Gatorade Sports Science Institute

Sports Science Exchange 101

VOLUME 19 (2006) ■ Number 2

Information herein is intended for professional audiences, including scientists, coaches, medical professionals, athletic trainers, nutritionists and other sports health professionals who have a fundamental understanding of human physiology.

OPTIMIZING TECHNIQUES FOR DETERMINING BODY COMPOSITION

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KEY POINTS

- Accurate body composition assessments are vital to monitoring growth, training outcomes, health, and nutritional status of athletes.
- Body composition assessment in athletes and others relies on non-invasive indirect methods that are based on theoretical models. Any errors in the theoretical models will produce errors in the indirect methods.
- Three- and four-compartment models that combine measures of body density with body water and mineral content dramatically reduce the errors associated with the traditional two-compartment model (fat and fat free mass) and should be used whenever possible.
- When used, two-compartment estimates should employ population-specific equations when they are available.
- Field methods, such as anthropometry and bioelectric impedance analysis, are useful for screening if the equations used are properly validated and cross-validated.

INTRODUCTION

Regular assessment of body composition is important for monitoring the nutritional status and health of athletes and other active individuals. In child and adolescent athletes periodic assessment may also be necessary to monitor their physical development. While physical activity is undoubtedly critical for optimal growth, there are certain health risks associated with the demands of training. Regular assessment of body weight and composition may allow for detection of potentially harmful changes that occur as a result of inappropriate nutritional practices, excessive training, or illness and to relate body composition status to performance.

Direct methods using body organs or whole cadavers are available to assess body composition on atomic, chemical, cellular and tissue/system levels of analysis (Wang et al., 1992), but for living people, of course, only indirect, non-invasive methods are suitable. Indirect methods are based on reference bodies or models (e.g., reference infant, reference adolescent, reference man, and reference woman) that have been developed from the results of chemical analyses of human organs and cadavers. These models assume certain expected relationships among body compartments and are only as accurate as the underlying assumptions. Field methods are typically validated against indirect laboratory methods and thus are doubly indirect, susceptible to errors in both the field and laboratory methods. It is essential that the methods used for athletes and other active people be developed against an appropriate model and, ideally, also be cross-validated in other studies.

RESEARCH REVIEW

Two-Component Body Composition Models

Theoretical models, based on the chemical analysis of organs and human cadavers, form the scientific basis for all indirect assessment methods. The classic two-component (2C) model describes the body as the sum of fat and fat-free compartments. Using this model, fat-free mass (FFM) can be estimated from body density, body water, or any other component of FFM if the relationship between that component and FFM is known. Percent fat is then calculated from total body weight and FFM. Commonly, FFM has been estimated from body density or body water using conversion factors derived from reference bodies (Pierson, 2005).

For valid and accurate estimation, an appropriate reference body for the population of interest must be used. Historically, 2C models developed by Siri (1956) and Brozek et al. (1963) have been applied almost universally, assuming little change in FFM chemical composition after early childhood. However, many studies have now demonstrated that errors of 3-4% or more are introduced when an inappropriate reference body is used, e.g., reference infant versus reference adolescent. When field methods and equations are developed and validated against the 2C model, the errors in the model are passed on to the new methods. Thus, a new method or equation is only as accurate as the method against which it is validated.

Multi-Component Models

The accuracy of the 2C models can be improved upon by measuring additional body compartments directly, thereby requiring fewer assumptions. Recent technological advances for measuring water, mineral, and other components of FFM have allowed for the development of multi-component models. Three-(3C) and four-component (4C) models that combine measures of body density with body water and mineral content dramatically reduce the errors associated with the 2C model and should be used whenever possible (Table 1). Unfortunately, the added expense and complexity of multi-component methods limits their application outside the laboratory setting. However, it is essential that they be used as the standard on which simpler methods are based.

Laboratory Reference Methods

Laboratory methods provide reference or criterion measures for the derivation and evaluation of field methods and prediction equations. Although they have greater accuracy, all laboratory methods make assumptions and are subject to some error. Reference methods based on 2C models, such as hydrodensitometry (underwater weighing), air displacement plethysmography (ADP), and hydrometry (measurement of total body water), generally have greater errors than do methods based on multi-component models, such as dual energy x-ray absorptiometry (DXA) and combined methods.

