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Frame Size, Circumferences, and Skinfolds

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Introduction

Numerous studies conducted over the past 70 years provide a large body of knowledge and evidence that simple methods of quantifying body size and proportions can be used in many settings to predict body composition and regional fat distribution. This section discusses the strengths, weaknesses, and potential best applications of three field anthropometric methods: frame size, skin folds, and circumferences. These methods have been widely studied and are commonly used because they yield valid and reliable results when applied correctly and because they are noninvasive, inexpensive, portable, and relatively simple to perform.

Applications to Practice

Important applications for the measurement and analysis of body composition and body dimensions using the above methods include:

- Evaluating how individuals or groups are faring in general or in response to changing economic or political situations (new leadership, prolonged drought or famine, war, decreased expenditures for health services, increase in number of individuals or families living in poverty, increased cost of food) (surveillance)
- Monitoring individual response to specific therapeutic interventions (surgery, medication, chemotherapy)
- Making comparisons of actual with "ideal" (weight for height, waist-to-hip ratio, level of body fatness)
- Formulating exercise or dietary programs/regimens
- Providing prognostic indicators in certain disease states linked to body composition (diabetes, certain types of cancer, osteoporosis, cystic fibrosis, HIV/AIDS)
- Providing periodic feedback regarding achievement of goals resulting from lifestyle modifications (diet, exercise, smoking cessation)

- Assessing level of potential risk for chronic disease (cardiovascular, cancer, diabetes, osteoporosis) and monitoring relative risk over time

The method chosen depends most often on practical considerations of availability of equipment, staff (number and expertise of personnel), time, and facilities. The degree of accuracy or precision needed based on the sample size and purpose for which the information is being collected must also be considered. For example, less precision may be accepted if the purpose is risk assessment or monitoring changes with initiation of an exercise program than if the information is needed for establishing health policy or making clinical decisions about treatment or disease prognosis.

Application to Different Populations

Many variables have been found to affect the validity of measurements of body composition, including age, gender, ethnicity, measurement site selection, weight status, and health status.[1] Therefore, it is imperative that the methods selected are those best suited to the persons or population being studied. Depending on the setting and application, it may be necessary to use different methods, different anatomical sites, or to apply different equations to the same methods.

Reference Methods: AKA "Gold Standards"

Many different methods have been employed over the past seven decades to measure the composition of the human body,[2] and new technologic developments and findings from validation studies both inform and complicate decisions about which method(s) to select for a given purpose. A primary consideration in the selection of a method is whether it can provide valid information for the specific application and population being studied. Many different tests have been employed to compare body composition from experimental methods with those from the "gold standard" including: analysis of variance (examining differences), correlation coefficients (examining similarities), standard error, coefficient of variation (examining the size of the standard deviation relative to the mean), level of bias (difference between "gold standard" and experimental measure), regression analyses to examine unique and additive contributions of different measures in improving the predictive power of body composition equations, and intra- and interobserver variance.

There is no absolutely perfect method to measure and find the true value for body composition in living humans. Thus, indirect methods, most commonly hydrodensitrometry (underwater weighing) and dual-energy x-ray absorptiometry (DXA), have been used as the "gold standards" against which the majority of measures of frame size, circumferences, and skinfolds have been evaluated.[3] The validation studies using underwater weighing were based on a two-compartment model that divides body composition into fat and fat-free components and assumes constant densities for these tissues that are not universally applicable. The more recent availability of DXA technology has provided a three-compartment method free of assumptions about tissue densities but dependent on assumptions of software used with the equipment. Differing results from comparisons of these two methods (ranging from close agreement to significantly higher or lower values) probably reflect differences in the subjects studied (ethnicity, age, level of activity, gender, etc). Therefore, even though it is not clear which method yields a "true" value, it appears that more investigators are leaning toward using DXA as the new standard

TABLE 31.1

Data Quality and Anthropometric Measurement Error[7,8]

Goal of Quality Measurement	Terminology, Definitions, and Causes or Contributing Factors
Repeated measures give the same value	Reliability: Differences between measures on a single subject (within subject variability) are not caused by errors in measurement (site or technique) or physiologic variation.
	Imprecision: Different results are obtained for a single subject when measurements are done either by one person (intra-observer differences) or two or more persons (interobserver differences) and reflect measurement errors.
	Undependability: Different results are due to physiologic factors (such as differences over the course of a day in weight [due to weight of food eaten or fullness of the bladder] or height [due to compression of the spine]).
	Unreliability: The sum of errors due to imprecision and undependability.
Measurement represents a "true" value	Inaccuracy: A systematic bias is present due to instrument errors or errors of measurement technique.
	Validity: Measurement is as close to the true value as it is possible to determine.

because it is more acceptable and easier for the subjects, and because it does not rely on assumptions about bone mineral content. More recent studies suggest the simultaneous use of multiple methods is best suited to measuring or accurately examining different body compartments to establish and/or validate field methods on diverse populations.[4]

Measurement Error

Once the field method has been selected as appropriate to the purpose or study at hand, adherence to guidelines for achieving acceptable levels of measurement error[5,6] are needed to evaluate the quality of data collected. (See Table 31.1).

