0.020	−0.044	0.126	−0.009	0.017
Arm skinfold	0.707	0.336	0.798	0.875	0.558	0.563	0.835	0.577	0.627	0.560	0.608	0.586
Scapula skinfold	0.851	0.606	0.823	0.870	0.692	0.729	0.841	0.727	0.804	0.696	0.772	0.747
Thorax skinfold	0.834	0.531	0.846	0.746	0.819	0.710	0.756	0.803	0.678	0.754	0.742	0.758
Abdomen skinfold	0.763	0.527	0.800	0.711	0.880	0.688	0.736	0.696	0.638	0.757	0.676	0.701
Average skinfold	0.890	0.640	0.886	0.876	0.843	0.796	0.864	0.753	0.780	0.814	0.770	0.772
Gubner index	−0.562	−0.738	−0.729	−0.657	−0.646	−0.653	−0.703	−0.634	−0.646	−0.622	−0.663	−0.629
Ponderal index	−0.829	−0.722	−0.854	−0.846	−0.721	−0.795	−0.856	−0.830	−0.797	−0.742	−0.824	−0.776
% standard wt.	0.927	0.811	0.908	0.958	0.828	0.883	0.937	0.907	0.915	0.844	0.912	0.879

variation for all body measurements within each group. For example, the overall range of percentage standard weight was 77–233 per cent. Correlation matrices* were prepared for all anthropometric measurements for the 2053 subjects by category.

Table 3 presents the means, standard deviations and ranges for anthropometric measurements, total body fat and LBM by subject category for those subjects who had laboratory measurements. The ranges of body measurements within categories for these laboratory subjects did not differ appreciably from those for all subjects. The overall range of percentage standard weight for the laboratory subjects was 77–203 per cent. Kilograms of body fat and of LBM showed similar widespread ranges within the subject categories.

Correlation coefficients of anthropometric measurements and the three indexes (percentage standard weight, Gubner and ponderal) with kilograms of body fat are presented in Table 4. Of particular interest is the correlation of percentage standard weight with body fat in kilograms. For the first five subject categories in the table these correlation coefficients (r values) vary from 0.811 to 0.958, the older white men and the Negro men having the lowest correlation coefficients. When the r values are calculated between percentage standard weight and body fat as percentage total body weight, the correlation is much lower and more variable. Thus, by subject categories this group of r values was: I, 0.782; II, 0.588; III, 0.584; IV, 0.842; and V, 0.613. Standard weight tables are derived from observations of population groups and therefore require revisions from time to time dependent in part on changes in the characteristics of the population and alterations of environmental factors. As shown above these tables provide an inconsistent indication of the relative body composition and the body fatness among race–sex–age groups.

Iliac crest and thigh diameters were not included in Tables 3 and 4 because they were not obtained on all subjects. However, trial computer runs revealed that they added practically no predictive information that was not already implicit in the other anthropometric measurements.

REGRESSION EQUATIONS

Using only those subjects on whom TBW–body density determinations had been made, the following procedure was used to develop regression equations for each subject category and combinations of categories. First, the best single-variable regression equation was calculated using that anthropometric variable which correlated highest with body fat. Second, a two-variable regression equation was calculated by adding that variable which correlated highest with the deviations between the actual and predicted body fat using the first equation. The second variable, in other words, was the one which best explained what was unaccounted for by the first equation. In a similar way, other anthropometric variables were added one by one. Anthropometric indexes were purposely omitted from the development of the equations to avoid unnecessary mathematical steps in the practical use of the equations.

For the most part, the variables entering the equations were ones for which excellent reproducibility between examiners was obtained (see *Discussion*). Subsequent

*Copies are available from the authors.

to the first variable, the variables entering the equations were not necessarily those correlating highest with body fat, since the purpose of each variable after the first was to explain what the earlier variables had missed.