Densitometry

Densitometry refers to estimation of body composition from body density, which is estimated from body mass and volume. Historically, underwater weighing has been the most common method for estimating body volume. (The reduced weight of the person underwater reflects the volume of water—and of the body—that the person displaces when submerged.) However, with the recent development of the Bod Pod™, it is possible to estimate volume and density via air displacement plethysmography. Best practices for both methods have been described (Going, 2005) and both give acceptable estimates of volume and density. However, both are limited by the validity of the assumptions underlying the 2C equations used to convert density to estimates of body composition.

Body density is inversely related to body fatness, and 2C approaches take advantage of this relationship to derive equations for converting

TABLE 1. *Body Composition models and equations*

	MODEL	EQUATION	REFERENCE
TWO-COMPONENT MOLECULAR LEVEL	**BW** = fat + fat-free body mass	$\%BF = [(4.57 / Db) - 4.142] \times 100$	Brozek et al., 1963
		$\%BF = [(4.95 / Db) - 4.50] \times 100$	Siri, 1956
THREE-COMPONENT MOLECULAR LEVEL	**BW** = fat + water + (mineral and protein combined)	$\%BF = [(2.118 / Db) - 0.78W - 1.354] \times 100$	Siri, 1961
		$\%BF = [(6.386 / Db) + 3.96M - 6.090] \times 100$	Lohman, 1986
	BW = bone mineral + bone-free lean tissue + fat	$\%BF = FM/BW \times 100$	Ellis, 2000
FOUR-COMPONENT MOLECULAR LEVEL	**BW** = fat + water + bone mineral + protein	$\%BF = [(2.559 / Db) - 0.734\,W + 0.983B - 1.841] \times 100$	Friedl et al., 2001
		$\%BF = [(2.747/Db) - 0.714\,W + 1.146\,B - 2.053] \times 100$	Selinger, 1977
		$\%BF = [(2.747/Db) - 0.718\,W + 1.148\,B - 2.050] \times 100$	Heymsfield et al., 1996 Baumgartner et al., 1991

KEY

BW = body weight.

%BF = body fat as a percentage of body mass.

Db = total body density (g/cc).

FM = fat mass (kg).

W = TBW (kg)/BW (kg), where TBW = total body water and BW = body weight.

M = TBM (kg)/BW (kg), where TBM = total body mineral (osseous + cell mineral) and BW = body weight.

B = TBBM (kg)/BW (kg), where TBBM = total body bone mineral (osseous mineral only) and BW = body weight.

density to percent body fat (Table 1). For example, the most common Siri equation was derived by assuming the densities of body fat (d_f) and fat-free mass (d_{ffm}) were equal to 0.9 kg/L and 1.1 kg/L, respectively. Chemical analyses support these estimates in healthy, young adults (Brozek et al., 1963), but work with multicomponent models (Evans et al., 2001; Prior et al., 2001) show considerable heterogeneity in the protein, water and mineral fractions of FFM, and thus its density, in growing children and adolescents, whose chemical components are changing, and in athletes and other special populations. Variation from the assumed FFM composition introduces error unless appropriate adjustments are made.

Hydrometry

Hydrometry is the measurement of total body water (TBW), which can be estimated accurately via isotope dilution (Schoeller, 2005). Because water is the most abundant body component and because it is located in the FFM compartment, measurement of TBW, as well as the distribution of water intracellularly and extracellularly, is important to body composition assessment. Once TBW is known, it can be used in combination with body density in 3C or 4C models to estimate percent fat and then FFM. Alternatively, if one knows the fraction of the FFM that consists of water, that constant can be used to convert TBW directly to FFM, after which the percent fat can be estimated. Because there can be significant variation in TBW, combining TBW and density in a 3C model provides a significant improvement over the traditional 2C model (Table 1). However, the water fractions of the FFM are well established for different ages and levels of maturation, and FFM can be accurately estimated from TBW as long as population-specific conversion constants are used (Lohman, 1992).

