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Body composition measurements in paediatrics – a review. Part 1

Metody pomiaru składu ciała w pediatrii – przegląd. Część 1

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Abstract

Overweight, obesity, and metabolic syndrome in paediatrics represent issues of increasing importance. To complete diagnostics and extend patient monitoring, body composition measurements can be used. Nowadays there are a number of methods that allow the estimation of the content of individual tissues. Their accuracy and replicability, contributing to the measurement's credibility, are the subject of numerous scientific publications. While choosing a method, one has to know its basic assumptions and be aware of the assets and weaknesses, as well as its cost. The mentioned aspects will be discussed in this article. Reference methods considered as most precise are multicomponent models (3C, 4C), requiring several (usually three) measurements with the use of various devices, which improves the precision of calculating the fraction of a given body composition component (fat, water, minerals, and/or protein). Therefore, the need to estimate tissue content with mathematical models can be minimised. The choice of the methods forming a multicomponent model differs depending on the place of the examination. However, the 3C and 4C models are time-consuming and require sustained cooperation with young patients. Moreover, measurements can only be taken by trained staff that use expensive, specialised equipment. The examination cost can be reduced by the use of screening methods, such as anthropometrics and more advanced bioelectrical impedance analysis (BIA). Due to published comparisons with reference methods, the precision limits of screening methods are known. However, when executed correctly, measurements obtained with these methods have an acceptable replicability and can become a valuable tool in everyday practice.

Key words:
overweight, obesity, body composition, body mass index, anthropometry, bioelectrical.

Streszczenie

Nadwaga i otyłość oraz choroby metaboliczne stanowią w pediatrii zagadnienie o narastającym od dekad znaczeniu. Chcąc uzupełnić metody diagnostyczne i poszerzyć zakres monitorowania pacjentów, w praktyce lekarskiej można korzystać z pomiarów składu ciała. Współcześnie istnieje wiele metod pozwalających na oszacowanie zawartości poszczególnych tkanek. Ich dokładność i powtarzalność składające się na wiarygodność pomiaru stanowią przedmiot licznych opracowań naukowych. Sięgając po daną metodę, warto znać jej podstawowe założenia oraz mieć świadomość zarówno jej zalet, jak i ograniczeń czy kosztów. Wymienione aspekty omówiono w niniejszej pracy. Za najdokładniejszą, referencyjną metodę uznaje się modele wielokomponentowe (3C, 4C), wymagające wykonania kilku (zazwyczaj trzech) pomiarów za pomocą różnych urządzeń, co służyć ma jak najdokładniejszemu obliczeniu udziału danej komponenty składu ciała (tkanki tłuszczowej, wody, składników mineralnych i/lub tkanki mięśniowej). Dzięki temu do minimum ogranicza się konieczność szacowania zawartości tkanek za pomocą modeli matematycznych. Dobór metod pomiaru składających się na model wielokomponentowy różni się w zależności od ośrodka, w którym przeprowadzane jest badanie. Metody 3C i 4C są jednak czasochłonne i wymagają długotrwałej współpracy ze strony młodych pacjentów. Ponadto pomiar może wykonać tylko przeszkolony personel korzystający ze specjalistycznego, kosztownego sprzętu. Koszt badania zostaje radykalnie ograniczony przy stosowaniu metod przesiewowych, do których zaliczyć można tradycyjne pomiary antropometryczne oraz bardziej zaawansowaną analizę impedancji bioelektrycznej. Dzięki dostępnym w piśmiennictwie porównaniom z metodami referencyjnymi znane są ograniczenia dotyczące

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dokładności metod przesiewowych. Uznaje się jednak, że prawidłowo przeprowadzone za ich pomocą pomiary cechują się zadowalającą powtarzalnością i mogą stanowić cenne narzędzie w codziennej praktyce.
Słowa kluczowe:
nadwaga, otyłość, skład ciała, wskaźnik masy ciała, antropometria, impedancja bioelektryczna.

