Non-invasive measurement of body composition in young people

Dana Sirbu, Daniela Curseu, Monica Popa, Alina Ionutas, and Dorina Vlassa

Abstract — Obesity is a serious health problem that reduces life expectancy by increasing one’s risk developing coronary artery disease, hypertension, type II diabetes, obstructive pulmonary disease, osteoarthritis and certain types of cancer. Too little body fat, also poses a health risk because the body needs a certain amount of fat for normal physiological functions. Analysis of body composition is an important aspect of clinical research in nutrition and in the clinical practice of medicine. Despite the importance of body-composition analysis, the current measurement techniques have numerous limitations that can reduce their availability and application. This article provides an overview of the present status of in vivo body composition methodologies that have potential for use in field studies. Bioelectrical impedance nearly anthropometric indices and skinfold are non-invasive, inexpensive, portable methods of body-composition analysis, which could be appealing for both research and clinical practice.

Keywords: body composition, skinfold thickness, bioelectrical impedance, anthropometric indices, fat mass, fat free mass.

1. INTRODUCTION

Body composition is used to describe the percentages of fat, bone and muscle in human bodies. The body fat percentage is of most interest because it can be very helpful in judging health in addition to body weight. Two people at the same height and same body weight may look completely different from each other because they have a different body composition. Body composition and topology are related to disease conditions. This correlation was established for heart disease, diabetes, gall bladder disease, certain cancers, osteoporosis, and arthritis.

We can describe the body in terms of a 2-component model (2-C model) of fat mass (FM) and fat free mass (FFM). This was the earliest attempt at describing in vivo body composition and is still the most common method today. The most variable component of the body is the FM. The National Institute of Health and Lohman [1] recommends that a healthy adult male's body should have between 13 and 17% fat and a healthy female's should be composed of between 20 and 25% fat. Levels significantly above these amounts may indicate excess body fat. Obesity is a serious health problem that reduces life expectancy by increasing one’s risk developing coronary artery disease, hypertension, type II diabetes, obstructive pulmonary disease, osteoarthritis and certain types of cancer. Youth obesity is increasing at an alarming rate and is predictive of adulthood obesity [2], with deleterious effects on future health status. The increasing obesity and strong relation with health risk highlight the importance of identifying accurate techniques for measuring total body fat in children. Too little body fat, also poses a health risk because the body needs a certain amount of fat for normal physiological functions.

2. METHODS FOR ASSESSMENT BODY COMPOSITION

Body composition can be measured by a variety of methods, which can vary in their sophistication, accuracy, feasibility, cost, and availability. Short of cadaver analysis, there is no direct method for measuring body composition. Most techniques for measurement of body composition require expensive, cumbersome equipment; isotope administration; radiation exposure; and multiple blood sampling.

Table 1. Methods for the measurements of body composition

<table>
<thead>
<tr>
<th>Type of method</th>
<th>Level of evaluation</th>
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<tbody>
<tr>
<td>1. Laboratory measurements of body composition</td>
<td></td>
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<tr>
<td>In vitro</td>
<td></td>
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<tr>
<td>Anatomical dissection</td>
<td>muscle, skeleton, adipose tissue, viscera</td>
</tr>
<tr>
<td>Chemical analysis</td>
<td>water, fat, protein, mineral, carbohydrate</td>
</tr>
<tr>
<td>Densitometry</td>
<td>whole body</td>
</tr>
<tr>
<td>Hydrometry</td>
<td>whole body</td>
</tr>
<tr>
<td>Neutron activation analysis</td>
<td>whole body</td>
</tr>
<tr>
<td>Dual energy X-ray</td>
<td>whole body and areas</td>
</tr>
<tr>
<td>Absorptiometry (DEXA)</td>
<td>regional, whole body</td>
</tr>
<tr>
<td>Magnetic resonance imaging</td>
<td>whole body areas</td>
</tr>
<tr>
<td>Computed tomography (CT)</td>
<td>regional areas and whole body</td>
</tr>
<tr>
<td>2. Field methods</td>
<td>regional subcutaneous adipose tissue areas estimating whole body composition</td>
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</table>
These methods are divided into four general categories: anthropometric measurements and indices, body volume measurements, body water measurements including bioelectrical methods, and imaging techniques [3]. The methods available for the measurement of body composition are shown in Table 1. The majorities of these are laboratory methods, or are expensive or require competent technical expertise. The most commonly used are the 2-C techniques of densitometry and hydrometry. The most commonly used field techniques are skinfold thickness and bio-impedance analysis, although the body mass index (BMI) is widely used as a measure of level of fatness. The apparent simplicity, speed and cheapness of some of the field techniques have led to their popularity in an unquestioning way.

