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REVIEW OF ASSESSMENT OF BODY COMPOSITION IN CHILDREN & ADULTS

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Abstract

The paper aimed at providing an overview of the quantification of body composition in children and adults, addressing the relative merits of each of the techniques presented. It discusses changes in body composition, assessment of body composition in which anthropometry, body mass index (BMI), waist-circumference and skinfold thickness. Densitometry, isotope dilution methods, absorptiometry and hydrometry were also highlighted. As part of the researchers' conclusion; useful prediction equations have been pointed out. Bioelectrical impedance analysis (BIA) has been pointed out to have advantages over skinfolds thickness measurement as a technique. Densitometry, hydrometry and dual-energy X-ray absorptiometry (DEXA) yield indirect estimates of body composition. Therefore, none can be considered a 'gold standard'. Part of recommendations is that the government should make hydro-densitometers, dual-energy X-ray absorptiometers (DEXA), magnetic resonance imagers (MR1) etc. available to researchers, coaches, physiotherapists and exercise and sport scientists.

Key words: Assessment, body composition.

Introduction

Although it is unpleasant to think about, the only way to directly assess body composition is by dissection of human cadavers. Not only are few bodies available for such studies, but the technique is also difficult and not without problems. From 1945 to 1984 (the time from the earliest to the latest reported studies), body composition analysis has been performed on only 40 cadavers. While the study of these bodies provided a great deal of information, particularly regarding the densities of body tissues, they were not used to determine the accuracy (validity) of the more commonly used laboratory techniques. Theoretically, direct cadaver analysis should be the most accurate technique; however, the newer cadaver studies have often been inconsistent with results from the earlier studies. Thus, when dealing with body composition analysis, keep in mind that some techniques are better than others, and none is likely to be 100% accurate (Behnke & Wilmore, 1974; Brodie, 1988).

Many methods are currently available for the laboratory assessment of body composition and could possibly serve as criterion measures. Techniques such as computed tomography, dual-energy X-ray absorptiometry, excretion of muscle metabolites, isotope dilution, magnetic resonance imaging, neutron activation, ultrasound, whole-body counting of potassium 40, total body electrical conductivity (TOBEC), and air plethysmography (Bod Pod system) are very accurate. Unfortunately, at this time they are also often expensive, cumbersome, and/or time-consuming, requiring sensitive instrumentation run by highly trained technicians (Plowman & Smith, 2008).

The range of available body composition assessment methods is extensive. The extremes range from relatively simple and inexpensive field methods to more complex and expensive laboratory techniques requiring advanced equipment. An understanding of the relative merits of each approach or the strengths and weaknesses of each is essential. Such an understanding is important in choosing the best method to match the particular needs or requirements for body composition information (Durnin, 1995; Hills & Parizkova, 2002).

The two main anthropometric indicators of physical growth in children and adolescents are body height and weight. Routine assessment of height and weight in children and comparison with normative data provide key information about physical maturation and nutritional status, including level of overweight. Similarly, such information provides a means of simple comparison between children of the same chronological age. One of the defining features of childhood obesity is early physical maturation. Earlier maturation of obese individuals is reflected in height to weight differences compared to normal weight children. The ratio of height and weight, the body mass index (BMI), provides another means of categorizing level of overweight and physical status (Hills & Kagawa, 2007).

The aim of this paper is to provide an overview of the quantification of body composition in children and adults. A concurrent aim is to address the relative merits of each of the techniques presented.

Therefore the paper focuses on the following: Changes in body composition, Assessment of body composition, Anthropometric measures which include: Body mass index (BMI), Waist circumference and Skinfold thickness. Densitometry (Isotope dilution methods), Absorptiometry [Dual energy X-ray absorptiometry (DEXA)], and Hydrometry [Deuterium oxide dilution and bioelectrical impedance analysis (BIA)].