TABLE 5. TWO, THREE AND FOUR VARIABLE REGRESSION EQUATIONS AND MULTIPLE CORRELATIONS BY CATEGORY

Category	Number of variables	Estimated fat in kg					Multiple correlation with measured fat in kg
White males 25–34 yr	2	0.647 I.C.C.*	+0.453 Arm S.F.	−43.659			0.939
	3	0.498 I.C.C.	+0.362 Arm S.F.	+ 0.435 Thigh C.	−52.836		0.949
	4	0.372 I.C.C.	+0.249 Arm S.F.	+ 0.449 Thigh C.	+ 0.380 Thorax S.F.	−45.464	0.959
White males 35–44 yr	2	0.573 Waist C.	+0.332 Arm S.F.	−33.286			0.897
	3	0.362 Waist C.	+0.314 Arm S.F.	+ 0.265 Chest C.	−41.093		0.906
	4	0.381 Waist C.	+0.368 Arm S.F.	+ 0.382 Chest C.	− 0.272 Scapula S.F.	−51.268	0.918
White males 25–44 yr	2	0.350 Waist C.	+0.444 I.C.C.	−50.560			0.909
	3	0.367 Waist C.	+0.351 I.C.C.	+ 0.287 Arm S.F.	−46.791		0.926
	4	0.352 Waist C.	+0.395 I.C.C.	+ 0.253 Arm S.F.	− 0.353 Arm Length	−35.689	0.930
Negro males 25–44 yr	2	0.372 I.C.C.	+0.386 Abdomen S.F.	−20.462			0.910
	3	0.342 I.C.C.	+0.289 Abdomen S.F.	+ 0.242 Thorax S.F.	−19.377		0.914
	4	0.333 I.C.C.	+0.212 Abdomen S.F.	+ 0.358 Thorax S.F.	+ 0.515 Thigh Length	−39.408	0.920
White and Negro males 25–44 yr	2	0.320 Waist C.	+0.451 I.C.C.	−48.910			0.900
	3	0.307 Waist C.	+0.410 I.C.C.	+ 0.169 Arm S.F.	−45.994		0.906
	4	0.282 Waist C.	+0.363 I.C.C.	+ 0.136 Arm S.F.	+ 0.175 Thorax S.F.	−41.448	0.909
White females 25–34 yr	2	1.176 Arm C.	+0.635 Thigh C.	−44.255			0.913
	3	0.861 Arm C.	+0.533 Thigh C.	+ 0.147 Abdomen S.F.	−34.949		0.930
	4	0.354 Arm C.	+0.403 Thigh C.	+ 0.159 Abdomen S.F.	+ 0.083 Weight	−26.189	0.937
White females 35–44 yr	2	0.338 Weight	−2.494 Wrist C.	+14.046			0.972
	3	0.283 Weight	−2.216 Wrist C.	+ 0.203 Arm S.F.	+12.125		0.977
	4	0.300 Weight	−1.855 Wrist C.	+ 0.169 Arm S.F.	− 0.511 Arm Length	+23.173	0.980
White females 25–44 yr	2	0.337 Weight	−3.294 Wrist C.	+24.859			0.946
	3	0.363 Weight	−2.710 Wrist C.	− 1.050 Biacromial D.	+49.864		0.963
	4	0.307 Weight	−2.239 Wrist C.	− 0.868 Biacromial D.	+ 0.185 Arm S.F.	+39.358	0.970
White males and females 25–34 yr	2	0.552 I.C.C.	+0.504 Thigh C.	−57.266			0.917
	3	0.377 I.C.C.	+0.489 Thigh C.	+ 0.319 Thorax S.F.	−44.904		0.933
	4	0.380 I.C.C.	+0.588 Thigh C.	+ 0.263 Thorax S.F.	− 0.334 Arm Length	−37.294	0.937
White males and females 35–44 yr	2	0.792 I.C.C.	−0.652 Biiliac D.	−32.813			0.914
	3	0.676 I.C.C.	−0.675 Biiliac D.	+ 0.338 Thigh C.	−39.297		0.922
	4	0.662 I.C.C.	−0.475 Biiliac D.	+ 0.342 Thigh C.	− 0.389 Arm Length	−29.836	0.927
White males and females 25–44 yr	2	0.562 I.C.C.	+0.457 Thigh C.	−55.227			0.914
	3	0.542 I.C.C.	+0.557 Thigh C.	− 0.513 Arm Length	−39.770		0.924
	4	0.515 I.C.C.	+0.317 Thigh C.	− 0.878 Arm Length	+ 0.062 Weight	−20.832	0.929
All subjects	2	0.592 I.C.C.	+0.360 Thigh C.	−53.107			0.905
	3	0.571 I.C.C.	+0.471 Thigh C.	− 0.472 Arm Length	−39.560		0.913
	4	0.489 I.C.C.	+0.439 Thigh C.	− 0.384 Arm Length	+ 0.187 Thorax S.F.	−36.165	0.918

*I.C.C. = Iliac crest circumference. S.F. = Skin fold thickness. C. = Circumference. D. = Diameter.

