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

INTRODUCTION AND METHODOLOGY

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THE DEVELOPMENT of laboratory methods to determine body fat in the human has given impetus to distinguishing obesity (excess body fat) from overweight (body weight greater than a standard weight for height and sex), and to developing simpler methods for predicting the amount of body fat. There has been much interest in distinguishing obesity from overweight since certain chronic diseases with high incidence and mortality rates have been associated with overweight. These diseases are of public health concern. The availability of a simple yet accurate anthropometric tool to estimate amount of body fat would aid in the epidemiological study of some common degenerative diseases and provide guidance for preventive measures. This paper presents the methods used in the development of such an anthropometric tool.

It is impossible here to review the voluminous literature on body composition. Two symposia conducted in the past five years [1, 2] and a monograph [3] provide documentation of the extensive and varied recent research in this field.

In 1921, MATIEGKA [4] first attempted to estimate body composition by anthropometric means in order to establish bases for physical fitness. He emphasized the need for validation with cadaver analyses. From his approach was developed the concept of standard weight for height. Other attempts to define optimum body measurements have been made [5–7]. Since BEHNKE *et al.* developed the measurement of body specific gravity [8] and the concept of lean body mass [9] considerable impetus has been afforded the correlation of physical measurements to reference determinations of body composition [10–13].

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Bases of reference for body composition have had several approaches. Cadaver analysis [14–17], body density [8, 18–21], total body water [22–24], combined density and body water determinations [25, 26], absorption of non-toxic fat-soluble gases [27], whole body counting of radioisotopic potassium (K^{40}) [28–30] and measurement of multiple parameters by dilution techniques [3] have been used.

SIRI has critically evaluated the methods of determining body composition from fluid spaces and from body density [31]. His conclusion that "combined measurements of corporal density and of total body water yield the only method for estimating body composition that does not require a reference body nor an explicit description of the composition of adipose tissue" has been upheld by the work of ALLEN *et al.* [26]. They state, "SIRI's original simplifying deductions can be shown to hold throughout a wide range in variation of bone mineral: fat: water: solids of healthy persons." The extensive body composition determinations by MOORE *et al.* [3] using multiple-isotope-dilution techniques provide an additional approach. Their skeletal weight nomogram has as its basis the work of ALLEN *et al.* [26] plus a measure of body potassium equivalents.

Additional approaches to body composition methodology have been measurements of subcutaneous fat by roentgenography [32] and by caliper measurements [13, 33, 34]. These have been used to estimate body fat or body density. SHELDON's approach has been that of defining the body build by somatotype [35].

While multiple techniques for measuring body composition have been developed, few have been correlated in order to develop a practical clinical tool of determined validity. The work of BROZEK and KEYS [19], BEHNKE [12], YOUNG and TENSUAN [11] and MOORE *et al.* [3] are exceptions. However, for the most part, these studies have been limited to one sex and to Caucasians. In addition there has been no study to compare in a large number of subjects lean body mass and body fat as determined by thet otal body water–body density technique with these as determined by whole body potassium-40 for the same individuals.

There is considerable evidence that body composition is dependent upon multiple factors including sex, genetic constitution, physical activity and nutritional status [36]. We are unaware, however, of previous attempts to correlate in man measured body fat and lean body mass with diet, physical activity and with somatotype.

OBJECTIVES OF STUDY

The primary objectives of this study were:

1. To develop for healthy adults valid regression equations using clinically applicable anthropometric measurements which estimate total body fat.
2. To compare in the same subjects determinations of lean body mass and total body fat as obtained by the total body water–body density technique and by the measurement of whole-body potassium-40.

Additional objectives were:

3. To relate estimated and measured total body fat to diet, physical activity and somatotype.
4. To relate whole-body cesium-137 to diet.

PURPOSE OF THIS REPORT

This report presents the selection of study subjects and the methods used. The methods are considered under the following headings: anthropometry, laboratory determinations (body density, total body water and whole-body counting of potassium-40 and cesium-137), diet and physical activity assessment and somatotyping technique. The anthropometric measurements are presented in sufficient detail so that the clinician may perform them exactly as recorded, a matter of import in employing the regression equations for estimation of body fat with the accuracy determined for the method.

Subsequent reports will present results of the various measurements, the regression equations and interrelationships of the assessed factors.