Guidelines for training and certification of measurers direct a repeated-measures protocol where the trainee and trainer measure the same subjects until the difference between them is very small. However, the definition of "small difference" is constrained to some extent by the technique itself (how precise can it be), equipment (how exactly can it be calibrated, how fine is the scale), and by the magnitude of the potential size of the measurement itself (measured in many centimeters, such as height versus in few millimeters, such as some skinfolds).

Some targets for difference to be achieved to certify competency have been proposed (Table 31.2).[9] Given the limits of what accuracy level is possible, investigators must also be aware of the proportion of the total measurement represented by the acceptable difference.[10]

TABLE 31.2

Recommendations for Evaluating Measurement Differences between Trainer and Trainee

	Difference between Trainer and Trainee			
Measurement	Good	Fair	Poor	Gross Error
Height (length) (cm)	0–0.5	0.6–0.9	1.0–1.9	2.0 or >
Weight (kg)	0–0.1	0.2	0.3–0.4	0.5 or >
Arm circumference (cm)	0–0.5	0.6–0.9	1.0–1.9	2.0 or >
Skinfolds (any) (mm)	0–0.9	1.0–1.9	2.0–4.9	5.0 or >

Methods

Even though literally hundreds of anthropometric studies have been done comparing methods and developing predictive equations,[11] there is neither clear evidence nor scientific consensus as to which methods, sites, or equations should be used. Thus, the best practice is to select a method with a preponderance of supporting evidence for the specific setting, population, and application, use good equipment, train staff well, understand the limitations, and be able to interpret the results within these limitations. Specific instructions for taking measurements or locating anatomical sites will not be covered in this section as detailed anthropometric manuals are available.[12,13]

Once a method and/or site of measurement has been selected as appropriate to the purpose for which the information is needed, the next steps include the logistics of selecting, calibrating, and using equipment, and training and certifying staff in the measurement procedures.

Frame Size

It seems intuitive that fat weight is unhealthy, and that persons with larger frames can weigh more and still be healthy. While there is general agreement that frame is a valid consideration in the assessment of weight for height, identifying an exact method for classifying frame size has been problematic.[14] The literature includes a variety of different concepts of frame size: body type and body proportions (length of trunk relative to total height), bone and skeletal size and thickness, and muscularity. There are two general schools of thought, one that frame is primarily a skeletal concept, and the other that it encompasses the fat-free mass (everything that is not fat including bone and muscle). Most researchers agree that a valid measure of frame must be independent of body fatness, while others believe that it must also be somewhat independent of height to be of value in the assessment of weight. However, studies have shown varying degrees of correlation of different measures of skeletal size and dimension with height (the linear dimension of the skeleton) and correlation of measures of both bone and muscle with body weight and fatness. Therefore, additional criterion for validity of frame size measures have been proposed:

1. The correlation of the measure with fat free mass (FFM) should be greater than the correlation of height alone with FFM
2. The measure should have little or no association with body fat beyond that accounted for by the association of FFM with fat[15]

Other studies have proposed more generalized methods or observations for classifying frame according to body type or morphology. The categories of leptomorph, metromorph, and pyenomorph[16] follow the idea that the human body is like a cylinder, and its mass is determined by height, breadth, and depth.

The main purpose for assessing frame size is to evaluate weight and recommend an optimal weight that would be associated with the best present state of health and longest life expectancy. One of the first proposed common uses of frame size was with weight tables published by the Metropolitan Life Insurance Company in 1954, based on mortality rates of insured adults in the U.S. and Canada.[17] These early tables suggested "ideal"

TABLE 31.3

Approximation of Frame Size by 1983 Metropolitan Height and Weight Tables

Women		Men	
Height (inches) in 1″ heels	**Elbow Breadth (inches)**	**Height (inches) in 1″ heels**	**Elbow Breadth (inches)**
58–59″ (4′10″–4′11″)	2 1/4–2 1/2″	62–63″ (5′2″–5′3″)	2 1/2–2 7/8″
60–63″ (5′0″–5′3″)	2 1/4–2 1/2″	64–67″ (5′4″–5′7″)	2 5/8–2 7/8″
64–67″ (5′4″–5′7″)	2 3/8–2 5/8″	68–71″ (5′8″–5′11″)	2 3/4–3″
68–71″ (5′8″–5′11″)	2 3/8–2 5/8″	72–75″ (6′–6′3″)	2 3/4–3 1/8″
72″ (6′0″)	2 1/2–2 3/4″	76″ (6′4″)	2 7/8–3 1/4″

TABLE 31.4

Frame Size by Elbow Breadth by Gender and Age

Age (years)	Males			Females		
	Small Frame	**Medium Frame**	**Large Frame**	**Small Frame**	**Medium Frame**	**Large Frame**
18–24	≤ 6.6	> 6.6 and <7.7	≥7.7	≤5.6	> 5.6 and <6.5	≥6.5
25–34	≤ 6.7	> 6.7 and <7.9	≥7.9	≤5.7	> 5.7 and <6.8	≥6.8
35–44	≤ 6.7	> 6.7 and <8.0	≥8.0	≤5.7	> 5.7 and <7.1	≥7.1
45–54	≤ 6.7	>6.7 and <8.1	≥8.1	≤5.7	> 5.7 and <7.2	≥7.2
55–64	≤ 6.7	> 6.7 and <8.1	≥8.1	≤5.8	> 5.8 and <7.2	≥7.2
65–74	≤ 6.7	> 6.7 and <8.1	≥8.1	≤5.8	> 5.8 and <7.2	≥7.2

