Pediatric obesity: the complexities of current definitions and measurement tools in children age 5 to 19 years

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PEDIATRIC OBESITY: THE COMPLEXITIES OF CURRENT DEFINITIONS
AND MEASUREMENT TOOLS IN CHILDREN AGE 5 TO 19 YEARS

by

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To Dr. Simon Levy: My success in the MAMS program is a testament to your support and guidance throughout the last two years. Thank you for making time to listen to my stories, give me advice on the next steps, and generally be a positive influence on my academic experience. I cannot wait to share my future life successes with you.

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To my family: Thank you for listening, through the ups and downs. I am so thankful to have such a strong support network of people to rely upon. Your love and support remind me that I can achieve any goal I set for myself.
In the United States, childhood and adolescent obesity is a problem of growing concern. With nearly 17% of children between the ages of two and 19 years classified as obese, healthcare providers, clinical scientists, and program managers must collaborate to reduce the prevalence of obesity. Obese children are more likely to be obese adults, who are at an increased risk to develop type two diabetes and cardiovascular disease, compared to non-obese individuals. Children are classified as obese based on body composition. CDC, WHO, and IOTF have developed definitions to classify the weight status of children; however, these definitions are based on reference populations’ data rather than physiological ideal growth and development. Physicians and scientists measure body composition with a variety of direct and indirect techniques. Although there are advantages and disadvantages to each method, there is no database to compare the measurements to determine whether the child has an increased risk for developing a disease based on his or her weight status. While the current literature debates the use of one definition or measurement tool over another, there is a need for longitudinal studies to establish a true definition for obesity and healthy model of child growth and development from birth to adulthood. This review summaries the current arguments and provides suggestions for further research to increase the understanding of obesity in children and adolescents.
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LIST OF ABBREVIATIONS

AAP.................................................................American Academy of Pediatrics
ADP.............................................................Air Displacement Plethysmography
BIA..............................................................Bioelectrical Impedance Analysis
BMI..............................................................Body Mass Index
CDC............................................................Centers for Disease Control and Prevention
CSFII............................................................Continuing Survey of Food Intakes by Individuals
CT...............................................................Computerized Tomography
CVD............................................................Cardiovascular Disease
DBP.............................................................Diastolic blood pressure
DEXA, DXA.....................................................Dual Energy X-Ray Absorptiometry
IOM.............................................................Institute of Medicine
IOTF............................................................International Obesity Task Force
MGRS..........................................................Multi-centre Growth Reference Study
MRI............................................................Magnetic Resonance Imaging
NCHS........................................................National Center for Health Statistics
NHANES......................................................National Health and Nutrition Examination Survey
NIH.............................................................National Institute of Health
PPV..............................................................Predictive Positive Value
SBP.............................................................Systolic blood pressure
SD..............................................................Standard deviation
SF..............................................................Skinfold
T2DM.................................................................Type 2 Diabetes Mellitus
UWW...............................................................Underwater weighing
WC.................................................................Waist Circumference
WHO...............................................................World Health Organization
WHR...............................................................Waist-to-Hip Ratio
INTRODUCTION

Scope of the Problem

Obesity is a world-wide epidemic affecting children and adults. Since 1980, the number of obese people in the world has approximately doubled.\(^1\) Obesity in adults is typically defined as excess body fat, resulting in a body mass index (BMI) greater than 30 kg/m\(^2\).\(^1\) This value reflects a ratio between the weight and height squared of the individual as a representation of his or her adiposity, the relative amount of body fat. However, in children, this ratio is adjusted for gender and age. The obese classification is associated with an increased risk for diabetes mellitus type two (T2DM), cardiovascular disease (CVD) risk factors, asthma, chronic inflammation, and psychological problems.\(^2\) The rise in high sugar diets, sedentary lifestyles, and availability of processed foods are contributing factors to the obesity crisis. In adolescence, peer pressure, the quality of school-provided meals, the level of health education, and the amount of physical activity additionally influence the risk for obesity. The presence of unhealthy lifestyle choices in childhood has lasting impacts into adulthood.\(^3\) Many studies have demonstrated that obese children are likely to become obese adults with a positive correlation between increased BMI in childhood and prevalence of obesity in adulthood.\(^2\) Thus, health education and treatment programs need to be systematically implemented in schools and communities to promote lifelong healthy behaviors and reduce the prevalence of obesity in children.
According to the National Health and Nutrition Examination Survey 2009-2010, nearly 17% of children aged two to 19 years were obese. The prevalence of obesity by age-group and gender are shown in Figure 1. The prevalence of obesity was greater in boys than girls for each age group. Additionally, obesity was more common in boys and girls over the age of five year than under the age of five.

**Figure 1. Prevalence of childhood and adolescent obesity in the United States, CDC/NCHS, 2009-2010.** Obesity was defined as children whose BMI was plotted at or above the 95th percentile for age- and sex-specific growth according to the 2000 CDC growth charts. The prevalence of childhood and adolescent obesity in the United States generally increased with age and is more common in boys than girls for each age-group. Reproduced from Figure 2.

However, many studies within the literature present higher frequencies of overweight and obesity within their sample populations. This may be attributed to the source of their subjects, such as a pediatric clinic or focus on a single racial group or income level. Children who are visiting a clinic for CVD risk factors or children who are Black or
Latino may be disproportionately fatter than their White peers. These factors must be considered when comparing data from different studies for analysis.

Hypertension, elevated insulin levels, elevated free triglycerides, and high cholesterol levels are risk factors for cardiovascular disease that have been identified in normal weight, overweight, and obese children. The presence of any three of these symptoms, including excessive body fat, results in a diagnosis of metabolic syndrome.

Based on an analysis of the USDA’s Continuing Survey of Food Intakes by Individuals (CSFII), “Blacks and Hispanics are more likely to become overweight or at risk of being overweight than non-black and non-Hispanic children.” Thus, Black and Latino children have an increased risk of developing metabolic disease. Although dietary habits and the level of physical activity are determinants of risk for obesity, children are more likely to be overweight if they are from a socioeconomically disadvantaged family, regardless of the structure and safety of their neighborhood. Socioeconomic status is linked to the availability of healthy and diverse foods, access to safe spaces to play and exercise, and quality of education in the community. This stresses the importance of the widespread distribution of health services and literature through schools to ensure all children are impacted by healthy lifestyle and obesity prevention programming. With over 95% of children in the United States enrolled in schools, school-wide programming provides the best option for accessing the majority of adolescents.
**Rational for Investigation**

School sites are targeted as the appropriate place for large-scale obesity surveillance and prevention efforts. The Centers for Disease Control (CDC), under the recommendation of the Institute of Medicine (IOM), released recommendations to the federal government to implement BMI surveillance and screening programs in public schools in 2007. Surveillance programs are typically anonymous and inform the schools about weight trends in subpopulations of the student population to guide policy and programming. Screening programs collect data on individual students to determine which individuals are at risk for weight-related diseases and notify parents of the results. Based on the data collected, schools can promote interventions through policy changes and programming efforts in an environment that supports healthy eating and physical activity for their student population.

Unfortunately, the school-based programs do not meet all the required criteria for a successful screening program, as defined by the American Academy of Pediatrics (AAP), shown in Table 1. Schools often fail to meet the criteria for screening test, screener, referral and treatment, site, and program maintenance. For obesity screening, school sites use BMI and the CDC recommendations to determine the child’s weight status. BMI is based on two measurements, height and weight, which are not as easy to measure accurately. Additionally, this value must be standardized for age and gender before comparing the BMI to the CDC’s definition for overweight and obesity. The screener must be trained to properly collect and evaluate BMI data before drawing
conclusions about the child. Once a child has been labeled as overweight or obese, the school must refer this child and their family for proper follow-up and treatment. The school site may not have the capacity to facilitate the mass communication with families and ensure this is handled sensitively. Children may be stigmatized for their BMI, if these criteria are not met. The CDC has proposed several safeguards to protect children, including training the staff to administer the program, how to use equipment accurately, and the importance of regular monitoring and evaluation of the program for intended and unintended consequences.