Table 5 presents the regression equations using two, three and four variables for each category and combinations of categories. Weight is in pounds; skinfold thickness is in millimeters; other measurements are in centimeters. Incorporation of additional variables resulted in little further increase in the multiple correlation coefficients. Although the linearity of the relationships has been questioned [10], the size of the multiple correlation coefficients indicates that the non-linearity, though perhaps statistically significant, is substantively not important.

TABLE 6. STANDARD ERROR OF ESTIMATE AND 95% CONFIDENCE INTERVALS FOR KILOGRAMS BODY FAT OF 'AVERAGE' INDIVIDUALS, BY CATEGORY AND NUMBER OF PREDICTOR VARIABLES

Category	No. of variables	Body fat in kg		95% confidence interval	
		S.E.	Mean	Individual	Population mean
I	2	2.840	17.14	11.28–23.00	16.16–18.12
	3	2.635	17.14	11.69–22.59	16.23–18.05
	4	2.402	17.14	12.17–22.11	16.31–17.97
II	2	2.761	20.67	14.96–26.38	19.70–21.64
	3	2.683	20.67	15.11–26.23	19.73–21.61
	4	2.557	20.67	15.37–25.97	19.77–21.57
III	2	3.037	19.00	12.70–25.30	17.92–20.08
	3	2.792	19.00	13.20–24.80	18.00–20.00
	4	2.690	19.00	13.41–24.59	18.04–19.96
IV	2	2.337	23.30	18.43–28.17	22.44–24.16
	3	2.151	23.30	18.81–27.79	22.51–24.09
	4	2.044	23.30	19.02–27.58	22.54–24.06
V	2	3.776	18.58	10.76–26.40	17.26–19.90
	3	3.747	18.58	10.81–26.35	17.27–19.89
	4	3.665	18.58	10.98–26.18	17.29–19.87

Table 6 illustrates the precision of estimation of the equations by considering, in each category, a hypothetical 'average' individual, each of whose anthropometric measurements is exactly equal to the mean for his category. In each case the 95% confidence interval [11] for the estimate of kilograms of body fat of an *individual* is given, as well as the 95% confidence interval for the estimate of the mean value for kilograms of body fat for a *population* in which all individuals had measurements equal to the mean for his category.

ESTIMATION OF LEAN BODY WEIGHT FROM K-40 CONTENT

Means, standard deviations and ranges for K^{40} measurements in counts/min and the measurements derived therefrom appear in Table 7. $LBW^{K\text{-}40}$ and LBM for subjects studied with both the whole-body counting and TBW–body density techniques are also presented. (The body weight as measured at the time of laboratory study was used for the calculation of LBM for this table. For Table 3, LBM was calculated from the body weight taken for anthropometric measurements. The largest discrepancy between these two measurements for any one individual was 0.7 kg).

TABLE 7. MEANS, STANDARD DEVIATIONS AND RANGES OF POTASSIUM-40 AND RELATED BODY COMPOSITION MEASUREMENTS

	Males 25–44 years (n = 44)			Females 25–44 years (n = 24)		
	Mean	S.D.	Range	Mean	S.D.	Range
K^{40} counts/min	148	20.6	105–208	99	12.4	84–133
K Total (g)	136	18.9	96–191	91	11.4	77–122
K-equivalents	3.48	0.48	2.46–4.89	2.33	0.29	1.97–3.12
Body wt. (kg)	77.41	12.7	57.21–121.59	62.46	14.2	46.93–107.81
K m-equiv/kg body wt.	45	5.4	32–57	38	5.6	27–45
LBW K^{40} (kg)	51.10	7.04	41.69–71.67	34.27	4.20	28.94–45.82
LBM* (kg)	58.42	8.41	40.33–84.11	41.74	7.72	33.43–69.42

*From TBW–body density technique.

Sixty-eight subjects (44 men and 24 women) had K^{40} determinations in addition to TBW–body density determinations (Table 7). The calculated K equivalents compare favorably with those found by ALLEN *et al.* [12]. They found an average of 3.975 K equivalents for 507 men aged 25–45 years and an average of 2.521 K equivalents for 156 women aged 24–44 years. For similar age groups reported here, mean K equivalents for men were 3.48 ± 0.48 and for women 2.33 ± 0.29.

The ranges of potassium content for our subjects were 32–57 m-equiv/kg for the men and 27–45 m-equiv/kg for the women. These are close to the ranges found by FORBES *et al.* [7] for 42 men aged 11–44 years, 35–58 m-equiv/kg, and for 8 women aged 7–23 years, 23–52 m-equiv/kg. The small differences may be attributed to the demonstrated differences of total body potassium with relation to age as shown by ALLEN *et al.* [12] and the small number of women in FORBES' group [7].