Source: Frisancho, A.R., *Am. J. Clin. Nutr.*, 40: 808; 1984.

weights by gender and by ranges of height and frame size (small, medium, and large), but provided no method or instructions for assessing frame.[18] The tables were updated in 1983 and provided instructions for measuring elbow breadth and applying cutoffs for classifying frame size using data from the U.S. National Health and Nutrition Examination Survey (HANES, 1971-75) that were to result in approximately 50% of persons falling in medium frame and 25% in small and large frame categories, respectively (see Table 31.3).[19] When these cutoffs were subsequently tested on a large Canadian sample (n = 12,348 males and 6957 females), they were found to classify only a small percent of the sample as having large frames, thereby increasing the probability of misclassification into incorrect frame size categories and consequent unrealistic weight recommendations.[20]

Practical evaluation of measures of frame size is complicated by several factors including a lack of national reference standards for any measure except elbow breadth (see Table 31.4). Because frame size can not be directly measured by any single parameter, there is no "gold standard" by which to judge proposed surrogate measures, nor is there consensus on how to assign cut points for small, medium, or large frame or a standard upon which to base expectations of how frame size is (should be) distributed in a normal population. Different conceptualizations include:

- Distribution by percentiles:
  - Terciles (equal numbers in each of three frame categories)
  - Distribution by quartiles where the lowest and highest quartiles constitute the small and large frame categories, respectively, with the middle two quartiles combined to indicate medium frame
  - Distribution by varying "border values" defined at the 15th, 20th , or 25th and 75th, 80th , or 85th percentiles for small and large frame

- Defining cut-points by standard deviations with medium frame falling within plus or minus one standard deviation of the mean and those with small and large frames falling below or above these values.

Many different skeletal measurements, including segmental lengths, breadths, circumferences, and radiographs have been examined for assessing frame size. (See Table 31.5) These include:

- Wrist and arm circumference
- Elbow, knee, shoulder, chest, hip, wrist and ankle breadths
- Combination measurements:
  - Ratio of wrist circumference to height,
  - Frame index ([elbow breadth (mm)/height (cm)] × 100)
  - Regression of the sum of bitochanteric and biacromial breadths (large calipers) on height; and
  - Ratio of sitting to standing height.

Circumferences

Circumference measurements have been widely examined because they are relatively easy to perform, inexpensive, noninvasive, and require only a tape measure and minimal training of personnel. Primary applications include:

- Monitoring brain growth in children
- Monitoring effectiveness of treatments (including physical exercise) to measure reduction or increase in selected body areas
- As a marker of protein-energy malnutrition
- Estimation of the relative proportion of body weight from fat versus lean both as an independent measure and as a measure of frame size
- Describing body shape or the relative distribution of body weight using ratios such as waist to hip or head to chest (children)

Techniques for taking circumference measures are relatively simple. However, significant errors can result from improper positioning or placement of the tape and from differences in tension applied. In general, the tape is placed perpendicular to the long axis of the body, but exceptions include the head and neck, where the measurement is made at the widest and narrowest points, respectively. In almost all cases except the head, the tension on the tape is just enough to place it snug against the skin without causing an indentation. However, if the purpose of the circumference is to estimate frame size (or skeletal size), it is not entirely clear whether the tape should be pulled more tightly to get as close to the bone as possible. Equipment includes a flexible, nonstretchable, relatively narrow (0.7 cm) tape measure that has metric measures on one side and English on the other. Special anthropometric tapes are available, such as those already interlocked to slip over the arm or head, with arrows to make reading the measurement or finding the midpoint of the back of the arm easier. Detailed instructions for technique for measurement

TABLE 31.5

Selected Validation Studies of Determinants of Frame Size (FS)

