Determination of human body volume from height and weight[1]

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SENDROY, JULIUS, JR., AND HAROLD A. COLLISON. *Determination of human body volume from height and weight*. J. Appl. Physiol. 21(1): 167–172. 1966.—A previously developed method of graphical determination of human body volume from measurements of height and weight has been extended for utilization from a limited range to one spanning the development of the male and female form from infant to adult. Equations best suited to express the relations of weight and height to show body volume and surface area over the periods of the life span for W/H = 0.04–0.1, 0.1–0.2, and 0.2–0.8, were found to be, respectively, for males: $V/S = 57.26\ (W/H)^{0.494} + 0.254$, $V/S = 50.6\ (W/H)^{0.436}$, and $V/S = 60.20\ (W/H)^{0.562}$; and for females $V/S = 60.36\ (W/H)^{0.507} + 0.254$, $V/S = 51.1\ (W/H)^{0.429}$, and $V/S = 62.90\ (W/H)^{0.578}$. A statistical evaluation and comparison with results of almost 1900 physical measurements taken from the literature indicate that this approach provides results acceptable for most clinical purposes, and is much more convenient and rapid than other, conventional methods of arriving at indices of body composition (volume, specific gravity, density, and body fat). The method permits the simultaneous determination of human body surface area as previously described.

body composition; body density; body fat; body surface area; anthropometric measurements; human body composition; body development and growth

FROM VALUES in the literature for human body weight (W), height (H), surface area (S), and volume (V) obtained by direct physical measurement, several empirical equations for the estimation of body volume for a limited range of male adults in terms of weight and height alone, have been derived and tested in this laboratory (29, 31). The most acceptable relationship found, in respect to reliability and convenience in use, was that expressed by

$$V = S\ (51.44\ W/H + 15.3) \qquad (1)$$

where V, S, W, and H are in liters, square meters, kilograms, and centimeters, respectively (31).

The use of this equation requires a prior estimate of surface area, derived from known weight and height by simple location of a point on a chart (30) or nomogram (32); this is then followed by a calculation of the volume according to *equation 1*. A further simplification, whereby volume may be obtained by direct reading from a chart with weight and height as coordinates, would be more desirable. Moreover, in developing such a relationship, it seemed advantageous to extend the previously restricted range of body size, age, and sex to be covered. Obviously, linear relationships, however satisfactory, apply only to a limited population. *Equation 1* was derived from a group of 78 young, normal males of a relatively restricted range of body parameters (27). A more general relationship, applicable to humans throughout growth and development from birth to maturity, would provide a more satisfactory and convenient basis for body volume estimates. The results of efforts toward the attainment of that objective are described in the following.

CONSTRUCTION OF CHART FOR VALUES OF VOLUME FROM WEIGHT AND HEIGHT

The basic diagram of Sendroy and Cecchini (Fig. 1 of (31)) for values of V/S plotted against W/H was expanded to cover a wider range of body sizes. As many individual values as possible for directly measured parameters of body V (or density)[2] and W and H, through the range of infants to adults, of both sexes, were gathered from the literature. From W and H, corresponding values for S were obtained from the enlarged diagram of Sendroy and Cecchini (Fig. 3 of (30)).

The data were then processed by means of an IBM 1620 computer to determine the relationship of V/S to W/H for the several groups of studies composed of 737 individual subjects.[3] The equations best fitting the data

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[2] Insofar as possible, all original data given in terms of specific gravity were converted to body density (with a correction for lung residual volume (7)) in accordance with principles discussed by Keys and Brozek (21, p. 268) and by the use of average respiratory space relationships (2) p. 34, 35, 38, 39, (23).

[3] The source references of the measurements used (all of living subjects with the exception of three*) are indicated by numerals in parentheses, and refer to the data shown in Table 1: (1) Table 1; (3)*; (5) Tables 4 and 9; (8), (9) Table 1; (12) Tables 13, 14, and 16; (14) Table 1, p. 35; (15) Tables 4 and 9; (16) Table 1;

