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Methods of assessing body composition and anthropometric measurements – a review of the literature

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Abstract
Introduction and purpose
Body composition assessment is an important element in determining the health of the body, which enables us to estimate the percent content of particular tissues in the body. Measured parameters include the amount of adipose tissue, muscle, bone tissue, and hydration. The aim of the study is to present a differentiation of methods of assessing body composition and anthropometric measurements after analysis of 29 scientific publications from Pubmed and Google Scholar.
A brief description of the state of knowledge
Bioelectrical impedance analysis, densitometry, magnetic resonance imaging, computed tomography, and air displacement plethysmography are methods that enable us to assess body composition and hydration. These methods differ from each other in equipment which is used, accuracy, test price, and technique of measurement. The differences in the accuracy of measurements result from the lack of correlation between the methods given. Skinfold thickness, body mass index, waist to hip circumference ratio, and growth charts in children are methods of assessing anthropometric measurements. The research shows the use of individual methods of assessing body composition and methods of anthropometric measurements among different age groups.
Conclusions
There are many devices and methods for measuring body composition and for anthropometric measurements, which can be used in different age groups. They are important in assessing human growth, development, and health status and can be used in clinical practice.

Key words: body composition; measures; weights; bioelectrical impedance

Introduction and purpose

The examination of body composition (BC) is an important element in determining the health of the body, both in healthy people and in those with diseases. Thanks to this examination, it is possible to estimate the percent content of particular tissues in the body. Assessment of the amount of adipose tissue is particularly important in some hormonal disorders and during improper nutrition [1,2]. Other parameters include the amount of muscle, bone tissue, and hydration. Body composition assessment allows the nutritional status of the entire population and individuals to be determined [1]. Assessing body composition is helpful in the diagnosis of some illnesses, for example, dual-energy X-ray absorptiometry or bioelectrical impedance analysis might be useful to diagnose sarcopenia [3]. Body composition is not a constant value, it depends on age, sex, and is genetically determined and modified by environmental factors, for instance, physical activity [2]. In the elderly, lean body mass decreases, especially the mass of muscles and bones, while the process of accumulation of adipose tissue increases. Normal body composition is as follows: adipose tissue 25%, bones 10%, non-skeletal muscle and soft tissue 29%, and skeletal muscle 36% [4].

The electrical properties of tissues have been known since 1871 when Hermann described them. In the mid-twentieth century, subsequent researchers wrote about the relationship between bioelectrical impedance measurements and the total amount of liquids in the human body. The first studies involved the use of two subcutaneous electrodes [5]. Later, Hoffer et al. used four electrodes by putting them on the skin surface [6]. In the 1970s, Nyboer et al. in pioneering research in the field of impedance plethysmography showed that changes in the impedance of the human body are associated with changes in the pulsatile blood flow in organs, respiration, and arterial pulse [5]. At the same time, a method of assessing body composition based on a hydrodensitometric test was investigated. The hydrodensitometric apparatus has become the basic tool for studying body composition. The body weight was divided into body fat (BF), which contains little water and its density is estimated at 0.9 g/ml, and fat-free mass (FFM), which contains much more water and its density is estimated at 1.1 g/ml. This two-compartment model served as the basis for research to evaluate body composition. Then another two-compartment division was proposed, in which body composition was based on the division into adipose tissue (AT) and lean body mass (LBM). In this case, adipose tissue also includes non-lipid elements of adipocytes [1]. In 1950, a four-compartment model was created. The body weight was divided into water, protein, bones, minerals (ash), and fat. Another four-compartment division consisted of body cell mass (BCM), BF, extracellular water (ECW), and fat-free extracellular solids (FFECS). Later, in addition to extracellular water, intracellular water was also distinguished, constituting 55% of total water in the body [1,5].

Other methods for measuring body composition are computed tomography, magnetic resonance, air plethysmography, and dual-energy X-ray absorptiometry [7]. The research method used to measure the length of the human body or its parts and body's weight is called anthropometry.

