Chapter

Diagnostic Methods in Childhood Obesity

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Abstract

Childhood obesity, the most frequent pediatric disease, a worldwide public health problem, is considered a global epidemic and the main risk factor for obesity in adulthood. Among its consequences, cardiovascular and metabolic diseases stand out, which can be diagnosed during childhood, potentiate morbidity and mortality throughout life. Anthropometry, which includes the analysis of body mass index and the measurement of waist circumference, has proven efficacy in pediatric clinical evaluation. However, these diagnostic methods do not differentiate between subcutaneous and intra-abdominal or visceral fat. In this sense, diagnostic imaging methods complement the assessment of abdominal fat. In children, ultrasography appears as an innocuous, reproducible, and reliable diagnostic imaging method. The importance of knowing diagnostic methods for better monitoring of childhood obesity is emphasized.

Keywords: pediatric obesity, anthropometry, subcutaneous fat, intra-abdominal fat, ultrasonography, diagnostic methods, diagnostic imaging

1. Introduction

Obesity can be defined in a simplified way as a clinical condition in which there is an excessive accumulation of body fat, in the form of adipose tissue, and not just excess weight [1], as a consequence of a positive energy balance [2], capable of causing damage to the health of individuals [3], leading to reduced life expectancy [4]. It is known that the etiology of obesity is multifactorial, with both environmental and genetic aspects being involved in its genesis [3, 5].

It is believed that the determinants of excess weight make up a complex set of biological, behavioral, and environmental factors that interrelate and potentiate each other [2, 3].

Childhood is a phase of intense and rapid growth and physical, psychological, and social development, which causes an increase in nutritional needs. The advances in modern life have caused changes in the lifestyle of families around the world, causing these nutritional needs to be inadequately met, through the consumption of high-calorie diets, fats, voracious food, exchanging meals for quick snacks. These factors are linked to physical inactivity, the result of changes in children's games, which currently focus on video games and the excessive use of computers and television [6, 7].

The aforementioned aspects corroborate the increase in the prevalence of childhood obesity, a chronic disease characterized by increased body fat and influenced by genetic factors that, combined with environmental factors, make it difficult to maintain a healthy weight [6].

Childhood obesity, the most frequent pediatric disease [1] has also become a major public health problem in recent decades, being considered a global epidemic by the World Health Organization (WHO) [8–10], and the main risk factor for obesity in adulthood [1, 2, 10, 11].

Between 1980 and 1994, the proportion of children and adolescents considered obese increased 100% in the United States of America (USA). It is estimated that 15.3% of American children, aged between 6 and 11 years, suffer from obesity. The high prevalence of obesity has also been observed in populations in developing countries and with low socioeconomic status [12].

In Europe, in the last 10 years, this disease has grown around 10–40% in most countries [10, 12]. A study of 9-year-old Irish children found 19.3% to be overweight and 6.6% to be obese. Of children with parents of normal weight, 14.4% were overweight or obese, while 46.2% of children with obese parents were overweight or obese [9].

Parental obesity is well established as an important risk factor for childhood obesity [2]. Having an overweight father doubles the risk of childhood obesity, while obesity between the two parents further increases the risk. The relationship between the weight of the father and the son is complex, as it is a consequence of shared genetic and environmental factors [9].

Brazilian data on the prevalence of overweight and obesity in children aged 12–59 months; of these, 14.7% were overweight and 4.1% were obese [13, 14]. These results, both in relation to overweight and in relation to obesity, placed Brazil as the fourth most prevalent country when compared to 12 other countries in Latin America and with the data of Mexican children residing in the United States of North America [14].

In Brazil, there was an important increase in the number of overweight children in the country, mainly in the age group between 5 and 9 years. The number of overweight boys more than doubled between 1989 and 2009, from 15 to 34.8%, respectively. The number of obese people increased by more than 300% in this same age group, going from 4.1% in 1989 to 16.6% in 2008–2009. Among girls, this variation was even greater (from 2.4 to 11.8%) [15]. Obesity affects about 30% of children, mainly in middle- and high-income families [10].

