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Human Body Density and Fat of an Adult Male Population as Measured by Water Displacement[1]

H. J. KRZYWICKI AND K. S. K. CHINN

SYSTEMATIC ATTEMPTS to characterize and estimate the main anatomical, compartmental, or chemical components of the human body mass have been reviewed by Keys and Brozek (1), Brozek and Henschel (2), and Brozek (3). Although the visual quantity of body fat is a crude index of nutritional status, the role of adipose tissue, the most variable component of the human body, requires further study in both normal and disease states. The discrimination of body fat from the other components of the whole body is important in the study of body composition of the individual or of various populations. The various procedures used for estimating body fat depend, ultimately, upon the derivations of equations that permit approximation of the fat compartment. Of the many existing fat estimating equations, Damon and Goldman (4) were able to validate densitometrically 2 of 10 equations tested.

A simple, rapid, and accurate measurement of body volume for computing body density is desirable for laboratory or field use. Robertson (5) was the first to have reported on the measurement of body volume employing water displacement. Two centuries later, Huff and Feller (6), and Allen et al. (7) described the construction and use of a body volumeter based on water displacement. Details of the construction and operation of the device have been reviewed by Consolazio et al. (8). Garn and Nolan (9) reported on the construction of a transparent body volume tank and its readout accuracy but made no mention of human body volume data. Nagamine and Suzuki (10) described the body density and percent body fat of Japanese students as estimated from direct water displacement volumetry. The present study attempts to evaluate the accuracy and reproducibility of repeated body volumes measured by water displacement on a group of subjects and then presents data on the estimated body fat of a random male adult population.

No single method for estimating the four main components (fat, water, protein, and mineral) of the human body exists although several techniques are available for approximating any one component. Routine body volumes for computing body density, measured by somewhat complex underwater weighing methods, have had wide acceptance but require semitrained subjects for reproducible results. A simple, more expedient method described by Huff and Feller (6) and again by Allen et al. (7) measures the body volume by direct water displacement in a calibrated tank. Information on the accuracy and reproducibility of this technique by repeated observations on the same subject is lacking. This study was designed to evaluate the limitations of the technique before additional body composition data of a mixed population were to be reported.

[1] From U. S. Army Medical Research and Nutrition Laboratory, Fitzsimons General Hospital, Denver, Colorado.

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METHODS

The human body volumeter in use at this laboratory had undergone very minor changes since it was originally described by Allen et al. (7) but the method of calibration is somewhat different. Aliquots of water were drawn off into a 2-liter volumetric flask from the portion of the volumeter served by a water level manometer. Centimeter scale changes in the manometer were recorded for each 2-liter change in water level. The factor obtained from the calibration was used for all human body volumes subsequently measured.

Body volumes obtained by direct water displacement include the errors contributed by the residual volume of air in the lungs following a forced maximal expiration as well as the volume of the gastrointestinal gas. Residual lung volume can be measured and reproduced to within 100 ml by the nitrogen washout method of Rahn et al. (11) or it can be estimated using Chinn and Allen's (12) predicting formula. No accurate technique exists for the direct determination of gastrointestinal gas volume but the volume of 125 ml, suggested by Bedell and coworkers (13), is generally accepted. However, Blair et al. (14) have reported maximal values of gastrointestinal gas as high as 2,600 ml.

Two groups of adult males were studied. The first group was composed of 14 males from 21 to 47 years in age, and from 46.8 to 79.2 kg in body weight. This group was observed at 4-hr intervals over a period of 24 hr to test the reproducibility of body volumes as well as observe the trends in volume changes that might be attributed to gastrointestinal gas formation when on ad libitum food intake. The second group of 173 males ranged from 17 to 69 years in age and from 55.9 to 117.7 kg in body weight. The body volumes of this group were measured once and were used to assemble data on body composition changes with respect to aging. This group consisted of civilian and military volunteers from our laboratory and Fitzsimons General Hospital.

