Body Composition Measurement: A Review of Hydrodensitometry, Anthropometry, and Impedance Methods

DAVID BRODIE, PHD,* VICKI MOSCRIP, MSC, HDCR,† AND ROB HUTCHEON, MSC‡

From the *Department of Movement Science and Physical Education; the †Department of Medical Imaging; and the ‡Department of Medicine, University of Liverpool, Liverpool, United Kingdom

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ABSTRACT

Human body composition is an expression of genetic and nutritional factors. It can change as a consequence of exogenous influences such as training, disease, or diet and is therefore of particular interest to nutrition professionals. Two of the main methods of estimating body composition in this review (hydrodensitometry and anthropometry) have been in use for decades, but the third method (bioelectrical impedance) is more recent. The procedure, theoretical basis, assumptions, standard error of estimates, and comparisons with other techniques are presented for each of the three methods. References to general and specific populations are presented that illustrate regression equations for different ages, ethnic groups, and gender. The advantages and disadvantages of the three methods are reviewed with reference made to the alternative compartment models. Other methods (DEXA, infrared interactance) are briefly reviewed.

Key words: body composition, hydrodensitometry, anthropometry, electrical impedance, DEXA, infrared interactance

INTRODUCTION

Body composition is of interest to nutritionists because of the impact that nutritional status, specific diet, exercise, disease, and genetics can have on the major components of the human body. These components can be considered at atomic, molecular, cellular, tissue-system, and whole body levels. As direct measurement in vivo is not possible in humans, a series of indirect estimates of body constituents have been developed. Most interest has been directed at the two-compartment model, which divides the body into fat mass and fat-free mass (FFM), largely because fat proportion is a major issue in health. However, with the advent of chemical and isotope-based methods, it has become possible to subdivide the FFM into water, mineral, and protein constituents.1 Alternatively, the use of imaging methods has enabled a different subdivision of body compartments into fat, muscle, bone, and other soft tissue.2

A combination of magnetic resonance imaging (MRI) and anatomic dissection has produced serial transverse images every 1 mm through the length of the human body. Such images are internationally available on the Internet,3 therefore providing anatomy students, teachers, and body composition scientists with a database of unparalleled precision. Such detailed information is currently only available on one male and one female subject and the cost of producing such material is, for most scientists, prohibitive. The issues of cost, availability, access, validity, portability, ethical acceptability, and intervention need to be considered in body composition research. This review will make reference to a range of methods but will concentrate on three procedures that have merit either in an epidemiological context (anthropometry and electrical impedance) or as a common criterion method (hydrodensitometry). As each of these methods is used to estimate fat mass and FFM components only, it is important to define these terms, especially as fat and lipid are often used interchangeably. Fat is the triacylglycerol family of chemical compounds, whereas lipid is a more general term including other compounds such as glycerophosphatides and sphingolipids.4 In the chemically based two-component model, the fat compartment includes all lipids (ether-extractable) with the FFM comprising all the remaining constituents.

HYDRODENSITOMETRY

Hydrodensitometry or underwater weighing is essentially a method to measure body volume. It is regarded as the most reliable of available techniques for the estimation of body...
density and alternative procedures are often judged and validated against this procedure. Accepting the assumptions stated later, it is recognized as a valid method of percentage body fat estimation. It usually involves the use of a specially constructed tank in which the subject is seated on a suspended chair or frame. Because the subject is required to exhale when submerged it requires a high degree of water confidence. This excludes approximately one-third of middle-aged women and if the top of the tank is not near floor level it is extremely difficult for excessively obese, pregnant, elderly, or disabled subjects. Archimedes’ principle is applied by comparing the mass of a subject in air and under water. This involves a sensitive and continuous measurement of underwater mass for which a single or multiple load cell configuration linked to a computer is ideal, as the value will fluctuate due to movement and level of exhalation. Total expiration is necessary, which takes several trials, and account is taken of the remaining residual volume, water temperature, and an estimate of gut volume. For those unable to access an appropriate tank, it is possible to construct a suitable frame within a swimming pool. Autopsy scales have been used as an alternative to electronic weighing methods, but the observer has to make rapid judgments as the scale fluctuates around a mean value. The technique has been described fully elsewhere.

Practical considerations for this method include when and how to measure residual volume, what allowance to make for the volume of gas in the gut, and the effect of pretest nutrition and exercise. The residual gas volume accounts for about 2% of the submerged volume, and the accuracy of this value becomes critical to the calculation, where a very small change of density produces a much larger change in the predicted percentage of body fat. There is an appreciable day-to-day biological variation of residual volume in any given subject and this can change the estimated body fat content by as much as 1%. Considerable controversy occurs over whether or not to measure the residual volume while in the tank or separately. Submerging the body has been shown by some authors to increase residual volume and by others to decrease the residual volume. Immersion was also found by several authors to make no difference in residual volume. The actual method depends largely on the facilities available and includes nitrogen washout and oxygen dilution. If residual volume cannot be measured by such direct methods Mayhew et al. (personal communication) recommend estimates from 24% of vital capacity or from the anthropometric method of Polgar and Promadhat. Garrow et al. suggested that residual volume could be measured by combining a body water displacement method with an air displacement technique for the head using a plethysmograph. This method eliminates the need for total submersion of the subject. Although the equipment is more complex than that required for hydrodensitometry, it does not require the additional equipment for measuring residual volume. The procedure requires minimal subject cooperation due to the fact that the patient stands in water to the neck level and the volume of air in the lungs and gastrointestinal (GI) tract is measured by observing the pressure changes produced by a pump of known stroke volume. Standard deviations of ± 0.3 kg were reported when replicate measures were made by this method.

The volume of gas in the intestine is usually included in the calculation as being 100 mL but should be increased for large adults and decreased for children. Measurements are most reproducible if taken in the fasting state. The prior consumption of food can change the estimated body fat content by up to 1%, and recent ingestion of carbonated drinks will also change the intestinal estimate. When converted into body fat estimation this can increase the error by 0.5%. Food consumption has doubled this effect on body fat estimation. Changes will similarly be caused by hyperhydration and dehydration. These effects will become relevant if immediate previous activity caused fluid loss or when high fluid retention occurs during premenstruation. As a minimum, testing should be undertaken several hours after a meal, with the subject defecating and urinating immediately prior to measurement.