While FORBES *et al.* [7] have suggested a new approach to body composition measurements, the method has not been studied sufficiently to define what is actually measured by whole body counting of K^{40} in terms of fat, muscle and bone. They have assumed this measurement to be indicative of all body weight exclusive of fat. However, we suggest that it may account for neither bone nor fat. This suggestion is based on the comparison of K^{40} data with TBW-body density data as measured in the same individuals, and reported here, as well as the following reasons. Potassium is primarily intracellular with little in bone (exclusive of marrow) and fat. The measurement of K^{40} is calculated on the basis of dilution of K^{42} after an equilibration period. Whether K^{42} appears during the equilibration period in the sparse cellular population of the bone is not known. In addition, chemical analysis of potassium by ashing procedures is not exactly comparable to the indirect isotopic method. For this paper, therefore, LBW K^{40} calculated from the measured total K and the factor, 68.1 (potassium content in meq/kg from cadaver analysis), is thus defined as body weight less bone and fat. Mean $LBW^{K\text{-}40}$ for the 44 men was 51.10 ± 7.04 kg and for the 24 women was 34.27 ± 4.20 kg (Table 7). Correlation coefficients for LBM and $LBW^{K\text{-}40}$ were 0.861 for the men and 0.798 for the women. Correlations of $LBW^{K\text{-}40}$ and TBW were slightly higher, 0.880 for the men and 0.813 for the women.

LBM, as calculated from TBW–body density technique and the body weight, is essentially equivalent to BEHNKE's 'lean-body mass' [13]. LBM differs from the fat-free mass as determined by chemical dissection of cadavers only by an undetermined quantity, perhaps 2–5 per cent, of essential phospholipids and cerebrosides present in bone marrow, spinal cord, brain and certain organs [13]. LBM differs from $LBW^{K\text{-}40}$ in that it includes bone mass and the essential lipids. Appropriate corrections of LBM for essential lipids and of $LBW^{K\text{-}40}$ for bone mass should result in comparable values which may be considered equivalent to the 'chemical' fat-free body. Thus:

'chemical' fat-free body $\cong$ LBM − essential lipids

and 'chemical' fat-free body $\cong$ $LBW^{K\text{-}40}$ + bone mass

Estimates of bone mass and of essential lipids may be made to apply in the above formulas. On the basis of measurements of weight, density, body water, height and joint diameters at elbow, wrist, knee and ankle on 30 subjects, ALLEN and co-workers [14] have estimated that 6.8 per cent ($2s$ range = 5.7 − 7.9 per cent) of the 'normally hydrated fat-free body' is bone mineral. Applying this factor to LBM ('normally hydrated fat-free body' $\cong$ LBM), mean bone tissue in our male subjects would be 3.97 kg and for female subjects 2.84 kg. This estimate of bone tissue added to mean $LBW^{K\text{-}40}$ may be assumed equivalent to the mean 'chemical' fat-free body. Mean value for men amounts to 55.07 kg and for women 37.11 kg. These mean values are slightly less than those for 'chemical' fat-free body obtained by subtraction of assumed essential lipids (3.5 per cent of LBM) from mean LBM—56.38 kg for males and 40.28 kg for females.

In the paragraphs above we have presented two ways of estimating lean body mass, namely by potassium measurement and by TBW–body density technique. As has been shown the correlation of these two measurements is very high. However, this correlation is not as great as that between body fat measured by TBW–body density and the regression equations using anthropometric measurements (Table 5).

COMPARISON WITH OTHER ANTHROPOMETRIC PREDICTIONS OF BODY FAT OR WEIGHT

It has been emphasized that prediction equations developed from anthropometric measurements should be compared with measurements of subjects other than those used for derivation of the equations. From the literature seven formulas were selected [10, 15–19, 21] which used the variables measured in our study of 167 subjects having body fat measurements. Anthropometric data from the present study were substituted appropriately in these seven formulas. Correlation coefficients were determined between the predicted and observed values for each formula and for each subject category where applicable.

The seven formulas used were as follows:

1. YOUNG [15]. Skinfold and percentage standard weight. This was based on 94 women aged 17–30 years measured anthropometrically and by body density. Specific gravity = $1.0884 - 0.0004321\,X_1 - 0.0003401\,X_{13}$

   Where X_1 = skinfold mid-abdomen line in mm.

   X_{13} = percentage standard weight according to Build and Blood Pressure Study, 1959 (according to HATHAWAY and FOARD [8] for our data).