Frame Size Measure	Subjects[a]	Methods and Criterion[b,d]	Results
Bony chest breadth[21]	n = 2201, ♂, Scotland.	a. Bony chest breadth measured by x-ray b. Criterion tested: 1, 3, and sig ↑ in wt with ↑ in FS	a. Correlation of bony chest breadth to wt > correlation of ht to wt b. Wt ↑ about 3.7 kg per each cm ↑ in bony chest breadth c. Wt ↑ about 12 kg per FS (S → M → L) d. Wt: bony chest breadth ratio correlated with FFM
Ratio of height (cm) to wrist circumference (cm)[23]	100 ♂ and ♀ adult patients at a university medical center, USA	a. Wrist measured distal to styloid process at wrist crease on right arm b. Frame size (S, M, L) assigned using this ratio by gender	a. Method for assigning frame size not stated. It appears that some sort or “normal” distribution was applied, but no other criteria of validity were tested. b. FS assigned by Ht:wrist ratio: ♂ S > 10.4; M 9.6-10.4; L < 9.6; ♂ S > 11.0; M 10.1-11.0; L < 10.1
Elbow and bitrochanteric breadths[24]	n = 16,494 ; age range: 18 to 74; ♂ and ♀; black and white; USA NHANES 1971-1974.	a. Criterion tested: 1, 3, and 4 b. Body fat determined by sum of triceps and subscapular skinfolds	a. Correlation coefficients of weight, elbow, bitrochanteric breadth to log-transformed sum of skinfold values done by gender by 3 age groups by race demonstrate lowest correlation with elbow breadth. b. Categories of SML FS established for elbow breadths with cut points at the 15th and 85th percentiles (values given by gender, race, and age group) demonstrate significant gender differences and some racial differences. c. Greater differences were observed for mean weights of subjects when they were categorized by FS (S, M, L) versus height (short, medium, tall) demonstrating that FS is more effective in weight discrimination
Elbow breadth[21]	n = 21,752; “adults” age range: 25-54; “elderly” age 55-74; ♂ and ♀; multiracial; USA NHANES I and II.	Based on this large data set, percentiles of weight, skinfolds (triceps, and subscapular), and bone-free upper arm muscle were developed by height, gender, and FS (using elbow breadth) for two age groups	a. Values of elbow breadth for S, M, L FS are given for males and females by age. (See Table 31.4) b. These standards can be used to identify persons who are at risk of being undernourished or overfat.
Height (H) and sum of biacromial (A) and bitochanteric (T) (HAT method) Body fatness estimated by hydrostatic weighing[25]	mean age = 22; n = 113 ♂, 182 ♀; H; university students; Ht and Wt representative of US population for this age group; Caucasian, USA.	a. Criterion: 3,5 b. Bivariate model developed based on height (H) and sum of biacromial (A) and bitochanteric (T) breadths c. Boundaries for FS (S, L) set by gender using mean ht ± 1 sd	a. Criterion satisfied. b. For ♂ differences in wt between FS primarily due to differences in FFM c. For ♀ there was small but sig. increase in FM per FS but no increase in FFM per FS d. FS equations: ♂ ht (8.239) + (A + T); ♀ ht (10.357) + (A + T) e. HAT FS boundaries: ♂ S <1459.3; M 1459.4-1591.9; L > 1592.0; ♀ S <1661.9; M 1662.0-1850.7; L >1850.8

TABLE 31.5 *(Continued)*

Selected Validation Studies of Determinants of Frame Size (FS)

Frame Size Measure	Subjects[a]	Methods and Criterion[b,d]	Results
Wrist, biacromial, elbow, hip, knee, and ankle breadths Body fatness estimated by hydrostatic weighing[15]	n = 225 ♂ and 215 ♀; age range =18-59; Canada, Quebec City, French descent. Tended to be leaner than either Canadian or US reference populations.	a. Criterion: 5-6 b. Differences in lean weight between FS categories (assigned by terciles) > differences in % body fat	a. All bone breadth measures were shown to be associated with FFM. b. Biacromial, elbow, hip, and knee did not meet criterion 6. c. Both criterion satisfied for wrist and ankle breadths. (Data not shown for FS cut points.)
Actual FS (AFS)[c] Body composition determined by JP, Br[26]	n = 17; $\bar{x}$ age = 20.9 ± 1.4; H; ♂; Caucasian; UK	a. Criterion: 1-5 and correlation with proposed measure AFS	a. Lack of agreement in assigning FS between methods 2-5. b. Criterion satisfied: ankle breadth and elbow breadth 1-5; AFS and hand length 1-3 and 5; HAT 1-3; chest breadth 1-4; wrist breadth 2,3; height:wrist 3. c. Additional correlations: ht → wt r = 0.68 (s); ht → FFM r = 0.70 (s); FFM → FM r = 0.20 (ns)
Frame index[5,27]	n = 21,648 ♂; 21,391 ♀ (sample size planned for 96% statistical confidence); age range = 18-70; Germany	Developed: a. Percentile curves for weight, height, BMI by gender and age b. Three categories of frame index using 20th and 80th percentiles as border values c. Median values for BMI and % BF by gender and age for each FS	a. Graph of median curves for frame-specific BMI by age (18-64) demonstrate important differences with age and gender and consistently higher BMI with for larger frame. b. Graph of median curves for frame-specific % BD by age (18-64) also demonstrate age and gender differences and consistently higher body fat with larger FS. c. Values used for cut points for frame index (at the 20th and 80th percentiles by gender and age) are not given for this sample. However, those published by Frisancho (derived from US NHANES data) could be used for other studies.
Biacromial, bi-iliocristal, wrist, and knee diameters and sitting height Body composition: DW[28]	n = 2512 ♂ age range = 45-59 South Wales	a. Criterion of effectiveness, improvement in correlation of BMI with body fatness when BMI is adjusted for FS	a. All 4 breadth frame measures were positively associated with BF (range of r = 0.16 [wrist] – 0.45) and height (range of r = 0.32 – 0.43). (Correlation of sitting height with BF or total ht not reported.) b. Adjusting BMI for FS did not improve the association of BMI with BF. c. Correlations of the BMI adjusted for FS by wrist and sitting height (both r = 0.74) were essentially the same as for BMI alone (r = 0.76). d. Correlations of the BMI adjusted for FS by biacromial, bi-iliocristal and knee diameters (range of r = 0.60 – 0.66) were lower than for BMI alone (r = 0.76), indicating a possible inflating effect of subcutaneous fat on these diameter measures.