2.1. Anthropometric Measurements and Indices

Anthropometry includes measurements of weight (Wt), height (Ht), circumferences and lengths at various body regions, and skinfold thickness (SF).

Body weight is more a dimension of size than composition but it has an important role in the assessment of nutritional status in children and adults, usually as a function of height as described below. Body weight may be the cardinal anthropometric measurement in the assessment of nutritional status; all of its uses in the area of body composition can be performed better by other measurements. So, a major stimulus to the field of body composition was the unsatisfactory performance of body weight and weight-height indices in assessing energy stores and obesity.

Many different Wt-for-Ht indices have been developed, the body mass index (BMI), defined as Wt/Ht², is the one most commonly used BMI has been adopted widely as a measure of obesity, energy stores and energy undernutrition [4, 5]. BMI has been used by the WHO as the standard for recording obesity statistics since the early 1980’s. In the United States, BMI is also used as a measure of underweight, owing to advocacy on behalf of those suffering with eating disorders, such as anorexia nervosa and bulimia nervosa. BMI is meant to broadly categorize populations for purely statistical purposes. As noted, its accuracy in relation to actual levels of body fat is easily distorted by such factors as fitness level, muscle mass, bone structure, gender, and ethnicity. People who are mesomorphic tend to have higher BMI numbers than people who are endomorphic, because they have greater bone mass and greater muscle mass, respectively, than do endomorphic individuals. Similarly, an ectomorphic individual could conceivably receive an unhealthy low reading, when in fact his body type makes him naturally thin no matter what he eats. Ectomorphs can also obtain healthy readings even when their body fat percentage is higher than recommended, as their low lean mass will lower the BMI. Generally, the Index is suitable for recognizing trends within sedentary or overweight individuals because there is a smaller margin for errors [6].

BMI can be calculated quickly and without expensive equipment, but BMI categories do not take into account many factors such as frame size and muscularity. The categories also fail to account for varying proportions of fat, bone, cartilage, water weight, and more. BMI is a statistical catagorisation and therefore is not appropriate to diagnosing individuals. One basic problem, especially in athletes, is that muscle is denser than fat. Some professional athletes are "overweight" or "obese" according to their BMI - unless the number at which they are considered "overweight" or "obese" is adjusted upward in some modified version of the calculation. This anthropometric indices is a better measure of fat content, (FM kg), than of fatness, (% fat), It is almost as much a measure of leanness, (FFM), as of fatness, (% fat). Methods for actually measuring body fat percentage are preferable to BMI for measuring body fat [7].

Mid upper arm circumference (MUAC) - is an established index of nutritional status in children and hospital patients. MUAC is highly correlated with BMI and in many instances it may replace BMI as a measure of chronic energy deficiency [8]. Other body circumferences are used as indicators of fat distribution, particularly abdominal fat distribution, e.g. waist-to-hip ratio.

Skinfold thickness has most of the characteristics of a good field method. The measurement is simple and quick, the calipers are inexpensive and portable and good reference data exists. Skinfolds are generally regarded as of low precision but proper training and continuous quality control prove the method to be acceptable [9]. Advantages and disadvantages of skinfold method are presented in table 2.