Table 1. American Academy of Pediatrics Criteria for Successful Screening Programs in Schools. Reproduced from Table 1.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Criteria for a Successful Screening Program in Schools</th>
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<tr>
<td>Disease</td>
<td>Undetected cases must be common or new cases must occur frequently, and the disease must be associated with adverse consequences.</td>
</tr>
<tr>
<td>Treatment</td>
<td>Effective treatment must be available, and early intervention must be beneficial.</td>
</tr>
<tr>
<td>Screening test</td>
<td>The test should be sensitive, specific, and reliable.</td>
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<tr>
<td>Screener</td>
<td>The screener must be well trained.</td>
</tr>
<tr>
<td>Target population</td>
<td>Screen should focus on groups with high prevalence of the condition/disease in question or in which early intervention will be most beneficial.</td>
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<tr>
<td>Referral and treatment</td>
<td>Those with a positive screening test result must receive a more definitive evaluation and, if indicated, appropriate treatment.</td>
</tr>
<tr>
<td>Cost/benefit ratio</td>
<td>The benefit should outweigh the expenses (i.e., costs of conducting the screening and any physical or psychosocial effects on the individual being screened).</td>
</tr>
<tr>
<td>Site</td>
<td>The site should be appropriate for conducting the screening and communicating the results.</td>
</tr>
<tr>
<td>Program maintenance</td>
<td>The program should be reviewed for its value and effectiveness.</td>
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However, the true weakness in the screening program lies in the measurement tool and the definition: BMI based on the CDC reference curves. BMI is a calculated value relating height and weight but, the raw value does not consider the distribution in
body fat and lean muscle or the developmental stage of the child, which influences the child’s body composition. The calculated BMI is then compared to a reference curve created by the CDC from a sample of children from the United States, rather than a biologically-based and developmentally-appropriate definition. The values on which BMI classifications are based should be correlated with the health status of children, not on how they compare to other children who have been identified as representing typical growth, development, and health.

**Specific Aims**

Clinical and school-based obesity prevention and treatment programs rely on BMI as a diagnostic and assessment indicator for childhood and adolescent obesity. However, BMI as a measurement tool, and therefore indicator of weight status, should be analyzed for its applicability to children. Specifically, BMI should be assessed for its ability to estimate adiposity because adiposity is associated with an increased risk for developing T2DM and CVD, especially in children six to twelve years of age. Healthcare providers, clinical scientists, and program managers should question whether BMI is really the information they need to inform their clinical decisions, rather than percent body fat, fitness level, or another measure of health. Once they have decided upon an indicator and measurement instrument, they must choose a definition or reference to compare the measured value and draw conclusions. They must question whether the reference is valid and appropriate or if further research is necessary to develop a more
accurate standard of comparison. This literature review aim to accomplish the following objectives:

- To analyze the foundation for current definitions of overweight and obesity in children and adolescents,
- To determine the advantages and disadvantages of the most commonly used body composition measurement techniques,
- To investigate the rationale for commonly used tools in intervention programs,
- To make recommendations to healthcare providers, clinical scientists, and program managers for the appropriate measurement of overweight and obesity in children aged five to 19 years.
BACKGROUND

Defining Obesity

Obesity is simply defined as an excess in body fat, but is not necessarily associated with comorbidities. For children, aged five to 18 years, a normal or healthy amount of body fat is considered 30% of body weight in females and 20-25% of body weight in males. There are only a few techniques to directly measure a person’s body composition, Magnetic Resonance Imaging (MRI) and Computerized Tomography (CT). These methods take images of the internal composition of the human body to determine the amount and distribution of body fat. MRI and CT scans reveal the level of central adiposity, the amount of fat in the abdominal region, which places individuals at an increased risk for CVD. These procedures are very expensive and require highly trained staff to complete them. Alternative measurements have been established to proxy for these methods, including Body Mass Index (BMI), because they are less invasive, less expensive, and easier to complete. BMI is the ratio of an individual’s weight in kilograms to height squared in meters. For adults, a BMI greater than 25 kg/m² is considered overweight and a BMI greater than 30 kg/m² is considered obese. Of note, the units are often dropped in the discussion of BMI.

However, due to the physiological and developmental difference between adults and children, these standards are not always applied to children and adolescents. The BMI of children increases in the first year of life as newborns gain weight, then decreases for the next five years as the child grows rapidly through infancy, and then, following a
slight drop around age six, increases throughout childhood, adolescence, and into adulthood. The raw BMI is adjusted for gender and age then compared to predetermined cut-off values for overweight and obese classifications. Some clinicians and researchers prefer to use the percentile on a growth chart to identify overweight and obese children. These growth charts compare an individual child to a standardized data set for height and weight. The most commonly used standards by the Centers for Disease Control and Prevention (CDC), International Obesity Task Force (IOTF), and World Health Organization (WHO) are presented in Table 1. The American Academy of Pediatrics (AAP) uses the CDC definition.

Table 2. Definitions of Adolescent Overweight and Obesity by Health Organizations. The definitions used by leading health organizations are presented alphabetically. Adapted from the summary table online. Abbreviations: BMI=Body Mass Index, SD=Standard Deviation.

<table>
<thead>
<tr>
<th>Organization</th>
<th>Applicable Age Range</th>
<th>Definition of Overweight</th>
<th>Definition of Obesity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centers for Disease Control and Prevention (CDC)</td>
<td>2 – 19 years</td>
<td>BMI in the 85th to 95th percentile</td>
<td>BMI ≥ 95th percentile</td>
</tr>
<tr>
<td>International Obesity Task Force (IOTF)</td>
<td>2 – 18 years</td>
<td>Age-specific cut-point based on BMI ≥ 25 kg/m²</td>
<td>Age-specific cut-point based on BMI ≥ 30 kg/m²</td>
</tr>
<tr>
<td>World Health Organization (WHO)</td>
<td>5 – 19 years</td>
<td>BMI &gt; 1 SD compared to WHO median</td>
<td>BMI &gt; 2 SD compared to WHO median</td>
</tr>
</tbody>
</table>

CDC Definition

In 2000, the CDC released a revised set of growth curves for height, weight, and BMI, which were age and gender specific. The previous height and weight growth curves were established in 1977. The CDC reviewed the National Center for Health Statistics (NCHS) data from 1963 to 1994 and the three National Health and Nutrition Examination
Survey (NHANES) data sets from 1988 to 1994. The NCHS and NHANES were nationally distributed surveys that collected anthropometric data on children living in the United States. To avoid underestimating the true prevalence of overweight and obesity with an increasingly heavy population, data for children aged six years and older in the NHANES III were excluded from the analysis. The remaining data points were smoothed for each percentile cut-off using a locally weighted regression model. In general, the updated curves followed a similar pattern as the previous but there are additional percentiles in the updated curves. The following percentiles are depicted on the 2000 CDC growth charts: 3rd, 5th, 10th, 25th, 75th, 90th, 95th, and 97th.

The 2000 CDC set of included BMI-for-age charts, which were not part of the 1977 growth charts, for children aged two to 20 years. Healthcare providers and program managers must plot the child’s calculated BMI by age on gender-specific charts to determine the child’s weight status. If the point lies between the 85th and the 95th percentiles, then the child is classified as overweight. If the point lies at or above the 95th percentile, the child is obese.

**IOTF Definition**

In 1999, the International Obesity Task Force assembled a workshop to establish globally applicable cut-offs for overweight and obesity for children, based on the adult cut-offs. The international community was dissatisfied with the CDC growth curve and wanted to establish a “less arbitrary and more international” definition.
The committee referred to six international datasets, each with over 10,000 subjects, but different prevalence rates for obesity. The data represented children from birth to 25 years of age from Brazil, Great Britain, Hong Kong, the Netherlands, Singapore, and the United States that was collected from 1978 to 1993. The data from several other countries were considered, but ultimately excluded, because they were not nationally representative or large enough samples. The centile BMI data from each country was plotted against age and smoothed using the LMS method so that the country-specific data could be compared. After averaging these lines, a list of international cut-off points was generated for males and females to extrapolate when the BMI curve would pass through the adult cut-offs of 25 kg/m$^2$ and 30 kg/m$^2$ at age 18 years, as shown in Table 3.