Once body volume is established, whole body density is estimated from the mass in air (Mₐ, kg) and the weight while submerged (Wₛ, kg), with allowances being made for residual gas volume in the lungs (Vᵣ) and GI gas (100 mL). Density is then calculated using the following equation:

\[
Dₖ = \frac{Mₐ}{(Wₛ - Wₛ/Dₖ) - Vᵣ + 0.1V}
\]

where Dₖ is the density of water at the temperature of submersion.

The calculation of percentage body fat from body density measures is based on the assumption that the body is composed of two homogenous components—fat and fat-free tissue—each having consistent densities. The main advantage of the two-component model is that it allows measurement of the only constituent of the fat-free body from which relative fat and fat-free body content can be estimated. Where certain assumptions hold, this approach offers a practical way to establish fat and fat-free body content. The main limitations of the two-component model approach are that separate estimates of various components of the body such as muscle and bone are not made. Individual prediction errors of fat content can be substantial, and estimates of body composition in populations other than young adult males may underestimate or overestimate fat content. The use of the two-component model has led to a lack of research in the development of new methods and limited the potential usefulness of various laboratory methods in estimating body composition in different populations. There has been a move away from the two-component model toward three-or four-component models with the aim of improving the prediction of body fat from body density. It is therefore necessary that new methods for accurate estimation of fat, fat-free body, and muscle and bone content are continually developed and evaluated.

Body density, however, is not the preferred value for nutritionists and other health professionals working with body composition. Percentage body fat is a measure to which more people can relate and if the density of fat and lean were consistently 0.90 and 1.1 g cm⁻³, respectively, the conversion would be relatively simple. The average value of studies that measured these densities was 0.9168 g cm⁻³ for fat and 1.0997 g cm⁻³ for lean tissue. Even this fails to account for more individual variations such as the potential for athletes to have denser bone and muscle, osteoporosis in the elderly, and different bone mineral content in preadolescents.

A variety of equations are available to estimate fat from body density. The most commonly used of these are those of Brozek et al.

\[
\% \text{ body fat} = \left( \frac{4.57}{D} - 4.142 \right) \times 100
\]

and Siri

\[
\% \text{ body fat} = \left( \frac{4.95}{D} - 4.5 \right) \times 100
\]

The equation developed by Brozek et al. for the conversion of body density to body fat was based on the chemical composition of reference man. The equation was developed from cadaver chemical analysis and was proposed to be used in a young, nonathletic, adult male population. Although the original equation...
has not been cross validated, it has been used in many research studies. Since its development, this equation has subsequently and frequently been applied to various populations including children, the elderly, women, athletes, and various racial groups. Bones are less dense in children, women, and older subjects of both sexes, which leads to an overestimation of body fat. Lohman\textsuperscript{47} discussed the need to limit the use of the Brozek equation and replace the concept of reference man with population specific reference bodies leading to additional development of population specific equations. This would enable more accurate estimates of fat content from body density in these populations.

Body density is converted to a corresponding percentage of body fat based on the assumption that the body is composed of two homogenous compartments—fat and fat-free tissue—each with a constant density. However, in reality, body fat comprises a complex mixture of glyc erides, sterols, phospholipids, and glycolipids. Some of these constituents are more labile than others and, therefore, the average density of fat varies between individuals and also within a given individual at different times. These complications are usually ignored in densitometric calculations.\textsuperscript{9}

As long as the assumptions implicit in these calculations are recognized then nutritionists could present body composition values in the form of percentage fat. However, if relative values are needed it seems logical to retain the body composition data from hydrostatic weighing as densities.

The validity of the underwater weighing technique has been extensively reviewed, including the biological and technical sources of error.\textsuperscript{48–51} The several sources of biological variation can be compounded by technical errors in the body density measurements. An estimate of the expected degree of association between fat content and density can be made by combining the technical and biological sources of variation. Biological error associated with estimating the percentage fat from body density is associated with the variability in the density and composition of the fat-free body. This error must then be added to the error associated with measuring or predicting body density to give the total error in estimation of the true percentage fat. The error associated with measuring or estimating body density is only part of the problem and the accuracy in determining body fat is ultimately limited by biological variation in the fat-free body. Lohman\textsuperscript{42} suggested that hydrostatic weighing techniques, when used to assess the percentage of body fat, may have a standard error of estimate (SEE) as high as 2.7%, primarily because of variations in the fat-free density within specific populations.

The main sources of technical errors that have been identified in measurement of body density include variation in residual lung volume, which appears to contribute the greatest source of error, and smaller amounts of error from combined factors of variation in body mass, underwater weighing, and measurement of the water temperature.\textsuperscript{48} The hydrostatic method remains a somewhat fallible criterion method. Signs of this fallibility have been attributed to the fact that simple indices of obesity such as total body mass and circumference measurements have shown closer correlations with skinfold measurements than percentage body fat estimated by the hydrostatic technique.\textsuperscript{52} The technical and biological assumptions inherent in this method clearly indicate that they are most likely to be violated at the extremes of fat percentages. Therefore, this method is most appropriate for segments of the population that do not exhibit the extremes, especially the excessively obese. Roche et al.\textsuperscript{53} provide a review on the practicalities of estimating body volume by underwater weighing.

The technical concerns of the hydrostatic weighing procedure, not the least water confidence, have been reduced by alternative body volume measurement such as acoustic plethysmography and air displacement. Acoustic plethysmography\textsuperscript{54–56} has been used predominantly in pediatric research. Air displacement has also been used in infants,\textsuperscript{57} babies,\textsuperscript{58} and adults.\textsuperscript{59–61} The procedure described by Gnaedinger et al.\textsuperscript{59} was abandoned because of high sources of error from lack of control over temperature, pressure, and relative humidity in the enclosed chamber. Gundlach and Visscher\textsuperscript{61} controlled isothermal conditions but in doing so made the procedure impractical for most subjects. More recently,\textsuperscript{62} a method has been described that has overcome most of these problems. The BOD POD Body Composition System, which uses the relationship between pressure and volume to derive the body volume of a subject seated in a fiberglass chamber, is described in detail for inanimate objects.\textsuperscript{62} It produced an average coefficient of variation (CV) of 0.026% over 2 d, with a SEE\textsuperscript{62} of 0.004 L for volumes in the range 25–100 L. This new air displacement plethysmograph was compared with hydrostatic weighing in 68 adults\textsuperscript{63} and was shown to be highly reliable and valid as a method of estimating percentage body fat. The mean difference in percentage fat (BOD POD = hydrostatic weighing) was −0.3 ± 0.2 (SEM). An advantage of this method of determining body composition is that it is quick and relatively simple to operate, and able to measure populations to which hydrostatic weighing is not appropriate such as the obese, elderly, and disabled.