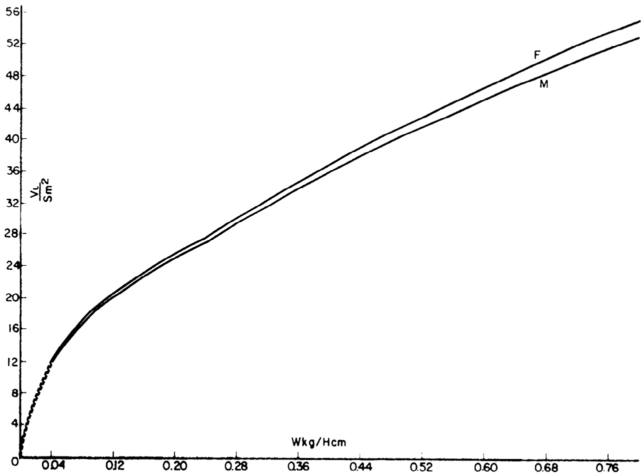

FIG. 1. Diagram for the relationship of V/S to W/H for male (M) and female (F) humans, based on physically measured values of weight, height, and volume taken from sources indicated in footnote 2, and the calculation of surface area according to Sendroy and Cecchini (30).

were found to be of the form $V/S = A(W/H)^b$. Determination of the contents of these gave: for 446 adult men and adolescent boys, ranging in W/H from 0.2 to 0.8,

$$V/S = 60.20\ (W/H)^{0.562} \tag{2}$$

and for 113 adult women and adolescent girls, in the same range,

$$V/S = 62.90\ (W/H)^{0.578} \tag{3}$$

Other data for 84 male infants in range of W/H from 0.04 to 0.1 gave an equation

$$V/S = 57.26\ (W/H)^{0.494} + 0.254 \tag{4}$$

and for 94 female infants in the same range,

$$V/S = 60.36\ (W/H)^{0.507} + 0.254 \tag{5}$$

A chart of coordinates of V/S and W/H was prepared on a large (2 x 3 ft) piece of 10 x 10 to ½ in. cross-section paper. Plots of lines m and m′, and f and f′, representing *equations 2* and *4*, and *3* and *5*, respectively, were made. This obviously left a break in what otherwise would be the best line representing the relationships among these body parameters from the prenatal to the adult state of development. Unfortunately, no data have been found available for physically measured values of body volume for children (for W/H values in the range of 0.1–0.2).[4] The gap in question was filled in the following manner.

Lines m and m′, drawn on a log-log plot, were connected by an interpolated straight line, as were lines f and f′. These interpolated lines, represented by equations

$$V/S = 50.6\ (W/H)^{0.436} \text{ for males, and} \tag{6}$$

$$V/S = 51.1\ (W/H)^{0.429} \text{ for females} \tag{7}$$

were then used to connect m and m′ and f and f′, respectively, to form the completed lines M and F in Fig. 1.[5]

A diagram showing the relationship of isovolume values to weight and height, corresponding to that for surface area by Sendroy and Cecchini (30), was then prepared as follows. On the surface area chart with weight on the abscissa scale and height on the ordinate (Fig. 3 of (30)), iso-W/H lines were drawn. Over a range of assumed physiological values for volume for each of progressive increments of such values of V, several appropriate values of W/H were taken. The corresponding value for S for each of these was calculated from the V/S value found from *equation 2, 4,* or *6* (line M, Fig. 1). Each of these values for S was then located on the corresponding value for W/H on the surface area chart, to obtain a point for the given value for V. Then, by joining these points for V values, isovolume lines were drawn on the chart already marked with isoarea lines, as shown in Fig. 2 of this paper.

For the sake of simplicity and convenience in use, the graph shown in Fig. 2 is directly applicable for estimations solely of males. However, body volumes of females from H and W values are obtained by corrections indicated at the head of each isovolume line. Thus, for a female weighing 70 kg and 180 cm tall, the V is found to be 67.7 instead of 66.0 liters.[6] Values for infants and children (to W/H values of 0.2) are obtained from the insert of Fig. 2 with tabular indication for the conversion of male to female values.

Obviously, Fig. 2 also serves for the estimation of body surface area from height and weight, to the extent that it duplicates the diagram of Sendroy and Cecchini (Fig. 3 of (30)). Since publication size does not allow the measure of accuracy and convenience desirable for

(18) Tables 1 and 2; (20) Table II; (27) Appendix; (34) Appendix; (37) Table 1; (39) Table 1; (40) Table 49.

[4] This is probably owing to the fact that the understanding and cooperation necessary for such experiments are difficult to obtain in subjects between the ages of 2 and 10 years.

[5] A plot of the large number of points representing individual measurements, 737 in all, was actually made. Although possibly desirable for visual assessment of the scattering of the data about the computed lines, its reproduction in Fig. 1 would be impractical and possibly misleading, in view of the repetitive overlapping of many of the data. A more adequate evaluation indicative of the reliability of the basic data used is afforded by the statistical treatment which follows in the text. Data on other individuals comprising 696 males and 428 females were also found in the literature (10, 12, 13, 24–26, 28, 35–38) but in the form only of average values of height, weight, and specific gravity or density for a group of subjects. The plot of such average values as point units, although in close proximity to the lines of Fig. 1, would likewise be unsatisfactory in that they would fail to serve as indicators in number and extent, of the nature of the scattering about the lines M and F, of the points representing the individual measurements made.