Percentage body fat was calculated from the Rathbun-Pace formula:

$$\%\ \text{fat} = \left(\frac{5.548}{\text{sp. gr.}} - 5.044\right) 100$$

2. CHINN and ALLEN [16]. Skinfolds, height, weight and age. This is based on combined data from 244 Caucasian and Asiatic men of military age.

   $\text{Fat} = [(0.00285\,\bar{S} - 0.0114)^{\frac{1}{2}} - 0.061]\,M + 1.1\,H^3 + 0.234\,A - 6.4$

   Where $\bar{S}$ = average of 2 skinfold thicknesses in mm (average of 4 skinfold thicknesses was used for our data).
   M = body weight in kg.
   H = height in cm.
   A = age in years.

3. HUNT [17]. Height, weight, and waist girth. This formula, based on two formulas predicting basal oxygen consumption and fat-free weight, was not tested by HUNT to establish the efficiency of the combined formula.

   $\text{Fat-free weight} = 1.49\,W - 1.76\,H^3 - 56.82\,G^3 - 6.45$

   Where W = body weight in kg.
   H = height in meters.
   G = waist girth in meters.

4. BROZEK [18]. Height, bicristal diameter, biacromial diameter, upper arm diameter (corrected for skinfold) and age. The formula was based on data for 238 Minneapolis firemen.

   Total body weight = 0.411 height + 1.204 bicristal diameter + 0.0885 biacromial diameter + 7.342 upper arm diameter, corrected for thickness of subcutaneous fat + 0.220 age − 137.510.

   All measurements are in cm and age in years.

   (For our data, biiliac diameter was taken as the same as bicristal diameter, and upper arm diameter was calculated from arm circumference.)

5. HECHTER [19]. Chest circumference, buttock circumference and stature. This formula is based on the 31 Navy men BEHNKE used for developing his reference standard [20].

   $W = 466 \times 10^{-7} \times C \times B \times S$

   Where W = weight in kg.
   C = chest circumference in cm.
   B = buttock circumference in cm (iliac crest circumference was substituted).
   S = height in cm.

6. PRYOR [21]. Height, biiliac diameter and lateral thoracic diameter. From measurements of 12,000 people aged from "one to 41 plus" years, she developed a linear regression equation predicting weight from these three variables.

   $W = C + (b_{14.23})(L) + (b_{13.24})(Bi) + (b_{12.34})(H)$

   Where W = weight prediction.
   C = constant from regression formula.
   L = lateral thoracic diameter (taken as biacromial diameter for our data).

Bi = biiliac diameter.
H = height in inches.
b = partial regression coefficient of weight with L, Bi and H.

7. MOORE *et al.* [10]. Body weight, age, sex and assumption of hydration factor of 0.73 for body fat-free tissue.
   Body fat = Body weight − (Total body water)/0.73
   The equations for calculation of total body water (TBW) together with number of subjects on which equations were based follow.
   Males, 16–30 yr (63): TBW = 13.26 + 0.404 body wt in kg
   Males, 31–60 yr (56): TBW = 11.03 + 0.397 body wt in kg
   Females, 16–30 yr (54): TBW = 11.63 + 0.318 body wt in kg
   Females, 31–90 yr (34): TBW = 8.84 + 0.331 body wt in kg

Table 8 presents the correlation coefficients obtained from the present anthropometric data calculated by the above seven formulas and the appropriate observed value.

TABLE 8. CORRELATION COEFFICIENTS OF DETERMINED WITH PREDICTED VARIABLE

Investigator	Variable predicted	Category I (n = 35)	Category II (n = 34)	Category III (n = 33)	Category IV (n = 31)	Category V (n = 34)
YOUNG [15]	% body fat			0.680	0.839	
CHINN and ALLEN [16]	Total body fat	0.196	−0.065			0.298
HUNT [17]	Fat-free body wt	0.896	0.751	0.582	0.779	0.851
BROZEK [18]	Total body wt	0.776	0.807			0.839
HECHTER [19]	Total body wt	0.938	0.944			0.946
PRYOR [21]	Total body wt	0.708	0.672	0.645	0.607	0.777
MOORE *et al.* [10]	Total body fat	0.726	0.707	0.857	0.959	0.773

Although the YOUNG formula (No. 1) was based on body density for women aged 17–30 years, the correlation coefficient with observed values for the older women (category IV) was greater than for the younger women (category III). Only a partial explanation may be made on the basis of the use of a different standard weight table. At the extremes of height, the Build and Blood Pressure table differs by one pound less for the shortest and by one pound more for the tallest women from the weights given in HATHAWAY and FOARD's table [8]. The range of height for category III, however, was less than for category IV: 153.2 − 174.9 cm as compared to 146.0 − 181.0 cm. YOUNG's group averaged 167.5 ± 6.03 cm. YOUNG's reference group was found by densitometry to average 28.69 ± 4.856 per cent of body weight as fat. Corresponding values determined by TBW–body density for our category III were 30.89 ± 6.1 and for category IV, 35.70 ± 5.7.