Changes in body composition

Growth and development during the childhood years is generally characterized as slow and gradual; however, marked changes in physical size, shape and body composition occur during puberty. During the adolescent period to follow, both genders show significant body weight increases with peak weight velocity in girls occurring approximately 6-9 months later than peak height velocity (Hills & Kagawa, 2007). In boys, peak height and weight velocity occur at approximately the same time. The preferential deposition of body fat in girls and skeletal muscle in boys are the defining body composition changes during the adolescent years. The combined effects of body fat increase and/or change in deposition, and skeletal changes result in the characteristic android and gynoid patterning males and females, respectively (Rogol, Clark & Roemmich, 2000).

Assessment of body composition

The assessment of body composition in children and adolescents is challenging because of differential maturation at a given chronological age (Heyward & Wagner, 2004; Hills, Lyell & Byrne, 2001). Body composition assessments methods at best provide estimations or predictions. Therefore, all methods except cadaver analyses are described as indirect. More exactly, many techniques should be described as doubly indirect if they build on the measurements and assumptions of another indirect method and the inherent estimation errors (Hills & Parizkova, 2002; Hills, Byrne & Parizkova, 1998). The most common approach to body composition analysis is to subdivide the body mass (weight) into two or more compartments based on elemental, chemical, anatomical or fluid components (Heymsfield & Masako, 1991; Hills & Kagawa, 2007). The indirect assessment of body composition has routinely used the two-compartment model, that is to divide the body into fat mass (FM) and fat-free mass (FFM). However, advances in chemical and isotope-based methods have enabled further subdivision of the FFM into water, mineral and protein; in addition, imaging techniques have enabled the consideration of body composition in terms of fat, muscle, bone and other soft tissue (Heymsfield, Lohman, Wang & Going, 2005; Wells, Fewtrell, Davies, Williams, Coward & Cole, 2005).

Two of the inherent assumptions in the two-compartment model are:

- ✓ the constant densities of FM and FFM (0.9 g/mL and 1.1g/mL, respectively);
- ✓ the relative amounts of the three major components of the FFM (aqueous, mineral and protein) are known, additive, and constant in all individuals (Hills & Kagawa, 2007).

As a consequence, when the two-compartment model is used with children and adolescents who differ from the reference population in bone mineralization or hydration of FFM, the model has serious limitations. The chemical composition of the FFM does not reach adult values until approximately 17-20 years of age. As a result, the FM is

commonly overestimated in children and adolescents when the two-compartment model is employed (Reilly, 1998).

Hills and Kagawa (2007) assert that the most field methods include anthropometric measures such as height, weight, skinfolds and circumferences, and the portable and relatively simple bioelectrical impedance analysis (BIA) approach. The more expensive laboratory methods include hydrodensitometry, air plethysmography (Pea Pod and Bod Pod™), dual energy X-ray absorptiometry (DEXA), total body water (TBW) measurement, magnetic resonance imaging (MRI), computerized tomography (CT) and total body potassium (TBK). These body composition methodologies are generally not available to most researchers and therefore are out of the reach of most school teachers, coaches, and exercise and sport scientists, especially in Nigeria.

Anthropometry

Anthropometric measures include height and weight, body proportions, circumference or girth measures, skinfold thickness, skeletal diameters, and segment lengths (Hills, Lyell & Byrne, 2001). Measures of relative fatness include weight and weight-for-height, circumferences (most commonly waist and hip), skinfold thickness and indices derived from height and weight measures. The most widely used index of relative fatness is the body mass index (BMI) (Lobstein, Baur & Uauy, 2004; McCarthy, Cole, Fry, Jebb & Prentice, 2006). The major advantages of anthropometric techniques are that they are generally non-invasive and equipment is commonly portable and therefore suited to use in a wide range of settings. Perhaps most importantly, anthropometry is often the preferred approach because it is relatively inexpensive. Despite the apparent simplicity of the approach, it is important to appreciate that the usefulness of anthropometric measurements is very much dependent upon the experience and reliability of the measurer (Ogle, Allen, Humphries *et al.,* 1995).