Hydrodensitometry has been the experimental basis for the two-component model of body composition assessment. Accurate estimates of percentage body fat can be expected provided the assumptions of proportions and densities are satisfied.\textsuperscript{64} In subjects whose fat-free body density differs from the assumed value of 1.10 g/mL, then the two-component model will be less satisfactory. The use of isotope dilution to measure the water compartment, dual-energy x-ray absorptiometry to measure mineral content and neutron activation analysis for protein has permitted the quantification of the subdivisions of the fat-free component. This has permitted the density of subgroups such as different races, levels of body fatness, gender, and physical activity levels to be estimated more accurately, largely as a result of the varying proportions of mineral and water. Multicomponent models not only refer to chemical constituents, but can also be used to describe anatomical models, molecular models, and fluid metabolic models. A more detailed discussion of multicomponent models is found in Heyward and Stolarczyk\textsuperscript{65} and Heymsfield et al.\textsuperscript{66}

ANTHROPOMETRY

Anthropometric techniques for the estimation of body composition utilize measurements of skinfold thicknesses at various sites, bone dimensions, and limb circumferences. These are used in equations to predict percent body density, converted to body fat using the equations shown above. The use of skinfolds to predict body fat has become one of the most common laboratory and field anthropometric techniques in body composition and nutritional status assessment.\textsuperscript{57} There have been numerous regression equations developed that use some combination of anthropometric measures as predictors of body density.\textsuperscript{58} Most have used skinfold measures or some combination of skinfold and circumferences. Few have used circumferences only.

The main purpose of skinfold measurements is to estimate general fatness and the distribution of subcutaneous adipose tissue. The extent that the subcutaneous adipose layer reflects total body fat varies with age, gender, and population. This method operates on the assumption that subcutaneous adipose tissue is representative of the total body fat. This is not an unreasonable assumption but there will be individual differences which will invalidate the established regression equations. As the method relies substantially on a limited number of skinfold sites, any differences in adipose tissue distribution from the original validated equation will impact on the prediction. Therefore, any
observed variation of adipose tissue distribution from the population originally used in the production of the regression equation should necessitate an alternative equation or method being used.

The accessibility of the subcutaneous fat layer and the noninvasive nature of skinfold measurement has led to many skinfold applications and derivations of formulae. These in turn have led to well over 1000 published articles that have dealt directly or indirectly with skinfold measurements. Numerous equations for the prediction of body composition have been developed, using skinfold measurements as part of the equation. There have been well over 100 equations developed that use skinfold measurements and other anthropometric dimensions in various populations ranging from athletic to sedentary and from children to the elderly.69–75 Most of these formulae have led to estimates of body density, although some studies have attempted a direct prediction of body fat.71–73,76 The problems associated in choosing an appropriate equation have been previously well documented. They have included excessive reliance on stepwise regression analysis, failure to consider the possible curvilinear relationship between total body fat and skinfold data, and failure to account for the effect of age on body fat distribution.73,74

Many of the skinfold prediction formulae developed are specific to a particular sample of the population, and are also dependent upon the age, sex, nutritional status, genetic background, and specialist activities.77–79

The most widely used equations are probably those of Durnin and Womersley,78 who tested various combinations of skinfolds to produce the following formulae for body density. These equations assumed a logarithmic relationship between obesity and the sum of bicep, tricep, suprailiac, and subscapular skinfolds. The equations met several of the earlier criticisms with regard to a fewer number of variables relative to the number of subjects; the intercorrelation of the individual skinfold reading and the curvilinearity of the relationship between density and subcutaneous fat.

Males 20–69 years

\[ D = 1.1765 - 0.0744(\log_{10} \sum S) \]

Women 20–69 years

\[ D = 1.5675 - 0.0717(\log_{10} \sum S) \]

where \( S \) is the sum of the tricep, bicep, suprailiac, and subscapular skinfolds. The equation assumes a logarithmic relationship between this sum of skinfolds and adiposity.

As with many of the previous skinfold equations the variable predicted by those of Durnin and Womersley73 is the body density rather than the percentage body fat. It is, therefore, possible for errors to occur in the calculation of predicted density and its subsequent interpretation as a fat percentage. This error of estimation has been reported to be ±3.5% in women and ±5% in men relative to the hydrostatic criterion method.9 Shephard9 also reported the importance of using age-specific equations because of the slope of the relationship changing with age.

The equations of Durnin and Womersley73 and those of Jackson and Pollock74 are said to be “generalized” because their development and application are from a wide range of ages and fatness. Durnin and Womersley73 were the first to consider the development of equations that could be used with more varied populations. They published equations with a common slope but adjusted the intercept to account for aging. Jackson and Pollock74 published generalized equations for males and females. They extended the concepts of Durnin and Womersley73 and additionally overcame some of the limitations of population-specific equations. The equations of Jackson and Pollock74 added age into the prediction equation to account for the potential changes in the ratio of internal to external fat and also bone density. In 1981, Lohman80 extensively reviewed the relationship between skinfolds, body density, and fatness. He agreed with the need for such generalized equations but also stated the need for their cross-validation when applied to specialized samples. Lohman80 formulated seven principles of cross-validation analysis including the use of comparable mean values and similar standard deviations for predicted and measured densities. It was also suggested that SEE should be reported rather than correlation coefficients because of the fact that correlation coefficients are apt to be affected by intersample variability of fatness whereas SEE is not. The other principles relate to the problems of nonlinearity of the relationship between skinfolds and body density and the need for large samples to cross-validate.

Differences in procedures and equipment selection may also contribute to systematic errors in cross-validation studies. Lohman et al.47 showed that different caliper types may affect estimates. This problem was also addressed by Sinning and Wilson,76 who agreed with Lohman for the need to standardize equipment. Sinning and Wilson76 also evaluated the use of generalized equations for college-aged women. They showed that each equation had to be validated and evaluated on its own merits. In 1984, Thorland et al.80 cross validated general curvilinear models as well as selected linear models. They also found, as did Sinning and Wilson,76 that different curvilinear equations were not equally effective in estimating body density while some linear models were fairly accurate. These studies have all identified the need for cross-validation of such equations prior to their use on specialized samples.