Dual Energy X-Ray Absorptiometry (DXA)

DXA is increasingly available and easily performed. Based on a three-component model (total body bone mineral, lean soft tissue, and fat), DXA estimates of bone mineral, soft tissue, and fat are relatively unaffected by variation in the chemical composition of FFM because DXA is designed to detect variation in bone mineral mass. For example, theoretical analyses in adults (Pietrobelli et al., 1996) and in children from infancy to 10 years of age (Testolin et al., 2000), have shown that the typical variation in water content of the FFM affects DXA estimates of percent fat by less than 1%. Consequently, DXA has emerged as a criterion method used to validate other methods. It is important to recognize that different manufacturers' scanners and software give different results, which is the main limitation of DXA (Lohman & Chen, 2005).

Population-Specific Equations

Population-specific equations are intended to be used to estimate the body composition of individuals from a specific homogeneous group. Given the expected differences in FFM composition due to race/ethnicity, growth and maturation, aging and training, it is expected that an equation derived from a group-appropriate reference body should be more accurate than an equation designed for the entire population. Both natural selection and specialized training (e.g., resistance training versus long-distance running) undoubtedly contribute to the differences among athletic groups in body shape, distribution of muscle and adipose tissue, and the chemical composition of FFM that invalidate the assumptions underlying standard 2C models and equations.

Unfortunately, systematic studies of the FFM composition of athletic groups have not been performed, although recent work with multi-component methods has begun to define the chemical composition of some groups (Heyward & Wagner, 2004). When the FFM composition is known, it is possible to derive adjusted 2C equations based on the actual composition and density of FFM rather than assumed values. An example of an adjusted 2C equation, derived using a population-specific estimate of the FFM density, is shown in Table 2. A similar equation for any athletic group can be derived if FFM density is known. It is important to note that while population-specific equations reduce errors due to differences across groups, variation in FFM composition among individuals in the population of interest remains as a source of error, albeit a smaller one.

TABLE 2. *Derivation of a 2C equation to estimate % body fat (BF) using population (athlete)-specific density of the fat-free mass*

Basic equation for estimating % BF from body density (Db)

$$\%\,\mathbf{BF} = [\,\frac{1}{D_b} \times \frac{D_{FFM} \times D_F}{D_{FFM} - D_F} - \frac{D_F}{D_{FFM} - D_F}\,] \times 100$$

Where D_{FFM} = density of the fat-free mass; D_F = density of the fat mass

For a resistance-trained male, aged 24 ± 4 y

Using D_{FFM} = 1.089 g/ml and D_F = 0.901 g/ml,

$$\%\,\mathbf{BF} = [\,\frac{1}{D_b} \times \frac{1.089 \times 0.901}{1.089 - 0.901} - \frac{0.901}{1.089 - 0.901}\,] \times 100$$

$$\%\,\mathbf{BF} = [\,\frac{5.21}{D_b} - 4.78\,] \times 100$$

Field Methods

Although practitioners may have access to university- or hospital-based laboratories, the body composition of athletes is typically assessed with field methods such anthropometry and bioelectric impedance analysis. Measurements of skinfold thicknesses and body circumferences, although dependent on technician skill, are relatively easy to make and can provide useful information about subcutaneous fatness and fat distribution. Serial measures of skinfold thicknesses and body circumferences plotted on a somatogram (Heyward & Wagner, 2004) give an anthropometric profile that is useful for monitoring changes over various training stages. Used in this way, the anthropometric measures need not be converted to estimates of FFM and percent fat, thereby avoiding the potentially erroneous assumptions that underlie such conversions. Often, however, there is a desire to use anthropometric data to estimate percent fat and FFM. Sport-specific equations and generalized equations that are often applied to athletes have been developed and cross-validated using hydrodensitometry and DXA. Unfortunately, athlete-specific equations derived from multi-component reference methods are generally not available.