The study aims to present a differentiation of methods of assessing body composition and anthropometric measurements. 29 scientific publications from the Pubmed and Google Scholar platforms were included.

Description of the state of knowledge

Bioelectrical impedance analysis (BIA)

Bioelectrical impedance analysis is a safe and easy to carry out method that allows us to determine the amount of water in the body, and then its composition by analyzing the resultant electrical resistance of the body to the current of low intensity and high frequency passed through it. Bioelectrical impedance is the resultant electrical resistance of the body, the total "obstacle" that body tissues pose to the current flowing through them, expressed in ohms [5,8,9]. It is based on the difference in electric current conductivity in the water and fat compartments [1]. BIA is a non-invasive, cheap, and reproducible method for measuring body composition not only in healthy people, but also in bedridden and not able to walk patients [8,9,10]. It is used in both sexes, in people of all age categories, regardless of their health condition [6]. The test is performed lying down or standing, depending on the device used for this purpose. There must be no objects such as jewellery, metal objects, zippers, or buttons in the measuring field [5]. The exclusion criteria are also: presence of metallic implants, limb amputation, presence of cardioverter, and pregnancy. Bioelectrical impedance analysis consists of measuring the electrical resistance of the body which includes reactance (largely due to the electric capacity of cell membranes, which act as capacitors due to their structure) and resistance (this phenomenon is related to individual tissues) [5,6]. In the case of measurement in the supine position, the subject's body is connected to the measuring apparatus by disposable surface electrodes stuck to the skin of the upper and lower limbs. The accuracy of the measurement is high, which results, for example, from the connection of the hand-foot electrodes. It allows the current to pass through a larger area of the body without the need to shorten the circuit [6]. The correct amperage and frequency of electricity are used [11]. The risk of measurement errors is initially estimated at 2% [1]. The measurement in a standing position is performed by the SECA mBCA analyzer or the Tanita body composition analyzer. The following manufacturer's recommendations should be taken into account to obtain reliable results: take care of all physiological needs before the measurement, avoid intense physical exertion, do not take a bath before the test, do not eat a meal at least 2 hours before the measurement, do not drink coffee, alcohol and taking diuretics, do not wear shoes and socks, do not perform the test during menstruation. The method assesses the following parameters: total body water (TBW), extracellular body water (ECW), intracellular body water (ICW), intercellular water, body cell mass (BCM), fat-free body mass (FFM), which means a mass of muscles and internal organs, and body fat mass (FM), a normal range for body fat, resting metabolism, lean body mass, total energy requirement, body density, body volume, protein weight, glycogen weight, mineral mass, cell mass, fluids containing proteins and electrolytes, extracellular mass, a mass of solutes, interstitial fluids, extravascular fluids [6,11]. TBW reflects primarily the body's fat-free mass. ICW is contained mainly in muscles and internal organs (to a very small extent in adipose tissue). BCM indicates primarily the mass of muscles and internal organs (excluding adipose tissue) and its changes are characteristic of some chronic diseases, such as AIDS or cancer [5]. The contraindications to the examination are metal implants, implanted pacemakers, and pregnancy [12]. Thanks to the bioelectrical impedance analysis, we obtain direct and indirect values. Direct parameters include impedance (Z), resistance (R), reactance (Xc), and cell membrane capacity (Cm). The values calculated using the formulas are intermediate parameters. These are phase angle (Ph), fat mass (FM), free fat mass (FFM), lean body mass (LBM), body cell mass (BCM), extracellular mass (ECM), total body water (TBW), and extracellular water (ECW).