**Table 2. Advantages and disadvantages of skinfold method**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
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<tbody>
<tr>
<td>• Easy to use once skill has been mastered</td>
<td>• Technical sources of error</td>
</tr>
<tr>
<td>• Does not require much time</td>
<td>• Mostly concerned with subcutaneous fat (under the skin)</td>
</tr>
<tr>
<td>• Non-invasive method</td>
<td>• May not be an ideal measurement for those who are obese and very lean</td>
</tr>
<tr>
<td>• Inexpensive way of estimating percent body fat</td>
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</table>

Estimation equations in order to assess whole body fatness have been derived by relating skinfolds to a laboratory measure of body composition, usually a 2-C model such as densitometry. Lohman [1] has proposed standards for evaluating estimation errors (SEE) for % fat, FFM and FM. The equations of Durnin and Womersley [10] for estimating body density and % fat from skinfold thickness based on large numbers of subjects have been found to be some of the most widely applicable estimation equations.
2.2. Body Volume Measurements

Body density is given by mass divided volume. The determination of the volume of the irregularly shaped human body is the difficulty of the measurement. This has traditionally been measured by underwater weighing (UWW) using the principle that the loss of weight underwater is equal to the weight of water displaced from which the volume of water displaced by the body can be calculated.

There is now one instrument [11], based on air-displacement plethysmography (ADP), which does not require immersion. It consists of two chambers: the subject sits in one chamber, while the other serves as a reference. The volumes of the two chambers are varied slightly and the difference in air pressure is recorded. The subject’s body volume is calculated using corrections for isothermal properties of the air in the lungs and near the skin’s surface. The most obvious advantage is that the subject does not have to be submerged under water; although the subject still needs to wear a swimsuit and cap, the measurement time is only a few minutes. Preliminary studies using ADP have shown very good agreement with the UWW method in healthy adults and children.

2.3. Body Water Measurements

For healthy adults and older children, the water content of FFM is relatively constant: 0.732L/kg. Thus, any measurement technique based on the assay for total body water (TBW) indirectly provides an estimate for FFM. The body’s percentage of fatness can be defined as:

\[
\%Fat = 100 \times \frac{Wt - FFM_{TBW}}{Wt}
\]

Several methods for the assay of body water have been developed based on the electrical properties of tissues. The most common method, and probably the most practical for field use, is bioelectrical impedance analysis (BIA).

The actually technology of BIA determines the electrical impedance of body tissues, which provides an estimate of total body water. Using values of TBW derived from BIA, one can then estimate fat-free mass and body fat (adiposity). In addition to its use in estimating adiposity, BIA is beginning to be used in the estimation of body cell mass and TBW in a variety of clinical conditions.

The BIA measurement is performed by attaching a pair of electrodes at the wrist and at the ankle so that a weak alternating current (800 µAmp) can be passed through the body. The voltage drop is measured and the resistance (R) calculated, while the current is kept constant. To estimate the volume of TBW, three assumptions are used: the whole body acts like a cylindrical conductor, the conductor’s length is proportional to the subject’s height and the reactance component of the voltage signal can be disregarded. For measurement purposes, the human body consists of 5 cylinders (arms, trunk, legs), which are connected electrically in series. The measurement of total body impedance (resistance and reactance) from a macroscopic perspective is the vector sum of resistance and reactance in the limbs and torso [12]. Under these conditions, the impedance index (Ht²/R) is assumed to be proportional to the volume of TBW. Activities performed within 4 h before the measurement, such as moderate to vigorous exercise, consumption of excessive alcohol or excessive sweating, can substantially alter the reading. BIA works well in healthy subjects and chronic diseases with a validated BIA equation that is appropriate with regard to age, sex and race. BIA is non-invasive, does not expose to ionizing radiation, has very limited between observer variations and can be performed in almost any subject because it is portable. The cost of a bioelectrical impedance instrument is relatively inexpensive, its operation does not require highly trained personnel and the results (obtained immediately) have good reproducibility. The accuracy of BIA results and their biological interpretation should be used with caution [13].

2.4. Imaging Techniques

Three major techniques are used for imaging of the body: computer tomography (CT), magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DEXA). In general, these techniques cannot be considered as field methods for body composition analysis because of the high initial capital investment, the need for a highly trained technical staff and the high annual maintenance and service costs, especially for CT and MRI.

3. Conclusions

This paper presents the advantages and limitations of each technique as a field method for body composition assessment in comparing with laboratory methods. Skinfolds thickness and bioelectrical impedance analysis offer good feasibility and cost and reasonable accuracy for assessment body composition in young people in field studies.

4. References