Body mass index (BMI)

Despite BMI (weight [kg]/height squared [m^2]) being the most common anthropometric index to predict relative overweight (Hall & Cole, 2006), the appropriateness of the index in children and adolescents has been questioned. BMI does not measure body fatness per se and therefore may not be sensitive to differences in actual body composition, including the influence of race. In children less than 15 years of age, BMI is not totally independent of height, and individuals with the same BMI may be quite different in terms of proportion of body fat and skeletal muscle tissue. Prediction of body composition from BMI may therefore be more reliable in individuals within the normal range for body weight and BMI, and biased in individuals with high or low body fat content (Hills & Kagawa, 2007).

Waist circumference

As a single measure, waist circumference is valued for its relationship with central adiposity in adults. The measure has gained increasing acceptance in younger people; however, cut-off points are not available to relate waist circumference to health status in children and adolescents (Rudolf, Greenwood, Cole *et al.,* 2004). The simple waist circumference measurement may be derived from one of three different measurement approaches. The preferred descriptor in this paper is consistent with the definition of the International Society for the Advancement of Kinanthropometry (ISAK) and is the abdomen at its narrowest point between the lower costal (10^{th} rib) border and the top of the iliac crest, perpendicular to the long axis of the trunk' (Marfell-Jones, Olds, Stewart & Carter, 2006). The hip circumference (maximum girth of the hips and buttocks) and additional girth measurements may be used to profile the size and shape of individuals (Hills, Lyell & Byrne, 2001); however, the once commonly employed waist-to-hip ratio is no longer in vogue.

Skinfold thickness

Skinfold thickness measures have been used traditionally to assess the subcutaneous fat layer at multiple sites (Hills & Parizkova, 2002). The double fold of skin and the underlying subcutaneous fat is measured using skinfold caliper (Hills *et al.,* 2001).

The skinfold technique has the advantage of being reasonably inexpensive and able to be used in a wide range of settings due to the portability of equipment. Despite the sensitivity of some skinfold sites for some individuals, there

is commonly a relatively low respondent burden for the most common sites. Despite the apparent simplicity of the skinfold technique, the approach does require a high degree of technical skill (Hills *et al.,* 2001). As is the case for all anthropometric measures, reliability can be enhanced with quality training and experience including the use of standardized methods (Norton & Olds, 2001). Unfortunately, measurement error is also related to the level of obesity of the individual being assessed such that skinfolds measurements are notoriously unreliable in the obese. It is common for the skinfold thickness of an obese individual to exceed the maximum aperture of the caliper.

Perhaps thanks to the high level of interest in body fatness in the wider community, many people have been preoccupied with the conversion of skinfold measurement into a percentage body fat value. The conversion of raw skinfold data is an unnecessary step as satisfactory intra- and inter-individual comparisons can be made using the sum of skinfold measurements from representative sites. However, some research has suggested that equations using skinfolds are valid for use in young people (Durnin, 1995). The use of equations to derive total body fat values from skinfold measurements requires that one understands the potential impact of the changing relationship between subcutaneous fat (skinfolds) and total body fat during puberty and adolescence (Hills & Parizkova, 2002).

Densitometry

Densitometry refers to the measurement of total body density and the estimation of body composition from body density. For many years, densitometry has been the mainstay in body composition assessment. Body density is the ratio of body mass to body volume; the latter measured by either water displacement or air displacement. Based on the assumed density constants of fat (0.9 g/mL) and FFM (1.1 g/mL) mentioned above and the measured density of the body, estimates of percentage body fat, FM and FFM can be derived using conversion formulae. For many years the hydrostatic (underwater weighing) technique was considered the 'gold standard' assessment method. Hydrostatic weighing is based on Archimedes' principle that the weight of the submerged individual is directly related to their body density (Hills *et al.,* 2001) with body density representing a combination of the density of body fat and FFM. As for other approaches, there are a number of shortcomings with the underwater weighing technique in children, mainly due to the need for the child to submerge by exhaling air and then holding their breath for a number of seconds. Additional shortcomings of the approach relate to the key assumptions associated with the method. The underwater weighing technique assumes a constancy of the density of FFM; however, this is influenced by both hydration status and the contribution of BM to FFM (Lukaski, 1997). Each component is variable during the growing years and also dependent on diet and physical fitness.

