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Body composition measurements in paediatrics – a review. Part 2

Metody pomiaru składu ciała w pediatrii – przegląd. Część 2

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Abstract
With the increasing recognition of overweight, obesity, and metabolic diseases in paediatrics, there is a need to apply more precise diagnostic methods to individualise the procedures and improve their monitoring. Advanced methods of evaluating body composition are a valuable addition to body weighing because they provide more precise data than screening methods such as anthropometry and bioelectrical impedance analysis (BIA). However, they require expensive equipment and highly trained staff. The availability of methods used in paediatrics is increasing. The article discusses the technical assumptions and summarises data from literature concerning the accuracy of chosen methods. From those, dual-energy X-ray absorptiometry (DXA) is distinguished as being widely accepted. Not only does it serve to evaluate bone density, but also to assess fat mass, making it a crucial element of multicomponent models (3C, 4C), which is often used separately as a reference method for other techniques. Methods based on body volume measurement are also of great importance. Traditionally they include hydrodensitometry (HW), which is being displaced by air displacement plethysmography (ADP), which is more acceptable among young patients. Numerous publications indicate that ADP may become a valuable alternative for widely used DXA. Isotope dilution methods are less popular in paediatrics, due to their cost and limited credibility, but are more commonly used among adults. The last group comprises imaging methods rarely used in the discussed indication. With the knowledge of available techniques and current clinical situation one can, for the patient's benefit, decide between screening and advanced techniques of body composition measurement.
Key words:
overweight, obesity, body composition, body mass index, densitometry, plethysmography.

Streszczenie
Wraz ze wzrastającą częstością rozpoznawania nadwagi i otyłości oraz chorób metabolicznych w pediatrii pojawia się konieczność stosowania dokładniejszych metod diagnostycznych w celu indywidualizacji postępowania oraz usprawnienia jego monitorowania. Istotnym uzupełnieniem pomiarów masy ciała są zaawansowane metody oceny jego składu. Dostarczają precyzyjniejszych danych niż metody przesiewowe, takie jak pomiary antropometryczne i analiza impedancji bioelektrycznej. Wymagają jednak stosowania kosztownego sprzętu oraz udziału wysoce wyszkolonego personelu. W ciągu ostatnich lat wzrosła dostępność metod odpowiednich do zastosowania w pediatrii. Publikacja zawiera omówienie technicznych założeń oraz podsumowanie dostępnych w literaturze danych na temat dokładności wybranych metod. Wśród nich, jako powszechnie uznana, wyróżniana jest densytometria techniką podwójnej wiązki RTG (DXA). Służy nie tylko ocenie gęstości mineralnej kości, lecz także oszacowaniu masy tłuszczowej. Z tego względu stanowi kluczowy element modeli wielokomponentowych (3C, 4C), a często sama jest wykorzystywana jako metoda referencyjna dla innych technik pomiaru. Ważną rolę odgrywają techniki oparte na pomiarze objętości ciała. Tradycyjnie uwzględniają one hydrodensytometrię (HW), która jest wypierana przez bardziej przyjazną dla młodych pacjentów pletyzmografię wypornościową powietrza (ADP). Liczne publikacje wskazują, że ADP może stanowić cenną alternatywę dla powszechniej stosowanej DXA. Do mniej popularnych, ze względu na koszt i ograniczoną wiarygodność w pediatrii, zaliczane są, szerzej uznane w populacji dorosłych, metody rozcieńczenia izotopów. Ograniczona rola współpracy pacjenta czyni je jednak interesującym kierunkiem badań w pediatrii. Ostatnią grupę stanowią

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techniki obrazowe, rzadko wykorzystywane w omawianym wskazaniu. Dysponując wiedzą na temat dostępnych technik i mając na uwadze bieżącą sytuację kliniczną, można z korzyścią dla pacjenta wybierać między metodami przesiewowymi i zaawansowanymi.
Słowa kluczowe:
nadwaga, otyłość, skład ciała, wskaźnik masy ciała, antropometria, impedancja bioelektryczna.