**Table 3. International Body Mass Index (BMI) Cut-off Points for Overweight and Obesity by Gender and Age.** Based on the six data sets from the International Obesity Task Force, the following cut-offs were calculated to correlate with adult overweight and obesity values. A BMI of 25 kg/m$^2$ is overweight and 30 kg/m$^2$ is obese. The cut-off points increase with age and are greater for females than males. Adapted from Table 4.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Body mass index 25 kg/m$^2$</th>
<th>Body mass index 30 kg/m$^2$</th>
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<tr>
<td></td>
<td>Males</td>
<td>Females</td>
</tr>
<tr>
<td>5</td>
<td>17.42</td>
<td>17.15</td>
</tr>
<tr>
<td>8</td>
<td>18.44</td>
<td>18.35</td>
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<tr>
<td>12</td>
<td>21.22</td>
<td>21.68</td>
</tr>
<tr>
<td>14</td>
<td>22.62</td>
<td>23.34</td>
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<tr>
<td>18</td>
<td>25</td>
<td>25</td>
</tr>
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</table>

**WHO Definition**

WHO updated its growth reference curves in 2007. WHO set out to identify international data to create a growth reference curve but the available data sets were neither sufficiently comprehensive nor rigorous enough to meet the inclusion criteria.
Instead, the revision relied on the NHCS data used in the previous 1977 NCHS/WHO curves and included the new WHO Child Growth Standards. From 1997 to 2003, the WHO Multicentre Growth Reference Study (MGRS) collected data from Brazil, Ghana, India, Norway, Oman, and the United States to establish the WHO Child Growth Standards. The birth to five year growth curve was based on the principal that all children develop the same for the first five years of life, regardless of ethnicity, as long as they have adequate nutrition and health. The purpose of the MGRS is to create prescriptive tools that demonstrate the physiological ideal growth and development.

The updated WHO growth curves for children aged five to 19 years accounted for the results of the MGRS and included data from children 18 months to 24 years of age. The Box-Cox power exponential method was used to construct the curves. When the 2007 BMI-for-age curves were compared with 1991 WHO curves for BMI in children age nine to 24 years old, the 1991 85\textsuperscript{th} and 95\textsuperscript{th} percentile curves corresponded to a greater BMI than the respective 2007 curves for boys and girls. This suggests a reduction in the cut-off points for overweight and obese children, based on BMI classification.

Summary of Definitions

The CDC, IOTF, and WHO definitions present three different thresholds for identifying overweight and obese children. Slight differences in these values, may cause confusion for healthcare providers and program managers, as providers and managers may not understand the relationship between z-scores, standard deviations, and the raw
BMI values. Figure 2 shows a comparison of the WHO and IOTF standard deviation cut-offs for BMI by age.\textsuperscript{20} The IOTF thresholds of 25 kg/m\textsuperscript{2} and 30 kg/m\textsuperscript{2} for overweight and obesity correspond with the 1 standard deviation (SD) and 2 SD for the WHO thresholds but, the IOTF values are greater for every age. Using the IOTF definition, children must have a higher BMI to be classified as overweight and obese, compared to the WHO definition.

\[ \text{Figure 2. Comparison of WHO and IOTF BMI standard deviations cut-offs for boys, Age 5-19 years.} \]

The trends with age are similar for BMI classification of underweight and normal. However, for overweight, defined by WHO as greater than 1 SD from the mean and by IOTF as a BMI of 25 kg/m\textsuperscript{2}, the IOTF threshold is greater. Additionally, for the obese classification, defined by WHO as greater than 2 SD from the mean and by IOTF as a BMI of 30 kg/m\textsuperscript{2}, the IOTF threshold was much greater, especially for children between 7 and 14 years of age. Reproduced from WHO website.\textsuperscript{20}

Figure 3 shows a comparison the WHO and CDC standard deviations for BMI by age.\textsuperscript{20}

The CDC curve of 2 SD above the mean corresponds to a higher BMI than the WHO curve. The CDC curve of 3 SD continues off the chart and does not appear to follow the
pattern of the WHO curve. However, these two thresholds are hard to compare in this graphical form because the CDC thresholds are based on percentile, not SD.

Figure 3. Comparison of CDC and WHO BMI standard deviations cut-offs for boys, Age 5-19 years. The WHO and CDC curves are very similar for underweight children and within the first standard deviation. There is significant deviation for the second and third standard deviations greater than the mean, suggesting inconsistency in the overweight and obese classification for children in this range using these two definitions. Reproduced from WHO website.

Body Composition Measurement Tools

There are a plethora of body composition measurement tools. The goal of these measurements is to determine the proportion of body composition that is fat and the proportion that is lean body mass. Several studies have correlated the amount of body fat to the risk for cardiovascular and other weight-related conditions. Measurement techniques can be divided into direct and indirect methods. Direct techniques, including
MRI and CT, directly view the body composition to distinguish fat from lean muscle. Indirect techniques rely on anthropometric measurements, volume displacement, or other values to estimate the percent body fat from a calculation. Some indirect techniques are Underwater Weighing (UWW), Air Displacement Plethysmography (ADP), Dual-Energy X-ray Absorptiometry (DXA), Bioelectrical Impedance Analysis (BIA), Skinfold (SF) thickness, Waist Circumference (WC), Waist-to-Hip ratio (WHR), and BMI. Certain tools are ideal for laboratory settings or to establish a reference for other tools, while others are more applicable in field settings when resources are limited and accuracy is not as important. Each of these measurement techniques presents advantages and disadvantages. The ideal measurement technique should be affordable, easy to replicate, precise, comfortable for the individual being measured, and, most importantly, accurate.

**Magnetic Resonance Imaging (MRI)**

MRI is a body imaging technique that uses radio waves to generate multiple cross-sectional images of the body. These images distinguish between bone, organ, fat, and muscle mass. This is the most accurate body composition tool, with the exception of an autopsy. The high resolution images show the amount and distribution of body fat, which has clinical significance for prevention and treatment recommendations.

Although the scans are safe for children because they use non-ionizing radiation, MRIs may be contraindicated for a child if he or she has a hard time lying still and is uncomfortable in enclosed spaces. Additionally, the equipment and expertise to complete and interpret the scans are expensive, ranging from $208 for a CT scanned covered by
Medicare to $2,800 for an MRI at a private clinic. Due to these limiting factors, MRI is not often used to assess body composition in a large number of children. Therefore, MRIs are most applicable in laboratory or clinical settings to establish a reference standard.

**Computerized Tomography (CT)**

CT scans send X-rays through the body at various angles to generate an image of the body. This image is two-dimensional and presents a contrast between bone and other body tissue. CT scans do not provide a cross-sectional view so they do not show the distribution of fat in the body. Some of the other limitations of CT scans are the cost and location of the equipment, the expertise required to conduct and interpret the scans, and the presence of radiation. Therefore, this imaging technique is not recommended for children or pregnant women because they would be exposed to harmful radiation.

**Underwater weighing (UWW)**

Hydrodensitometry, or underwater weighing, is often considered the “gold standard” of indirect body composition measurements. This method is based on Archimedes’ principle, which states that the upward buoyant force of the water is equal to the weight of the water displaced. To perform this technique, the subject must exhale and submerge himself in a tank of water for several seconds. The test conductor then measures the volume of water displaced. By taking into consideration the temperature of the water, density, and volume displaced, the test conductor can calculate the proportion of fat and lean muscle mass in the subject. UWW can be challenging to conduct for some
individuals who have a lot of excess fat and float or who are afraid to be submerged under water, such as children.\textsuperscript{21} However, this is a highly accurate technique so clinical researchers and healthcare providers should utilize this method whenever possible.

The biggest limitation to this technique is the setting for conducting the test. The size of the equipment and nature of the measurements require that UWW is completed in a highly controlled environment in a clinical or research setting. While the test itself may cost only $10 to $75 per person, the tank and associated equipment requires an initial investment of approximately $9,000.\textsuperscript{23,24} These prices do not include the manpower required to conduct and analyze UWW results.

**Air Displacement Plethysmography (ADP)**

ADP, sometimes referred to as a “Bod Pod,” is a modification of UWW. This technique measures the volume of air displaced in a chamber, rather than water.\textsuperscript{21} The subject is required to wear a swimsuit and sit inside a pod. The amount of air displaced is used to calculate the percent body fat. Some of the challenges of UWW, such as fear of drowning, are eliminated but the fear of claustrophobia and need to disrobe persist. This measurement tool is ideal for children because they do not need to be still; they simply sit within the chamber. The Bod Pod is also advantageous because it can be transported to a school site or athletic facility for measurement of a large number of children. Most clinical and athletic facilities charge $40 to $65 per test, while the Bod Pod device costs approximately $35,000.\textsuperscript{23} The overall expense of the device is the biggest limiting factor to widespread use of ADP beyond clinical and laboratory settings.
Dual Energy X-Ray Absorptiometry (DEXA or DXA)

DXA is gaining popularity as an accurate measurement tool for assessing body composition, although DXA is also used to measure bone density.\textsuperscript{25} DXA uses low-energy X-ray beams to determine bone from soft tissue and fat from fat-free mass.\textsuperscript{21} The results have been validated against UWW.\textsuperscript{13} DXA is advantageous over UWW because the patient lies on table instead of submerging him or herself in a tank of water and does not require the person to expose their body. This measurement can be taken multiple times without harm to the child. The level of radiation generated by DXA is much lower than from CT scans but, DXA scans are still contraindicated for use in pregnant women. Although the equipment is expensive and restricted to a laboratory and clinical settings with highly trained personnel to operate the equipment, the accuracy of the results would allow DXA to serve as a reference measurement for children’s weight status.