Several authors also carried out log transformation of their skinfold data.72,81 The main reasons for these transformations were the skewing of the data, measurement errors being greater for thicker skinfolds than for thin skinfolds, and experimentally skinfold measurements not linearly related to body density. Nonlinearity differs from sample to sample but is quite significant in the obese. It is, therefore, advisable to introduce such transformations when the population under study includes subjects of extreme body types.

The skinfold caliper has been the most frequent method of measuring subcutaneous adipose tissue thickness. The popularity of this technique is attributed to the many advantages associated with its use. These advantages include the fact that it is a noninvasive and fairly pain-free technique and that the skinfold calipers are inexpensive, easy to maintain, and simple and convenient to use. They may be used in field testing as well as in the laboratory due to their portability and they do not require extensive training for reliable use. In order to ensure validity, proper procedures must be used when obtaining anthropometric measures. Potential sources of measurement error include caliper selection and tester reliability. Tester reliability includes inter- and intrameasurement error as well as the variance associated with selection of skinfold site. A major limitation associated with skinfold measurements is the failure to estimate simultaneously all possible sources of measurement error. Different caliper types and testers have been examined separately and it is these two major sources of error that may interact and give different degrees of error variance for different conditions.82,83

As with most body composition assessment techniques there are limitations associated with skinfold measurements, which may result in inappropriate estimates of the subcutaneous fat thickness and consequently total body fat. These limitations have been well documented and include factors such as the inability to palpate the fat/muscle interface and the difficulty in obtaining interpretable measurements in obese subjects.84–86 Other problems include compression of the fatty tissue during measurement, the inability to control inter- and intrasubject variations and the fact that measurements may only be useful at certain sites.87,88 Interopera-
tor variability as well as the use of different types of calipers has also contributed to errors in measurement of the subcutaneous fat layer.32

With so many prediction equations available it is difficult to know which one to select. A full account of the merits of different equations is provided by Brodie48; the categories include generalized prediction equations, population-specific prediction equations, equations for infants and children, and equations for athletes. The concept of population specific anthropometric regression equations for the estimation of body composition is well known and well documented. Regression formulae show that although they may meet suitable limits for reliability, their applicability to different samples is poor resulting in large errors in estimating individual values. The population specificity of body composition prediction equations can be traced largely to the use of homogenous samples that lack sufficient size. The validity of their findings rests on the assumption that for each population studied the composition of the fat-free body is similar. It is assumed that the density of the fat-free body is the same from one population to another. Womersley et al.89 proposed that some of the differences associated with population-specific equations are due to the differences between males and females in their fat-free body density with females having a lower fat-free density. This led to the overestimation of fat content in females when the fat-free body was taken to be the same as males. Their application is, therefore, limited to specific subsamples. Validity coefficients between predicted and measured body density values range from \( r = 0.72 \) to 0.84 for women and 0.85 to 0.89 for men. Therefore, these formulae are said to be population specific and their use for predictive purposes must be questioned. Recently, generalized equations have been developed. This generalized approach uses large heterogeneous samples and builds a regression model to fit the data. The regression model accounts for age and the nonlinear relationship between skinfolds, fat, and body density. The major problem with population specific equations is their limited generalizability. The main advantage of the generalized approach is that one equation can replace several population-specific equations without a loss of prediction accuracy; they are valid for a greater range of age and body composition than population-specific ones. Most prediction equations are by the very nature of their data collection population-specific but scientific economy can be achieved by using generalized equations.68 They have been cross-validated in males,74 females,90 and in athletes.76,91 It is essential that equations using skinfold data are cross-validated on other samples from the same and other populations to determine its general applicability. It is not possible to be certain that equations developed on one sample will predict body density with the same degree of accuracy when applied to the data of a different sample. The cross-validation process involves testing prediction equations on samples other than the ones used in the initial derivation. This process will provide information regarding the true external validity of the equations. Several studies have compared their prediction equations with other samples and when the populations were similar in age, gender, and fatness, correlations and SEE were found to be similar.92–97

The strongest evidence in cross-validation of generalized equations with regard to their accuracy and validity appears to be provided by the standard error when the equation is cross-validated on the second sample. The closer the SEs are to each other the more accurate and valid is the equation. As well as reporting the SE, the SD of the predicted density value should also be reported. There is a relationship between SEE and the coefficient of determination \( r^2 \). It involves knowing the standard deviation of the criterion variable, which for percent fat is often bigger in women, and the \( r^2 \) between the variables being measured. The SEE is calculated from the formula SEE (e.g., percentage body fat) = SD \( \sqrt{1.0 - r^2} \). Therefore, for males with a mean and standard deviation for percent fat of 20.5 ± 7.1%, and a correlation between variables of 0.58, the SEE is 5.78%. Although SEEs are not provided for each component prediction model, Heyward and Stolarczyk65 make the case strongly for their inclusion to evaluate the relative worth of a regression equation. Jackson et al.90 caution the use of the generalized equations for women over 40 years of age. The validity of generalized regression equations was questioned by Norgan and Ferro-Luzzi,29 as they found a statistically significant difference between five such equations. An alternative strategy was to combine data from other sources90,100–102 into a single regression equation using the sum of triceps, abdomen, and subscapular skinfolds alone.

The development of population specific equations has shown that age and gender are important sources of body density variation.70,103,104 The effect of age has been shown to be significant when individual differences in skinfold fat are statistically controlled.74 Substantial gender differences in body density determined by hydrodensitometry have been reported in the literature.105 Body density differences between men and women have largely been attributed to differences in fat patterning and distribution, internal to external fat ratios, and gender specific essential fat.48,104 Fat patterning refers to differences in the anatomical placement of adipose tissue. The pattern of subcutaneous adipose tissue is known to exhibit large variations between individuals. Garn106 maintained that women carried a greater proportion of subcutaneous fat than men, whereas Dunnin and Womersley73 came to the opposite conclusion. Research on population specific equations has shown that age, gender, and degree of fatness need to be taken into account when estimating body density from anthropometric variables. To provide valid estimates of body composition it is, therefore, essential that equations representative of the study sample are used.

Population-specific prediction equations have been produced for college students,72,92,93,95,103,107,108 soldiers,109,110 male youths,111 boys and girls separately,81,112 obese girls,113 and premenarchal and postmenarchal girls.114 Optimizing the regression equations have included such methods as stepwise regression,115 maximum \( r^2 \) improvement,116 and factor analysis.117,118

Equations have been specially produced for infants and children. Oakley et al.119 showed greater fat thicknesses in newborn females compared with males and concluded that skinfold levels could be a valuable indication of nutritional status in neonates. Triceps and subscapular skinfolds have been shown to be adequate predictors in older boys120 but not in girls. Older children have been studied by various researchers,8,112–123 and Nelson and Nelson124 found that the best predictor of fat was a combination of triceps and subscapular. Two skinfolds were also found to be good estimates of body density in 8–11-y olds122 but methodological and biological variability in children still requires additional examination.