Excess weight can cause serious health problems for children and adolescents due to the increased risk of cardiovascular diseases [16], dyslipidemia, glucose intolerance, diabetes, systemic arterial hypertension [17], respiratory diseases (obstructive airways, such as asthma and sleep apnea), orthopedic and postural disorders, dermatitis and some types of neoplasms; or even to become obese adults with a greater propensity to develop such pathologies [10, 12, 18, 19]. In addition to disorders in the emotional sphere [3] and non-alcoholic fatty liver disease (NAFLD) [7, 8, 10, 11, 20–22].

The growing trend in childhood obesity is related to the increase in the diagnosis of systemic arterial hypertension in children [6, 17, 23] and atherosclerosis in young people [24]. Metabolic changes resulting from obesity also increase the risk of developing hepatic steatosis [25], which has been proposed as one of the components or the hepatic manifestation of the metabolic syndrome [12]. Hepatic steatosis (HE) has an overall prevalence of 2.6% in children, ranging from 23 to 53% in obese children [10, 25].

NAFLD in childhood reduces life expectancy as it can progress to severe liver dysfunction [11, 22]. It is important to understand the natural history of HE not only because of the risk of progression of liver disease, but also because of the potential association with other pathologies such as type 2 diabetes mellitus and cardiovascular diseases [25].

Metabolic syndrome (MS), a group of disorders that includes obesity, insulin resistance, dyslipidemia, and hypertension, has been gaining importance due to its association with the subsequent development of cardiovascular disease and type 2 diabetes. The extent of coronary atherosclerosis in children and young adults increases considerably with the increasing number of multiple risk factors [17].

There is evidence that the atherosclerotic process starts in childhood [21], progresses with age and exhibits severity directly proportional to the number of risk factors presented by the individual. That is why it is believed that the primary prevention of cardiovascular diseases should begin in childhood, mainly through the process of education for the promotion of cardiovascular health with an emphasis on the importance of diet and the maintenance of a regular practice of physical activity for life [17, 26].

Pediatricians' attention to the consequences of obesity in childhood and adolescence probably started because of the significant increase in its prevalence in developed and developing countries [12]. In view of the increase in the frequency of overweight and obesity among children and adolescents, the diagnosis of nutritional status must be part of the routine medical evaluation [11, 15].

2. Visceral fat

Excess body fat (mainly visceral fat) has been associated with increased mortality, as there has been an increase in obesity prevalence rates [14]. It is assumed that visceral obesity is a risk factor for cardiovascular morbidity and mortality [27], regardless of the associated dyslipidemia, hypertension, and diabetes mellitus [28].

Since then, the relationship between subcutaneous, gluteal-femoral, and visceral fat with the action of insulin has been extensively studied and, today, it can be said that at least the association of visceral fat with the components of MS is well established [29].

It has been shown that the accumulation of visceral fat is related to the development of steatohepatitis and that this accumulation continuously influences the histological changes in NAFLD, from the beginning of the deposition of fat in the hepatocytes to the appearance of inflammatory changes [29, 30].

Both steatosis and abdominal visceral fat are independent correlates of cardiometabolic risk, but the associations are stronger between visceral fat and steatosis [29]. Currently, the type of fat distribution in the body, especially the accumulation of intra-abdominal fat (IAF), is considered the most important factor in the associations between these clinical entities [20].

Evidence suggests the importance of measuring abdominal obesity, in addition to general obesity, to assess health risks in the first decades of life [18].

Obesity, usually assessed by anthropometric measurements, has idiosyncrasies that are beyond common sense. For example, individuals with a low body mass index may have a high incidence of typical MS changes. Then, attention is drawn to the fact that it would not be the excess of total body fat but the distribution of that fat that would be related to insulin resistance and, consequently, to MS [29].

Over the years, research has shown that weight gain alone is less relevant than the distribution of body fat in determining metabolic changes [28]. Central obesity, characterized by the accumulation of fat in the trunk and abdomen, has visceral abdominal fat (VAF) as one of its components, whose thickness measurement is of great importance, as it is an indicator of cardiovascular risk due to metabolic changes resulting from this fat deposit [30, 31].

Visceral fat can be assessed by measuring waist circumference or by means of imaging tests, such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography (US).

3. Assessment of nutritional status

The assessment of nutritional status aims to verify growth and body proportions in an individual or in a community, with a view to establishing intervention attitudes. Thus, the standardization of the evaluation to be used for each age group is of fundamental importance, thus standardizing the criteria used by the health team [32].