[6] The point for 70 kg and 180 cm is located at about 0.6 of the distance from the 60 liter line to the 70 liter line. With corrections, a female of these dimensions is calculated as (70 + 1.9) − (60 + 1.5) = 10.4, of which 0.6, or 6.2 added to 61.5, becomes 67.7.

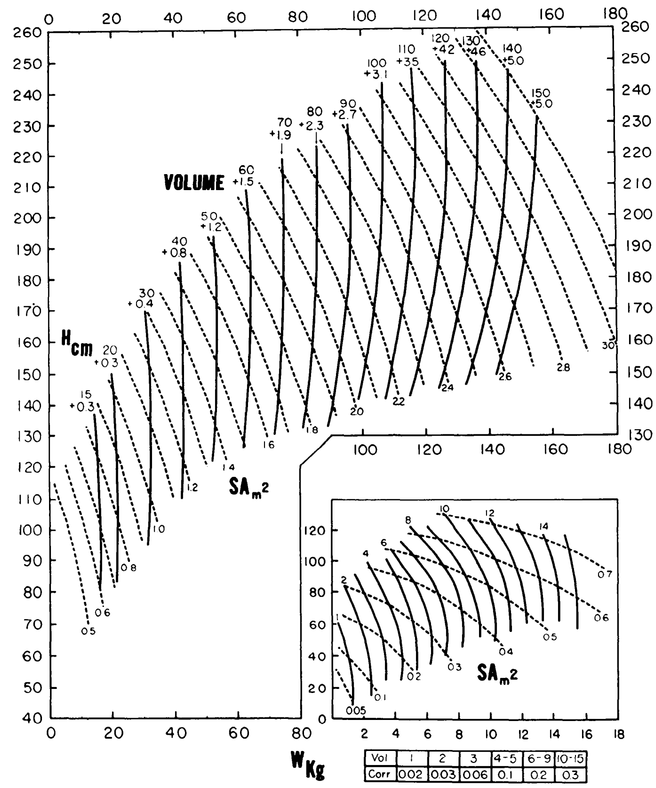

FIG. 2. Diagram for the calculation of human body volume from measurements of height and weight. Values for V (solid lines) are for male subjects, with a correction shown to be added for females. (Insert is used for low range of infants from birth to attainment of volume of about 7 liters). This diagram may also be used for the estimation of body surface area (dashed lines) as developed by Sendroy and Cecchini (30).

practical use, Fig. 2 should be reproduced on an enlarged scale[7] for determining surface area and/or volume.

RESULTS AND DISCUSSION

Table 1 shows a statistical treatment of results for human body volume as found by a method of direct physical measurement (weighing in water, helium, or air displacement, etc.) compared with volumes obtained by the use of the diagram of Fig. 2. In effect, Table 1 shows the results of applying *equations 2–5* derived by computer processing of measured data for human subjects, to the calculation of the individual V values of the subjects of the various studies comprising the whole.

The relationship of empirical expressions representative of human anatomical and geometrical configurations has been discussed in previous publications (29, 31). The difficulties and limitations of applying equations to populations other than those from which the basic data were derived have also been made apparent, and pointed out by others (5, 14, 33).

The assessment of the reliability of the results obtained by calculation is affected not only by the aberrations of individuals from the average of other members of their particular group. There is, in addition, an added variation encountered in this study of subjects over a lifetime span, in a continuing change in shape and body proportions from the newborn to the oldster (Fig. 1).[8] Imposed upon these limitations, or running concomitantly with them, are those of the possible errors involved in the values obtained by actual measurement, especially on the part of earlier or inexperienced workers.

The foregoing comments are amply confirmed and illustrated by the data of Table 1. The values for male adults show a range of body volumes from 19 to 126 liters. However, the statistical evaluation of the entire group of 446 adult individuals compares favorably with that of most of the 10 separate studies comprising the whole. With especial reference to the work of Osserman et al. (27), it is apparent that the general *equation 2* for adult males applies almost equally well as does the linear one (*equation 1*), previously based solely on the measured data of these particular 78 individuals (see Table 1 of (31)). Damon and Goldman (14) used a similar but much smaller group of 13 males in a test of 10 formulas for the prediction of total fat from body measurements. If one calculates from the mean W, H, and body fat (F) of their Table 1, the body volume from the best of these equations found by them (14) for body fat (F = (4.0439/density) − 3.6266), based on Grande's work cited by Brozek in a comment attached to a paper by Behnke ((6), p. 128) the value of 66.0 liters is likewise in good agreement with that of 66.3 liters obtained by the use of our *equation 2*.