In athletes, regression equations have been established for distance runners,125 volleyball, hockey, synchronized swimming,126 wrestlers,102 baseball, track and field, football, tennis,94 gymnasts,127 swimmers,126,128 male athletes,94,102,125 and female athletes.127–129

An excellent example of the process to select specific regression equations for children, adults, seniors, the obese, anorexics, athletes, and different racial groups is described by Heyward and Stolarczyk.65 For example, not only does it provide a generalized equation for white women aged 18–55 y, but the specific equation for an obese, Japanese, female group can be accessed.130
In addition to the choice of sites and regression equation, the experience of the tester, the type of caliper, and the subject's state of hydration all need to be considered with care. Studies in caliper type have shown that cost is not necessarily a good predictor of performance. The issue of technical characteristics of available skinfold caliper is debated fully in Brodie. For practical purposes, ideally use the same caliper with an established technique after checking the experimenter’s reliability and ensuring comparable test conditions. Even having taken such precautions, the measurement of extremely obese patients should proceed with caution, ensuring that the caliper remains in one position over a well-defined skinfold.

Biological variations include aspects of age, gender, overall fatness, and body size. Older people have a greater total body fat for a given skinfold thickness. Likewise, women have more fat than men as a result of a higher level of sex-specific essential fat. A greater proportion of fat is stored internally as total fatness increases. Katch et al. propose that to compensate for the biological variability caused by body size that both surface area and skinfolds are included in body composition estimation.

Lohman summarized the main sources of error in the prediction of body fat from skinfold data as biological variations in the proportion of subcutaneous fat (±2.5%), biological variations in the distribution of subcutaneous fat (±1.8%) and technical measurement errors (±0.5%). Each source of error is independent and so the total error is ±3.3% fat, slightly better than the figure claimed for densitometry and of similar order to that obtained by many of the more sophisticated indirect methods.

External body measurements such as diameters and circumferences can be used independently to estimate body fat or in combination with skinfolds. One of the earliest workers was Matiegka who used cadaver data to develop a series of equations, using external body measurements, to estimate four body compartments of muscle, skin, and subcutaneous fat, deep fat, and viscera and bone. The masses of skin and subcutaneous tissue, bone and muscle were estimated independently from a series of empirical constants and anthropometric measurements. The other component was determined by subtracting the sum of skin and subcutaneous tissue, bone, and muscle from body mass. The equations developed for estimating the four component models are:

\[
\text{Skin + subcutaneous adipose tissue mass (g)} = 0.065 \Sigma S/6 \times A
\]

where \(\Sigma S\) was the sum of six skinfolds and \(A\) was the body surface area (cm\(^2\)).

\[
\text{Bone mass (g)} = 1.20\,^2 H
\]

where \(\Theta\) is the average diameters of the humoral and femoral condyles, the ankle, and wrist in centimeters and \(H\) is the height in centimeters.

\[
\text{Muscle mass (g)} = 6.5\,^2 H
\]

where \(r\) is the mean of the radii calculated from the maximal circumferences of the arm, forearm, calf and thigh, and \(H\) is the height, all in centimeters.

\[
\text{Deep fat and adipose tissue mass (g)} = 0.206 M
\]

where \(M\) is the body mass in grams. In each case, adipose tissue mass refers to the total mass, not the fat within adipose tissue.

This four component anatomical model has been largely neglected with the increasing popularity of the two component model, which estimates the masses of the fat and fat-free components of the body.

In 1979 Katch et al. suggested that total fat mass could be estimated from skinfold thickness (\(\Sigma S\)), surface area (\(A\)), and a population specific constant (\(K\)), which varied with the sum of 11 girth measurements. The equation developed was:

\[
\text{Fat mass (kg)} = A \times \Sigma S \times K
\]

In 1980 Drinkwater and Ross proposed some changes to the constants that Matiekgka had used. They had found that in an athletic population the formulae of Matiekgka showed errors of 8% in the prediction of total body mass. The main change to the constants by Drinkwater and Ross was in the constant used in the estimation of skin and subcutaneous fat. They used a smaller coefficient of 0.036 rather than Matiekgka’s original 0.065. The changes of the muscle and bone constants were smaller; muscle changed from 6.5 to 6.41 and bone from 1.2 to 1.25. Applying these new constants to their data Drinkwater and Ross predicted total body mass with an accuracy of 0.8%.

Drinkwater et al. reported the results of correlations between Matiekgka’s original anthropometric estimates and the measurements taken from the cadaver evidence of the Brussels study. It was found that the Matiekgka’s formulae when applied to the cadaver data underestimated the mass of skin and subcutaneous tissue by 21.9%, the mass of muscle by an average of 8.5%, and the mass of visceral tissue by 11.6%. The mass of the bone component was overestimated by 24.8%. Based on these findings a new set of coefficients were developed for use in the original formulae. The new co-efficients underestimated the fat content of the females by 15.9% and underestimated the male fat content by 12.3%. It was evident that the results being obtained were only specific to the sample of cadavers which were relatively elderly subjects. Based on these findings, it became clear that there was a need for the development of sex-specific equations. The prediction of body composition from cadaveric skinfold sites produces theoretical concerns when applied to free-living humans. One is that the body temperature of cadavers is lower, which could affect compressibility of skin, and another is the natural dehydration that occurs even in a relatively fresh cadaver. The elastic nature of skin is lost shortly after death and will contribute to skin compression variability.

Assessment of muscle volume has been performed by anthropometric methods such as circumference or girth measurements of the limb. The thigh and arm are two of the sites where these measurements have been obtained in the estimation of changes that have resulted from disuse, orthopaedic dysfunction, and exercise training. Anthropometric techniques have been useful for measuring body and limb volumes but have had a limited use in the determination of component tissue volumes. The main problem that has been identified includes the fact that anthropometric measurements are only indirect indicators of muscle volume, and girth measurements cannot differentiate between components within the circumference. One additional limitation is that any circumference measurement has limited construct validity as it is determined by a combination of bone dimensions, skin thickness, body fat, and muscle volume.