Body Mass Index (BMI)

The body mass index (in units of kg/m^2), calculated from body weight (kg) and height (m), has become a common index of overweight and obesity. In athletes, who tend to have greater muscle mass per unit height than do non-athletes, there is significant potential for misclassification, and more direct estimates of composition are preferred. Some studies suggest that weight and height alone provide a reasonable estimate of body composition in athletic populations (Heyward & Wagner, 2004), especially in homogeneously lean groups in which FFM accounts for much of body weight. In general, however, the errors associated with estimating body composition from BMI are larger than desirable, and estimating composition from height and weight is not recommended.

Skinfold Equations

Some research suggests that population-specific and generalized skinfold equations developed for women and men can be used to accurately estimate the body density of athletes. Many potentially useful equations have been reviewed by Heyward and Wagner (2004), and recommended equations are given in the supplement accompanying the present article. Skinfold equations that include three or more skinfold sites are more generalizable than those that use only one or two sites because including more sites helps to account for differences in patterns of fat distribution throughout the body.

Once body density has been estimated with skinfold equations, percent fat and FFM can be calculated using a 2C equation. An equation based on an appropriate reference body must be used to avoid introducing model error that adds to the error associated with the estimation of body density. Reference bodies designed specifically for various athletic groups are not well developed, although there has been some attempt to define FFM density for resistance-trained athletes (Modlesky et al., 1996) and different races (Schutte et al., 1984). When a population-specific estimate is not available, it may be useful to substitute a race-appropriate estimate or an estimate from an athlete group with similar training requirements.

Bioelectrical Impedance Analysis (BIA)

Estimation of body composition from BIA is based on the electrical properties of the FFM, with its large water content relative to other compartments, and basic assumptions about the geometric shape of the body. The traditional BIA method involves measurement of whole-body resistance using a wrist-to-ankle surface electrode configuration at a single frequency. Recent technological advances and theoretical modeling have led to a number of variations in the traditional method (Chumlea & Sun, 2005; Heyward & Wagner, 2004). These newer instruments use sophisticated models to assess segmental body composition and fluid subcompartments, thereby improving the clinical usefulness of BIA. In healthy individuals, the traditional approach gives valid estimates of TBW and FFM and there is little improvement with the use of more sophisticated methods. In clinical populations with abnormal fluid distribution, other BIA methods such as multiple frequency analyzers may give more accurate estimates of fluid compartments, cell mass, and FFM. User-friendly BIA analyzers have been developed for home use and individual monitoring. They use upper-body and lower-body impedance measures to estimate body composition. Systematic investigation of these devices in athletes has not been undertaken and most of these instruments do not have athlete-specific equations. Often, the actual impedance data are not provided, and one must rely on body-composition formulas programmed into the instrument. . Reported errors with upper and lower-body analyzers have generally been similar to or greater than those associated with whole-body analyzers (Heyward & Wagner, 2004).

The accuracy of the BIA method is highly dependant on control of factors that may increase measurement errors. A major source of error is intra-individual variability in resistance due to factors that alter hydration status. Factors such as eating, drinking, dehydration, and exercising alter hydration and should be controlled, and the same instrument should be used to monitor changes in composition over time. Typically, manufacturer equations are proprietary, and it is difficult to determine their utility. Ideally, BIA prediction equations should be selected based on the individual's age, gender, ethnicity, physical activity level (or athletic group) and level of body fatness. With an appropriate equation, the prediction accuracy of the BIA method is similar to that of the skinfold method. BIA may be preferable in some settings because it does not require a high degree of technician skill and is useful in fatter individuals in whom measurement of skinfolds is difficult. However, unlike skinfolds, BIA does not give information about the pattern of fat distribution.

Equation Selection

Prediction equations are either population-specific or general. Population-specific equations are derived for use in a specific population (e.g., adolescent females, wrestlers, runners). Thus, they often systematically under-or overestimate body composition if applied to individuals from other populations. In contrast, generalized equations are developed from diverse heterogeneous samples, and they account for multiple sites or anthropometric characteristics and for differences in age, sex, race/ethnicity, and other characteristics by including these variables as predictors in the equation. Unfortunately, systematic development and testing of equations for athletes has not been undertaken. Although a number of athlete-specific equations exist (Heyward & Wagner, 2004), few have been cross-validated. Some general equations are suitable for use in athletes (see recommended equations in the supplement accompanying this article). When an equation in a specific athletic group is not available, an equation developed for a group with similar body morphology and training requirements may be acceptable.