CHINN and ALLEN's formula (No. 2) for predicting body fat gave low or negative correlations with determined body fat. Probably this is in part related to the high percentage of Oriental and young men in the reference group. The correlations were not significant.

It was expected that HUNT's formula (No. 3) would have good predictive value since waist circumference and weight were found to have high correlation coefficients with body fat in kg (Table 4). For categories I and V, predicted 'fat-free body weight' and observed LBM had correlation coefficients of 0.896 and 0.851 respectively. For the remaining three groups the correlation coefficients, although significant, were less.

Of the three formulas predictive of total body weight, that of HECHTER (No. 5) for men provided consistently high correlation coefficients despite the substitution of iliac crest circumference for buttock circumference. BROZEK's formula (No. 4), also predictive only for men, correlated significantly with total body weight. For comparison with PRYOR's formula (No. 6), partial correlations of weight with anthropometric measurements, *L*, *Bi* and *H*, were calculated from our data in accordance with her procedure. The resultant correlation coefficients were significant for all groups.

Total body fat prediction by the formula of MOORE *et al.* (No. 7), based on calculated TBW, provided significant correlation coefficients for all groups but was highest for categories III and IV. This probably relates to the higher body fat content of women and reflects the inherent error of determining total body fat from TBW alone. SIRI [22] has calculated the standard error in total fat determination by this method at ± 3.6 per cent of total body weight even if there were no error in TBW measurement. The standard error in total body fat for the TBW–body density technique used in the present study is only ± 1.7 per cent of total body weight [22].

Therefore by using appropriate data from this study in predictive formulas from other studies it appears that only one had as high a correlation between predicted and observed values as determined for the present study.

COMPARISON WITH AN ANTHROPOMETRIC MEASURE OF TOTAL POTASSIUM

MOORE and co-workers [10] on the basis of body weight, sex, and age have formulated a series of equations to estimate potassium equivalents. The number of subjects on which each formula was based is given in parentheses. The equations are:

Males, 16–30 years (97): K equiv. = 735 + 38.01 body weight in kg
Males, 31–60 years (34): K equiv. = 1385 + 26.23 body weight in kg
Females, 16–30 years (59): K equiv. = 1250 + 18.30 body weight in kg
Females, 31–60 years (28): K equiv. = 1176 + 16.93 body weight in kg

Using the appropriate formula for our subjects, the mean K equivalents have been calculated and correlated with the mean determined K equivalents. The correlation coefficient for male subjects was 0.647 and for females 0.769.

DISCUSSION

Three possible sources of error in the development of anthropometric equations to predict body composition are: the population from which the measurements have been derived, the reproducibility of the anthropometric measurements and the accuracy of the reference laboratory measurements. This study has taken these factors into account.

The study group, although not a random sample from a defined population, was a reasonably representative selection from a large heterogeneous group with a wide variety of occupations. Subgroups for laboratory study were equally heterogeneous.

Reproducibility of the anthropometric measurements was determined by comparing results obtained by two examiners. For those measurements entering the equations, the discrepancy between examiners amounted generally to less than 2 per cent. However, despite careful attention to technique, certain of the measurements, i.e., thigh length and antero-posterior diameter of thigh and iliac crest, were consistently taken by the two examiners with discrepancies greater than 2 per cent. Of these, only the thigh length entered one of the equations.

Analysis of the accuracy of the laboratory measurements has been presented [22]. The combined TBW–body density technique is considered the most accurate *in vivo* measurement of body fat; the standard error for fat measurement by this method is ± 1.7 per cent of total body weight. In addition fewer assumptions of body composition relationships are necessary with the combined technique than are required for the estimation of body fat from the single determination of TBW or of body density.