Dual-energy X-ray absorptiometry (DXA) – densitometry

Dual-energy X-ray absorptiometry is used to accurately assess body composition and to measure bone mineral density [2,13]. DXA scans of total body are used to derive a body composition model, consisting of bone mineral content, fat-free mass, and fat mass [9,13]. The soft and bone tissue differ in the degree of absorption of two energies (43 and 110 keV), which makes it possible to determine the body fat content. Densitometry uses the phenomenon of weakening the ionizing radiation beam that penetrates through various tissues in the body. Both the whole body and its regions (limbs, abdominal cavity) are examined [1]. The X-ray tube is the source of radiation used in densitometry. Examination of any bone, despite the surrounding soft tissues, is possible thanks to the use of a beam of radiation with two energies by applying a pulse voltage change or filters on the tube [14]. X-ray absorptiometry allows the assessment of the total amount of adipose tissue and its types, such as subcutaneous fat and intraperitoneal fat [15]. The densitometric technique enables an accurate assessment of total and regional fat mass. In obese people, the assessment of adipose tissue in different regions of the body using X-ray absorptiometry may not be very precise. To calculate the amount of adipose tissue in different regions of the body, it is necessary to define anatomical landmarks, which in obese individuals might be difficult [16]. Scanning in the DXA examination takes place in the supine position, and the bodyweight of the examined person cannot exceed 130 kg due to technical limitations. The scans are analyzed by computer software. The content of fat and lean tissue is assessed [17]. The total radiation dose absorbed during the examination is approximately 10% of the dose absorbed during the chest radiograph. Densitometric testing allows for an accurate assessment of adipose tissue distribution. X-ray absorptiometry makes it possible to assess the amount of fat in different regions of the body. The test duration is approximately 20 minutes [18]. DXA is considered to be the gold standard for body composition measurements due to its safety, accuracy, non-invasiveness, and reproducibility [8]. The disadvantage of densitometry is limited availability, as it requires specialized equipment that generates costs [2].

Skinfold measurements

A skinfold caliper is a device used to measure skin and fat folds. It allows it to determine the size of subcutaneous fat stores [11]. This study is based on the assumption that the thickness of the subcutaneous fat is a reflection of the total body fat [19]. Approximately half of the body's fatty tissue is directly beneath the skin. It enables you to detect underweight or overweight. According to the device manual, the measurement of skin and fat folds is performed at anthropometric points, like biceps, abdomen, chest, scapula line, armpit line, calf, hip point, triceps, and thigh. Skinfold measurements should be taken directly on the skin, on the right side of the body, and the patient should stand. The advantages of this method are easiness, quickness, safety, and lack of contraindications to the test. Both women and men of all age categories, regardless of their health condition, can be examined. Prepubertal girls should use the same body fat percentage scale as boys. Skinfold thickness measurements can be used also in infants and are generally one of the best screening methods for individual assessment of body fat. However, the assessment of the skinfold thickness is considered to be an imprecise method [19].

Magnetic resonance imaging (MRI)/ computed tomography (CT)

Magnetic resonance imaging enables the visualization of human body structures, assessment of the chemical composition of tissues (MRS spectroscopy), imaging of water diffusion (diffusion, DWI, and diffusion tensor – DTI), and similarly to computed tomography it allows to distinguish two types of abdominal fat – visceral and subcutaneous [20]. Abdominal fat is quantified by tracing the inner walls of the abdominal cavity. They are delineated by the spine or the anterior surface of the aorta and the edges of the oblique abdominal muscles. Subcutaneous fat is assessed in the region between the outer surface of the abdominal muscles and the skin [15]. In the case of fat tissue assessment using computed tomography, the so-called reconnaissance image is made. It enables to accurately determine the position of the scan, located at the level of the intervertebral space between the fourth and fifth lumbar vertebrae [3,18]. Computed tomography and magnetic resonance imaging have some limitations, like the high cost of the examination and the need to employ staff with a high level of technical skills. Magnetic resonance imaging, unlike computed tomography, does not expose the examined person to X-rays [10].

Air displacement plethysmography (ADP)

It is a quick and non-invasive method of measuring body volume. It is used to calculate the total body density and its composition. Total adipose tissue and lean tissue are measured. During this test, the body is placed inside a sealed chamber with a changing volume in which air moves. The volume of displaced air is determined based on the change in its pressure [21,22,23]. The duration of this measurement is approximately 5-8 minutes/person [21]. This method is used in adults, children from 5 years of age, and infants from birth to 6 months of age (8 kg). The use of air displacement plethysmography is limited in children from 6 months to about 5 years of age due to the intolerance of this method by children in this age range [23].