With regard to the identification of cases of obesity in children, an important issue has been discussed, that is, which is the most accurate method to classify it [6].

When defining methods for assessing the nutritional status, those which best detect the nutritional problem that is intended to be corrected in the study population should be chosen. The costs for its use, the level of personal skill required to apply them properly, the time needed to perform them, the receptivity on the part of the population studied, and the possible health risks must be considered [32] .

Determining obesity is, establishing excess body fat [14]. This concern is justified by the increase in the prevalence of obesity worldwide and the potential risks of developing chronic diseases in adulthood [32].

Among the various methods, anthropometric diagnosis and imaging diagnosis stand out.

4. Assessment and diagnostic anthropometric

Anthropometry, which consists of assessing the physical dimensions and the global composition of the human body, has proved to be the single most used method for nutritional diagnosis at the population level, especially in childhood and adolescence, due to its ease of execution, low cost, and innocuity. Based on the publications of Jellife, edited by WHO, in the 1960s, based on studies that had started in the 1950s, anthropometry was systematized as a method of assessing nutritional status. It was from these studies that anthropometry developed rapidly in industrialized countries, which only occurred in the mid-1970s in developing countries. Since then, anthropometry has constantly evolved, being a useful method in population, clinical, and intervention studies, and its application has enabled advances in interpretations and in the search for mathematical formulations that improve the accuracy of body compartment estimation and its predictive power. Since 1978, WHO has adopted data from the National Center for Health Statistics (NCHS) as an international reference standard [32].

Anthropometric values represent, at the individual or population level, the degree of adjustment between the genetic potential for growth and the favorable and harmful environmental factors. The ideal anthropometric pattern, then, would be that obtained from populations or ethnic groups whose individuals had enjoyed the opportunity to fully develop their growth potential. In this sense, we use the statistical results obtained from populations in developed areas of the world, or in underdeveloped regions, from human groups of high socioeconomic standard, who probably had better opportunities to fulfill their genotypic growth possibilities [32].

Results from studies around the world have shown and show the possibility of using a single, international benchmark to assess growth and nutrition status in different regions. There is evidence that the growth in height and weight of healthy children of different ethnic origins, submitted to adequate living conditions, is similar up to 5 years of age [32].

Among the almost unlimited number of possible body measurements, the most frequently used measures are intended to determine body mass, expressed by weight; linear dimensions, especially height; body composition and energy and protein reserves, estimated by the main superficial soft tissues: subcutaneous fat and muscle mass [32].

4.1 Body mass index

Anthropometry, then, even considering its limitations, has been the most widely used method and also the one proposed by WHO [32].

It is recommended that the weight be measured in kilograms (kg), with an anthropometric scale, with the child barefoot, with light clothing and in an orthostatic position in the center of the scale, and that the height be measured in centimeters (cm), using a stadiometer, to the nearest 0.1 cm, with the child barefoot, with the back to the wall, feet together and parallel, in an upright position and looking forward in the horizon line.

The body mass index (BMI) is obtained by dividing body weight, in kilos, by height in square meters [2]; therefore, in kg/m2 [33–35], it is an anthropometric measure widely used to identify excess weight in children, adolescents, and adults [2, 6, 27, 36].

The stratification of nutritional status is obtained from the percentiles in the BMI/age ratio according to gender, from WHO, and allows children to be classified as eutrophic, overweight, or obese. Obesity is diagnosed in children with the percentile is equal to or greater than 97 and, overweight, in children with the percentiles between 85 (inclusive) and 97 [33–35].

The following BMI scores for age are considered, according to the WHO [33–35], illustrated in **Figure 1**.

The values of these anthropometric data should always be analyzed according to the child's age and sex, which are the main determinants of its evolution [2]. Although they are usual and simple procedures, they must be applied carefully, with standardization, and the instruments used must be calibrated frequently [32].

Obesity in children is not defined by an absolute number, but by a percentile [2, 37]. To establish a comparison of a set of anthropometric measurements with a reference standard, several scales can be used, the most common being the percentile and the Z score [32].