Although K^{40} whole-body counting was not used as the reference laboratory method for measuring body composition, an analysis of the error of this method is pertinent. The error of the method, as used here, was 9.7 per cent. Others [23] using an Argonne type whole-body counter have achieved apparently lower errors, but the inherent error in counting statistics is always at least 2–3 per cent. With the more favorable geometry of the 4π scintillation counter, the errors related to height and weight of the subject are lower. Although these relationships may exist [23], we were unable to find a correction factor for height and weight to apply to the data presented. An additional source of error for methods using K^{40} analysis may be associated with the use of the results of chemical analysis of potassium available for only 4 adult human cadavers.

Comparison of calculations of $LBW^{K\text{-}40}$ with LBM calculated from results of the TBW–body density technique gave correlation coefficients of 0.861 for 44 men and 0.798 for 24 women. These correlations, while high, are less than those for four anthropometric variables with the TBW–body density technique. Correlation of $LBW^{K\text{-}40}$ with TBW was slightly higher than with LBM calculated from TBW–body density measurements. Since the ratio of muscle to bone is not accounted for in the TBW–body density technique and little K^{40} is in bone, TBW measurements with K^{40} measurements may be a better indicator of muscle as ANDERSON has suggested [24]. Our data would indicate, however, that when the estimated essential lipids are subtracted from LBM the resultant estimates of 'fat-free body' differ on the average only by 1.31 kg for men and by 3.07 kg for women from similar estimates based on ALLEN's bone prediction [14] plus $LBW^{K\text{-}40}$.

DAMON and GOLDMAN [25] have compared results of 10 anthropometric formulas predicting body composition to measurements of 13 athletic young men, aged 18–29 years, who were also measured densitometrically. Their work showed best correlation with formulas using two standard skinfold thicknesses. Unsatisfactory correlations were obtained with other formulas for several possible reasons among which are selection of reference population, size of reference population or too small a validating population.

Similar comparisons of seven anthropometric formulas predicting total body weight, body fat or lean body weight and one estimating K equivalents have been made with our data. Our results have been similar to those of DAMON in that the CHINN and ALLEN [16] equation provided poor correlation with laboratory results.

For the remaining equations, correlations with laboratory measures for the appropriate age–sex–race groups were satisfactory but in only one instance were they as high as those obtained in the present study.

The linear regression equations developed for five race–sex–age categories estimate total body fat from four variables with multiple correlations of 0.918 to 0.980. The standard errors in kilograms body fat range from 2.044 to 3.665. The highest standard error was obtained for the Negro men, perhaps because the age range was greater for this group. Even so, on the basis of a 70 kg man, the error of fat prediction in this group would be ± 5.2 per cent of total body weight. These regression equations for estimating body fat provide greater accuracy and have been derived from laboratory measurements of greater validity than others previously developed [10, 15, 16, 26]. The predictability of body fat provided by the regression equations is completely adequate for epidemiological and most clinical purposes.

SUMMARY

Study of body composition is important in epidemiology, medicine, nutrition, surgery, physiology and other related fields. While laboratory methods are sufficiently refined to determine body fat and lean body mass with accuracy, they remain specialized research tools. In this and the preceding paper, regression equations using anthropometric measurements are developed by which total body fat and lean body mass can be predicted easily with an accuracy suitable for clinical and epidemiological studies.

Regression equations for estimating body fat from two, three and four anthropometric variables are presented for five race–sex–age categories of healthy adults and for combinations of these subject categories. Validation of the equations was based on determinations of body fat from laboratory measurements of total body water (tritium) and body density by helium dilution on 167 subjects randomly selected from a total of 2053 subjects who were measured anthropometrically. Multiple correlation coefficients on kilograms body fat for all equations were 0.897 or greater. With four variables, the highest r was 0.980 obtained for women aged 35–44 years, inclusive; the lowest was 0.918, obtained for white men of the same age.

For 68 subjects, comparison has been made of the lean body weight obtained from K^{40} measurements with lean body mass calculated from total body weight and body fat determinations.

Calculations of either body fat, total body weight, fat-free body weight, percentage body weight as fat or potassium equivalents according to anthropometric formulas have been correlated with the appropriate measured variable for the data obtained in this study.

The methodology of predicting body composition from anthropometric measurements provides a useful tool in the further epidemiological and clinical study of chronic diseases associated with overweight.