On the other hand, one may compare two groups of extremes of variation from the average standard error of estimate of volume for male adults referred to measured values, namely, that of Behnke's (5) 17 subjects consisting in part of weight lifters and others of a wide range of body builds (SEE = ±1.97 liter), with the 13 of Damon and Goldman (14) (SEE = ±0.74 liter). The t-test (Mainland (22), page 169) indicates that the standard error of the coefficient of variation (here, SEE × 100/mean) is significantly different for these two groups ($P < 0.01$). On the other hand, the set of experiments (5) showing the greatest deviation (SEE = ±1.97 liter) from that of the whole group (SEE = ±1.06 liter) shows no significant difference from the latter for the standard error of the coefficient of variation ($P > 0.10$).

From the foregoing, one may conclude that for the estimation of body volume of adults varying from 19 to 126 liters, 95% of the results calculated by means of the present method will be within 3.5% of the "true"

[7] For maximum convenience and accuracy in reading large-scale grid diagrams, the indicated coordinate scale marks may be joined by the desired number of lines drawn across the chart. Since accurate reproduction of such charts may present a problem to many users, enlarged copies of Fig. 2 will be made available upon request to the authors.

[8] These lines may be regarded as reflections of the growth and development of the "average" human body in terms of the indicated corporeal dimensions. The obvious break where W/H is approximately 0.24, in what would otherwise be smooth curves corresponds to the cessation of "normal" development at the end point entering upon adolescence, beyond which increase in body size and shape follows a somewhat altered course. These considerations are discussed at length in a previous paper ((30) p. 10).

TABLE 1. *Human body volume V, from height and weight chart, compared* with direct physical measurement*

Ref No.	Authors	No. of Subj and Sex	Range of V and (Mean), liters	MD, liters	MDa, liters	SEE, liters	SEE, %
1	Allen et al.	55 M	40–91 (53)	0.57	−0.15	±0.76	±1.4
5	Behnke	17	54–115 (79)	1.63	−0.10	±1.97	±2.5
8, 9	Behnke et al.	31	49–115 (74)	1.37	+1.14	±1.74	±2.3
12	Brozek et al.	20	71–126 (90)	1.29	−1.19	±1.58	±1.8
14	Damon and Goldman	13	50–79 (66)	0.56	+0.56	±0.74	±1.1
15	Durnin and Taylor	10	51–73 (61)	0.49	+0.27	±0.72	±1.2
27	Osserman et al.	78	49–100 (71)	0.72	+0.14	±0.90	±1.3
34	von Dobëln	35	47–83 (65)	0.63	+0.19	±0.84	±1.3
37	Welham and Behnke	25	71–111 (85)	1.51	+1.47	±1.68	±2.0
40	Zook	162	19–74 (43)	0.62	−0.01	±0.80	±1.9
	Mean of male adults	446	(59.7)	0.80	−0.01	±1.06	±1.8
1	Allen et al.	26 F	37–65 (48)	0.44	−0.17	±0.52	±1.1
18	Goldman et al.	31	56–100 (74)	1.07	−0.58	±1.47	±2.0
18	Goldman et al.	12	51–78 (66)	0.75	−0.68	±0.86	±1.3
34	von Dobëln	35	48–76 (60)	0.62	+0.54	±0.77	±1.3
39	Young et al.	9	58–96 (73)	1.05	+1.00	±1.25	±1.7
	Mean of female adults	113	(62.4)	0.75	−0.02	±1.00	±1.6
3	Barnum	3 M	2.4–2.7 (2.5)	0.06	−0.003	±0.08	±3.2
16	Friis-Hansen	14	2.5–4.0 (3.3)	0.09	−0.08	±0.11	±3.4
20	Kastner	67	2.0–6.8 (3.8)	0.17	+0.02	±0.26	±6.7
	Mean of male infants	84	(3.63)	0.16	+0.003	±0.23	±6.3
16	Friis-Hansen	15 F	2.7–3.7 (3.2)	0.08	−0.03	±0.11	±3.4
20	Kastner	79	2.2–6.5 (3.5)	0.13	+0.01	±0.18	±5.1
	Mean of female infants	94	(3.45)	0.13	+0.007	±0.17	±4.9

* MD = Arithmetical mean of individual deviations of calculated from measured V. MDa = Algebraic mean of such deviations. SEE = Standard error of estimate = $\sqrt{\Sigma D^2/N - 1}$ where N = number of subjects for the group. The percentage SEE = SEE × 100/mean V, for the group.

measured value. Very nearly the same considerations and conclusions in the foregoing hold true for the values for adult females ranging in body volume from 47 to 100 liters.