Bioelectrical Impedance Analysis (BIA)

BIA measures the conductance of an electric current through the body to estimate the amount of body fat present.\textsuperscript{13} Fat is a poor conductor of electricity so it impedes the movement of an electric current through the body. The amount of resistance to an electric current can be measured as the time it takes for the electric current to travel from one electrode to the other: the more body fat present, the more resistance, and the longer time for the current to travel. This information can be used to calculate fat-free body mass.\textsuperscript{25} BIA is safe for children, fast, and easy to complete. There are several portable measurement devices that perform BIA through the hands or feet. BIA is a cost-effective
technique that sacrifices some accuracy for ease of obtaining body composition information. However, this method does require the investment in the device itself, proper calibration, and children may need to lie down during the measurement. The individual’s body water may be affected by dehydration or illness.\textsuperscript{21}

**Skinfold (SF)**

SF thickness measurements use calipers to measure subcutaneous fat at various sites: the front of the arm, the back of the arm, below the scapula, and near the hip.\textsuperscript{25} These measurements can then be inserted into gender- and age-specific equations to determine the total body fat and predict its distribution. However, the SF measurements are hard to repeat and are subject to error. If the incorrect site is used or more than the subcutaneous fat is pinched, the results will be inaccurate. The results are hard to replicate between multiple researchers on the same individual due to differences in caliper use.\textsuperscript{13} Additionally, this method is challenging if the individual has more fat than the caliper is designed to measure. While SF measurements are relatively easy to obtain with properly trained researchers, inexpensive, and convenient, they are less accurate than other measurement methods because they make predictions about total body fat from measurements of subcutaneous fat.\textsuperscript{21}

**Waist Circumference (WC)**

WC is the measurement around the smallest part of the waist between the rib cage and the hips.\textsuperscript{25} Some researchers define WC as the measurement around the natural

19
Comparing these two definitions, the resulting WC may be different, especially if the individual has a large amount of abdominal fat and the waist is difficult to identify. WC indirectly measures the amount of abdominal fat, which is a risk factor for CVD. The accumulation of visceral fat has negative implications on heart and internal organ health. With training or a strict measurement protocol, researchers can accurately collect this data. WC is the simplest way to predict abdominal obesity. Additionally, this measurement technique is inexpensive and easy to measure. The caveat in children is that there is no reference data for comparison.

Waist-to-Hip Ratio (WHR)

WHR builds on the WC method. The hip measurement is taken from around the widest point of the hips. The use of two separately measured data points increases the risk of measurement error and results in a loss of information when reported exclusively as WHR. Two people with the same WHR may have a different combination of height and weight. It is not customary to present WHR as a ratio of two numbers to retain this information.

Despite the inaccuracies in measurement, the WHR correlates positively with an increased risk of CVD, regardless of the prediction from BMI. WHR measurements are relatively easy to obtain, inexpensive, and easy to complete in the field. The WHR is not commonly applied to children and adolescents due to the differences between body fat distribution in children and adults.
Body Mass Index (BMI)

BMI is another body composition measure calculated from two other anthropometric measures, weight and height. BMI is calculated as the weight in kilograms divided by the height in meters squared. Standardized cut-off points have been established for adults. However, there are several thresholds as defined by the CDC, IOTF, and WHO to categorize children as underweight, normal, overweight, or obese. Many studies have shown a positive correlation between BMI and abdominal body fat, which is a risk factor for cardiovascular disease. BMI, however, is inaccurate for individuals with a greater proportion of lean body mass, such as athletes. Individuals with large muscle mass will be incorrectly classified as overweight or obese because they weigh more than is expected for someone of his or her stature. BMI does not distinguish between weight due to lean body mass and weight due to fat. This misclassification is of particular concern for children and adolescents who are at various stages of growth and development. BMI is a commonly used body composition measurement in intervention programs, despite criticisms, due to the ease of calculation and consistent correlation with risk level.

Summary of Measurements

There are many body composition measurement techniques practiced by healthcare providers, clinical scientists, and program managers, summarized in Table 4. Each of these techniques provides valuable information independently or can be combined to create new standards or validate new measurement strategies.
Table 4. Summary of Features of Body Composition Measurement Techniques. The table compares the precision, ability to measure total fat, and ability to measure regional fat for several direct and indirect measurement techniques. Adapted from Table 17.3.25

<table>
<thead>
<tr>
<th>Method</th>
<th>Precision</th>
<th>Measures total fat</th>
<th>Measures regional fat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Imaging Techniques</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Magnetic resonance imaging (MRI)</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Computed tomography (CT)</td>
<td>High</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Densitometry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underwater weighing (UWW)</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Air displacement plethysmography (ADP)</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Absorptiometry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dual energy absorptiometry (DXA)</td>
<td>High</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Impedanciometry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bioelectrical impedance (BIA)</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td><strong>Anthropometry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skinfolds (SF)</td>
<td>Low</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Waist Circumference (WC)</td>
<td>Moderate</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Waist-to-hip ratio (WHR)</td>
<td>Moderate</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Height, weight, body mass index (BMI)</td>
<td>High</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

The most appropriate measurement tool for measuring body composition varies based on the goal of the situation. This depends on the conditions of the data collection, the subject’s individual characteristics, and the level of accuracy and precision of the tool desired by the researchers. The cost of the measurement varies proportionally with the accuracy of the tool: the more precise, the more expensive. The high cost of accurate equipment is justified if a large number of subjects will be measured to establish a database or reference sample, which can be used again in future investigations.

In laboratory or clinical settings, in which the objective is to establish a reference standard for other measurement techniques or for a baseline comparison, ADP or MRI are the ideal methods. The high price for each test or scan and the equipment is justified by the quality of the results. This data can then serve as a reference sample for future studies on a larger scale with less expensive techniques.
If the goal of the program is to assess the body composition of a large number of children quickly, such as at community health clinic, BIA is cost-effective. For the investment in the device, the program managers and healthcare providers can have accurate predictions of percent body fat. This information can then be used to guide the clinical recommendations for obesity prevention or treatment. However, in low-resource settings, such as in developing countries or public school sites, an anthropometric measure is sufficiently accurate to guide clinical practice. Depending on the rigor of the measurement and goal of the study or intervention, clinicians and program implementers may choose one or several techniques.

**Stages of Child and Adolescent Development and Body Composition**

One of the biggest challenges in measuring and assessing body composition in children and adolescents is the change in body composition with development. Some investigators focus on the early development of children as indicators of future growth and obesity risk. The identification of early adiposity rebound is a risk factor for adolescent and adult obesity. Adiposity rebound is a specific change in body composition between approximately age two and six years: the child’s percent body fat decreases until age five then increases again as the child approaches six years of age. However, adiposity rebound must be identified retrospectively so it does not have clinical applications in the child’s early development. Additionally, some studies have shown rapid weight gain to be reflective on an increased risk of obesity. In children who do not exhibit adiposity rebound, according to the WHO Child Growth Standards, the child’s
BMI increases quickly in the first six months of life and then decreases slightly as the child approaches five years of age.20

As children age through adolescence into adulthood, they grow taller and the distribution of fat changes with puberty. Based on the 1999 to 2004 NHANES survey, at age 8 years, the mean body fat percentage in boys was 28% and 31% in girls.26 At age 19 years, boys had 23% body fat and girls had 35%, as seen in Figure 4.26 As boys aged, their percent body fat remained relatively constant until early adolescence, corresponding with puberty, and then decreased until the teenage years, during which the percentage leveled off. However, as girls aged, their percent body fat generally increased over time.26 Therefore any measured body composition value must be considered in respect to age and gender of the subject, including BMI.13

Figure 4. Mean percentage body fat in children, Age 8 to 19 years, NHANES, 1999-2004. Based on the NHANES data from 1999 to 2004, boys’ percentage body fat decreases around puberty and slowly increases, while girls’ percentage body fat generally increases with age. Reproduced Figure 1.26
Before making suggestions to clinicians, scientists, and program developers, further investigation of the definitions of obesity, measurement strategies, and integration of the two is necessary. In general, there is a lack of agreement amongst professional scientists and clinicians about the preferred definition for overweight and obese children and adolescents. The support for and against the use of each definition suggests that the creation of a new criterion may be easier than modifying the existing standards. Additionally, each of the indirect body composition measurement techniques previously described have been analyzed for specificity and sensitivity compared to direct measurement methods. This summary of the literature presents multiple perspectives in the current research to achieve improved health outcomes from children, especially in regard to weight status.