Body heights of both groups were recorded to the nearest 0.1 cm on a centimeter rule and body weights were recorded to the nearest 0.05 kg using a Toledo scale (model 2071) or Plima scale. Arm and scapula skinfolds were measured with the U. S. Army Medical Research and Nutrition Laboratory (USAMRNL) calipers (15). Residual lung volumes were computed from Chinn and Allen's (12) formula which incorporates body weight, age, and the average of the bilateral arm and scapula skinfolds. Gastrointestinal gas was not considered in the gas-free body volume. Body fat was calculated from Allen and co-workers (7) formula wherein percent body fat = [4.834/density − 4.366] · 100.

RESULTS

The calibration of the body volumeter by repeatedly drawing off 2-liter aliquots of water and noting the manometer scale changes resulted in a factor of 2.100 ± 0.014 liters/cm. The water level manometer is backed by a machine-engraved centimeter rule (0.05 cm graduations) and could be interpolated to 0.01 cm with the aid of an enlarging lens. Each 0.01 cm represented 0.021 liter of volume. Error propagation based on two manometer scale readings and the subject's ability to effect a forced maximal expiration reproducible to 100 ml permitted fat to be estimated to within ± 0.488 kg if the observed body volume is corrected for the measured residual lung volume. However, this precision is decreased to ± 1.52 kg when a mean residual volume of 1.250 liters is accepted to correct for body volume.

The data in Table I show the means and standard deviation for body weight, body volume, and the calculated body density for each of the 14 subjects of the first group measured at seven intervals over a 24-hr period. The greatest observed standard deviation was found in *subject 4* who exhibited changes in body mass of ±0.062 kg, volume ±0.59 liter, and ±0.004 density unit. The lowest standard deviation occurred in mass and volume of *subject 2* (0.020 kg and 0.163 liter, respectively) while the body density had a standard deviation of ±0.002 unit. An analysis of variance for the body density unit change of all 14 subjects over the 24-hr period was performed and showed the standard deviation of a single observation to be 0.002 density unit (Table II).

Table III depicts the mean body weight,

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density, and percent body fat subgrouped into 5-year-age increments for all of the 173 subjects studied. Residual lung volumes were estimated for this group and the gastrointestinal gas was ignored in the calculation of body density. The data show a progressive decline in the mean body density with age (1.060 g/ml at ages 17–19 to 1.017 g/ml at ages 65–69) as well as a gradual increase in body fat (19.6% at ages 17–19 to 38.7% for the oldest age group).

TABLE I

Body Weight, Volume and Density of 14 Subjects Measured Seven Times at 4-hr Intervals

Subject	Body Weight, kg	Volume, liter	Density, g/ml
1	79.19 ± 0.43	75.921 ± 0.479	1.043 ± 0.002
2	76.73 ± 0.02	72.429 ± 0.163	1.060 ± 0.002
3	75.29 ± 0.53	70.974 ± 0.519	1.061 ± 0.002
4	72.72 ± 0.62	67.036 ± 0.591	1.085 ± 0.004
5	72.50 ± 0.49	68.615 ± 0.440	1.056 ± 0.001
6	69.98 ± 0.24	66.497 ± 0.193	1.052 ± 0.001
7	69.83 ± 0.37	66.807 ± 0.287	1.045 ± 0.002
8	66.80 ± 0.56	63.055 ± 0.485	1.059 ± 0.002
9	64.69 ± 0.37	61.658 ± 0.360	1.049 ± 0.001
10	63.68 ± 0.54	59.750 ± 0.508	1.066 ± 0.001
11	58.23 ± 0.56	54.240 ± 0.325	1.074 ± 0.004
12	57.36 ± 0.31	53.420 ± 0.295	1.074 ± 0.002
13	57.32 ± 0.38	54.335 ± 0.226	1.055 ± 0.003
14	46.76 ± 0.22	42.964 ± 0.221	1.088 ± 0.002

TABLE II

Analysis of Variance of Diurnal Variation in Body Density of 14 Subjects at 4-hr Intervals

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Men	13	0.01741214	0.00133395
Hours	6	0.00005982	0.00000997
Residual	7	0.00034712	0.00000445
Total	97	0.01781908	

Standard deviation of single observation = 0.0021 density unit.