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REFERENCES

1. Steinkamp, R. C., Cohen, N. L., Siri, W. E., Sargent, T. W. and Walsh, H. E.: Measures of body fat and related factors in normal adults. I. Introduction and methodology, *J. chron. Dis.* **18**, 1279, 1965.
2. Cohen, N. L., Steinkamp, R. C. and Bron, G.: Measures of body fat and related factors in normal adults. VI. Anthropometric measurements of adult Orientals and Negro females. To be published.
3. Hutson, E. M., Cohen, N. L., Kunkel, N. D., Steinkamp, R. C., Rourke, M. H. and Walsh, H. E.: Measures of body fat and related factors in normal adults. III. Diet and physical activity. To be published in *J. Amer. diet. Ass.*
4. Steinkamp, R. C., Cohen, N. L., Sargent, T. W., Hutson, E. M., Kunkel, N. D. and Isaacs, E.: Measures of body fat and related factors in normal adults. IV. Cesium-137 and diet. To be published.
5. Steinkamp, R. C., Cohen, N. L., Huber, A. T. and Bron, G.: Measures of body fat and related factors in normal adults. V. Somatotype. To be published.
6. Siri, W. E.: The gross composition of the body, *Advanc. biol. med. Phys.* **4**, 239, 1956.
7. Forbes, G. B., Gallup, J. and Hursh, J. B.: Estimation of total body fat from potassium-40 content, *Science* **133,** 10, 1961.
8. Hathaway, M. L. and Foard, E. D.: Heights and weights of adults in the United States. *Home Econ. Res. Rep.* No. 10, U.S. Department of Agriculture, Washington, D.C., August 1960.
9. Gubner, R. S.: Personal communication.
10. Moore, F. D., Oleson, K. H., McMurrey, J. D., Parker, H. V., Ball, M. R. and Boyden, C. M.: *The Body Cell Mass and Its Supporting Environment.* Saunders, Philadelphia, 1963.
11. Mood, A. M. and Graybill, F. A.: *Introduction to the Theory of Statistics.* McGraw-Hill, New York, 1963.
12. Allen, T. H., Anderson, E. C. and Langham, W. H.: Total body potassium and gross body composition in relation to age, *J. Geront.* **15,** 348, 1960.
13. Behnke, A. R.: Comment on the determination of whole body density and a resume of body composition data, in *Techniques for Measuring Body Composition*, p. 118. (Ed. by Brozek, J. and Henschel, A.) National Academy of Sciences, National Research Council, Washington, D.C., 1961.
14. Allen, T. H., Welch, B. E., Trujillo, T. T. and Roberts, J. E.: Fat, water and tissue solids of the whole body less its bone mineral, *J. appl. Physiol.* **14,** 1009, 1959.
15. Young, C. M.: Predicting body fatness of young women on the basis of skinfolds, *N.Y. St. J. Med.* **62,** 1671, 1962.
16. Chinn, K. S. K. and Allen, T. H.: Body fat in men from two skinfolds, weight, height and age, *U.S. Army Med. Res. and Nutr. Lab.* (Fitzsimmons General Hospital, Denver, Colo.) Rep. No. 248, July, 1960.
17. Hunt, E. E., Jr.: Human growth and body form in recent generations, *Amer. Anthrop.* **60,** 118, 1958.
18. Brozek, J.: Body dimensions and the estimation of men's reference weight, *Science* **124,** 685, 1956.
19. Hechter, H.: The relationship between weight and some anthropometric measurements in adult males, *Hum. Biol.* **31,** 235, 1959.
20. Behnke, A. R.: The estimation of lean body weight from 'skeletal' measurements, *Hum. Biol.* **31,** 295, 1959.
21. Pryor, H. B.: *Width–Weight Tables,* 2nd revised edit. Stanford University Press, Stanford, Calif., 1940.
22. Siri, W. E.: Body composition from fluid spaces and density: analysis of methods, in *Techniques for Measuring Body Composition,* p. 223. (Ed. by Brozek, J. and Henschel, A.) National Academy of Sciences, National Research Council, Washington, D.C., 1961.
23. Meneely, G. R., Ball, C. O. T., Ferguson, J. L., Payne, D. D., Lorimer, A. R., Weiland, R. L., Rolf, H. L. and Heyssel, R. M.: Use of computers in measuring body electrolytes by gamma spectrometry, *Circ. Res.* **11,** 539, 1962.
24. Anderson, E. C.: Three-component body composition analysis based on potassium and water determinations, *Ann. N.Y. Acad. Sci.* **110,** 189, 1963.
25. Damon, A. and Goldman, R. F.: Predicting fat from body measurements: densitometric validations of ten anthropometric equations, *Hum. Biol.* **36,** 32, 1964.
26. Brozek, J. and Keys, A.: The evaluation of leanness–fatness in man: norms and interrelationships, *Brit. J. Nutr.* **5,** 194, 1951.