Introduction

Reports prepared by the World Health Organisation (WHO) and epidemiological studies have reported a consistently increasing incidence of overweight and obesity in children for the last 30 years. These data refer mainly to developed countries; in North America and Europe the incidence rates of overweight and obesity in the paediatric population reach 40% [1]. Data from Poland do not determine unequivocally the trend among Polish children. According to research conducted under the supervision of the Institute of Mother and Child, 30.7% [2] of second- and third-grade schoolchildren and 18% of teenagers [3] are overweight or obese. Population research on a representative group of children and adolescents (7-18 years) determined the incidence of overweight and obesity in relation to international standards of body mass index (BMI) as 18.7% in boys and 14.1% in girls [4]. Body mass index is widely used to diagnose overweight, because it allows us to determine quickly its presence in relation to growth charts. However, considering dynamics of growth in adolescence and individual variability [5], the index is not a useful tool in assessing the presence of excess adipose tissue [6]. The scale of the obesity problem and the awareness of its relationship with numerous complications, such as metabolic syndrome (in which pathogenesis not only the excessive body mass matters, but even more the increased adipose tissue content and its improper distribution [7]), create the need for wider diagnostics and careful monitoring of the treatment. Proper assessment of the participation of particular tissues in the body structure requires the use of specific measurement methods. In practice indirect body composition measurements are used, in which, on the basis of the knowledge of physical properties of tissues, their contents are measured in the body, and then, using mathematical formulas, the contribution of individual compartments is estimated [8]. Measurements are divided into two- and multi-component ones. A single test usually provides information on the content of one type of tissue, most often fat (fat mass – FM), with the remaining mass qualifying as fat-free (fat-free mass – FFM); in this way a two-component model (2C) is created. Other methods, including e.g. water content in the body (total body water – TBW), allow the next component to be isolated, creating a three-component model (3C) [5]. The four-component model (4C) is considered to be the gold standard, requiring several independent measurements in the examination of one patient. Owing to this, it is additionally possible to extract the content of protein and minerals from the lean body mass, ensuring the highest accuracy analysis among the available methods [9]. It is possible thanks to the densitometry examination with the double X-ray technique (X-ray dual-energy absorption – DXA) completed with the body volume measurements (body volume – BV) and TBW [10]. Body composition measurements are applicable not only in the fight against the obesity epidemic, but also in paediatric oncology [11] and monitoring of treatment and complications in chronic diseases [12]. The methods used are characterised by variable accuracy of measurements and require the use of a variety of equipment, and multi-component models can be created with different combinations of these tests [13]. The following paper presents an overview of the methods available in paediatrics for body composition measurements, taking into account their accuracy and the possibilities of clinical use. The current part discusses multicomponent models (considered to be the most accurate), screening of two-component anthropometric methods, and bioelectrical impedance analysis (BIA).

Multi-component models

The four-component model (4C) [14] is considered to be the gold standard in body composition measurements. It is intended to provide more precise results than simple methods because it presupposes, apart from the fat content assessment, an accurate measurement of various components of lean body mass instead of assessment based on constant values of tissue density and water content in the body. In order to obtain the results, as well as weighing the patient, it is necessary to perform three independent measurements with various methods to measure individual parameters: body volume, bone mineral content (BMC), and water content in the body [13]. A typical set of methods that make up the 4C model includes BV measurement with ADP or HW (hydrostatic weighing), BMC with DXA, and TBW with D_2O (deuterium oxide). Depending on the availability of devices to make a given measurement, TBW can also be obtained using the BIA method [15]. An alternative approach to creating multi-component models assumes the measurement of potassium content in the body, which allows accurate assessment of the muscle mass and protein, and thus the identification of all key components of lean body mass (TBW, BMC, protein) [16]. However, this is a highly specialised method with very limited access. Therefore, in most studies, protein content is included in the remaining FFM.

The advantage of using a multi-component model in children is elimination of the assumptions of a constant proportion of the relevant tissue content in the body. These values change significantly as children grow up, and this process does not occur in every child at the same pace [9]. In clinical practice, each body composition measurement with the 4C model would be too time-consuming and would require constant access to devices that measure the components of this model and the participation of personnel trained in carrying out measurements with each of the required methods. There are attempts to simplify the creation of the 4C model by combining the measurement of two components using one method, e.g. BV using DXA instead of ADP or HW. This solution has been proposed so far in adult studies [17]. The search for this type of improvement may be important in the studies carried out on the paediatric group because in the case of children the preferable methods are those that allow faster achievement of the desired effect and require shorter cooperation on the patient's part [18].