Introduction

The first part of the review discusses the multi-component models (3C, 4C) considered to be the gold standard and screening methods, such as anthropometric measurements of body composition and bioelectrical impedance analysis (BIA). This section presents advanced methods that allow assessment of body composition by means of a single measurement, which include densitometry by double-ray X-ray technique (DXA), air displacement plethysmography (ADP), isotope dilution method (e.g. deuterium – D_2O), and imaging methods. The discussion of air displacement plethysmography was also preceded by a paragraph describing the traditional technique, i.e. hydrodensitometry (hydrostatic weighing – HW), in order to present in a complete way the methods of evaluating body volume (BV).

Densitometry with double-ray X-ray technique

Dual-energy X-ray absorptiometry body composition measurement is based on differences in the extent of X-ray absorption by different types of tissues. As a result, it is possible to obtain a proportion of bone and soft tissue contents and, through appropriate algorithms, fat content (fat mass – FM) and lean body mass (fat-free mass – FFM) [1]. In clinical practice DXA plays a role in the diagnosis of bone diseases because its primary application is bone mineral density (BMD) [2]. By allowing the extraction of bone mineral content (BMC), FM and FFM, and BV measurement (body volume), DXA can be responsible for more than one parameter in the multi-component models, and also can be used independently to develop the 3C model [3]. Although the method requires the use of X-rays, the doses used are widely recognised as harmless, also for children [4]. The dose to which the patient is exposed during a one-time measurement corresponds approximately to one-day exposure to natural background radiation [5]. Depending on the equipment available, the test lasts from a few to several minutes and requires the patient to be kept motionless in the designated space between the source of the radiation beam and the detector. In many cases, however, this space is so limited that it does not allow the measurement of older, obese children to be conducted [6]. There are reports claiming that this problem can be eliminated by making measurements of obese children only on the half of the body, without any loss of the study's credibility [7].

Dual-energy X-ray absorptiometry is often used as a reference method to assess the accuracy of other indirect methods [8]. However, the results of studies on the paediatric group do not determine its high compliance with the multi-component models, especially in cases of groups with fat content that is too low (states of malnutrition) or too high (obesity) [6]. Despite these limitations, DXA is considered a reliable method recommended for use both in scientific research and clinical practice [9].

The development of the measurement technique with the DXA method has led not only to its increased accuracy, but also its use in extreme age groups, such as infants [10] or even preterm infants [11]. Lack of age restrictions is an important advantage of DXA as compared to other two-component methods. To perform the measurements, pharmacological sedation is not usually necessary; examination of the youngest patients is performed during their sleep or they are made motionless within the apparatus [10, 11]. An important advantage of DXA is that standards have been developed in research of healthy children in specific age groups in many countries [8, 12], thanks to which the researchers do not have to rely only on the reference values provided by the producer of the apparatus. However, the developed standards should be interpreted with caution, due to use of different apparatus and software [5].

In contrast to more advanced but more expensive and less available techniques, such as computed tomography (CT) and magnetic resonance imaging (MRI), DXA does not distinguish soft tissue types (muscles, internal organs) [5]. With modern software it can provide information on fat distribution in the body by distinguishing visceral fat [12]. In this way, DXA is used to assess the risk of cardiovascular and metabolic complications. In recent years, it has been proven that the measurement of this parameter in children with DXA shows a high correlation and no significant differences in relation to CT, considered to be the reference method [13].

Although there are no absolute contraindications to conducting the DXA measurement, there are situations in which another method should be considered – for example, in pregnant patients, when exposure to radiation is to be avoided [2].

Dual-energy X-ray absorptiometry is undoubtedly a well-researched, credible, and secure method. However, due to the high cost of equipment and the need for measurements performed by trained personnel [1], it is not suitable for use in paediatric clinics in smaller health care units.