To develop prediction equations, it is necessary to select a representative sample of the specific population. The predictor variables (e.g., height and weight, age, race, skinfolds, or BIA) and the criterion estimates of body composition (percent fat or FFM) are measured in the same subjects, and the equation is developed using appropriate statistical methods. The usefulness of the equation depends on the strength of association among the variables and the accuracy with which the dependent variable, e.g., percent fat or FFM, is estimated. Useful equations give estimates of percent fat or FFM that are highly correlated ($R \geq 0.8$) with criterion measurements. Moreover, the means and standard deviations of the estimated and criterion scores should be nearly equal, and the standard error of estimate (SEE) for predicting the criterion measurements from the estimated values should be approximately $\leq$ 2.5-3.5% for percent fat and $\leq$ 2.5-3.5 kg for FFM.

To select the most appropriate equation, the following questions should be considered (Going & Davis, 2001; Heyward & Wagner, 2004):

1. ***To whom does the equation apply?*** The answer lies in a careful examination of the characteristics of the population used to derive the equation. Factors such as age, race, sex, physical activity levels, and amount of body fat must be examined carefully. Unless the equation has been shown to be generalizable to other groups, it should not be applied to groups with different characteristics.
2. ***Was an appropriate reference method for body composition used to develop the equation?*** Error in the reference method is propagated and contributes to the total error in the equation. Multiple-component models require fewer assumptions and give more accurate reference measurements than methods based on the 2C model. Equations derived from reference measurements based on 3C and 4C models should be used in populations for whom the assumptions underlying the 2C model are not valid. Alternatively, population-specific conversion formulas should be used to derive reference estimates of FFM and percent fat.
3. ***Was a representative sample of the population studied?*** Large, randomly selected samples (100-400 subjects) are needed to ensure that the sample is representative. If random sampling is not possible and convenience samples are used, the procedure is acceptable as long as a sufficient number of subjects is studied. With an appropriate sample size, a more stable, valid, and generally applicable equation will be derived.
4. ***How were the predictor variables measured?*** When any equation is applied, it is important that the predictor variables be measured exactly as the investigators who developed the equation measured them. Although it is recommended that standard procedures and sites be used, this is not always done, and errors are larger if the original procedures are not followed (Roche et al., 1996).
5. ***Was the equation cross-validated in another sample of the population?*** Because of investigator- and laboratory-specific procedural differences, equations that sometimes give accurate validation results may not be accurate when used in a different laboratory or by a different investigator, and the equation should be tested in other samples of the same population. Sometimes this is done by dividing the original sample into validation and cross-validation groups and testing in both groups. Although this approach is reasonable, it does not demonstrate whether the equation is reliable outside of the laboratory where it was developed. It is preferable to test the equation in samples in a different laboratory to determine its validity and generality. In addition, cross-validation studies in different populations are necessary to determine the accuracy in different groups.
6. ***Does the equation give accurate estimates of composition?*** In validation studies, the multiple correlation coefficient between the dependent (predicted or estimated score) and independent (predictors) variables should be greater than 0.80, and SEEs should range from 2.5-3.5% when estimating percent fat and 1.8-3.0 kg when estimating FFM. In addition, the prediction equation should yield comparable averages and distribution (range and standard deviation) of scores, and the total error should not be much larger than the SEE (Lohman, 1992).

The task of equation selection has been made easier by Heyward and colleagues (1996; 2004), who have thoroughly reviewed the literature and suggested equations based on cross-validation results and their proven utility over time. Based on their findings, they have developed "decision trees" for selecting the most useful equations. Although not all equations they recommend have been formally cross-validated according to the criteria above, they are considered the most useful to-date. Skinfold equations that include multiple sites and a quadratic component are often suitable for use in a variety of subject populations.