The percentiles are derived from the distribution in ascending order of the values of a parameter, observed for a given age or sex; the classification of a child

Value found for the child		Nutritional Diagnosis
percentile < 0.1	< Z score -3	Marked thinness
percentile ≥ 0.1 and ≤ 3	≥ Z score -3 and ≤ Score -2	Thinness
percentile > 3 and < 85	> Z score -2 and < Score +1	Eutrophy
percentile ≥ 85 and < 97	≥ Z score +1 and < Score +2	Overweight
percentile ≥ 97 and ≤ 99.9	≥ Z score +2 and ≤ score +3	Obesity
percentile > 99.9	> Z score +3	Severe obesity

Figure 1.
Reference values for diagnosing nutritional status using BMI curves for age. World Health Organization, Geneva (2000, 2006 and 2007).

in a given percentile allows to estimate how many children, of the same age and sex, are greater or lesser in relation to the evaluated parameter [2, 32]. The Z score means, in practical terms, the number of standard deviations that the data obtained are removed from their reference median [32].

The WHO Classification can be used for children regardless of age. Regarding the assessment of childhood obesity, the following criteria can be used: weight/height ratio equal to or greater than 120%; percentile equal to or greater than 97; or Z score equal to or greater than +2.0 [32].

To monitor growth, the curve (growth graph) is used in at least three successive measurements of weight and height, with intervals compatible with their growth rate according to age, allowing to assess the nutritional process. This instrument is extremely useful in establishing situations of nutritional risk [32].

Such curves are essential for both the diagnosis and the assessment of the patient's evolution during treatment. Only by viewing the child's graph can it be seen how small variations in weight and, consequently, in BMI can be significant [2].

The assessment of body composition becomes difficult in children due to its constant change during growth, in addition to not knowing what percentage of body fat increases the risks in relation to their health. It is mainly indicated to verify changes presented by children undergoing treatment for obesity [32]. When interpreting the data obtained in nutritional assessment, sexual maturation criteria should also be considered, given the great individual variability in the maturation process [2, 32].

BMI validity is based on the good correlation it presents with total body fat, especially with the amount of internal fat. However, it does not distinguish between fat mass and lean mass, making it difficult to differentiate between overweight with excess fat and that with hypertrophy of muscle mass [32, 36]. In addition, it does not determine the distribution of body fat [6] and does not reflect stunting, common among children of low socioeconomic status [32].

However, its ease of measurement must be considered since it uses anthropometric data of weight and height, which are easy to obtain and have good reproducibility [7, 32].

4.2 Waist circumference

The waist circumference (WC) defined by measuring the smallest circumference between the iliac crest and the costal margin is, in particular, a better predictor of visceral obesity, a condition that represents a high risk for the development of chronic noncommunicable diseases such as diabetes mellitus type 2, MS, HE, and cardiovascular diseases and, thus, it has been highlighted in national and international studies [6, 8, 38].

The use of this measure in screening and in primary health care helps in the early diagnosis and in the identification of those potential candidates to manifest such diseases in adulthood [1]. This measure is noninvasive, uses a minimum of equipment when compared to laboratory techniques, is fast to apply, easy to be used by trained evaluators, and is very affordable [38].

Waist circumference (WC) is measured in centimeters (cm), using a flexible and inelastic measuring tape, with the child in an orthostatic position, at the midpoint between the iliac crest and the costal rim, under clothing and at the end of a normal exhalation.

The authors stressed the importance of measuring waist circumference as a mandatory part of the pediatric semiological examination [22].

The classification of WC for each child is performed according to age, sex, and the percentiles of McCarthy et al. [39], considering the 90th and 95th percentiles to identify overweight and obesity, respectively (**Figure 2**).