In the case of infants ranging from 2 to about 7 liters in body volume, a standard error of estimate of about ±0.20 liter represents a 5–6 % variation from the "true" measured value, for 95 % of the calculated values.[9] By direct physical measurements of 29 infants less than 24 hr of age, Friis-Hansen (16) obtained an average body density of 1.030, SD of ±0.030. The use of our Fig. 2 (insert) predicts an average of 1.045 SD of ±0.017.

It is well known that the female has a thicker layer of adiposity tissue with resultant lower body density and increased volume as compared with the male of the same height and weight. Brozek's reports (10, 11) on the variation of experimentally determined body specific gravity and fat content of males and females at different ages is satisfactorily borne out by the curves of Fig. 1 and the subsequent discussion. The quantitative significance of the difference in calculated from measured values of V between the samples over the entire range of body sizes and shapes is represented by the data of Table 1 for adult dimensions. Comparison of the standard error of the mean measured volume for females (62.4 liters) and males (59.7 liters) leads to a standard error of difference between the two sets of data of ±0.49 liter, which is more than five times the difference in their means. Volume measurements for adult females are quite significantly higher than for males of the same height and weight by from 2 to 3.3 %, from one end of the range of volumes to the other (15 to 150 liters). These differences are also reflected in, and indicated by, the corrections to values found by Fig. 2, to be applied to values for females.

Although the values of measurements of corporeal density have long been established in physiological and clinical observations and investigations, interest in the relationship of density to the fat content of the body has increased tremendously during the last two decades (8). The military aspects of the subject have been particularly considered and well studied by Behnke (4). Despite the essential limitations of biological variation and human error, and the resultant variation in the number and variety of relationships proposed by many workers (6, 12, 14, 21, 24, 33), with an awareness that the present proposed calculation of body volume *is not intended for the more exacting demands of research activities*, one may test its value under less rigorous requirements.

As examples, a normal adult male and female of height 170 cm and weight 74.5 kg, Fig. 2 shows V values of 70

[9] It should be noted that Kastner's studies (20), upon which the relationships for infants here developed are predominantly based, were one of the earliest in the field and were done on subjects almost all of whom were clinically not normal but pathological.

and 71.9 liters, with values of D = 1.0643 and 1.0362, respectively. By calculation according to Grande's equation, $F = (4.0439/D) - 3.6266$, body fat of the male and female will be 17.3% and 27.6%, respectively, values only a little higher than most of those in the literature. Thus, a difference of 0.01 density unit, or 1 liter of body volume, represents a difference of 3.7% or 5.47% of body fat, respectively. Since the standard errors of estimate of density measurements will be ±0.019 and ±0.013 units for males and females, respectively, the estimate of body fat will compare with those obtained by standard methods for body density, the SEE values of which are -0.008 units. In other words, the error in estimating body fat by the proposed use of the chart of Fig. 2 may be up to twice that incurred in the use of current classical methods of estimating that portion of total body composition.[10]

CONCLUSION

The importance and significance of measurements of human body volume, density, or fat have been simply and clearly discussed by many workers, who have been concerned with the pitfalls, difficulties, errors, and variations in their evaluations, especially by densitometry. Under the conditions prevailing, one may conclude that the graphical method here presented is the simplest available for the prediction of human body volume, and is useful and adequate for most practical and clinical purposes.

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[10] As this work was near completion, the results of the paper of Hix, Pearson, and Reineke, obtained by air and helium displacement methods, appeared (19). Unfortunately, it did not appear that their results could be used inasmuch as their individual data, and the mean specific gravity found, 1.1266 and 1.1236 for 24 males and 24 females, respectively, would indicate that two-thirds of their subjects of each sex had a body specific gravity considerably higher than that of a fat-free individual. According to Brozek et al. (12) the human "reference body" has a density of 1.064 and an estimated value of 1.100 for the fat-free human body. In a previous work (7) the Michigan investigators could not establish a significant relationship between density results on humans obtained by air displacement, with those obtained by underwater weighing.

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