Air-displacement plethysmography (Bod Pod™) represents a more suitable alternative to underwater weighing (Elia & Ward, 1999; Ellis, Yao, Shypailo, Urlando, Wong & Heird., 2007). However, a potential source of measurement error in both underwater weighing and air-displacement plethysmography is the conversion formula used to estimate percent body fat from body density. Although densitometry yields an accurate measure of body density, some have speculated (Lohman, 1992) that variability in the FFM may lead to an error of approximately 2.8 percent body fat when estimating relative body fat from body density in individuals of similar age, gender and ethnicity. As a result, densitometry techniques are not considered the 'gold standard'.

Isotope dilution methods

The stable isotopes deuterium oxide ($^{2}H_2O$) and ^{18}O occur naturally in the body. The use of these isotopes is non-invasive, safe and effective in estimating total body water (TBW) in infants, children and adults (Wells *et al.,* 2005). Isotope dilution is used to estimate FFM and FM but, like underwater weighing, estimations assume a constant relationship between TBW and FFM and therefore fail to account for the chemical immaturity of the child. The hydration of lean FFM can vary before and after puberty (Hills & Kagawa, 2007).

Absorptiometry

***Dual energy X-ray absorptiometry* (DEXA)**

Total and regional body composition can be assessed using the DEXA procedure. The method is based on the three-compartment model that divides the body into FM, hone mineral mass and lean body mass and is measured by attenuation of the dual energy X-ray beams. As each tissue varies in density, attenuation properties differ and this enables the determination of each of the tissue compartments. The precision of DEXA in the measurement of percentage body fat is estimated at approximately 1.2 percent body fat (Lohman, 1996). Further, DEXA is highly reliable with good agreement between body fat estimates from underwater weighing and DEXA. The radiation exposure from a DEXA scan is extremely low and the procedure is quite fast so the technique has gained widespread acceptance for use in all age groups (particularly as an alternative to densitometry).

The advantages of the DEXA technique may be summarized as follows (Hills & Kagawa, 2007) it is highly reliable; measurement is rapid; minimal subject cooperation is required; and it accounts for differences in bone mineral density of subjects. Some of the main disadvantages include the requirement of further validation of the technique for children and also the ethical issues associated with exposure to radiation, albeit minimal. Heyward (1998) has indicated that estimates of FM depend on the manufacturer of the DEXA equipment (i.e. Lunar, Hologic or Norland), the mode of data collection (pencil beam versus array beam) (Lohman, 1996) and the software used.

Hydrometry

***Deuterium oxide dilution and bioelectrical impedance analysis* (BIA)**

The measurement of TBW or hydrometry also has limitations if used alone to generate reference measures of body composition. The use of the stable isotope deuterium oxide (^2H_2O) to estimate TBW is commonly recognized as the 'gold standard' (Wells *et al.*, 2003).

Bioelectrical impedance is an indirect method of measuring TBW. The BIA method involves passing a low-level electrical current through the body and measuring the impedance or opposition to the flow of current. The electrolytes in the body water are excellent conductors of electricity. Using an equation (different for each instrument), TBW and therefore FFM are calculated and FM (and usually percentage body fat) derived. Because adipose tissue is a relatively poor conductor of electricity because of its small water content, the resistance in an individual with large amounts of body fat will be higher than that of an individual with a greater percentage of FFM. More recent research has considered measurement across multiple frequencies (MFBIA) instead of the customary single frequency and also segmental versus whole-body bioimpedance. The limbs primarily influence electrical resistance, which suggests that the BIA technique may be relatively insensitive to differences in tissue composition of the trunk (Hills & Kagawa, 2007).