SUMMARY

Regular assessment of body composition is vital to following the growth and development of child athletes and for monitoring the health, nutritional status, and training status of athletes of all ages. Laboratory methods provide more accurate assessments than do field methods but are often not practical. Traditional two-component (2C) models are often limited by invalid assumptions, and the resulting errors are passed on to field methods that rely on those models. Population-specific 2C equations that are based on appropriate reference bodies are more accurate and can be used when multiple component models are not feasible. However, ideally, field methods should be validated and cross-validated against multiple (3C and 4C) component models. Systematic development of athlete-specific equations for athletes has not been undertaken, but some generalized equations have proved useful in athletes, and some population-specific equations have been reported. The accompanying "equation finders" can be used to find prediction equations that have proved useful to date. New equations and methods are regularly reported. To determine their utility, it is important to understand the methods and models against which they are validated and cross-validated.

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Sports Science Exchange 101

VOLUME 19 (2006) ■ Number 2

S U P P L E M E N T

CHOOSING THE BEST EQUATION FOR ESTIMATING BODY COMPOSITION

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Estimating the body composition of athletes and others is important for monitoring the effects on lean and fat tissue of diet changes and/or exercise training. Although laboratory techniques such as dual-energy X-ray absorptiometry (DXA), underwater weighing, and isotope dilution to determine total body water should be used to determine body composition when feasible, acceptable estimates of body fat and lean tissue can be obtained from more practical and relatively simple methods such as measuring skinfold thicknesses and bioelectrical impedance analysis (BIA). However, each of these latter techniques relies on special equations to convert the data on skinfold thicknesses or bioelectrical impedance into percent body fat and lean tissue. If the equations have not been validated with a population of individuals similar to the subjects being tested in age, race, ethnic background, gender, maturity, and exercise training, large errors in estimating fat and lean tissue can occur.

This supplement provides guidance on choosing the best equations for estimating body composition for a variety of subject populations. Unfortunately, there are relatively few validation studies for different types of athletes, so even the equations suggested may not be ideal for all athletes. Still, it is important to choose the equations validated with populations as similar as possible to the subjects undergoing testing.

Once the number of the presumably best equation is located in Table S1, "The Equation Finder," locate the equation in Table S2 if the skinfold technique is to be used or in Table S3 if bioelectrical impedance is to be used to estimate body composition.