SELECTION OF SUBJECTS

Altogether 2301 healthy* individuals aged 25–44 years were obtained as volunteer subjects from many work or other groups in the San Francisco Bay area. Small as well as large business concerns, companies, agencies and other groups (list appended) were contacted through personnel offices or their associated medical facilities for permission to request employee or group participation on a volunteer basis. Each individual, qualifying by age, received a letter which described the purpose of the study and the parameters to be measured and requested voluntary participation. Anthropometric measurements and diet and physical activity interviews were performed at facilities of the company. Persons, randomly selected for the laboratory measurements, were taken subsequently to the Donner Laboratory, University of California, Berkeley. Only graduate students of this university were somatotyped at the Cowell Memorial Hospital Constitutional Research Laboratory.

Owing to limitations in the time schedule for laboratory work and the small numbers of volunteers from several races, race–sex–age categories (*vide infra*) were arbitrarily defined. From these categories, subjects were randomly selected for diet and physical activity interviews and for laboratory measurements. If for any reason a subject so selected was unable to continue in the study, another subject of the same race–sex–age category was selected. The five arbitrary categories were:

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.

Table 1 presents the number by category, including oriental and other race groups, who participated in each of the phases of the study.

*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.

Table 1. Number of participants

Race	Sex	Age (yr)	Anthropometric measurements	Interview	Laboratory measurements: TBW, body density	Laboratory measurements: K^{40} Cs^{137}	Somatotype	Somatotype and lab. measurements
Caucasian	Male	25–34	478	106	35	23	113	9
		35–44	416	105	34	25	26	3
Caucasian	Female	25–34	379	101	33	12	17	1
		35–44	438	101	31	16	9	1
Negro	Male	25–44	342	103	34	4	—	—
		Subtotal	2053	516	167	80	165	14
Negro	Female	25–44	154					
Oriental	Male	25–44	32					
	Female	25–44	42					
Other	Male	25–44	16					
	Female	25–44	4					
		Total	2301	516	167	80	165	14

Note: TBW = Total body water.

METHODS

One individual (R.C.S.) measured all the women and a few of the men. The majority of the men were measured by a second investigator (G.B.). The two examiners thoroughly compared techniques to establish uniformity and to assure reproducibility of results. Measurements were recorded by another individual (N.L.C.) on the data collection sheet which served as the code sheet for keypunching.

1. *Weight.* A Homs portable scale (capacity 300 lb) accurate to 1 oz was used and was checked at frequent intervals by the California State Department of Weights and Measures. Weights were made to the nearest ounce with women subjects wearing only a disposable examining gown (weight 3 oz) and either barefoot or with stockings and with men wearing only shorts and either barefoot or with socks. Shorts and socks typical of those worn were weighed and averaged 5 oz. The weights of the subjects were corrected to nude weights. Ounces were transposed to hundredths of a pound for coding.

2. *Height.* Heights were measured to the nearest 0.1 cm by means of a free-standing portable Swiss-made steel measuring bar, calibrated to 0.1 cm and having a sliding straight edge. The subject, either barefoot or with stockings, was positioned with heels, buttocks and back pressed firmly to a wall with the examiner applying firm upward pressure to the subject's mastoid processes without allowing heels to be raised from the floor. The straight edge was then adjusted to the cranial vertex.

The following measurements (3–11) were taken on the right side of the body and recorded to the nearest 0.1 cm with a steel tape closely fitted to the nude body surface but not so tight as to indent the skin. These body measurements were later rounded to the nearest whole centimeter. If the number ended in a half-centimeter, odd whole numbers were raised to the next highest centimeter; even whole numbers were unchanged. A single tape was used for approximately 200 subjects and then discarded.

3. *Upper arm length.* With the subject standing, right arm relaxed but flexed 90° at the elbow, the tape was applied from the lateral margin of the acromial process of the scapula to the tip of the olecranon process. The distance between these landmarks was recorded. A skin mark was made at half this length for use in the arm circumference and skinfold measurements.

4. *Arm circumference.* The tape was applied to encircle the mid-point of the upper arm length.

5. *Wrist circumference.* The tape was applied to encircle the right wrist over the styloid processes of the ulna and the radius.

6. *Chest circumference.* With the subject standing, arms at sides, and breathing quietly, the tape was applied to the chest so as to encompass the areolae for men and the axillae above the area of breast fullness for women.