Review of the Definitions of Obesity

There are three primary thresholds of obesity used in the discussion of children and adolescent overweight and obesity: the Centers for Disease Control and Prevention (CDC), the International Obesity Task Force (IOTF), and the World Health Organization (WHO). Each of these definitions seeks to identify children with a high percent body fat, which places them at and increased risk for weight-related diseases. Most organizations use these definitions to provide recommendations to families or complete their
investigations. The current literature provides pros and cons for each definition but does not come to a consensus of a single definition.

**Review of the CDC Definition in the Literature**

The CDC definition applies to children age two to 19 years. BMI is measured and compared to age- and gender-specific growth charts. Obesity is defined as a BMI greater than or equal to the 95th percentile. Overweight is a BMI falling between the 85th and the 95th percentile. Normal or healthy is any BMI between the 5th and the 85th percentile. The CDC updated the growth charts through statistical analysis of nationally representative data collected on children from the United States. The American Academy of Pediatrics uses the CDC definitions in the clinical assessment of adolescent weight status.

However, the CDC definition has been criticized for the origin of the reference data and its application. The CDC growth charts were not developed as standard of ideal growth but as a reference for typical growth. The curves released in 2000 were based on the distribution and proportion of children at various heights and weights in data collected from 1963 to 1994. The new measurements of children are plotted against a reference population rather than a gold standard of theoretical development. As the height and weight of children in the reference population increases with time, as was the case with the updated curves in 2000 compared to 1977, the mean and percentile cut-offs for BMI also increased. The CDC excluded some of the newer data points to account for this growth. However, critics argue this was insufficient, and the inclusion of newer data
points skews the reference sample to the right, underestimating of the true prevalence of overweight and obesity.\textsuperscript{27} Additionally, the reference data has a wide confidence interval and does not take into account ethnic differences.\textsuperscript{2,28}

**Review of the IOTF Definition in the Literature**

The second definition, authored by the IOTF, reflects an attempt by the international community to establish a common definition to be used to compare individuals and populations on a global scale.\textsuperscript{11} The IOTF used data from Brazil, Great Britain, Hong Kong, the Netherlands, Singapore, and the United States to establish a definition of childhood obesity for children from birth to age 20 years.\textsuperscript{28} The IOTF cut-offs for overweight and obesity align with the adult definitions: overweight is a BMI greater than or equal to 25 kg/m\textsuperscript{2} and obesity is a BMI greater than or equal to 30 kg/m\textsuperscript{2}.\textsuperscript{15}

Support for the IOTF data is based on its correlation with the 2000 CDC definition. The IOTF overweight cut-off corresponds to the 82\textsuperscript{nd} to 84\textsuperscript{th} percentile on the CDC curves, and the obesity cut-off corresponds to the 96\textsuperscript{th} to 97\textsuperscript{th} percentile.\textsuperscript{28} The CDC cut-offs are at the 85\textsuperscript{th} and 95\textsuperscript{th} percentile for overweight and obesity, respectively.

While the IOTF appears to expand the CDC definition to an international context, there are several weaknesses. First, the measurement instrument used in the IOTF definition has low sensitivity.\textsuperscript{11} Sensitivity is the proportion of children with the highest body fat percentage as identified by a direct standard of measurement who were correctly identified by BMI.\textsuperscript{2} This means that the IOTF definitions underestimate the prevalence of overweight and obesity. This also means the number of children with elevated fasting
lipids, glucose, and insulin levels, as well as high blood pressure, are underestimated.\textsuperscript{5} Additionally, the data supporting the IOTF definition is pooled from six international data sets.\textsuperscript{2} This is not widespread enough to take into account all ethnic and regional differences in body composition. Lastly, the IOTF is not appropriate for the classification of individual children.\textsuperscript{2} The IOTF definition includes only the two cut-off points for overweight and obesity and does not include percentiles stratification within these.\textsuperscript{28} Therefore, the IOTF definition should not be used for clinical guidance.\textsuperscript{2}

**Review of the WHO Definition in the Literature**

The third common definition is that proposed by the WHO. For children under age five, the WHO MGRS created a theoretical physiological development curve.\textsuperscript{19} For children age five to 19 years of age, the WHO defines overweight as a BMI greater than one standard deviation from the median and obesity as greater than two standard deviations from the median.\textsuperscript{15} The median was established by evaluating data from Brazil, Ghana, India, Norway, Oman, and the United States.\textsuperscript{28} The WHO definitions demonstrate a correlation between BMI and CVD risk factors.\textsuperscript{5} However, the CVD risk data for children is adapted from data for adults so it may not be accurate.\textsuperscript{5}

Until the WHO extends its Child Growth Standards through adulthood, the median data will continue to be the reference point. The data source has been accused of using homogenous samples and excluding the heaviest children, which narrow the upper percentiles and z-scores of BMI, resulting in a higher prevalence of children who are
identified as overweight and obese compared to the 2000 CDC curves. However, the WHO data is still relatively new and has not been validated extensively.

Overall, the three definitions differ only slightly in their classification of overweight and obese children, summarized previously in Table 2. In practice, most children will be correctly identified as overweight or obese, regardless of the chosen definition. In an independent review, Reilly et al stated that there is no reason to suggest that the IOTF definition was better than national references, such as the CDC definition. However, the AAP supports the use of the CDC definition over the IOTF definition because the IOTF definition does not provide percentiles to classify individual children. Depending on the objective of a research study or population, the CDC, IOTF, and WHO definitions may prove to be more effective. Lastly, the definitions should only be applied to children older than five years of age because not enough is yet known about the development of children under five to apply these definitions.

Review of Measurement Tools

Once the investigator or clinician selects a definition for overweight and obesity, he or she must then choose a method for measuring body composition. Each measurement technique seeks to determine the percent body fat directly or indirectly, through calculation. Whenever possible, the most accurate method should be chosen. The sensitivity, specificity, and positive predictive value (PPV) are ways to determine accuracy, summarized in Table 5. According to Krebs et al, sensitivity is the proportion of children who are fattest when measured with a standard method, such as DXA, and
also correctly matched with BMI.\textsuperscript{2} Specificity is the proportion of children who are not the fattest with standard method (DXA) and also correctly matched with BMI classification. PPV is the proportion of children who are truly overweight or obese according to BMI and also the fattest with standard method. Lastly, 1 - PPV is the proportion of children who are incorrectly identified as fat with BMI compared to standard method.\textsuperscript{2}

\textbf{Table 5. 2x2 Table of Standard Method Compared to BMI Classification.} This table depicts the relationship between sensitivity, specificity, false positive, and false negative for BMI classification as a screening test for obesity. Dual X-ray Absorptiometry (DXA) is used as the standard or accurate method of obesity measurement.\textsuperscript{2}

<table>
<thead>
<tr>
<th>BMI classification</th>
<th>Fattest</th>
<th>Not Fattest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overweight or obese</td>
<td>High sensitivity</td>
<td>False positive</td>
</tr>
<tr>
<td>Not overweight or obese</td>
<td>False negative</td>
<td>High specificity</td>
</tr>
</tbody>
</table>

The most accurate techniques are UWW, ADP, DXA, CT, and MRI and could be substituted for DXA in the above table.\textsuperscript{15} The only “gold standards” of measurement are body composition models, which integrate several measurement techniques together.\textsuperscript{11} However, the most accurate methods require highly trained personnel, expensive equipment, and a laboratory-controlled environment. Some alternative measures are more cost-effective, fast, and easier to implement, such as SF, BIA, WC, WHR, and BMI.
SF in the Literature

SF measures subcutaneous fat at least three sites on the body, which can be extrapolated to total body fat via calculations.\(^2\) SF equations predict total body fat with high precision and are preferred to BMI in predicting body fat percent.\(^{28}\) Additionally, SF performs as well as WC in terms of sensitivity and specificity.\(^2\)