Standard error of estimate = 0.0002 density unit.

TABLE III

Body Density and Percent Fat in Adult Males

Age Group	*n*	Body Weight, kg	Density, g/ml	% Fat
17–19	9	71.9±14.4	1.060±0.016	19.6±7.0
20–24	35	73.6± 7.5	1.060±0.013	19.5±5.5
25–29	29	76.8±14.0	1.053±0.017	22.6±7.3
30–34	15	85.8±17.6	1.044±0.013	26.3±6.1
35–39	13	76.2±10.6	1.043±0.012	26.9±3.6
40–44	25	75.4±11.1	1.042±0.012	27.1±5.5
45–49	24	76.2±10.0	1.038±0.010	29.3±4.5
50–54	12	75.5±10.1	1.032±0.026	32.8±9.1
55–59	4	79.0±10.3	1.031±0.021	32.5±4.8
60–64	5	69.7± 7.5	1.026±0.010	34.7±4.5
65–69	2	68.6± 2.1	1.017±0.001	38.7±0.6
Total	173			

TABLE IV

Estimated Fat-Free Weights on Groups of Adults 20–40 Years of Age from Body Density Determinations

Investigator	Year	*n*	Density, g/ml	Range	Fat-Free Body Weight, kg
			Underwater Weighing		
Behnke	1942	99	1.064	1.016–1.092	61.3
Osserman	1949	81	1.063	1.016–1.095	63.5
Brozek	1952	25	1.063		60.2
Von Dobeln	1956	35	1.072	1.020–1.099	61.2
Pascale	1956	88	1.068	1.020–1.089	59.1
			Gas Displacement		
Siri (Behnke)	1957	31	1.051	1.014–1.081	61.9
			Direct Water Displacement		
USAMRNL	1960	93	1.052	1.010–1.094	59.1

Comparisons are made in Table IV of the body density and the fat free mass of 93 males between the ages of 20–40 years from the group of 173 subjects studied, with that as reported by several investigators and collated by Behnke (16). The mean body density of the 93 males resembles the values of 31 males reported by Siri (Behnke) in this table but the fat-free body weight was less for our subjects. Table V presents the body weight, density, and percent body fat of 60 males aged 17–25 years from the group

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Table v
Body Density and Percent Fat in Adult Males

Investigator	Age Group	n	Body Weight	Density, g/ml	% Fat
Pascale	17–25	88	68.3 ± 11.1	1.068 ± 0.012	16.0
Brozek	23–29	25	70.6 ± 8.3	1.063 ± 0.013	14.4
USAMRNL	17–25	60	73.1 ± 10.3	1.059 ± 0.013	19.9

of 173 subjects for comparison with earlier literature values as reported by Pascale et al. (17) and Brozek (18). The 60 subjects exhibit the highest mean body weight (73.1 kg) and the lowest mean body density (1.059 g/ml) which reflects a higher percent body fat (19.9%).

DISCUSSION

Calibration of the volumeter resulted in lowering Allen and co-workers' (7) calibration factor slightly from 2.114 ± 0.064 to 2.100 ± 0.014 liters/cm, but improved its precision approximately four times. This is in agreement with a second volumeter reported by Allen (19). Garn and Nolan (9) reported a greater readout volume accuracy in their volumeter by tilting the water manometer (33 ml/mm). However, such accuracy is questionable since it requires a body weight scale of comparable accuracy. Other measurements requiring improvement are the means of estimating residual lung volume and accurate determinations on quantities of intestinal gas present.

Food and water intake was ad libitum during the 24-hr diurnal study of body weight and body volume changes as shown in Table i. These measurements were done to observe any extreme variation in body volume that could have been attributed to gastrointestinal gas. Conflicting reports by Bedell and co-workers (13) and Blair et al. (14) cite gastrointestinal gas to be approximately 125 or up to 2,600 ml, respectively. Chinn (20) suggested that the gastrointestinal gas production and volume followed a diurnal pattern and were predictable, reaching their lowest ebb between the hours of 10 AM and 12 noon. However, no such trends were observed in this study. The greatest variation in body volume as seen in *subject 4* (Table i), when coupled with body weight variation, produced a standard deviation of only ± 0.004 density unit change. A 70-kg man with a body density of 1.064 could alter his body density by 0.001 unit had he consumed 1 liter of water, and as Durnin and Taylor (21) cite, this is equivalent to a 0.4% change in estimated percent body fat. Thus, estimates of body fat in *subject 4* could be over- or underestimated by 1.6%, which by calculation from given data showed fat to vary from 7.29–10.58% of body weight (5.30–7.69 kg actual body fat) for one standard deviation.