In a few studies, the 3C model appears as the reference method, which extracts only TBW from the body lean mass, but does not require the use of the DXA method [19]. As a result, the body composition is divided into the following compartments: FM, TBW, and FFM. Determining the accuracy of simple, two-component methods in comparison with the 3C model does not raise any objections and allows a reliable comparison in the lack of availability of DXA or other technique provided in 4C.

The most advanced models include the use of special formulas or methods, such as neutron activation analysis [20] to measure the content of minerals in soft tissues and glycogen, making it possible to create five- or even six-component models [18]. These models are used in individual studies in groups of sportsmen [21], and their discussion goes beyond the scope of the current study.

Anthropometric body composition measurements

Anthropometry, due to the simplicity of measurements and low cost, is a commonly used group of methods for assessing body composition, in particular the content of adipose tissue [22]. Practical applications are primarily body mass measurements, BMI, waist circumference, and skinfold thickness.

Body mass

Body mass measurement plays a key role in assessing the nutritional status of both adults and children. Together with height, this parameter is used to estimate the fat content using the body mass index. Assuming that the most variable body component is adipose tissue, changes in body mass may serve as an independent determinant of fat content fluctuation [5]. In order to increase the accuracy of measurements, the test should be carried out in light clothes and without shoes, and in the youngest children – with a dry diaper [22]. However, it should be remembered that, apart from clothing, the level of hydration or the presence of oedema also affects the obtained values, which, together with the daily variability of obtained results, reaching up to 0.5 kg and more, limits the predictive value of this method [5].

Body mass index

Body mass index, obtained from the formula: weight (kg)/height (m)^2, is the most frequently used tool for assessing relative body mass and nutritional status [9, 23]. It is a faster and more intuitive tool for assessing the degree of nutrition than the Cole index (CI). Cole index, shown as a percentage and calculated on the basis of the formula (body mass $\times$ standard body length)^2/(standard body weight $\times$ body length^2), requires a comparison of the patient's height and weight with gender and age values in a growth chart, which is not is necessary when calculating BMI. The assessment of BMI is important in assessing the risk of diseases associated with increased body weight, such as type 2 diabetes or coronary heart disease in adults, but its use in children and adolescents is questionable. Body mass index does not differentiate between adipose tissue and lean body mass, which may lead to misinterpretation of the results obtained, both among malnourished people, who tend to increase relative fat tissue and decrease FFM, as well as in sportsmen with increased muscle mass in relation to fat content [9]. In addition, difficulties in developing a range of normal values due to the natural changes in the body composition of growing children significantly reduce the usefulness of the indicator in the paediatric population [23]. Therefore, BMI should not be used as the only method for assessing the body fat level of the subject [22].

Waist circumference

Waist circumference (WC) is the basic method of assessing abdominal obesity and predicting its adverse effects, such as insulin resistance or lipid metabolism disorders [9], and it is an equally effective technique for assessing total obesity as BMI [22]. The measurement is carried out in a standing position at the level of the navel or halfway between the rib arch and the iliac crest. WC lacks universal recommendations due to the proven dependence of the results obtained on age, gender, height, and ethnicity. Some conditions, such as constipation or ascites, may also limit the accuracy of this method [22].

The modification of this technique, also used for the estimation of central obesity, is the ratio of the waist to the hip (waist-hip ratio – WHR) measured in the upright position at the widest point of the hips and buttocks. However, it should be remembered that WHR values decrease with the age of the child due to the natural increase in the size of the pelvis, especially marked in girls. What is more, people with higher BMI and with even body fat distribution may have WHR values comparable to patients with lower BMI, which is the greatest disadvantage of this technique [22].