TABLE S1. *The Equation Finder*

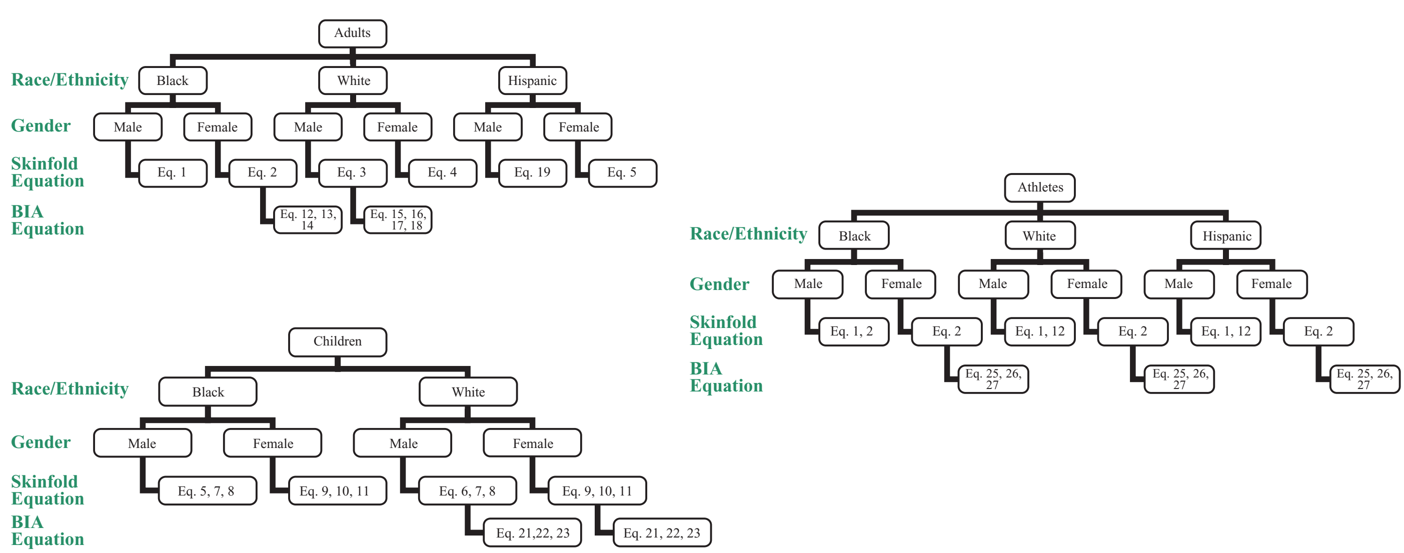

TABLE S2. *Skinfold Prediction Equations*

ETHNICITY		GENDER	AGE	EQUATION	REFERENCE
1	Black	Males	18–61	Db (g/cc) = 1.1120 – 0.00043499 (∑ 7SKF chest, abdomen, thigh, triceps, subscapular, suprailiac, midaxillary) + 0.00000055 $(\sum 7SKF)^2$ – 0.00028826 (age in years)	Jackson & Pollock, 1978
2	Black	Females	18–55	Db (g/cc) = 1.0970 – 0.00046971 (∑ 7SKF chest, abdomen, thigh, triceps, subscapular, suprailiac, midaxillary) + 0.00000056 $(\sum 7SKF)^2$ – 0.00012828 (age in years)	Jackson et al., 1980
3	White	Males	18–61	Db (g/cc) = 1.109380 – 0.0008267 (∑ 3SKF chest, abdomen, thigh) + 0.0000016 $(\sum 3SKF)^2$ – 0.0002574 (age in years)	Jackson & Pollock, 1978
4	White	Females	18–55	Db (g/cc) = 1.0994921 – 0.0009929 (∑ 3SKF triceps, suprailiac, thigh) + 0.0000023 $(\sum 3SKF)^2$ – 0.0001392 (age in years)	Jackson et al., 1980
5	Hispanic	Females	20–40	Db (g/cc) = 1.0970 – 0.00046971 (∑ 7SKF chest, abdomen, thigh, triceps, subscapular, suprailiac, midaxillary) + 0.00000056 $(\sum 7SKF)^2$ – 0.00012828 (age in years)	Jackson et al., 1980
6	Black & White	Males	≤ 18	%BF = 0.735 (∑ 2SKF triceps, calf) + 1.0	Slaughter et al., 1988
7	Black & White	Males (∑ 2SKF > 35 mm)	≤ 18	%BF = 0.783 (∑ 2SKF triceps, subscapular) + 1.6	Slaughter et al., 1988
8	Black & White	Males (∑ 2SKF < 35 mm)	≤ 18	%BF = 1.21 (∑ 2SKF triceps, subscapular) – 0.008 $(\sum 2SKF)^2$ + I*	Slaughter et al., 1988
9	Black & White	Females	≤ 18	%BF = 0.610 (∑ 2SKF triceps, calf) + 5.1	Slaughter et al., 1988
10	Black & White	Females (∑ 2SKF > 35 mm)	≤ 18	%BF = 0.546(∑ 2SKF triceps, subscapular) + 9.7	Slaughter et al., 1988
11	Black & White	Females (∑ 2SKF < 35 mm)	≤ 18	%BF = 1.33 (∑ 2SKF triceps, subscapular) – 0.013 $(\sum 2SKF)^2$ + 2.5	Slaughter et al., 1988
12	Black, White, Hispanic	Males	14–19	Db (g/cc) = 1.0973 – 0.000815 (∑ 3SKF triceps, subscapular, abdomen) + 0.00000084 $(\sum 3SKF)^2$ – 0.0001392 (age in years)	Lohman, 1981; Thorland et al., 1991

KEY

Db = Body density

SKF = Skinfolds

BF = Body fat

* = Use the one of the following values for the intercept (I) according to maturation and ethnicity of the subjects:

AGE	BLACK	WHITE
Prepubescent	-3.2	-1.7
Pubescent	-5.2	-3.4
Postpubescent	-6.8	-5.5

TABLE S3. *Bioelectrical Impedance Analysis (BIA) Prediction Equations*

ETHNICITY		GENDER	AGE	EQUATION	REFERENCE
13	White	Males	18–29	FFM (kg) = 0.485 (HT^2/R) + 0.338 (BW) + 5.32	Lohman, 1992
14	White	Males (<20% BF)	17–62	FFM (kg) = 0.00066360 (HT^2) – 0.02117 (R)+ 0.62854 (BW) – 0.12380 (age) + 9.33285	Segal et al., 1988
15	White	Males (≥20% BF)	17–62	FFM (kg) = 0.00088580 (HT^2) - 0.02999 (R) + 0.42688 (BW) – 0.07002 (age) + 14.52435	Segal et al., 1988
16	White	Females	18–29	FFM (kg) = 0.476 (HT^2/R) + 0.295 (BW) + 5.49	Lohman, 1992
17	White	Females	30–49	FFM (kg) = 0.493 (HT^2/R) + 0.141 (BW) + 11.59	Lohman, 1992
18	White	Females	50–70	FFM (kg) = 0.474 (HT^2/R) + 0.180 (BW) + 7.3	Lohman, 1992
19	White	Females	22–74	FFM (kg) = 0.00151 (HT^2/R) - 0.0344 (R) (BW) + 0.140 (BW) – 0.158 (age) + 20.387	Gray et al., 1989
20	Hispanic	Males	19–59	FFM (kg) = 13.74 + 0.34 (HT^2/R) + 0.33 (BW) + 0.14 (age) + 6.18	Rising et al., 1991
21	Hispanic	Females	20–40	FFM (kg) = 0.00151 (HT^2) - 0.0344 (R) + 0.140 (BW) – 0.158 (age) + 20.387	Gray et al., 1989
22	White	Males & Females	6–10	TBW (L) = 0.593(HT^2/R) + 0.065 (BW) + 0.04	Kushner, 1992
23	White	Males & Females	10–19	FFM (kg) = 0.61 (HT^2/R) + 0.25 (BW) + 1.31	Houtkooper et al., 1992
24	White	Males & Females	8–15	FFM (kg) = 0.62 (HT^2/R) + 0.21 (BW) + 0.10 $(\sum_c)$ + 4.2	Lohman, 1992
25	Black, White, Hispanic	Female Athletes	18–27	FFM (kg) = 0.282 (HT) + 0.415 (BW) – 0.037 (R) + 0.096 $(\sum_c)$ – 9.734	Fornetti et al., 1999
26	Black, White, Hispanic	Female Distance Runners	16–37	%BF = 7.32 – 0.572 (HT^2/R) + 0.664(BW)	Hannan et al., 1993
27	Black, White, Hispanic	Female Gymnasts	13–17	FFM (kg) = 0.52 (HT^2/R) + 0.23 (BW) + 7.49	Van Loan et al., 1990

Adapted from V.H. Heyward and L.M. Stolarczyk, *Applied Body Composition Assessment.* Champaign IL: Human Kinetics, 1996, pp.173-185, and V.H. Heyward and D.R. Wagner, *Applied Body Composition Assessment,* 2nd edition. Champaign, IL: Human Kinetics, 2004, pp.159-173.

KEY

Age (years)

FFM = Fat free mass

HT = height (cm)

BW = body weight (kg)

R = resistance (Ω)

$\sum_c$ = reactance (Ω)

TBW = total body water (L)

To convert TBW to FFM, use the following hydration constants:

BOYS

5–6 yr: FFM (kg) = TBW/0.77

7–8 yr: FFM (kg) = TBW/0.768

9–10 yr: FFM (kg) = TBW/0.762

GIRLS

5–6 yr: FFM (kg) = TBW/0.78

7–8 yr: FFM (kg) = TBW/0.776

9–10 yr: FFM (kg) = TBW/0.77

SUGGESTED ADDITIONAL RESOURCES

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