Elbow breadth and height:wrist ratio Body composition: BIA-Lu[29]	n = 42 ♀; 38 ♂ age range = 18-55; USA	a. Criterion tested: 3, measures result in normal distribution of FS, and produce the same FS in an individual	a. Criterion 3 met for ♂ but not ♀. b. Both measures resulted in a FS distribution highly skewed to small frame (53-73% of subjects) with 0-3% in large frame. c. These two FS measures produced the same FS in 69% of the subjects.
Arm and wrist circumferences; ankle, elbow and wrist breadths; subscapular skinfolds; frame index 2; ht and wt; visual assessment.[30]	n = 300 (71 ♂ and 229 ♀); mean age = 72.6 ± 5.1; H; Caucasian; Midwest, USA	a. Criterion tested: 3 and agreement across methods in classifying FS	a. Distribution of FS designation varied by determinant but was not influenced by age. b. Visual assessment and elbow breadth[19] classified about 75% of subjects as medium frame. Elbow breadth[21] and Frame Index 2[5] resulted in more even distribution of FS. c. Association with "fatness" (subscapular skinfold) was noted for women with elbow breadth and for men with height:wrist. d. Ankle and wrist breadth had lowest correlations with subscapular skinfold, but lack of population-based standards limits their application.
Wrist and knee width used as FS measures; ht and wt; sitting ht Slenderness index (ht/wrist + knee width) % BF measured by UWW and BIA.[31]	n = 120, matched for age, gender, and BMI. China (Singapore and Beijing Chinese) and Netherlands (Caucasian)	a. Measured % BF compared by matched BMI between ethnic groups b. % BF calculated from BMI compared to measured c. Skeletal mass calculated from ht, wrist, and knee width	a. % BF differences observed between groups for the same BMI, with % BF ↑ with ↑ FS. b. % BF calculated vs. measured not different for Beijing Chinese and Dutch. c. % BF calculated underpredicted true value by 4% in Singapore Chinese. d. Differences in FS are at least partially responsible for differences in relationship of BMI → % BF among different ethnic groups.

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[a] Footnotes: Subjects (all information provided in the original reference is given): n = number of subjects; age in years; health status: H = healthy; gender: ♂ = male; ♀ = female.

[b] Criterion applied: 1 = highly correlated with weight; 2 = highly correlated with fat free mass (FFM); 3 = minimally correlated with body fatness; 4 = minimally correlated with height; 5 = correlation with FFM is greater than the correlation of height alone with FFM; 6 = little or no association with body fat beyond that accounted for by the association of FFM with fat.

[c] In this study, the authors propose a reference measure "actual FS" comprised on the sum of a battery of 22 different skeletal measures (11 breadths, 9 lengths, and 2 depths) as described in text of Logman et al.[12]

[d] Methods for determing body composition: UWW = underwater weighing; BIA = bioelectrical impendance analysis; JP = regression equations of Jackson and Pollack;[32,33] Br = formula of Brozek et al.;[34] DW = regression equation of Durnin and Wormersley;[35] BIA-Lu = bioelectrical impedance analysis using the equations of Lukaski et al.[36]

[e] Abbreviations: FS = frame size; S, M, L= small, medium, large; ht = height; wt = weight; FFM = fat free mass; FM = fat mass; % BF = percent body fat; r = correlation coefficient; sig = statistically significant; ns = not statistically significant; sd = standard deviation.

of the head, neck, chest, waist, abdomen, hips or buttocks, thigh, calf, ankle, forearm, and wrist are described by Callaway et al., who recommend intra- and intermeasurer limits of agreement of 0.2 cm for relatively small sites (calf, ankle, wrist, head, arm, forearm) and 1.0 for the large sites (waist, abdomen, buttocks, chest).[37]

One of the most commonly measured and clinically practical anthropometric methods is the arm muscle area. This method was originally developed for use in the field for the evaluation of undernourished children.[38] Arm circumference and tricep skinfold measurement can be used to compare an individual to a reference population[39] and estimate the relative proportion of fat and muscle[40] or to estimate the severity of undernutrition in seriously ill hospitalized patients.[41] The use of arm circumference has importance when either undernutrition or overnutrition are of concern, and it can be easily used in the field, hospital, or community setting. Similarly, head circumference is a common measurement for infants in the first two to three years of life and can be plotted on standard growth charts to be compared with population norms.