However, the challenges of measuring the SF themselves limit the reliability of the results.\(^{28}\) There is a high risk of measurement error when pinching fat, and this is compounded through the calculation.\(^2\) If SF data was collected by highly trained personnel, the findings do not directly yield useful clinical findings as there is no reference data for children. For these reason, the AAP does not promote the use of SF as a diagnostic tool for overweight and obesity.\(^2\)

BIA in the Literature

BIA measures the amount of resistance to a low energy current through the body. This value is used to calculate the fat free mass in the individual, which can be used to determine fat mass and percent body fat. These calculations are more accurate than predictions made from other indirect measures of body composition because they are related to total body fat, not just fat in a region of the body that was measured specifically. Although the gender- and age-specific equations used with BIA data are not specific to each individual measured, they correlate with data collected from DXA.\(^{26}\) BIA-based reference curves in England and Turkey have a similar shape to DXA curves.
derived from NHANES data, further supporting the acceptability of BIA as an alternative to DXA.\textsuperscript{26}

On the other hand, the equations are the basis of the limitations of BIA. There is inherent bias in the equations because they are not specific to each subject.\textsuperscript{28} Additionally, BIA data varies by body hydration and illness. Even if more accurate equations existed, there is no reference standard of acceptable body fat percentages in children.\textsuperscript{28} Therefore, this information must be compared to adult standards to be useful.

**WC and WHR in the Literature**

WC is often a preferred measurement tool because it only requires one measurement.\textsuperscript{15} WC measurements are linked to abdominal fatness and are better at estimating visceral fat than BMI, when compared to a MRI standard.\textsuperscript{2} WC, as a measure of abdominal obesity, was correlated with high cardiometabolic risk.\textsuperscript{29} Therefore, WC is “significantly more efficient than BMI in predicting insulin resistance, blood pressure, serum cholesterol levels, and triglyceride levels.”\textsuperscript{2} With further research about the impact of abdominal obesity in children, WC may prove to be a more valuable measure than BMI. In a study of Spanish children and adolescents aged six to 17 years, WC yielded a greater prevalence of obesity than established by the IOTF standard, based on the BMI cut-off of 25 and 30 kg/m\textsuperscript{2}.\textsuperscript{29} WC at or above the 90\textsuperscript{th} percentile was selected as the cut-off for abdominal obesity, based on correlation with high trunk fat observed with DXA.\textsuperscript{29} If reliance on BMI as the preferred indicator is underestimating the true level of
overweight and obesity among children, the health status of the entire population of children may be worse than is thought.

The primary limitation of WC is the lack of reference for comparison. Neither the international community nor CDC has established a threshold for adolescent abdominal obesity. Two individuals may have the same WC but different body fatness. Therefore WC information should be supplemented with other data, such as height or BMI, to draw further conclusions about an individual’s health status. WHR may be an acceptable addition to build on the information by WC alone, but the addition of a second anthropometric measure increases the likelihood of measure error.

BMI in the Literature

BMI was the most frequently encountered measurement tool in the literature. BMI has been praised for the relative simplicity of the measurements and calculations but criticized for its assumptions about body fat distribution. Compared to direct measurements of body fat, such as DXA, BMI has high specificity and moderate sensitivity. This means BMI is both able to accurately classify children who are the fattest when measured with DXA and children who are not the fattest. The primary goal of BMI is to identify children with the highest percentage of body fat. This is clinically relevant as their body fat percent is correlated with adverse levels of cholesterol and lipids in the blood. To increase the accuracy of these measurements, Himes suggested using the mean of multiple measurements of height and weight to reduce random error in the BMI calculation. The CDC has also made their measurement protocols available
online so that they can be used by other investigators. The strong correlation between BMI and percent body fat is the driving argument for its use. As depicted in Figure 5, the higher the BMI classification, the greater prevalence of children with high percentage body fat.

![Figure 5. Prevalence of children with percentage body fat 65th to 85th percentile, by BMI classification, Age 8-19 years, NHANES, 1999-2004. BMI classifications are based on the CDC growth charts: low-normal (<75th percentile), high-normal (75th to <85th percentile), low-intermediate (85th to <90th percentile), high-intermediate (90th to 95th percentile), moderately high (95th to <97th percentile), and very high (≥95th percentile). As BMI classification increases, the prevalence of a higher percentile of percentage body fat increases, suggesting the accuracy of BMI in predicting percent body fat. The data source is NHANES 1999-2004. Reproduced Figure 1.](image)

In opposition, BMI is not a measurement of body fat but a relationship between height and weight. BMI is justified as a proxy for body fat percent based on the assumption, as height increases, any disproportionate increases in weight are due to an increase in body fat. However, the weight measurement used does not distinguish between lean body mass and body fat. BMI cannot account for the distribution of fat either. As a child grows and develops, he or she will gain weight but this may be in the form of muscle, visceral fat, or subcutaneous fat, depending on the stage of
development. Additionally, BMI varies between males and females, by age and level of maturity, and by relative leg length related to height. The BMI development curves do not reflect the growth spurt of adolescence, common in puberty. Since the BMI curves are based on arbitrary points in the reference data, rather than evidence of ideal growth, they lack power.

Some studies have attempted to reduce the error in BMI calculation by taking multiple measurements of height and weight to account for daily and seasonal variability. However, the use of two measurements compounds the systematic and random error in BMI. Additionally, the inter-observer error was hard to eliminate, especially for large studies or screening events, which require the measurement of many subjects. After reviewing the literature for acceptable measures of error in anthropometric measurement, Ulijaszek et al., concluded that error was unavoidable. There were several strategies suggested by the AAP to reduce errors, presented in Table 6. These strategies should not be implemented independently but occur simultaneously to increase the precision of the measurements and yield more accurate results.
Table 6. American Academy of Pediatrics Recommendations to Minimize Data Collection Error for Height, Weight, and BMI. This is a summary of practices suggested to reduce systematic and random errors in measuring height and weight and calculating BMI. Modified from Table 1.28

<table>
<thead>
<tr>
<th>Recommendations to minimize data collection error for height, weight, and BMI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equipment and space</strong></td>
</tr>
<tr>
<td>Choose appropriate equipment</td>
</tr>
<tr>
<td>Check and calibrate equipment regularly</td>
</tr>
<tr>
<td>Keep extra batteries for scales</td>
</tr>
<tr>
<td>Provide a private area for child measurements, if possible</td>
</tr>
<tr>
<td><strong>Measurement protocols</strong></td>
</tr>
<tr>
<td>Choose a protocol that matched that used in the growth charts</td>
</tr>
<tr>
<td>Have written copies of measurement protocols for review</td>
</tr>
<tr>
<td>Train and standardize data collectors</td>
</tr>
<tr>
<td>Make sure data are recorded in the appropriate units (eg, kilograms, pounds)</td>
</tr>
<tr>
<td>Make sure data are measured and recorded to the nearest unit specified in the protocol (eg, 0.1 cm for height, 0.1 kg for weight)</td>
</tr>
<tr>
<td>Collect some replicate measurements for assessment of reliability, if possible</td>
</tr>
<tr>
<td><strong>Personnel</strong></td>
</tr>
<tr>
<td>Use as few observers as is feasible to make measurements, especially for research studies</td>
</tr>
<tr>
<td>Identify observers on data-collection forms or data-entry programs</td>
</tr>
<tr>
<td><strong>Data management</strong></td>
</tr>
<tr>
<td>Use as exact ages as possible</td>
</tr>
<tr>
<td>Have unique identifiers for children</td>
</tr>
<tr>
<td>Calculate BMI, percentiles, and scores by using tables or computer programs</td>
</tr>
</tbody>
</table>

Despite the criticisms of BMI, the affordability and association between percentage body fat lead to its widespread use. The raw BMI data can be standardized into BMI z-scores or BMI percentiles. BMI z-scores must be calculated by a computer and are not well understood by clinicians.2 However, z-scores are useful for the assessment of adiposity but minimize the fatness in the most obese children.34 The “centile scale attenuates BMI change in both fat and thin children.”34 BMI z-scores are most helpful for patients on the extreme ends of the curve and for comparison to a reference group.28 In intervention programs, BMI and BMI z-scores can be used as proxies for change in percent body fat.35
adiposity, BMI, BMI percent, BMI z-scores, and BMI percentile, raw BMI units and percent change in BMI are the best methods for measuring change in adiposity.\textsuperscript{34}