Percentiles								
Genders	Ages*	5	10	25	50	75	90	95
Female	6+	46,3	47,3	49,2	51,5	54,2	57,0	58,9
	7+	47,4	48,4	50,3	52,7	55,6	58,7	60,8
	8+	48,5	49,6	51,5	54,1	57,1	60,4	62,7
	9+	49,5	50,6	52,7	55,3	58,5	62,0	64,5
	10+	50,7	51,8	53,9	56,7	60,0	63,6	66,2
Male	6+	47,2	48,2	50,7	52,2	54,6	57,1	58,7
	7+	47,9	48,9	50,9	53,3	56,1	58,8	60,7
	8+	48,7	49,9	52,1	54,7	57,8	60,9	62,9
	9+	49,7	51,0	53,4	56,4	59,7	63,2	65,4
	10+	50,8	52,3	55,0	58,2	61,9	65,6	67,9

Figure 2.
Parameters for classifying waist circumference between genders, adapted from McCarthy et al. [39].
** 6 + = group of children aged 6.00–6.99 years.*

4.3 Relationship between BMI and WC

Regarding the knowledge produced about the use of BMI or WC to assess the pattern of body fat, scholars of the subject in search of an answer demonstrated that there is a strong correlation coefficient between both measures, indicating that the waist circumference can determine, satisfactorily, children with high BMI [6, 7]. Investigations found important correlation values between BMI and WC, suggesting the joint use for the diagnosis of obesity, overweight, and central obesity [6], including in children and adolescents [7, 8].

BMI expresses changes that may occur in the distribution of fat, but does not verify the pattern of body fat. Thus, correlating this measure with other anthropometric measures is necessary, considering that the type of deposit of fat distribution is related to the health prognosis. However, WC is the measure that best represents the distribution of visceral fat and this, in turn, is more related to metabolic changes than subcutaneous fat, indicating the risk of children or adolescents to develop cardiovascular disease in future life. In addition, the relationship of this anthropometric measure with dyslipidemia, with arterial hypertension, and with the metabolic syndrome is evidenced in the literature and, therefore, should support professional practice [6].

McCarthy et al. stated that BMI may be a less sensitive indicator of fat among children and does not provide any indication of fat distribution. Information about WC in children can be as useful as BMI in population studies [39].

WC can be adopted as an alternative or additional measure to BMI in children. It is a direct measure that requires simple and inexpensive equipment, with the registration of a single value. BMI requires more complex equipment and mathematical calculations [39].

Researchers stressed the difference between ethnic groups and the importance of developing specific population patterns, as visceral adiposity is highly variable in children and is related to ethnicity [39]. The relative distribution of intra-abdominal tissue in relation to the subcutaneous abdominal region is significantly less in African American children than in whites [40].

For the same BMI, there may be individuals with more or less cardiovascular and metabolic risk, depending on the amount of intra-abdominal fat, which is also true for children [41]. It was shown that 23.4% of eutrophic children by BMI had high waist circumference [7].

4.4 Other anthropometric measurements

The waist-hip ratio and sagittal diameter are methods that indirectly determine visceral fat [28], predicting cardiovascular risk [38]. These anthropometric measures are methods used to assess body adiposity; however, they are unable to differentiate visceral from subcutaneous fat and have relatively high intra- and inter-examiner variability [29].

The assessment of adiposity through skinfold measurements is poorly reproducible and its usefulness in clinical practice is limited [15].

5. Diagnosis by imaging exams

Imaging exams are the methods of choice to assess and quantify visceral fat, since anthropometric measurements are unable to differentiate intra-abdominal from subcutaneous fat, as they are indirect measures [2, 29].

Dual-energy X-ray absorptiometry (DXA), a "scanning" technique considered to be reliable, whose mechanism occurs through two X-ray beams that cross the body, is used for the evaluation of the total and regional body composition of lean mass, fat mass, and bone mineral density. However, in the case of children, although it is a reference method, radiation exposure and high cost must be considered [6, 36].

Studies that concluded that anthropometric measurements have a strong correlation with the fat distribution indicated by DXA [6, 42] stand out. DXA estimates abdominal adiposity, but does not specifically quantify intra-abdominal fat [43].

Computed tomography (CT) is the gold standard method for the determination of visceral abdominal fat (VAF), due to its ability to differentiate between subcutaneous and visceral adiposity [44]. CT has the advantage of not depending on the operator's ability to identify structures during the examination and not be influenced by ultrasound transducer pressure on the abdomen during measurements. However, CT is an expensive method and submits patients to ionizing radiation, which limits its use mainly in epidemiological studies [31, 44].

Full-body CT measurements are accompanied by high radiation exposure and; therefore, they are not recommended for scientific purposes in healthy individuals. Thus, CT had to be restricted to some characteristic slices in most studies [36].