The upper mid-arm circumference has been used in several nutritional studies to assess protein and energy malnutrition. Unfortunately, a single circumference measurement confounds the relative measures of fat, muscle, and bone. In 1973 Gurney and Jelliffe proposed a formula for calculating the upper arm muscle cross-sectional area.

\[
\text{Muscle cross-sectional area} = (C - \pi T)^2 / 4\pi
\]

where \(C\) was the maximum arm circumference over the triceps and \(T\) was the triceps skinfold measurement. The problem with
this formula is that there is no allowance made for the cross-sectional area of the bone contained in the area. In 1982, Heymsfield compared the formula of Gurney and Jelliffe against computed tomography measurements. They found that at the maximum circumference of the triceps the cross-sectional area of bone was 6.5 cm$^2$ in women (17% of the total cross-sectional area) and 10 cm$^2$ in men (18% of the total cross-sectional area).

In 1982 Jelliffe and Jelliffe suggested that muscle volume of the upper arm could be estimated as 20% of the upper arm length multiplied by the muscle cross-sectional area from the formula of Gurney and Jelliffe.

There have been several studies that have used anthropometric principles to calculate regional fat, lean tissue, bone mass, and limb volumes. Segmental zone techniques have been shown to be a valid method of estimating segmental lower limb volumes in adult men and women. These volumes have subsequently been converted to either a limb muscle volume or percentage fat content. The theoretical development of the segmental zone method for estimating total body volume and percentage fat is based on the intrinsic relationship that exists between body volume and body mass. Katch et al. and Weltman and Katch were the first to establish this theoretical model for the prediction of total body volume and, therefore, percentage body and lean body mass. The main reason for the development of this method was to try and overcome the problems that were associated with previous procedures that had been developed to predict body density, percentage fat, and lean body mass. They demonstrated that there was an intrinsic relationship between segmental volume, segmental circumferential measurement, and body mass, showing that it was possible to predict total body volume and percentage fat using circumference measurements, and body mass. Regression equations were found not to be population specific and associated SE of less than ±6% for predicting percentage fat in all samples of subjects were better than any previously published equation.

In general, these calculations have been restricted to the limbs, which have taken the form of four or more truncated cones, each containing concentric cylinders. The basic principle underlying this technique is that the whole segment volume will equal the sum of its part volumes. By taking the appropriate measurements, the volume of each geometric shape can be calculated using geometric formulae.

Jones and Pearson used a number of girth and height measurements taken serially along the limb and then used a mathematical model of truncated cones to calculate the volume of the thigh. They suggested that the mathematical calculation of segmental volumes could be used in place of water displacement or conventional x-ray techniques. The volume of limb segments was calculated using the formulae:

$$\frac{1}{3}L \left[ a + b + \sqrt{(ab)} \right]$$

where $a$ and $b$ were the areas of two parallel cross-sections estimated from circumference measurements and $L$ was the distance separating the two cross-sections. The volume of the foot was calculated using the formula:

$$\frac{1}{2}L (h, b)$$

where $L$ was the length of the foot, $h$ was the height from the sole of the foot to the first cross-section at the ankle, and $b$ was the average breadth of the foot. Correlations of 0.98 in men and 0.99 in women were found when the total limb volume was compared with a water displacement criterion value. Muscle plus bone volume was calculated by taking skinfold measurements at the thigh and calf, and correcting cone dimensions for overlying fat.

Fat was calculated as total limb volume, minus “muscle plus bone.” Comparison of the fat with a radiographic criterion found correlations in the thigh to be 0.95 and 0.85 and in the calf 0.83 and 0.86 in men and women, respectively.

Weltman and Katch extended the technique of Jones and Pearson to calculate segmental volumes of the arm and hand, thigh and leg, and leg sites. They, therefore, suggested that circumference measurements were good predictors of total body density and percentage body fat.

Shephard et al., proposed the following formulae for the estimation of limb volume, limb fat, limb muscle, and limb bone:

$$\text{Limb volume (mL)} = \left( \Sigma c^2 \right) \frac{1}{L} \times 62.8$$

where $\Sigma c^2$ was the sum of the square of five circumference measurements (cm) and $L$ was the length of the limb (cm).

$$\text{Limb fat (mL)} = \left( \Sigma c/5 \left( \Sigma s/2n \right) \right) L$$

where $\Sigma c$ was the sum of the five limb circumferences (cm), $\Sigma s$ was the sum of skinfolds measured over the limb (cm), $n$ was the number of skinfolds taken over the limb, and $L$ was the length of the limb (cm).

$$\text{Limb bone (mL)} = 3.14R^2L$$

where $R$ was the average bone radius of the limb, and $L$ was the length of the limb (cm).

In validation of proposed equations, Shephard et al. demonstrated good correlation between maximum oxygen intake and muscle volume in the lower limb, while the percentage of fat that was calculated in the limbs coincided closely with percentage fat estimated by the skinfold method.

Sady et al. and Freedson et al. suggested that total body volume could be approximated from anthropometric measurements made on 10 body segments using three geometric shapes. Coefficients of correlation with hydrostatic weighing were high (0.96 in females, 0.98 in males) but there were substantial systematic and random sources of error relative to the criterion, which suggests that the accuracy of their methods is too low to provide useful body composition information (5.46 ± 1.86 L in women; 1.74 ± 1.88 L in men).

The many technical difficulties associated with the accurate measurement of skinfolds have resulted in studies that have used circumference measurements as an additional means of predicting body fat or as a means of adding precision to skinfold predictions. There have been different prediction equations developed using circumference measurements on each sex and different age groups. Although these equations have been cross-validated on different samples with good results, they still appear to be population specific and should not be used in the prediction of body fat in individuals who appear extremely obese or extremely thin.

The circumference-based prediction equations have been found to be useful in ranking individuals within a group according to their relative fatness. Katch et al. presented a series of equations and constants for young and older men and women that could be used in the prediction of percentage body fat. They reported the error in the prediction of body fat associated with the circumference equations to be ± 2.5–4.0%. In view of these relatively low errors, they suggested that the equations could be particularly useful in circumstances where there is no access to laboratory facilities.

It has been shown that the reliability of moderately trained observers is substantially greater for circumference measurements.
rather than skinfold measurements.9 Nevertheless, the greater construct validity of skinfold data has been found to outweigh the negative impact of poor measurement reliability, and skinfold predictions have been found to be more accurate than those based on circumferences.74,122

There appear to be no studies that have used circumference measurements to predict the volume of a body segment and compare the calculated circumferential segmental volume with volumes obtained from a water displacement technique.