Hydrodensitometry

Another technique of body composition measurement included in the group of two-component methods is hydrodensitometry (hydrostatic weighing HW). The assumption of this technique is the calculation of the patient's body volume based on Archimedes' law and the use of body density data to assess the proportion of adipose tissue and lean body mass, using the knowledge of the constant density of these components [14]. The disadvantages of HW are: the long test period (in total about 75 minutes), the need for additional training, and total immersion of the patient in water, which make it difficult to obtain reliable results in children and represent a significant problem limiting the use of this technique in younger patients [15], although the method was considered in the past the gold standard for density measurement as well as for the body composition. Currently, it is mainly used in research works as a reference method for assessing body composition, especially for validation of another densitometric method, which is air displacement plethysmography [14-16].

Air displacement plethysmography

A method of increasing popularity as an alternative to the traditional methods of assessing body composition in the paediatric group is air displacement plethysmography. Based on basic gas laws, this technique is simple to do and does not require immersion in water, as it does in the case of HW [17].

The test is performed with a plethysmograph, which uses whole-body densitometry (density = mass/volume) to define by computer the fat and lean body mass ratio. Based on Boyle's law, the device uses air to calculate the volume, which is the main difference and the advantage of this method over HW. During the measurement, the movements of the membrane between the test and reference chambers induce small changes in volume and pressure. The patient's body volume is obtained by measuring the difference between the volume of air in the empty test chamber and after the patient's entering. Unlike HW, where full exhale is required during the test, free breathing is allowed during ADP measurement. Temperature measurement in the chamber is not required, but the air inside it is compressed and expanded adiabatically, i.e. it can lose and gain heat freely without affecting the measurement values. In turn, air trapped in the lungs, between the skin and the patient's clothes, and between the hair, as isothermal air, compresses much more easily than adiabatic, causing the lowering of the calculated patient's volume [1]. To minimise this effect, the patients wear swimming caps and swimsuits and adjustments are made taking into account the body surface and the thoracic gas volume (TGV) during normal breathing [18].

Air displacement plethysmography can be used to measure body composition in every age group [1]. Introduced in 2004 by the Cosmed company, the PEA POD system enables the examination of infants who weigh up to 8 kg, giving consistent results with other methods of body composition measurement [19]. Studies assessing the effectiveness of the system BOD POD (Cosmed) used for measuring adults give promising results also in the group of children from six months to six years of age [14-16]. Recently, the remaining gap in the possibility of interpreting ADP results in the group of children from six months to six years of age, due to the patients being too small to use the BOD POD system but being too heavy to use the PEA POD system, can be minimised thanks to the paediatric option of the BOD POD system (2008-2009).

The changes introduced in the software and the adjusted chamber, limiting children's movement, enable an accurate and credible assessment of the percentage fat content in children in the above-mentioned age group [20].

Undoubtedly, the advantages of this technique are convenience, non-invasiveness, safety, including the lack of exposure to radiation, and the speed of measurement [17]. In addition, ADP is a method adapted for use and accepted in many groups of patients: adults and children, obese or disabled [18].

The technique, although gaining popularity, is not perfect. Like other two-component methods, ADP takes into account the assumption of constancy of lean body mass properties, which in fact change with the age and maturity of the body, as well as in states of dehydration or overhydration, which can have a significant impact on the results [21]. The results obtained through it depend to a large extent on environmental factors – temperature, pressure changes caused by opening/closing doors in the room, movement, and regular breathing of the patient (yawning, grunting, breath holding) [18, 19]. The selection of an appropriate system (BOD POD, PEA POD) also plays an important role because the accuracy of the method depends on the patient's height and weight; when the volume of the patient decreases in relation to the chamber volume, measurement errors increase [17].