Magnetic resonance imaging (MRI) has also developed criteria for assessing visceral fat, with good accuracy [29, 44]; it is a method with which it is possible to assess the distribution of adipose tissue in children [10]. This test has the advantage of not emitting ionizing radiation [36] and the ability to quantify the fraction of fat [10]; however, it is more subject to artifacts than CT [29]. In addition, due to the high cost, greater need for sedation, and its limitation in claustrophobic patients, MRI has not been used routinely [10]. Among the limitations of the method for young children, there is the need to remain completely immobile during image capture [45].

Ultrasonography, in recent years, has been proposed as a noninvasive technique for the assessment of intra-abdominal fat [43], as it is a useful method for the determination of visceral adipose tissue [28, 44]. The possibility of measuring visceral fat attributes to US an important role in the assessment of MS [29].

In contrast to the disadvantages of CT, MRI, and anthropometric measurements, US has been establishing a simple, low-cost method, without radiation risk [29], free of side effects [10], with reproducibility and reliability already proven in the quantification of visceral fat [29], despite the need for specific equipment and well-trained observers, which can be repeated when necessary [28] and on a large scale, such as population screening [10].

Ultrasonography appears as one of the methods of diagnosis and characterization of abdominal fat, allowing the correlation of its findings with data from anthropometric physical examination in all age groups, being of great value in the evolutionary monitoring of obesity treatments.

In addition to measuring abdominal fat thickness, the method assesses the presence of liver fat. While some authors describe a sensitivity of ultrasonography in mode B for the detection of hepatic steatosis of just over 60%, other authors report a sensitivity of up to 90% [36].

Among its advantages, the ability to differentiate accumulation of intraperitoneal, pre-peritoneal, and subcutaneous fats, in addition to the safety of the examination, practicality, and speed, especially in the evaluation of the pediatric population, stands out.

US in children to measure pre-peritoneal fat and intra-peritoneal fat is a valid method for epidemiological and clinical studies [20, 46]. Statistical significance was observed between the thickness of intra-abdominal fat and subcutaneous tissue in relation to obesity in children [20]. US can be useful in measuring intraperitoneal fat in children and adolescents [20, 47]. The thickness of the subcutaneous fat showed no statistically significant difference between the sexes, between the age groups and in relation to the presence or not of steatosis. However, US can be used as a treatment control in individual cases [29].

The ultrasound technique consists of measuring the thickness of the subcutaneous and visceral abdominal fat, separately, using a transducer placed 1 cm (cm) above the umbilical scar. The thickness of the visceral adipose tissue obtained with this technique has a good correlation with the area of that same tissue quantified by computed tomography [29].

The knowledge acquired can be useful to employ a new method of assessing visceral fat and also to seek ultrasound parameters that change with the increase in BMI [20].

The techniques must be accurate and suitable for use both at the cross-sectional level (i.e., a single measure) and for monitoring the effects of interventions (behavioral, pharmacological, and surgical) aimed at promoting a healthy life [45].

6. Conclusions

Considering that the first signs and symptoms of obesity and its consequences can be determined in childhood, it becomes evident the importance of assessing subcutaneous and visceral fats in children, a population in which obesity may still be the only morbidity.

The pediatric detection and control of intra-abdominal obesity are important because it is associated with the metabolic syndrome in childhood, adolescence, and adulthood, and its progression can increase rates of morbidity and mortality due to cardiovascular disease among young adults.

Therefore, this population should be the target of prevention policies and programs, early diagnosis, and medical-nutritional monitoring, aiming to identify the risks of these pathologies and their health consequences.

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Conflict of interest

The authors declare no conflict of interest.

Nomenclature

BMI	body mass index
CT	computed tomography
DXA	dual energy X-ray absorptiometry
Et al.	and others
HE	liver steatosis
IAF	intra-abdominal fat
NAFLD	non-alcoholic fatty liver disease
NCHS	National Center for Health Statistics
MRI	magnetic resonance imaging
MS	metabolic syndrome
US	ultrasonography
USA	United States of America
VAF	visceral abdominal fat
WC	waist circumference
WHO	World Health Organization
%	percent
<	less than
≥	greater than or equal to
≤	less than or equal to
>	greater than
cm	centimeter
kg	kilogram
kg/m^2	kilogram per square meter

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