Schaefer, Georgi, Zieger & Scharer (1994) found higher intra-observer and inter-observer reliability with BIA than with skinfold measures in children with a mean age of 11.8 years; however, FFM estimates were similar for both BIA and anthropometry. Okasora *et al.,* (1999) in Hills and Kagawa, (2007) compared BIA and DEXA as methods of body composition assessment in children and found close correlation between %BF, FFM and body fat content. The limitation of this study was that equations used by the researchers were those of Brozek. These equations are widely recognized as inappropriate for use in youth, as they do not account for the variability of the composition of the FFM in young individuals. Bland and Altman (1986) as cited in Hills and Kagawa, (2007) that plots or an analysis of the size of the prediction error should be utilized to determine if there is agreement between the two measures.

The BIA technique is recognized as a useful body composition assessment technique in children and adolescents because measurement is fast and non-invasive. It is also inexpensive and painless, requires little subject cooperation, and does not require a high level of technical skill (Schaefer *et al.,* 1994). However the derived values using the BIA technique are only as good as the prediction equation utilized in the software. That is, if the group of individuals being assessed is representative of the population from whom the algorithm was derived the greater the potential value of the approach (Hills *et al.,* 2001). The equations of

Houtkeeper, Going, Lohman, Roche & Van Loan (1992) are recommended for boys and girls 10-19 years of age. Further, the reliability of the method is dependent on the protocol used in the measurement. The following factors can influence BIA measurements: the level of hydration of the subject, posture, environmental and/or skin temperature, age, gender, athletic status, body composition status and ethnic origin. Ideally, if the BIA technique is used to assess changes in an individual over time, biological and environmental variables such as hydration status, timing and content of last ingested meal, skin temperature and menstrual cycle must he controlled for (Hills & Byrne, 1997; Ellis *et al.,* 2007).

Conclusions

Bioelectrical impedance analysis (BIA), skinfolds and anthropometry are the most appropriate and practical for use in the field. These techniques are most commonly used at present as they have satisfactory validity provided that appropriate equations are used for the specific population (gender, age category, level of adaptation to exercise and so on). Useful prediction equations have been noted in this paper. BIA may hold the advantage over skinfolds as the technique is less invasive, requires less technical skill, has both higher inter-tester and intra-tester reliability, is quicker and may be easier to administer to a wider range of individuals. When experimental assessment is required, densitometry or DEXA measurement procedures are preferred. This is especially the case when longitudinal observations are made (especially during puberty).When the two-compartment model is used with children and adolescents who differ from the reference population in bone mineralization or hydration of FFM, the model has serious limitations.

The three reference methods: densitometry, DEXA and hydrometry; yield indirect estimates of body composition so none can be considered as the 'gold standard' for in vivo body composition assessment. Ideally, for research purposes, the use of three methods is recommended in conjunction with a multi-component model to derive valid reference measurements of percentage body fat, FM and FFM (Heyward, 1998). Further development of methods for the evaluation of body composition is essential. The major advantages of anthropometric techniques are that they are generally non-invasive and equipment is commonly portable and therefore suited to use in a wide range of settings.

In children less than 15 years of age, BMI is not totally independent of height, and individuals with the same BMI may be quite different in terms of proportion of body fat and skeletal muscle tissue.

The more expensive laboratory methods which include hydro-densitometry, air plethysmography (Pea Pod and Bod Pod™), dual energy X-ray absorptiometry (DEXA), total body water (TBW) measurement, magnetic resonance imaging (MRI), computerized tomography (CT) and total body potassium (TBK). These body composition methodologies are generally not available to most researchers and therefore are out of the reach of most school teachers, coaches, physiotherapist and exercise and sport scientists in Nigeria.

Recommendations

- ✓ When experimental assessment is required, densitometry or dual energy X-ray absorptiometry (DEXA) measurement procedures are preferred. This is especially the case when longitudinal observations are made especially during puberty.
- ✓ The government should make hydro-densitometers, air plethysmography (Pea Pod and Bod Pod™), dual energy X-ray absorptiometers (DEXA), magnetic resonance imagers (MRI), and computerized tomographers (CT) available to researchers, coaches, physiotherapists and exercise and sport scientists.

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