Depending on the goals of the study or outcomes desired by the clinician, the appropriate measurement tool varies. The investigator or clinician must weigh reliability, accuracy, and ease of collecting the data. The most reliable measurements are height and weight, followed by BIA, SF, and, lastly, WC.\textsuperscript{28} This was confirmed by a review of measurement error, which stated there were greater differences between observers in WC measurements than in the measurements of height and weight.\textsuperscript{33} If the goal is to measure subcutaneous fat, SF is the ideal measurement. If the goal is to measure visceral fat, WC is the preferred measurement. The objective of the investigation or intervention drives the measurement tool. Moreno et al. found no difference between BMI, WC, or SF to predict metabolic syndrome.\textsuperscript{2} Katzmaryzk et al suggested that WC should supplement the BMI data to give a more accurate prediction of CVD risk.\textsuperscript{2}
DISCUSSION

The topics of childhood obesity and adolescent have attracted the attention of parents, providers, and policymakers alike but the present research is redundant and incomplete. While several publications demonstrate unique study methods or new intervention strategies, the results are often inconclusive because there are no standards for healthy body fat percentage or body composition for children. The study populations are often too small to yield powerful results and too homogenous to be generalizable to other populations. The goals of this literature review were to compare commonly used body composition techniques, to discuss the rationale for using each measuring tool, and to make recommendations for interventions targeting school-aged children. However, if healthcare providers, clinical scientists, and program managers want to reduce the prevalence of overweight and obesity in children, the following recommendations promote more longitudinal studies and rigorous research to establish physiologically-based standards.

Recommendation for a New Definition of Obesity in Children

Of the three definitions presented for childhood obesity, the CDC definition has the most widespread implementation. The CDC definition is based on a review of over 10,000 children in the United States over several decades. The large sample size adds power to the growth curves. The CDC growth charts include separate graphs for weight-for-age, height-for-age, and BMI-for-age for boys and girls. Unlike the IOTF definition,
the CDC definition is applicable to populations as well as individuals. However, the CDC’s reference sample has been getting taller and heavier over time, which may positively skew the normal distribution if more data is in the right tail, if the data exclusion principle applied by the CDC was incorrect. This means the CDC thresholds are too high and result in fewer children being correctly identified as overweight or obese.

Although the CDC definition is preferred by the AAP, there is no clinical difference between the three definitions at the extreme ends of weight status, when it is most important to identify children at risk for overweight and obesity. The definitions proposed by the CDC, IOTF, and WHO are not really definitions at all but threshold levels to classify a patient’s level of risk. High BMI values are correlated with high adiposity. High adiposity is correlated with elevated blood lipids, which places children at an increased risk for cardiovascular and other weight-related diseases in childhood and adulthood.

In order to create a true definition for obesity, children with varying levels of body fat should be followed from birth until adulthood in a prospective study. These children will be randomly selected at birth from geographically and ethnically diverse hospital populations in the United States. Every six months for the first five years of life and annually until age twenty years, the selected children will have a clinical visit to collect anthropometric and other biological data. Each child will receive an MRI, have his or her height or recumbent length, weight, waist, and head circumferences measured, and provide a sample of blood for analysis of lipids, triglycerides, glucose, insulin, and
other markers of disease. This information will be tracked in a database to draw conclusions about the impact of these indicators on disease outcomes. While a study of this nature is expensive and time-consuming, there are many unknown variables in human growth and development. A comprehensive study can provide insight into the biological and physiological foundation of many disease states, not only obesity.

Until a study of this magnitude can be implemented to determine how much body fat is considered to be an excess amount, guiding a true definition of obesity, providers and scientists must rely on the available proxy measures that exist to guide their clinical recommendations. The best available threshold for overweight and obesity is the CDC definitions based on the 85th and 95th percentile cut-offs on the age- and gender-specific growth curves. For children under age five, the WHO Child Growth Standards should serve as the reference because these are based on the ideal physiological growth of children.

**Recommendations for Measurement Tools**

There are numerous direct and indirect measurement techniques for determining the body composition, especially the percent body fat. The measurement tools vary in price, precision, expertise to complete, and reliability of repeated measures. Depending on the goal of the investigation or the use of the data measurements, different techniques are most appropriate.

For studies and clinical trials that require an accurate assessment of body composition, ADP is the ideal measurement technique. This tool provides reliable and
accurate data, even in children. This tool could be used to establish an updated CDC growth curve or provide data to extrapolate to the ideal WHO curves. The expense of the equipment, training of the investigators completing the measurement, and laboratory space required for ADP limit its use in all clinical scenarios. However, there are new mobile designs, such as the Bod Pod, which can be transported to various sites, such as hospitals, gyms, and schools, which allows a large number of individuals to be measured. This method is also advantageous because it eliminates the fear of underwater submersion associated with UWW and avoids the radiation exposure associated with CT scans. Whenever possible, ADP is the preferred assessment tool.

When funding or properly trained personnel are minimal, the next best method is BIA. BIA devices measure the percent body fat rather than estimating body composition from other anthropometric metrics. The measurement can be completed in a variety of settings, even rural or inconsistent environments. The device is easy to use and transport. The two lingering challenges are the initial calibration and assumptions about the individual’s hydration level. With some training and qualitative patient questions, these issues can be overcome. The accuracy of this tool is acceptably lower than other direct measurement techniques. BIA should be used in clinical assessments by nurses, physician, or other providers in community clinics or schools to determine the body fat percent of children and adolescents.

In the lowest resource settings, WC is the simplest and fastest indicator of risk for cardiovascular disease. WC allows the investigative team to quickly distinguish between individuals with an increased risk for weight-related diseases from those who do not have
an elevated risk. WC provides information about visceral fat not total body fat.\textsuperscript{28} This means WC can be indicative of risk for CVD, which is correlated with abdominal fat.\textsuperscript{2} In children, the distribution of body fat changes with time but the addition of visceral fat is more significant to a child’s health status than the addition of subcutaneous fat. In a study of Spanish children, 67.5% of overweight and 9.6% of normal weight children aged six to eleven years old had a WC at or above the 90\textsuperscript{th} percentile.\textsuperscript{29} Similarly, 67.5% of overweight and 5.3% of normal weight children aged 12 to 17 years had a WC at or above the 90\textsuperscript{th} percentile. The weight classifications were based on BMI, indicating that BMI may not be the best indicator of health status.\textsuperscript{29} In a review of several studies, BMI was not advantageous over other measures in predicting cardiometabolic risk.\textsuperscript{11} BMI may, however, be advantageous for collecting baseline data and measuring change over time. Therefore, WC is the preferred field measurement tool in resource-poor environments or when quick classification for risk is the goal of the study.

While the presented body composition techniques have been compared to other more accurate measures, they do not provide a sound foundation for an improved obesity definition. There are no established body fat percentages, BMIs, or WC values to confirm a risk of disease or poor health outcome for children. For example, even if every child could be evaluated with an MRI or ADP, there is no database or reference to compare the measured percent body fat. The best available option is to rely on studies performed in adults. Children, however, are still growing and developing so they may be influenced by body fat in different ways than adults. The only way to determine the impact of body fat
on children in order to establish a reference is to follow children for many years to draw conclusions about weight status and health status.

**Recommendations to Improve the Understanding of Obesity in Children**

The existence of multiple definitions and tools for defining, assessing, and quantifying childhood and adolescent obesity are indicators of the complexity of this topic. While new research is drawing new conclusions about the risk factors associated with adolescent obesity, there are still several gaps in the knowledge. The first step is to establish a single criterion for defining obesity. This will eliminate some of the redundancy and confusion in the literature. Second, the WHO Growth Standard curves need to be extended beyond age five to present the idealized growth for all children. The use of median or reference data is not an appropriate standard.

To accomplish these two suggestions, there needs to be more long-term studies to assess the growth and development of children over time, especially from adolescence into adulthood. This requires the collaboration between healthcare providers, clinical scientists, and program managers. Until new standards can be established and validated, the current best practices must continue to prevent and treat obesity in children and adolescents. Healthy People 2020 has set a goal to reduce the proportion of obese children in the United States aged two to 19 years from 16.1%, as reported by NHANES for 2005 to 2008, to 14.5% by 2020. The United States government and private research institutions must allocate more funding to the stakeholders to enable them to reduce the prevalence of childhood obesity and to learn more about adolescent development.
For Healthcare Providers

Healthcare providers, including pediatricians, nurse practitioners, and nurses, play an important role in preventing obesity in children. Providers can identify changes in the child’s weight and body composition over time and give recommendations to improve the child’s health status. The AAP suggests that providers record the child’s height and weight at every preventive care visit, such as a check-up or to receive vaccinations. However, an analysis of 19,033 ambulatory care visits found that the height and/or weight measurement was missing in 20.8% of visits. This implies that healthcare providers are missing important documentation in approximately one out of every five patients. Pediatric clinics are often the only place where children have their height and weight measured so this represents a missed opportunity to identify children who are overweight or obese. Physicians, especially, need to set an example amongst all healthcare providers to collect anthropometric data on their patients. This allows a child to serve as his or her own reference subject to see how he or she grows over time.