Body mass index (BMI)

Body mass index, which is one of the most widely used measures and also known as the Quetelet II index, is calculated by dividing body weight in kilograms by the square of height in meters. The value is given in units of kg/m^2. BMI indicates quite generally a regularity or disturbance of body weight, but does not allow to determine body composition. Body mass index makes it possible to recognize disturbances of the body weight to height ratio [5,24].

Table 1. BMI values, interpretation and risk of developing diseases related to improper body mass according to the World Health Organization [24].

BMI range	Interpretation	The risk of developing diseases
<16	III degree of thinness	severe malnutrition
16-16.99	II degree of thinness	increased malnutrition
17-18.49	I degree of thinness	moderate malnutrition
18.50-24.99	correct values	the lowest risk
25.00-29.99	overweight	pre-obesity condition
30.00-34.99	I degree of obesity	moderate risk
35.00-39.99	II degree of obesity	increased risk
≥40.00	III degree of obesity	serious risk

Growth charts in children

When assessing the nutritional status of children and adolescents up to 18 years of age, percentile growth charts appropriate for the age and sex of the children are used [24]. In particular cases, it is more appropriate to use charts illustrating the relationship between body weight and height, while the BMI index should be used to assess the groups [25]. In younger children, the Cole index (LMS – least mean square) is usually used to assess body composition. The formula for calculating LMS is as follows: LMS = [(MR [kg] x WS [m]^2)/(MS [kg] x WR [m]^2)] x 100 [%], where MR – actual body weight of the tested child, WS – standard height for the age and sex of the tested child, WR – the actual height of the tested child (50th percentile for a child of a given age), and MS – standard body weight for the age and sex of the tested child (50 percentile of body weight for a child of that age). LMS is normal when it is in the range of 90-110%, overweight occurs at values of 111-120%, and obesity at values >120% [26]. Cole index needs a comparison of the patient's height and weight with gender and age values in a growth chart. It is not essential when calculating BMI, which makes BMI a better tool for evaluating the degree of nutrition [19].

Waist to hip circumference ratio (WHR)

Waist to hip circumference ratio is calculated by dividing the waist circumference [cm] by the hip circumference [cm]. The indicators of risk are ≥0.85 for women and ≥1.0 for men. WHR assesses lower and upper body fat distribution and place of its storage. An elevated WHR signals a high risk of health problems related to obesity. Men present more frequently excess body fat in the upper part of the body, while women – in lower parts [21].

Examples of assessing body composition and anthropometric measurements in research among different age groups

Children and youth

Jakubowska-Pietkiewicz et al. presented the results of the study in which 56 children aged 6-18 years at the Regional Centre of Menopause and Osteoporosis at the Clinical Hospital No. 3 of the Medical University of Lodz were enrolled. Anthropometric measurements of height, weight, waist and hip circumference, and the thickness of the skin and fat folds were performed in 23 girls and 33 boys. Medical scales (SECA) were used to assess body weight with an accuracy of 0.1 kg. Body height was measured with a Martin anthropometer with an accuracy of 0.1 cm. A tailor's tape was used to measure the waist circumference with an accuracy of 0.5 cm. The measurement was performed twice. The fold meter was used to measure the thickness of two skin and fat folds: above the triceps muscle of the shoulder and under the scapula with an accuracy of 0.1 mm. The average of three measurements was used in the analysis. Densitometry was performed using the Prodigy apparatus from GE Lunar (Madison, USA) using the dual-energy X-ray absorptiometry (DXA) method. Total body fat was assessed and bioelectrical impedance analysis (BIA) was performed using a Tanita Corporation balance. Slaughter's algorithm was used to assess the content of adipose tissue based on anthropometric tests. High correlations were obtained between the results of measuring the percentage of body adipose tissue in bioimpedance – DXA ($r^2 = 0.83$, $p < 0.001$) and Slaughter's method – DXA ($r^2 = 0.87$, $p < 0.001$). However, the percentage of adipose tissue determined using bioimpedance and Slaughter's algorithm in comparison with densitometry was underestimated [2].