**BIOELECTRICAL IMPEDANCE**

Bioelectrical impedance analysis (BIA) is based upon the relationship between the volume of the conductor (i.e., the human body), the conductor’s length (i.e., the subject’s height), the components of the conductor (i.e., fat or FFMs) and its impedance (Z). Impedance itself reflects frequency-dependent opposition to the flow of an alternating electric current, and comprises of resistive (R) and reactive capacitive (Xc) components, defined as the square root of the sum of the squares of the resistance and reactance (Z = \( R^2 + Xc^2 \)).159 Both R and Xc components are found in biological systems, although Xc is usually very small relative to Z at lower frequencies (<4%).160 so R and Z are often reported interchangeably. The distinction between Z and R becomes more important with the advent of multifrequency analyzers, as Xc may no longer remain so small as frequency increases.

BIA assumes that the volume of a conductor can be deducted from measurements of its length (L) and resistance. This stems from Ohm’s Law, which states that between two points of a conductor, R = V/I, where R is measured in ohms, V is measured in volts and I, (current) in amperes. In a symmetrical isotropic conductor, R is directly proportional to its length (L, cm), and inversely proportional to its cross-sectional area (A, cm²), R = \( \rho L/A \), where \( \rho \) is the specific resistivity measured in ohm centimeters. As volume (V) equals L X A, algebraic rearrangement shows that \( r = \frac{\rho L}{R} \). Statute (S) is used as an index of the length of the body, and S/R or S/Z forms the basis for predicting FFM or total body water. This estimation assumes that the conductor is a perfect cylinder with a uniform cross-sectional area, whereas, in reality, there are five cylinders (excluding the head). Each cylinder has a different cross-sectional area and, therefore, contributes a different resistance.161 Additionally, the differences in cross-sectional area are not proportional to the differences in percentage body mass. The trunk, for example, may comprise 46% of body mass, but has little influence (3%) on whole body resistance when measured conventionally, the main influencing factors being the arm and the leg.159 Variations in body proportions may, therefore, enhance the error associated with percentage body fat predictions. Differences in structure also affect the conduction of the current. The human body as a conductor is highly anisotropic, especially in the trunk, which additionally leads to an indication that the relationship between whole body resistance and the conductor volume with its electrolytic concentration is not strictly linear. FFM predictions at the extremes of body fatness are less accurate, as prediction equations tend to overestimate fat mass in the lean and underestimate fat mass in the obese. Electrical conduction in biological systems is mainly ionic,159 and proportional to fluid volume and the number of free electrolytic ions.160 It is also inversely related to temperature.164 This infers that the bioelectric resistance is affected by changes in body geometry, volume, temperature, and electrolytic concentration, and these effects should be taken into consideration.

The overall conductivity of the human body is closely related to lean tissue and has been validated with criterion methods such as hydrodensitometry and skinfold measurement.165,166 The technique involves attaching adhesive surface electrodes to specific sites on the dorsal surface of the hand and anterior surface of the ipsilateral foot of the subject who lies flat on a nonconducting surface with legs abducted, preferably with the thighs not touching, although this may not be possible in extremely obese subjects.

It is important that there is no metal close to the subject that may influence impedance readings (such as a metal frame on a hospital bed, metallic jewelry) as it may exert an influence on high frequency measurements,167 and that these standard test conditions are maintained. The applied current is usually in the order of 500 \( \mu A \) for single (50 kHz) frequency machines, or 500 \( \mu A \) to 1 mA for multifrequency machines (5 kHz to 1 MHz), and tests times may last from a few seconds for a single frequency scan to several minutes for a full frequency scan. The raw outputs are generally visible immediately on the analyzer (resistance and reactance), and subsequently transmitted to a host computer whereby dedicated software processes the data. To maintain regression data accuracy, interchanging processing software from difference manufacturer analysers should be avoided.

It has been used in a range of specific groups including the elderly,168 children and adolescents,169 –175 the overweight,176 –178 middle-aged,179 malnourished,180 –182 dialysis patients,183 –190 infants,191,192 for nutritional analysis,193,194 during growth,195 in eating disorders,196 for cancer patients,197 in ethnic groups,198,199 and in patients with cystic fibrosis.200

Bioelectrical impedance has been used to assess lean-body mass in HIV-infected men,201 showing no statistically significant results between the mean lean-body mass estimate by total body electrical conductivity and those measured by BIA or a prediction equation on the basis of body mass index. Ott et al.202 reported that phase angle alpha was the best single predictive factor for survival in a 3-y study of patients with AIDS, and Kotler et al.203 reported more accurate predictions of body cell mass using reactance rather than the values reported from the BIA. Kotler et al.203 found that modeling equations derived after logarithmic transformation of height, reactance, and impedance were more accurate predictors than equations using height/ resistance. Others have found that BIA measurements within these patient groups is greatly dependent upon the prediction equations used, with reported variations in the FFM content of weight loss ranging from 55% by total body water, 57% from skinfold thickness, 60% from dual energy x-ray absorptiometry, to 65% and 78% using two different prediction equations using BIA.204 The use of gender-dependant equations also affects accuracy. Body composition within AIDS patients using in vivo neutron activation analysis has shown high reliability with 0.99 for total body chloride to 0.84 for total body phosphorous.205,206

It is recognized that the measurement of bioelectrical impedance is influenced by other factors that should either be controlled or reported. These include electrode configuration such as bipolar or tetrapolar,207 –209 the menstrual cycle,210,211 skin temperature,212 use of oral contraceptives,213 exercise-induced dehydration,33 prior food,214 and different body positions.215 If such features are controlled the prediction errors to calculate body fat are 3–5%. Most studies report that the impedance method is reliable and valid,165,166,216 –219 even although some report caution in the use of a single frequency device in a clinical setting,220 and others found that body mass alone estimated FFM as accurately as any of the bioelectrical equations in lean males.221 The single frequency machine may be replaced by multiple frequency analyzers that are able to differentiate between total and extracellular fluid compartments in the body.222 –224 This is based on the current flow at low frequencies (5 kHz) passing primarily through extracellular fluids and at higher frequencies (>200 kHz) penetrating all body tissues. This will increase the value for assessing clinical and nutritional status considerably. Multifrequency analysers have been shown to produce significant improvements in the prediction of body water225 –229 and improves the standardization of the method over the
single frequency approach.\textsuperscript{215} It should be of particular value when hydration states need to be monitored such as in renal dialysis,\textsuperscript{230} or in the management of lymphoedema.\textsuperscript{231} A comparison between the single frequency and multiple frequency approaches yield similar results.\textsuperscript{215} Comparisons with different single frequency devices shows that some models record a lower impedance value than others.\textsuperscript{240} It is interesting to note that cost does not seem to be a major factor, mean differences of only 0.6\%,\textsuperscript{232} between machines.