7. *Waist circumference.* The tape was applied, with the subject standing and breathing quietly, to the circumference encompassing the lower borders of the tenth ribs at the mid-axillary lines.

8. *Iliac crest circumference.* With the subject standing, the tape was applied to encircle the body at the iliac crests and was maintained parallel to the floor.

9. *Thigh length.* Measurement was made from the skin surface over the right greater trochanter to that over the right inferior border of the lateral epicondyle of the femur. These landmarks were located by having the subject stand with the right knee slightly flexed, leg abducted and with the right foot remaining on the floor. A skin mark was made at half this distance for the thigh circumference and diameter measurements.

10. *Thigh circumference.* The tape was applied to encircle the right thigh at the mid-point of the thigh length.

11. *Ankle circumference.* The ankle was encircled with the tape at a point just superior to the lateral malleolus.

The following measurements (12–16) were taken with a curved-arm metal caliper (Martin) calibrated to 0.5 cm. The readings were recorded to the closest 0.5 cm and later rounded for coding purposes to whole centimeters as previously detailed. Firm pressure on the caliper arms was used to displace insofar as possible any fat deposits over the bony prominences.

12. *Biacromial diameter.* With the subject standing erect, relaxed and breathing quietly, the distance between the most lateral margins of the acromial processes of the scapulae were measured.

13. *Antero-posterior chest diameter.* With the subject in position as for biacromial diameter, the distance between the sternal angle and the fourth thoracic vertebral spinous process was measured.

14. *Bi-iliac diameter.* With the subject erect, the calipers were applied firmly to the most lateral margins and the distance measured across the widest flare of the iliac crests.

15. *Antero-posterior diameter at iliac crest level.* With the subject standing, and breathing quietly, the calipers were applied to the spinous process of the vertebra at the level of the iliac crests and to a parallel position over the mid-abdominal wall. In this instance only the caliper arm over the bony prominence was pressed firmly; the anterior arm touched but did not indent the skin.

16. *Thigh diameter.* At the mid-thigh, the calipers were placed in an antero-posterior position parallel to the floor with the subject standing and relaxed. The caliper arms rested easily on the skin surface with no skin indentation made.

The following measurements (17–20) were made with Lange skinfold calipers (Cambridge Scientific Intruments, Cambridge, Maryland) in accordance with the techniques described by the Interdepartmental Committee on Nutrition for National Defense [37]. Spring tension of the calipers exert a pressure of 10g/mm² over a 40 mm² surface area. The right side was used except for those subjects having a right lower quadrant abdominal scar. In these subjects, the abdominal skinfold was measured on the left side.

17. *Arm.* With the subject standing, right arm relaxed and flexed 90° at the elbow, the calipers were applied adjacent to the fingers grasping a fold of skin and subcutaneous tissue over the triceps at mid-arm level.

18. *Scapula.* With the subject standing, a fold of skin and subcutaneous tissue over the inferior angle of the right scapula was grasped so as to parallel a line about 45° from the horizontal level going medially upward. The calipers were applied to the skinfold adjacent to the grasping fingers.

19. *Thorax.* With the subject supine, breathing quietly and knees raised to relax the abdominal muscles, the skin and subcutaneous tissue over the right 10th rib was grasped parallel to the rib in the anterior axillary line and the calipers applied adjacent to the grasping fingers.

20. *Abdomen.* With the subject in position as for thorax skinfold measurement, a fold of skin and subcutaneous tissue of the abdomen 1 in. to the right of the midline halfway between the umbilicus and the symphysis pubis was grasped so as to parallel the mid-abdominal line. The calipers were applied and the measurement read.

Laboratory determinations

Laboratory determinations were usually done within two weeks after the anthropometric measurements. Women were studied when non-menstruating. The body weight and height were recorded at the time of the measurements for total body water and body density. If the weight differed by ±2 per cent of that obtained in the anthropometric examination, the anthropometric measurements were retaken for subsequent use in calculations.

1. *Body density* determinations by the method of SIRI [21] measure whole body volume in a closed-circuit system which utilizes a gas-dilution principle. With the subject in one chamber and helium in the other, the gases in the two systems are mixed. The helium concentration, measured by thermal conductivity, is related to the volume displacement by the subject. The standard deviation in volume determination is estimated at ±0.12 liter. Since the error is little affected by absolute volume, the corresponding error in density ranges from ±0.0024 g cm^{-3} for a 50 kg subject to ±0.0012 g cm^{-3} for a person weighing 100 kg.