Durnin and Taylor (21) measured body density by underwater weighing five times over a 2-week period in 10 subjects whose body weight varied by 0.5 kg during this period. These authors reported that the standard deviation of a single observation of body density measurement was ±0.002 unit, which is in agreement with our observations. The reproducibility of the estimated body density from body volumes measured by water displacement volumetry also falls within the prescribed limits of ± 0.005 density unit set forth by Siri (22) wherein he had determined the inherent errors of such densitometric techniques.

A progressive increase in the mean body weight to age 34 is noted in Table iii with a decline in body density which reflects increased body fat. The body density continues to decline although the body weight has decreased by approximately 10 kg at age 49. In the older age groups body density

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is further decreased demonstrating an increase in body fat. Fryer (23) reported information on 60 males aged 60 years or older and cited a mean body density of 1.0296 g/ml which indicated 31.7% body fat and is comparable to the 60–64 year old males in Table III.

Behnke (16) showed 20- to 40-year-old males to have a rather constant fat-free mass and cited the observations of several investigators (Table IV). Siri's data (as reported by Behnke) may be more reliable since he considered hydration of the body in his fat-estimating equation. It is unusual that our data may be in agreement with Siri's because of the fact that the residual lung volumes were estimated for our subjects while the residual lung volumes are automatically corrected by Siri's technique. Allen (7) considered the water content of body tissues in deriving the USAMRNL fat-predicting equation; however, his formula also estimates body fat as much as 2.5% higher than Siri's predicting equation.

The early data of Pascale et al. (17) and Brozek (18) have been compared with data of the young adults from the 173 subjects in Table V. These comparisons are of interest insofar as Pascale (17) reported a mean body density of 1.068 which represented 16.0% body fat as calculated by Allen's (7) equation. Our group of 60 soldiers was approximately 5 kg heavier per man and of a lowered body density which reflected a mean body fat burden of 19.9%. Brozek (18) reported a specific gravity of 1.0695 which was corrected to a density value of 1.063 at 30–32 C for this group and cited 14.4% body fat; however, when Allen and co-workers' (7) equation is applied to this mean value, body fat is estimated at 18.2%.

It is noteworthy that this technique of water displacement volumetry effectively ranks population groups in different degrees of body fat independent of body weight but obviously age related. The technique is relatively simple, requires no source of electrical power, and is quite useful in backward or remote population areas. It might be far more effective to rank populations studied in nutrition surveys in terms of relative fatness by this method rather than to relate skinfold thickness to standard height and weight tables since body density serves as a better index of percent body fat. Plough (24) cites that skinfold thickness measurements made in Interdepartmental Committee on Nutrition for National Defense (ICNND) surveys (25) did not give more information than did height and weight tables alone, based on the preliminary results of such surveys. The actual estimate of percent body fat from direct water displacement volumetry may be in error in the individual but is of little consequence when the population is considered in terms of age groups.

SUMMARY

Body volume was measured on 14 male adults at 7 intervals during a 24-hr period using a water-displacement technique. The variation in body densities fell within the accepted limits of error propagated by the technique. Body densities were also performed on 173 male adults ranging between the ages of 17–69. Values were effectively ranked in terms of age and body fat, demonstrating a continued increase in body fat with an increase in age. These values were independent of body weight.

The human body volumeter is a simple, rapid, and effective device which compares favorably with the underwater weighing technique for estimating body density in large populations. The precision for estimating body fat is ±0.488 kg when the residual lung volume is measured but is reduced to ±1.52 kg when the volume is estimated.

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