In comparison with the gold standard represented by the 4C model, ADP lowers the fat content (%BF) by 2-3% [18]. The results obtained by the two-component group techniques are also not consistent. Comparison of ADP with the reference method of body volume measurement, HW, showed good agreement in the assessment of body composition in children [14, 17]. However, there are many studies showing statistically significant differences in the results obtained by the above methods (overstated %BF by ADP), which is particularly marked in the smallest children [15, 16]. On the other hand, when comparing the results obtained by this technique with the values obtained through the DXA method, considered to be highly accurate, a significant correlation and compliance in the% BF range is observed [22].

Promising, although inconsistent, conclusions regarding the consistency of results obtained with the ADP and other methods of body composition assessment with ever better availability of plethysmographs, simplicity, and the ability to carry out measurements in a broad age group, encourage further research on the use of this method in common practice.

Isotope dilution method

This method is based on the measurement of total body water (TBW), which allows the calculation of the approximate FFM, using the formula: TBW/hydration constant, dependent on age and gender [23]. The test requires oral administration of a stable isotope-labelled (hydrogen, deuterium, oxygen-18) fluid (water, milk, juice). After reaching the equilibrium state of the isotope in the body (2-3 h after administration of the marker), a sample of saliva, blood, or urine is taken to analyse the saturation of the fluid with a marker. The analysis is carried out using isotope mass spectrometry [24].

The isotope dilution method, including the most widely used deuterium oxide dilution method (D_2O), considered as a reference for TBW assessment, is often used to assess the accuracy of other techniques [23, 25]. The test is safe, easy to carry out, and requires minimal cooperation on the part of the patient, which can be used in the measurement of newborns and infants [21]. Some authors, however, consider using this method in the given age groups as controversial due to technical difficulties resulting from physiological differences in the youngest patients [26].

However, evaluation of TBW by the isotope dilution method is time-consuming and requires adequate laboratory facilities, which may limit the use of this technique on a large scale [24]. Like the other two-component techniques, the method assumes the constancy of FFM hydration, and therefore biological differences and disease states may lead to errors in the obtained fat content of up to 3.6% [3, 21].

Imaging methods

Imaging methods, such as computed tomography or magnetic resonance imaging, are considered to be the most accurate techniques for body composition assessment at the tissue level [21]. They provide information about the spatial distribution of organs and tissues on the basis on differences in their tissue and molecular properties [27]. The computed tomography method uses for this purpose X-rays passing through successive layers of tissues, giving them a specific numerical value. The main limitation of CT in the paediatric group is exposure to radiation to a greater extent than in the case of DXA [3, 27]. Magnetic resonance imaging is devoid of this disadvantage, as its action focuses on interactions between hydrogen molecules and the human body, using the collected data to differentiate tissue types, and then to assess their local volume [21]. Magnetic resonance imaging is currently considered the only technique that faithfully assesses first of all the local intra-abdominal adipose tissue and is more accurate in assessing changes in adipose tissue content than the more popular DXA [21]. Both CT and MRI, however, are expensive methods requiring the patient to be kept still for a long time [1, 24]. The ultrasound (US) technique is faster and less troublesome for the patient. It uses the degree of ultrasound reflection to determine the density of individual tissues. Ultrasound is described as a comparable or even better method than the measurement of skinfold thickness in the assessment of adipose tissue content, especially in very obese people and in cases when it is impossible to use body fat calliper in a given area of the body [21] and the change in total fat content after weight loss correlates with the results obtained with DXA [27]. In addition, this method makes it possible to distinguish between subcutaneous and visceral fat, which is not possible with anthropometry [1]. In the case of ultrasound, CT, and MRI, the lack of universal guidelines regarding the technique of measuring adipose tissue, the need for intensive training of people carrying out measurements, limited availability of equipment, and the cost of a single test considerably limit the use of these methods in practice [24].