2. *Total body water* was measured after an oral tracer dose of tritiated water, given on the same day as body density was determined. The methods employed involved equipment and procedures in general use. Four to five timed urine specimens, collected within the first 24-hour period after the dose ingestion, were assayed for tritium with a Tri-Carb liquid scintillation coincidence counter (Packard Instrument Co., LaGrange, Ill.). The liquid scintillator formulated by WERBIN *et al.* [38] was used.

It was found that 15 ml of scintillator with 2.0 ml water (the usual sample volume) counted with an efficiency of 17 per cent. Samples were always recounted with an internal standard of tritiated water and appropriate corrections were made for quenching. Vacuum distillation of urine specimens reduced the volume to an appropriate amount. In general, counting, pipetting, weighing, or other errors were maintained well below 1 per cent by suitable precautions.

3. *Total body fat* was calculated for each subject from the combined measurements of body density and of total body water. The order of magnitude of the error of this calculation, based on the above values for the experimental errors in density and water determinations and for the variability in the combined densities for protein and mineral, has been found to be ±1.7 per cent of the total body weight [25]. For a 70 kg individual the standard deviation in the determination of body fat is therefore ±1.2kg. This error is smaller than that expected when body fat is estimated by either density or water measurements since fewer variables are unaccounted for. In addition total body water–body density technique for measuring body fat is completely independent of the state of hydration of the subject.

4. *Lean body mass* was calculated from the body weight less total body fat.

5. Under the supervision of one of the authors, (T.W.S.), potassium-40 (K^{40}) and cesium-137 (Cs^{137}) were determined using an Argonne type whole-body counter [39]. Immediately before the subjects entered the counting chamber they showered (men also shampooed their hair while women shampooed their hair the night before, avoiding the use of hair sprays, rinses, etc.) and put on cotton garments and disposable slippers supplied by the laboratory. These precautions were taken to remove all traces of external activity, such as potassium salts on the skin or scalp, or from fallout occasionally found in dust on hair, skin and clothing. Whole body counts were performed usually on the same day, and always within one week, of the body density and total body water measurements. The counting geometry was that of the 'tilting chair' [39].

Cs^{137} activity was determined from the area under the 0.66 million electron volts (MeV) gamma photopeak of this isotope, from 0.57 to 0.75 MeV. Cs^{137} counting efficiency was determined in a group of eight volunteers by injection of calibrated doses of Cs^{137} (half-life=6.2 days); the mean counting efficiency was 8.1 counts per minute per nanocurie (nc) with a standard deviation of 0.96 counts/min/nc.

Calibration of the counter for K^{40} was performed by injection of known doses of K^{42} (half-life=12.5 hr) into nine volunteer subjects. An average counting efficiency of 1.09±0.10 counts/min/g with a standard deviation of 9.7 per cent was determined. The total body potassium for each subject was obtained by dividing K^{40} counts/min by the efficiency factor. This calibration method is strictly empirical, compared with the theoretical–empirical calibration obtained by MENEELY *et al.* [40]. The latter method considers the subject's height and weight and yields values with a lower standard deviation. No such correlation between height and weight and counting efficiency was found in the present study, so the efficiency used here is simply the mean of values for the subjects used for calibration.

Diet and physical activity assessment

Nutritionists (E.M.H. and M.H.R. during the first part and E.M.H. and N.D.K. during the last part of the study) interviewed individually each subject selected for dietary intake and physical activity estimate. The interview required approximately 30 min and was conducted immediately after the anthropometric measurements were completed. Since selection of subjects was made at the time of the anthropometric measurements, these individuals were previously unaware they would be interviewed.

The nutritionist asked the individual to describe his physical activity chronologically and by amount of elapsed time for the immediately preceding 24-hour period with the reference point as time of awakening. Concurrently, description of food eaten was recorded for each time of eating.

Food was described by kind, preparation and amount. Reference was made to food models, measuring cups, spoons, rulers and glasses of known volume. Whenever possible, composite ingredients for mixed dishes such as casseroles and sandwiches were noted. Weights or prices (to estimate weight) of individually packaged foods, candy bars, soft drinks, nuts, popcorn, beer, or other, were obtained when available. Brand names of special diet items were noted.