Skinfold thickness

Skinfold thickness is the measurement of the thickness of two layers of subcutaneous adipose tissue by pinching them with a body fat calliper [22] in selected areas of the body (most often at biceps and triceps, subscapular, supraumbrilical, and thigh areas). It is assumed that the thickness of subcutaneous fat measured this way reflects its total content in the body [24]. The method gives comparable results to the 3C and DXA models in estimating the average fat content in group measurements and is also the best screening technique for individual assessment of body fat, which can be used also in infants [5, 9, 25]. The disadvantage of the presented technique is first of all the necessity to use the formulas developed to determine the body composition, which limit its use to the population for which they were created [5, 9]. The assessment of the skinfold thickness is considered to be an imprecise method, with a tendency to increase the occurrence of errors together with the increase in the adipose tissue content and the age of the subject [5, 9, 22, 24]. Limited precision also results from the variety of available body fat callipers, differences in the selection of measurement sites, or techniques of skinfold by examining subjects [24]. Although the investigator's experience and constant quality control allow more replicable results to be obtained [5], this method should be used only for screening body composition [9]. Taking into account the advantages and disadvantages of the presented methods, it can be concluded that anthropometric measurements are sufficient for general diagnostics of overweight and obesity in children, while more advanced and accurate techniques should be used for further detailed examination of body composition [22, 26].

Bioelectrical impedance analysis

Bioelectrical impedance analysis is a popular, non-invasive method of body composition measurement, based on the presence of differences in the electrical impedance of individual tissues, which is generated by electric current at a specific frequency [27]. As a screening indirect measurement method, BIA requires the use of equations with certain assumptions. They concern the geometry of the examined body (the cylinder volume depends on the measured body mass and on data of the subject height entered into the device), the uniform distribution of tissues in the body and the constancy of the environment in which the measurement is made [28]. The non-conductive FM mass is isolated, and dry cell mass (which consists of protein, bone mass, and electrolytes) and TBW divided between intracellular fluid (ICF) and extracellular fluid (ECF) can be estimated from the remaining FFM. These estimates are elaborated on the basis of appropriate formulas, which, especially in paediatric groups, should take into account variables such as age, gender, and ethnicity. The level of nutrition and physical activity and the proportions of the limb length to the patient's torso also influence the analysis course. The inhomogeneity of the group and the lack of appropriate modifications of the equations limit the reliability of the study [27, 29, 30].

There is a high commercial availability of devices that allow the body composition measurement by the BIA method. They differ technologically. Therefore, it is possible to distinguish devices generating a signal with one or more frequencies (in the range of 5-200 kHz) and using a different number and arrangement of electrodes in foot-foot configurations (leg-to-leg/foot-to-foot), hand-to-foot, and hand-to-hand [31]. Newer devices present the analysis results for five separate body segments – four limbs and torso, allowing the estimation of the distribution of adipose tissue within the body [5]. The multitude of available solutions is conducive to the widespread use of BIA, but it limits the possibilities of comparing the results obtained by means of various devices, and even more by different methods. This is shown by studies in which the body composition of the test group was measured in the same conditions with a different number of devices, location of electrodes, and frequency of current used. The compared analysers showed variable compliance of the fat percentage (% BF) and FFM with the reference method (DXA) in paediatric groups; however, it is impossible to determine which BIA model would be the most accurate [32].

The advantages of BIA in the context of usefulness in clinical practice undoubtedly include the simplicity and quickness of analysis and the relatively low cost of the apparatus. The measurement can be carried out by one person after basic training. Modern analysers resemble a scale with a built-in display and electrodes, which should be in contact with bare skin during the measurement. Depending on the type of device, it is required that the patient stays still, usually in a standing position (in the case of traditional hand-foot electrodes, the position should be lying), from a few dozen seconds to several minutes. In order to ensure credibility and repeatability, each study should be conducted to meet certain conditions. The patient should be properly hydrated, optimally on an empty stomach, and avoid intense exercise for 12 hours before the test, and for a few hours should not take diuretics or caffeine. The patient should be dressed lightly and loosely, should not wear jewellery, and should not use creams for hands or feet immediately before the test [28].

Bioelectrical impedance analysis is the subject of numerous comparisons with methods considered as reference, such as DXA [32], ADP [33], D_2O [34], or HW [35], or multi-component methods [19]. The research provides ambiguous data on the accuracy of BIA; depending on the publication, it is indicated that there is a tendency to overestimate [35] or underestimate [32] FM or the BF percentage. Regardless of differences in the compliance of measurements with BIA and reference methods, a high correlation between the obtained results is observed [36]. While maintaining repetitive analysis conditions, BIA is an invaluable help in monitoring changes in body composition in individual patients [37]. An interesting direction is also the development of norms specific for a given population of parameters measured by BIA [38].

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