Because of some of the difficulties of applying traditional height-weight tables to individuals who are either very lean or very fat and because of the practicality of doing circumference measurements, various researchers have evaluated the validity of using circumferences to estimate body composition and physical fitness (see Table 31.6). Using underwater weighing as the "gold standard," tables have been developed to estimate percent body fat within 2.5 to 4% for women and men using the following circumferences:

Young Women (ages 17–26)	**Older Women (ages 27–50)**	**Young Men (ages 17–26)**	**Older Men (ages 27–50)**
Abdomen	Abdomen	Right upper arm	Buttocks
Right thigh	Right thigh	Abdomen	Abdomen
Right forearm	Right calf	Right forearm	Right forearm

Source: Katch, F.I. and McArdle, W.D. in *Nutrition, Weight Control, and Exercise,* Lea & Febiger, Philadelphia, 1988.

The U.S. Navy requires personnel to pass certain physical fitness screening tests including having an appropriate weight for height. In this setting it is quite important to use a method that provides more specific information than traditional height-weight indices in differentiating individuals who have excess lean weight from those individuals with excess fat. Because of the large numbers of potential recruits and enlisted personnel being measured, practicality is also very important. Equations using circumference measures have been used to estimate percent body fat and body density since the early 1980s.

Skinfold Measurements

The skinfold (sometimes referred to as fatfold) technique is performed by pinching the skin and underlying fat at a given location between the thumb and forefinger, pulling the fold slightly away from the body, placing calipers on the fold, and measuring its thickness. Some skinfold sites are relatively easy to locate and measure, while others are not. Many individual factors can affect the accuracy of skinfold measurements:

- Degree of leaness or fatness
- Muscle tone (including presence of muscle wasting)
- Changes with growth
- Younger or older age (as they affect accuracy of assumptions about tissue composition, muscle tone, skinfold compressibility, and elasticity)

TABLE 31.6

Selected Validation Studies of Circumference Measures

Circumference Site(s)	Subjects[a]	Methods	Results
Waist, hip[43]	n = 18 ♂ and 22 ♀, BMI ≥30; Scotland.	IAF measured by MRI, and central abdominal fat measured by DXA.	In obese ♀, DXA, waist and hip were equally well correlated with IAF (r = 0.74, 0.75, 0.70, respectively) In obese ♂, only DXA was moderately correlated with IAF (r = 0.46)
Neck, abdomen, thigh[44]	n = 5710 ♂ and 477 , Navy personnel, USA	% BF estimated from standardized Navy equations for men {% Body Fat = (0.740 × abdomen) – (1.249 × neck) + 0.528[a] 2. Body Density = –[.19077 × Log10 (abdomen – neck)] + [.15456 × Log10 (height)] + 1.0324; Percent body fat = [(4.95/body density) – 4.5] × 100[a]} and women {% Body Fat = (1.051 × Biceps) – (1.522 × forearm) – (0.879 × neck) + (0.326 × abdomen) + (0.597 × thigh) + 0.707[a]} % BF estimates correlated with 3 measures of physical fitness	Estimates of percent body fat derived from these circumference measurements and equations correlated better with performance on the Navy's physical fitness tests than did commonly used weight-height indices
Waist, hip[48]	n = 32,978; age range = 25-64; participants in 19 ♂ and 18 ♀ populations participating in a WHO MONICA project.	Identification of obesity compared by cut points for waist circumference at 2 levels (1. ♂ ≥ 94 cm; ♀ ≥ 80 cm; 2. ♂ ≥ 102 cm; ♀ ≥ 88 cm) vs cut points for BMI (≥ 25 kg/m^2) and WHR (♂ ≥ 0.95; ♀ ≥ 0.80).	Sensitivity was lowest in populations with fewer overweight individuals and highest in populations with more overweight. Use of waist cut points vs BMI or WHR cut points would correctly identify most people without obesity but miss some with obesity. Optimal screening cutoff points for waist circumference may be population specific.
Waist, hip umbilical[49]	n = 91, ♀; age range 20-54; BMI: 18-34 kg/m2	% BF by DXA compared with %BF from predictive equations.	Comparability and precision of % BF estimates from predictive equations can be improved by adjusting for umbilical circumference and BMI.
Waist, hip[50]	n = 385 (140 ♂ and 245 ♀); mean age = 80 (range = 65-96); USA.	% BF by DXA and BIA. BF distribution by skinfolds.	% BF < % vs &, upper body obesity > % vs & even in older age; Strong age adjusted correlations among obesity measures (BMI, %BF [DXA & BIA], skinfolds) were observed for both % and &; Weak associations among measures of upper body obesity differed by gender .

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[a] Subjects (all information provided in the original reference is given): n = number of subjects; $\overline{x}$ age = mean age (years); gender: ♂ = male; ♀ = female.

[b] Methods for determining intra-abdominal fat: MRI = magnetic resonance imaging.

[c] Methods for determining body composition: UWW = underwater weighing; DXA = dual energy x-ray absorptiometry; DD = deuterium dilution; TBK = total body potassium; BIA = bioelectrical impedance analysis; SKF = JP = regression equation of Jackson and Pollack;[32,33] Br = formula of Brozek et al.;[34] DW = regression equation of Durnin and Wormersley;[35] BIA-Lu = bioelectrical impedance analysis using the equations of Lukaski, et al.[36]

[d] Abbreviations: IAF = intraabdominal fat; WHR = waist to hip ratio; ht = height; wt = weight; BMI = body mass index; ffm = fat free mass; fm = fat mass; % BF = percent body fat; r = correlation coefficient; sig = statistically significant; ns = not statistically significant; sd = standard deviation.