Summary

From the data available in the literature a certain hierarchy of the body composition measurement techniques described above emerges. In addition to the credibility and repeatability of the method, there are also practical considerations in clinical situations. In case of uncooperative patients, such as children, these issues can be decisive. Therefore, methods such as multicomponent models, which require several measurements, are of limited applicability because they involve the patient for a long time [28]. In addition, simultaneous access to the methods that make up the 4C model (e.g. DXA, ADP, D_2O) is only possible in specialised centres conducting advanced body composition research. The need to use several devices increases the cost of measurement and requires the involvement of highly trained personnel [28]. Among the individual techniques, the limited usefulness presents the isotope dilution method (e.g. D_2O) [24], requiring specialised laboratory facilities and several hours waiting for the result. Hydrodensitometry, effectively displaced by ADP as a method of measuring body volume [15], should be regarded as archaic and unpleasant for patients. In the study suggesting equally high accuracy of ADP and reference HW in a group of children and adults, patients, when asked for their preferred method, indicated plethysmography [16]. Requirements considering apparatus, software, and operator skills as well as an insufficient number of studies based on imaging methods (CT, MRI, and USG), significantly limit their use [24].

A method suitable for paediatric use in general should be (in addition to having satisfactory accuracy and repeatability) safe for the patient, have short measurement time, be without complex requirements for patient preparation, and, on the part of the staff, be simple to conduct and without the need of advanced training. The most widely recognised and thoroughly tested method suitable for use in a hospital setting is DXA [26]. Being highly credible, also in relation to multicomponent models [9], it is used as a reference in validation studies of other techniques [8]. There are available data on the possibility of DXA, effective use in any age group, including newborns [10, 11]. An alternative to DXA is ADP, which, thanks to the adaptation of apparatus and software, has gained the possibility to be used in paediatrics [17, 20]. With acceptable, though unambiguously agreed, compatibility between ADP and DXA [22, 26], the use of plethysmography may limit the anxiety, of parents and patients, associated with the presence of ionising radiation, although it should be remembered that the doses used in DXA are considered absolutely safe [4].

The body composition analysis is applicable not only in hospital conditions; the test may provide valuable information also in the primary care surgery or paediatric clinic. Striving for regular assessment of the patient's condition in smaller units of health care, it is worth reaching for cheaper, more widely available methods, such as anthropometry and BIA (bioelectrical impedance analysis). It has been reported that a properly performed skinfold thickness measurement can provide data on fat content even as accurately as DXA [29]. At the same time, the results of this test are very much dependent on the researcher's skills, which in many cases affect their credibility [24]. In addition, more advanced methods, including BIA, owing to appropriate estimates provide information of approximate content and distribution of other tissues (muscles, bones) and water in the body, which is an advantage over simple anthropometric measurements.

Although correctly conducted bioelectrical impedance analysis requires the conditions discussed in the previous part of the work to be met, it is a simple and fast measurement. The extensive offer of commercially available analysers allows selection of equipment appropriate to the needs of surgery. The accuracy of the method, also due to the multiplicity of available devices, is questioned by researchers [30], nevertheless satisfactory repeatability of measurements performed with the same apparatus allows profound monitoring of the patient's condition over time [31]. In addition, the result obtained in the form of a sheet with graphically presented relevant data is attractive to the patient in its reception and can have a mobilising effect in the context of cooperation with the doctor.

Body composition analysis is gaining wider application in paediatrics. Knowledge about the advantages and disadvantages of popular measurement methods allows the choice of the technique appropriate for the given indication for the test. After excluding from consideration the most difficult and expensive methods (4C, D_2O, imaging), DXA measurements and, alternatively, ADP can be considered the most useful in scientific studies and diagnostics of metabolic disorders. BIA, which provides more data than traditional anthropometric measurements, can play a key role in regular monitoring of nutritional status and metabolic complications. When selecting the measurement method for the tested group, it is worth remembering that some of the techniques cannot be used in the youngest groups of patients, newborns and infants, due to the need for close cooperation (multi-component, hydrodensitometry) or having to stand up during the test (most BIA analysers). Research carried out worldwide will bring more data on the credibility of individual methods in the coming years, and work to create reference values [8, 32] for a selected method in a specific population may contribute to increasing this credibility.

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