Bioelectrical impedance is used to estimate total body water (TBW) measured by isotopic dilution techniques. In this instance, the standard error of the estimate of TBW, under carefully controlled conditions, is <2 L of water. This is less than a 4\% error for an adult comprising of 50 L of TBW. Prediction errors for young adults, based on the coefficient of variation, have for FFM been reported at 4\% or less. Errors in the measurement of height and weight, error in BIA measurement, error of measurement of the criterion method, and errors from the prediction equation all sum to produce this prediction error.\textsuperscript{215}

Although the standard error of estimates is at best reported as 2.5\% in humans,\textsuperscript{233} its advantages such as speed of operation, safety, portability and lack of intrusion make it an ideal tool for epidemiological investigations.

Validation studies have generally involved healthy adults. The elderly, youth, children, and neonates provide far more limited data. Ethnic minority groups are less commonly reported than Caucasian. Individuals who differ substantially from the reference population will limit validity as will the accuracy of the measurement of the criterion variable. Specific validation would be necessary for any individuals who did not conform to the basic assumptions applying to BIA measurement. These would include any conditions causing asymmetry or producing localized changes in tissue atrophy or perfusion.\textsuperscript{234}

Baumgartner’s contribution\textsuperscript{53} reviews the assumptions, applicability, equipment, measurement procedure, precision, and accuracy of the BIA method and is highly recommended.

Clinicians value knowledge of body composition in health and illness because of the additional information provided compared with height, mass and derived measures such as body mass index. TBW’s predictive value is only valid in disease when the central and peripheral body components are affected similarly. This is likely to apply in moderate obesity, many noninflammatory diseases, and in early HIV infection. In these and others, nutritional status is likely to be the main use of the technique. Haemodilution is a probable area for BIA investigation as is any disturbance of the intracellular/extracellular water ratio as in protein malnutrition, injury, or inflammation. This whole area is, to date, poorly researched and will need to be cautiously investigated as critically ill patients will have variable ratios of TBW to FFM. Measurement of nutritional replenishment for malnourished patients may be a more productive line of investigation.

OTHER METHODS

A full review of techniques of body composition\textsuperscript{79} and a critique on the variability in the measures of body fat\textsuperscript{235} are outside the scope of this article and have been undertaken elsewhere. It is, however, valuable to consider just two alternative approaches briefly as they are gaining current popularity for body composition assessment. The first is near-infrared interactance, which is based on the principle of light absorption and reflection. An infrared light beam is placed over the biceps muscle and reflected energy from the fiberoptic probe is monitored by an optical detector. It compares the light absorption properties of two wavelengths and in combination with other anthropometric data predicts body composition utilizing an appropriate regression equation. It has been shown to be reliable\textsuperscript{236–238} and has been validated with ethnic groups,\textsuperscript{239} in the middle aged,\textsuperscript{238} women of varying ages,\textsuperscript{240} and in children and adults.\textsuperscript{239} Standard errors of estimate were in the range 4.9–5.5\%,\textsuperscript{237} and it was found that the method underestimated the percentage body fat of obese women.\textsuperscript{238,240} This was considered to be related to the bigger differences between skinfold and optical density values in sites of higher fat depths.\textsuperscript{240} It is generally considered that additional work needs to be undertaken with infrared interaction to demonstrate its utility. More studies should be completed to cross-validate the technique for general and specific populations. Its appeal, not unlike impedance, is its lack of intrusion, its speed, and portability.

The final method to consider is that of dual energy x-ray absorptiometry (DEXA). Originally developed for bone content analysis, especially the clinical study of osteoporosis, it is now being heralded as a potential criterion method for body composition. Compared with MRI, it is currently more widely available as a research tool and is likely to be less expensive to operate and maintain. DEXA has the advantage of being able to partition the body into three components: namely bone mineral, fat and lean tissue. This division is somewhat based on assumptions incorporated into the manufacturer’s software but the results when compared with hydrodensitometry compare well, providing errors in the equation used to calculate percent fat from density are accepted. Additional support for DEXA as a method of body composition measurement comes from the sum of the three components that is within 1\% of the actual body mass. The technology of DEXA is reviewed by Nord and Payne\textsuperscript{241} and validation studies have been undertaken against potassium-40,\textsuperscript{242,243} total body water using deuterium dilution,\textsuperscript{243,244} skinfolds,\textsuperscript{245,246,248–251} bioelectrical impedance,\textsuperscript{245,247} and even compared with lard as a soft tissue substitute.\textsuperscript{252} It was also found to have satisfactory short-term reproducibility.\textsuperscript{253} The general conclusions are that DEXA is a safe method for routine use in humans,\textsuperscript{254} is precise with a low standard error of estimate\textsuperscript{247} and has initial promise as a method for estimating body composition.\textsuperscript{255–257} It has already been used widely in addition to post-menopausal women,\textsuperscript{258–260} by such groups as children,\textsuperscript{261–266} young adults,\textsuperscript{267,268} the newborn,\textsuperscript{269,270} men,\textsuperscript{271} athletes,\textsuperscript{256} and growth hormone deficient adults.\textsuperscript{272} Nonetheless, it is important to appreciate within-manufacturer variability, which can be as high as 15\% for the mass of bone mineral.

Any user of DEXA for fat mass must remember that estimated fat is lipid (the chemical component) not adipose tissue (the anatomical component). Nonetheless, once validated against an imaging criterion such as MRI, DEXA may prove to be a useful addition to the body composition options. Any validation would need to take account of the theoretical differences in the imaging modalities.

SUMMARY

The range of options available for body composition measurement includes chemical, electrical, physical, and anthropometric. A number of these are restricted to research institutes that have committed high capital investment such as whole body counters or computer tomography scanners. Many nutritionists will find low-cost systems that can be applied rapidly and noninvasively a useful adjunct to their clinical experience. Body composition using hydrodensitometry, surface anthropometry, bioelectrical impedance, or infrared interactance provides evidence for fat and fat free components, which is becoming increasingly popular in the literature and in practice. This article provides an overview of the current literature and gives a basis for future research, for purchase of equipment or for making decisions to include body composition as part of nutritional activity.
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