- Subject cooperation (small children may be frightened or uncooperative)
- Ethnicity
- Health status (bedridden vs. ambulatory)
- Hydration status

Use of this method relies on two main assumptions: 1) skinfolds provide good measures of subcutaneous fat; and 2) there is a good relationship between subcutaneous fat and total body fat. The ability to predict total body fat varies by site, with some sites highly correlated with total fat and others relatively independent of total fat. Studies show that the relationship between subcutaneous and total body fat (ranging from 20 to 70%) is affected by age, gender, degree of fatness, and race.[51-53] Thus, it is important to review the literature carefully and select sites and predictive equations that have been validated for the population being measured and provide sufficient precision for the desired application.

Guidelines for skinfold measurement technique, location of measurement sites, and information on reliability of measurement at the various sites have been published.[54] Considerable supervised practice is required before an individual can take accurate skinfold measurements. Training by an experienced person should be conducted, and measures practiced until consistency is achieved between the expert and trainee and by the trainee on within-subject repeated measures. Experts agree on the importance of using standardized techniques in both locating the site and using calipers to take the measurement, yet some argue that in light of the many biologic variables affecting body composition, technical errors in skinfold measurement are of comparatively little importance.[55] Nonetheless, given a standard level of training and care in measurement, high levels of reliability can be achieved (see Table 31.7).

Many different models of skinfold calipers are available, but only those designed to maintain a constant tension (10 g/mm) between the jaws should be used. However, even with the higher quality calipers, there is a difference in the pressure exerted by the jaws and therefore in the degree of compression of the skinfold.[56] Differences in compression have also been attributed to differences in caliper jaw surface area such that calipers with smaller surface area and lighter spring tension (such as the Lange) give larger values than

TABLE 31.7

Reliability of Selected Skinfold Measurement Sites

Site	Intermeasurer Error	Intrameasurer Error
Subscapular	SEM: 0.88 to 1.53 mm	SEM: 0.88 to 1.16 mm
Midaxillary	SEM: ± 0.36; 1.47 mm (children); ± 0.64 mm (adults)	SEM: Children: ± 0.95 mm Adults: ± 1.0,1.22, 2.08 mm
Pectoral (chest)	R: .9, .93, .97; SEM: 2.1 mm	R: .91 to .97 mm; SEM: ± 1-2 mm
Abdominal		R: .979; SEM: 0.89 mm
Suprailiac	SEM: 1.53 mm (children); 1.7 mm (adults)	R: .97; SEM: 0.3-1.0 mm
Thigh	R: > .9, .97, .975; SEM: ± 2.1, ± 2.4, 3-4 mm	R: .91, .98, .985; SEM: 0.5-0.7 mm, 1-2 mm
Medial calf		R: .94, .98, .99; SEM: 1.0-1.5 mm
Tricep	SEM: 0.8-1.89 mm	SEM: 0.4-0.8 mm
Bicep	SEM: ± 1.9 mm	SEM: 0.2-0.6, ± 1.9 mm

[a] Information in this table has been summarized from Harrison GG, Buskirk ER, Carter JEL, et al. Skinfold Thickness and Measurement Technique. In: Lohman TG, Roche AF, Martorell R. *Anthropometric Standardization Reference Manual.* (1988) Champaign, IL: Human Kinetics. pp 55-80. This chapter includes the specific citations for the reliability studies.

[b] Abbreviations used: SEM: Standard error of measurement; R: reliability coefficient.

[c] Multiple error estimates represent differing results from different studies.

calipers with larger surface area and tighter spring tension (Holtain and Harpenden).[57] Because of these differences attributable to the calipers themselves, it is important to calibrate often,[58] and to consistently use the same equipment in order to compare data within or across subjects.

Importance of Frame Size, Skinfolds, and Circumferences to Disease Risk

A variety of approaches have been employed to better understand the validity of using these field measurements for the assessment of risk for the most prevalent and serious diseases: heart disease, diabetes, cancer, and osteoporosis. Major interest has been in evaluating these measures for their ability to measure, estimate, or predict:

- Total fat or percent body fat
- Fat or weight patterning or distribution
- Skeletal size or density
- Biochemical markers such as lipids and insulin sensitivity/resistance
- Health outcomes such as elevated blood pressure, morbidity or mortality (cancer, diabetes, coronary artery disease, myocardial infarction)