Additionally, physicians need to collect anthropometric data on their patients to provide treatment recommendations. For children who are identified as overweight or obese on the CDC growth charts, the pediatrician has the responsibility of educating the parent on nutritional strategies and other interventions to reduce the amount of body fat in the child. In order to make well-informed recommendations, healthcare providers should demand exemplary definitions and measurement protocols to provide their patients with accurate information. Physicians can influence research institutions to improve the diagnostic and assessment tools for childhood obesity or conduct studies of their own.
For Clinical Scientists

Clinical scientists have the opportunity to partner with physicians or conduct their own independent investigations. Scientists have the advantage of access to more accurate measurement techniques and statistical analysis tools to evaluate large data sets. The responsibility of generating a new definition for obesity and its true correlation with health outcomes falls on these scientists. Many scientists can rely on their affiliations with governmental agencies, such as the CDC or National Institute of Health (NIH), or education institutions, such as public and private universities, to request funding for their research proposals. The severity and scope of the issue of adolescent obesity should encourage funders to provide ample funding to investigate the origin, prevention, and treatment of obesity in children and adolescents.

Furthermore, the national and international health community can join together to track children from birth into adulthood to learn more about development and the impact of childhood overweight and obesity on adult health. An international effort can track children from various ethnic and regional backgrounds to compare lifestyles, diet, and genetic variations in development. This information can provide additional evidence to funders to continue supporting clinical investigations. Without further research, the current definitions in use continue to be unsupported and the time and money spent on intervention programs based on these definitions may be wasted.
For Program Managers

The role of program managers is to design and implement obesity prevention and treatment programs. Prevention programs distribute nutrition and physical activity recommendations to all children and their families to encourage healthy lifestyle choices. Treatment programs provide physical and biological interventions, such as medications, to children with high levels of body fat to promote weight loss and minimize cardiovascular risks. In order to identify the appropriate children to make the appropriate behavior changes, the program manager needs an accurate criterion to recruit children to participate in the intervention. Program managers can work with physicians and clinical scientists to target patients, collect data, and draw conclusions about the impact of the intervention on the child’s weight and health status. Until new definitions are confirmed, program managers should use the best practices described in the literature to shape their programs.

Conclusion

In the United States, 17% of children aged two to 19 years are obese. Many more children are overweight or at risk for becoming obese. Some schools have attempted to screen their student population for obesity to prevent and treat this problem, but they are ill-equipped. The responsibility to reduce the prevalence of obesity falls on healthcare providers, clinical scientists, and program managers. They must encourage the international community to develop a true definition for obesity and collect more information about body composition. This requires a collaborative effort with public and
private organizations to design and implement longitudinal studies on children from birth through adulthood.

Until this happens, healthcare providers and clinical scientist need to think critically about which definition they chose for obesity and how to measure the body composition of children. They should weigh the pros and cons of each before classifying the child’s weight and making recommendations to children and their families. Unfortunately, the existing body of research is incomplete and the best practices available rely on typical growth of a reference population rather than ideal growth. Clinical scientists and healthcare providers must work together to collect anthropometric and biological data to better understand how children grow and develop. Program managers can help identify children who are overweight or obese to support the clinical investigations. As the body of knowledge grows about physiologically-appropriate development, risk factors for poor health outcomes, and the long-term effects of excess body fat in children, the field of adolescent obesity will continue to change and hopefully the prevalence of childhood obesity will decrease.
REFERENCES


19. De Onis, Mercedes, Garza, Cutberto, Victoria, Cesar G., Bhan, Maharaj K., Norum KR. The WHO Multicentre Growth Reference Study (MGRS): Rationale,


CURRICULUM VITAE

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EDUCATION

**Boston University School of Medicine**, Boston, MA  
Candidate for Masters of Science in Medical Sciences  
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**Alliant International University**, San Francisco, CA  
Intern Teaching Program: Early Completion Option  
June 2010

**University of Southern California (USC)**, Los Angeles, CA  
Bachelor of Science, Kinesiology  
May 2009

WORK EXPERIENCE

**Study Point, Inc.**, Seattle, WA  
Tutor  
January 2012 – June 2012

- Planned and implemented weekly two-hour tutorial sessions in preparation for the SAT and ACT exams for three students using provided study materials
- Designed unique study plans to accommodate students’ academic strengths and weaknesses to boost their confidence and performance in high stress environment

**Oakland Unified School District**, Oakland, CA  
Teacher  
August 2009 – June 2011

- Developed engaging and interactive lesson plans and formative and summative assessments aligned with California’s Department of Education Science Standards for 130 students per year, including lectures, teambuilding activities, and scientific experiments
- Participated in workshops and conferences about best teaching practices, cross-cultural and cross-curricular education, and diversity competencies
- Documented action plans as the Science Department Representative and Secretary for the Faculty Council
COMMUNITY SERVICE

bWell Center, Boston, MA  May 2013 – Present
Volunteer, Intern

- Provided health and community resources to patients and their families who visited the Pediatric Department at Boston Medical Center
- Registered and followed-up with patients in the Jump Rope Clinic
- Facilitated hourly activities to develop motor skills and nutrition knowledge

Rosie’s Place, Boston, MA  January 2013 – Present
Volunteer

- Prepared and served meals to 150 underserved women from the greater Boston area
- Distributed monthly ration of fresh produce and nonperishable goods to women
- Communicated instructions and general pleasantries with Spanish-speaking visitors

Ventanilla de Salud, Seattle, WA  January 2012 – July 2012
Coordinator Assistant

- Created and presented health education sessions on cardiovascular health, diabetes prevention, and other healthy lifestyle topics to visitors of the Mexican Consulate
- Translated and coordinated presentations for third party organizations who presented at educational sessions
- Assembled and distributed informational packets with brochures and resources covering a wide variety of health topics, including smoking cessation, child immunizations,

University of Washington Medical Center, Seattle, WA  February 2012 – June 2012
Volunteer

- Escorted patients and transported laboratory specimens throughout the hospital
- Supported nursing staff in the Interventional Cardiology Recovery Unit by restocking patient recovery rooms, ordering food, and creating IV start kits
- Observed physicians and surgical staff in the Cath Lab as they performed angiograms, diagnostic tests, valve replacements, biopsies, and innovative procedures
Somos Hermanos, Quetzaltenango, Guatemala July 2011 – December 2011
Participant
- Translated from Spanish to English for visiting physicians and took vital signal of patients in rural and urban medical clinics
- Integrated in daily Guatemalan life through Spanish language courses, volunteer work, and a home-stay
- Engaged in discussions and presentations about the history, culture, and politics of Guatemala, as well as the current state of public education and health in comparison to Mexico and El Salvador

Teach for America, Oakland, CA June 2009 – June 2011
Corp Member
- Participated in workshops and conferences about best teaching practices, cross-cultural and cross-curricular education, and diversity competencies
- Attended six-week summer institute to develop teaching skills while providing summer school instruction to 45 7th graders

Cedars-Sinai Hospital, Los Angeles, CA August 2007 – May 2009
Trojan Health Volunteer
- Shadowed an anesthesiologist, spinal specialist, and the Director of Orthopedic Trauma in both clinical and surgical settings
- Learned about the medical field from a first-hand perspective
- Discussed current issues in medicine at small group sessions with other volunteers

RESEARCH EXPERIENCE
University of Washington Metabolism Group, Seattle, WA May 2008 – Aug 2008
Research Assistant
- Performed ICC and Catecholamine tests on brain tissue samples
- Mounted and stained tissue samples for analysis

Healthy Lifestyle Choices: An innovative approach to high school health and fitness education, Los Angeles, CA August 2007 - December 2007
Co-investigator
- Taught high school health students about obesity prevention and physical activity
- Collaborated with other researchers to develop lesson plans and teaching techniques
- Designed project goals and objectives to objectively evaluate lessons