The subject of body composition research was also described by Kolmaga et al. who examined 161 students aged 15-17. Measurements were made of the waist circumference, weight, and body height in 78 boys and 83 girls. On this basis, the body mass index (BMI) was calculated and the body composition was determined using the electrical bioimpedance method (BIA). Adipose tissue, body water, and lean mass were measured with the Bodystat 1500 MDD device. Based on the test results, it can be concluded that the values obtained (except for BMI) were within the correct range. The surveyed girls have lower average body weight values compared to boys of equal age. Individual distribution of BMI in adolescents of both sexes revealed abnormalities – underweight in 3.1% of students (including 3.6% of girls and 2.6% of boys), overweight was found in 21.1% of the examined adolescents (including 13.1% of girls and 17.9% of boys), and obesity in 5.6% of the youth (including 2.4% of girls and 9.0% of boys) [27].

Students

Janiszewska described the research which assessed 65 students between 21 and 23 years old from the university in Radom. The subjects were divided into two groups depending on the level of physical activity. One group contains physically active people, while the other group – physically passive people. Bioelectrical impedance (BIA) was used to assess the body composition of both study groups. Measurements such as body height and weight, subcutaneous and visceral adipose tissue, BMI, percentage of muscle tissue, and resting metabolism were performed. The research showed that students with low physical activity had 11 kg more average body weight, 3.36 kg/m² more BMI, 7.5% higher content of subcutaneous fat, and 3.17% higher visceral fat in comparison with a physically active group. In the group of physically active students, the average content of muscle tissue was higher by 4.3% higher and the resting metabolism was lower by 131 in comparison with the less active group. Analysis of BMI index indicates that in over 60% of passive students it is above normal. In this group in more than half of the students, the BMI value exceeded 25 kg/m² and in 12% it was higher than 30 kg/m². In the group of active students, 20% of them were classified as overweight and obesity was not found in any student [28].

Adults

Major-Gołuch et al. described a study that included 145 women aged 22-40. The weight of adipose and lean tissue and the percentage of fat were measured with the LUNAR Prodigy (DXA) densitometer and the Tanita BC 420 SMA (BIA) body composition analyzer. The average percentage of fat content was 32.05 ± 5.2% measured by DXA method and 26.05 ± 5.1% in BIA ($p < 0.02$). Bioelectric impedance compared to DXA showed good specificity

(96%), but low sensitivity (35%) in young, healthy women with normal body weight and fat percentage above 30% [7].

Seniors

Ignasiak et al. tested 31 women with an average age of 67 years. Body composition tests and measurements of somatic features were performed, such as height (measured with an anthropometer with an accuracy of 0.1 cm), body weight (measured with an electric scale with an accuracy of 0.1 kg), and waist and hip circumference ratio (measured with a tape with an accuracy of 0.5 cm). BMI and WHR were calculated. The FUTREX 6100 apparatus was used to assess body composition. The results showed that the distribution and average BMI values in the analyzed material indicate the presence of abnormal weight-height ratios in almost 78% of women, including overweight in 52% and obesity in 26% of seniors. Increased WHR values (> 0.86) was noted in 37% of women. The average percentage of adipose tissue in the total body weight reached almost 41%, which was alarming. This value far exceeded the upper limit of normal. It is assumed that the amount of adipose tissue in women should not exceed 32% of the total body weight. In the analyzed group, this limit was exceeded by 96.3% of women [29].

Conclusions

There are many devices and methods for measuring body composition and for anthropometric measurements. They are important in assessing human growth and development and are also a significant element in examining nutritional status in several pathological conditions in different age groups. The choice of the most suitable method depends on their advantages and disadvantages, parameters currently needed for the evaluation, and possible equipment at our disposal.

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