In addition to the detailed food and physical activity record, each individual was questioned concerning adherence to any special diet, use of vitamin supplements, of other food supplements, of 900 calorie preparations and of salt. Body weight change within the previous year was also recorded.

Calculations of diets to obtain intakes of eleven food nutrients, alcohol and food groups were performed by the mechanical method of the U.S. Department of Agriculture [41]. Total 24-hour food consumption as well as the amounts consumed during 2-hour intervals after arising were calculated. Master cards were available for nutritive values of 512 different foods [42]. Since the 516 diet records listed over 500 items or composites of individual foods not available in the master deck, additional master cards necessarily were calculated. Whenever feasible, substitutions were made for specific food items using nutrient comparable foods; i.e., chicken for turkey, cornstarch pudding for tapioca pudding, papaya for mango and similar substitutions.

Physical activity was accounted for by time spent sleeping or performing each of four arbitrary classifications of expended energy. These were adapted from PASSMORE and DURNIN [43] and were very light (<2.5 Cal/min), light (2.5–4.9 Cal/min), moderate (5.0–7.4 Cal/min) and strenuous (≥ 7.5 Cal/min). Since energy expenditure for comparable physical activity is greater with higher body weight, an attempt was made to define the body weight above which the arbitrary categories of caloric expenditure would be greater. Application of the regression equation for energy expenditure in slow walking [43], $C=0.047\,W+1.02$ in which C is energy expenditure in Calories per minute and W is body weight in kilograms, was made for various weights. At body weights of 260–310 lb, activities grouped as light (2.5–4.9 Cal/min) were reclassified as moderate (5.0–7.4 Cal/min).

Somatotyping technique

Somatotyping was carried out by another of the authors (A.T.H.), according to the technique originated [35] and modified by SHELDON [44], at the Cowell Memorial Hospital Constitutional Research Laboratory, University of California, Berkeley, under the direction of HENRY B. BRUYN, M.D.

This procedure determines the position of the physical constitution of an individual within a three dimensional taxonomy which includes the normal variations of human physique. A somatotype is a point in space where three determining parameters cross, or simply, where three metric distributions cross. These are height, trunk index and somatotype ponderal index; the latter two are defined below. Tables* based upon these parameters, determined by SHELDON for more than 5000 subjects, present the distribution of the specific somatotype. The latter can be determined from these tables in the same manner by which various number functions are obtained from mathematical tables.

Height, weight and standardized medical black and white photographs were taken. The maximum weight experienced by the subject at any age was recorded. From these data the somatotype ponderal index and trunk index were determined. The somatotype ponderal index is the determined height divided by the cube root of the *maximum* experienced weight. Trunk index is the ratio of the thoracic area to the abdominal area as measured with a planimeter on the dorsal photograph.

By the use of the tables, the somatotype, described in terms of three components, was determined from the subject's height, trunk index and the somatotype ponderal index. The somatotype components—endomorphy, mesomorphy and ectomorphy—are measured on a 13-point scale, 1 to 7, with intervals of ½ unit, *i.e.*, 3, 3½, 4. Data accumulated on several thousand subjects [44] have established standards for each component as follows:

Component	Males Range	Females Mean
Endomorphy	3½–4	5
Mesomorphy	4–4½	3
Ectomorphy	3–3½	3

SUMMARY

A valid clinically applicable anthropometric method to estimate body fat and lean body mass in adults would aid in the epidemiological study of diseases associatedwith overweight. Such a method has been developed from anthropometric measurements of 2053 healthy Caucasian men and women and Negro men between the ages of 25 and 44 years and from laboratory determinations of body density and total body water for 8 per cent of all subjects. This is the subject of the following report [45].

Successful employment of this method depends upon exact duplication of the measurement techniques. The anthropometric measurements have been detailed for reproducibility by interested clinicians.

Methods used to study additional parameters associated with body composition are given: diet, physical activity and somatotype. Potassium-40 and cesium-137 techniques have been described.

Subsequent papers will present results and interrelationships of the several studied factors.

*These unpublished tables are six in number for each sex; one set for each of the following age groups by sex: (1) 18 years and less; (2) 18–23 years; (3) 24–28 years; (4) 29–33 years; (5) 34–38 years; and (6) 39–43 years.

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