The preponderance of studies relating anthropometric measures to disease have been in the area of cardiovascular disease (CVD) in an attempt to identify potentially modifiable body factors and to understand potential markers for and predictors of disease. An extensive summary of studies done in men illustrates the methodological and statistical difficulties that are encountered when assessing the relationship between CVD and various body measurements.[59] In general, studies have not shown a consistent relationship between obesity and CVD using a variety of measures (weight for height, relative weight, total body fat, etc.). The strength of association between central fat distribution and CVD is stronger than that of body fat alone, yet a large percent (30 to 50%) of the variation remains unexplained. Potential sources of difficulty in conducting these studies include inability to identify adequate surrogates for obesity, confounding effects of cigarette smoking or subclinical disease, short followup periods, and inadequate methodology for identifying subgroups of obese persons who are at risk. For example, several studies suggest that persons who have undesirable patterns of body fat distribution that develop early in life may be at increased risk.[60,61] While one study of three distinct populations found a consistent direct association between abdominal obesity as measured by waist circumference and waist:hip ratio and dyslipidemia,[62] others have found the sagittal abdominal diameter to be a better predictor of risk than BMI, waist circumference, or waist-to-hip ratio.[63,64]

Several studies evaluating the ability of simple anthropometric measures to identify those at risk for low bone mass and fractures have found a strong association between weight and bone mineral density (BMD), while others have not. (See Table 31.8). Possible factors affecting the relationship between body weight and/or size and bone mineral density include simple mechanical loading (a larger and heavier body will need a stronger skeletal support), the influence of endogenous sex steroids, and possibly muscularity (either directly by its contribution to total body weight or indirectly by its association with increased activity). For these reasons, anthropometric measures related to gender-related weight distribution (central versus lower body), FS, and measures of muscularity/adiposity have been investigated for their value in estimating BMD.

TABLE 31.8

Selected Studies Examining the Relationships between Anthropometric Measures and Bone Mass or Bone Mineral Density

Anthropometric Measures	Subjects	Methods	Results
a. Frame: biacromial, biiliac, bicofemoral, bicohumeral, and wrist breadths; b. Skinfold: triceps, biceps, forearm, subscapula, suprailium, calf, abdomen, thigh; c. Circumferences: calf, waist, upper arm, abdomen d. Height and weight[65]	n = 342; mean age = 44.1 (range = 25-79); ♀; USA	Correlation of anthropometric measures to: a. Measured (photon absorptiometry) bone mineral density (g/cm^2) at the radius, femoral neck, Ward's triangle, trochanter, lumbar spine b. Constructed summary bone density score (radius, spine, femoral neck) Muscle mass (termed "muscularity") estimated from circumferences and skinfolds[a] Multiple regression models constructed to test the usefulness of measures in predicting bone mass.	a. For all skeletal sites one frame measure (biacromial width [BW]), one skinfold (subscapular[SSF]) and one circumference (calf[CC]) provided the strongest correlations. b. The greater trochanter was more strongly correlated with all anthropometric measures than any other skeletal site. c. After inclusion of age, BW, SSF, and muscularity in multiple regression model, BW was a significant predictor for all sites except the radius, and SSF and muscularity were significant for all sites. d. Neither height nor weight contributed significantly to the model after BW, SSF, and CC or muscularity were included. e. Despite the strength of the associations, none of the models accounted for more than 40-45% of the variability in bone mass at any site and therefore are not adequate to predict bone mass for individuals. f. No measures of distribution of body fat were significantly associated with bone mass. g. Cross-sectional data not adequate to address questions of rates of bone loss.
a. Elbow breadth b. Height, weight and BMI c. Waist:Hip ratio[67]	n = 6705; ♀ mean age = 71.2 ± 5, Non-black, USA	Bone mineral density (BMD) measured by single-photon (proximal and distal radius and calcaneus) and dual-energy x-ray absorptiometry (lumbar spine and proximal femur) Adiposity measured by bioelectrical impedance	a. Weight was the major determinant of BMD at all sites, explaining 6-20% of the variability. (Weight explained more of the variability at direct weight bearing sites — proximal femur and os calcis.) Effect of weight on BMD did not seem to vary with age. (Age had independent significant effect on BMD decline.) b. Although the measures of BMI, elbow breadth, height, and waist:hip ratio resulted in statistically significant ($P<0.001$) improvements in fit of the model, they added very little explanatory power over weight alone. c. A modest proportion of the weight effect was explained by adiposity (36-63% at weight bearing sites and 8-12% at forearm sites). d. These data suggest that both mechanical loading and metabolic mechanisms affect BMD.
Waist:Hip ratio, wt, BMI, arm muscle and fat area	n = 1873 ♀ (97% post-menopausal), Italy	Bone mineral content (BMC) and density (BMD) evaluated by DXA as normal (N), osteopenic (OPN) or osteoporotic (OPR)	Body wt., BMI, arm muscle and fat sig > in N than either OPN or OPR groups. WHR not different between groups. Wt and age sig predictors of BMC and BMD but high levels of variation in BMC for the same level of wt (under, normal, over) negate its usefulness as a predictive indicator.

Conclusion

Even though there is an extensive body of literature examining the validity of using measures of frame size, circumferences, or skinfolds to predict disease risk or disease outcomes, conclusive findings and consensus on which measures are best remain elusive. Nonetheless, the ability of researchers to build on the lessons learned from these early studies and apply emerging new technologies give reason for optimism about reaching the goal of using simple, inexpensive techniques to improve individual and public health.

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