

A Guide to Methods for Assessing Childhood Obesity

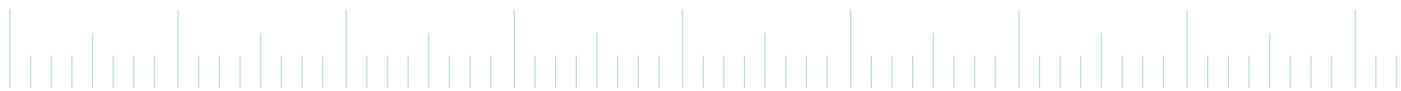
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GLOSSARY

Accuracy: Closeness of measured value to a gold standard or known value; it is related to validity.

Adipose tissue: Loose connective tissue composed of cells that primarily store fat for energy (adipocytes).

Adiposity: The state of having excess body fat.

Air displacement plethysmography: A method of measuring body composition that uses air displacement to measure body volume in a closed chamber.

Anthropometry: The study of human body measurements that provides information on body size and dimensions.

Bioelectrical impedance analysis: Indirect method of measuring body composition that estimates total body water, fat-free mass, and fat mass by measuring the resistance of the body as a conductor to a small electrical current.

Body composition: The relative proportion of fat and fat-free mass in the human body.

Body fat: A component of the body that is composed of fat cells (adipocytes). It is found under the skin (subcutaneous) or around organs (visceral) as well as in other tissues and organs of the body.

Body mass index: A person's weight in kilograms divided by the square of height in meters. It can be used to screen for weight categories that may lead to health problems, but it is not diagnostic of the body fatness or health of an individual.

Body weight: The sum of fat and fat-free mass.

Childhood overweight: Body mass index at or above the 85th percentile and below the 95th percentile for children and teens of the same age and sex.

Childhood obesity: Body mass index at or above the 95th percentile for children and teens of the same age and sex.

Dual energy X-ray absorptiometry: A method of measuring body composition that provides total-body and regional estimates of bone mineral, bone-free fat-free mass, and fat.

Extracellular water: The component of extracellular fluid that surrounds cells and provides a medium for gas exchange, transfer of nutrients, and excretion of metabolic end products of the cell.

Fat-free mass: A component of the body that consists of muscle, bone, organs, tissues, and water.

Fat mass: The total proportion of body weight that consists of fat, including fat deposited in non-adipose tissue and adipose tissue.

Growth chart: A tool for assessing child growth and defining obesity that can be based on data from a reference population (growth reference) or a standard population (growth standard).

Growth reference: A growth chart that is used to assess child growth as compared to children from a reference population. It is based on data from a specific population at a point in time.

Growth standard: A growth chart that is used to assess optimal and desirable child growth. It is based on data from children who were assumed to have optimal growth as a result of being exposed to a variety of factors that promote optimal growth such as mode of feeding, term birth, health care, etc.

Intracellular water: Fluid contained within cells.

Lean mass: Body mass that consists of organs, bone, the brain, water, and muscle.

Measure: Tools and methodologies used to assess body composition such as instruments and electrical devices.

Measurement: The size, length, or amount of something, as established by measuring.

Method: Means in which body composition can be assessed both directly and indirectly.

Population-level research: The field of research that seeks to characterize, explain, and/or influence the levels and distributions of health within and across populations.

Precision: The closeness of the values of two or more repeated measurements to each other; it is related to reliability.

Physical activity: Bodily movement produced by skeletal muscles that results in energy expenditure.

Reference population: The standard against which a population that is being studied can be compared.

Reliability: The consistency with which something is measured.

Skinfold thickness: An indirect method of measuring body composition that estimates the thickness of the subcutaneous fat layer at specific sites on the body.

Subcutaneous adipose tissue: Fat found just below the skin that is typically not related to many obesity-related diseases.

Technical error of measurement: Common way to express the error margin in anthropometry.

Total body water: The sum of intracellular water and extracellular water.

Validity: The truthfulness, or accuracy, of the value obtained or the closeness of a measured value to a gold standard or known value.

Visceral adipose tissue: Fat stored within the abdominal cavity surrounding several major organs. Excess visceral adipose tissue is linked to numerous obesity-related diseases. Also referred to as visceral fat.

Visceral fat: See visceral adipose tissue.

Waist (abdominal) circumference: A measurement of the circumference of the body at the level of the waist, which provides an indirect estimate of body composition and information on body fat distribution.

Z-score: The numerical measurement of a value's relationship to the mean, represented in terms of standard deviations from the mean. It can be calculated for BMI as well as other measures used in research.

ABBREVIATIONS

ADP	air displacement plethysmography
BIA	bioelectrical impedance analysis
BMI	body mass index
DXA	dual energy X-ray absorptiometry
ECW	extracellular water
FFM	fat-free mass
FM	fat mass
ICW	intracellular water
MRI	magnetic resonance imaging
MRS	magnetic resonance spectroscopy
NHANES	National Health and Nutrition Examination Survey
QMR	quantitative magnetic resonance
SAT	subcutaneous adipose tissue
TBW	total body water
TEM	technical error of measurement
VAT	visceral adipose tissue

1

Introduction



SECTION 1 Introduction

OVERVIEW

Measurement is a fundamental component of all forms of research, and it is certainly true for research on childhood obesity.

Measurement is a fundamental component of all forms of research, and it is certainly true for research on childhood obesity. A top priority for the National Collaborative on Childhood Obesity Research (NCCOR) is to promote accurate measurement by encouraging the consistent use of high-quality, comparable methods across childhood obesity prevention and research. NCCOR recognizes it can be challenging for users to choose the most appropriate methods to assess childhood adiposity. To address this need, NCCOR developed this Guide to describe various methods of adiposity measurement, present case studies that walk users through the process of using various adiposity assessment methods, and direct users to additional resources.

The goal of this Guide is to assist users on how to select the most appropriate method of measuring adiposity in children when conducting population-level research and/or evaluation on obesity. This Guide is also designed for researchers and for public health practitioners engaged in research as well as other professionals and practitioners who have an interest in evaluating weight-related outcomes within their clinic or community-based weight management or health promotion programs.

ORGANIZATION OF THIS GUIDE

A Guide to Methods for Assessing Childhood Obesity is organized into several sections that present key concepts and measures for assessing childhood adiposity. These sections are as follows:

- 1 Introduction**
- 2 Overview of Body Composition and Measuring Adiposity**
- 3 Key Factors Influencing Body Composition and Its Distribution**
- 4 Clinical Utility of Assessing Adiposity in Children**
- 5 Assessing Adiposity**
- 6 Using Secondary Data to Assess Obesity**
- 7 Measuring Body Composition in Population Health Research: Case Studies**
- 8 Conclusion**

2

Overview of Body Composition and Measuring Adiposity



SECTION 2

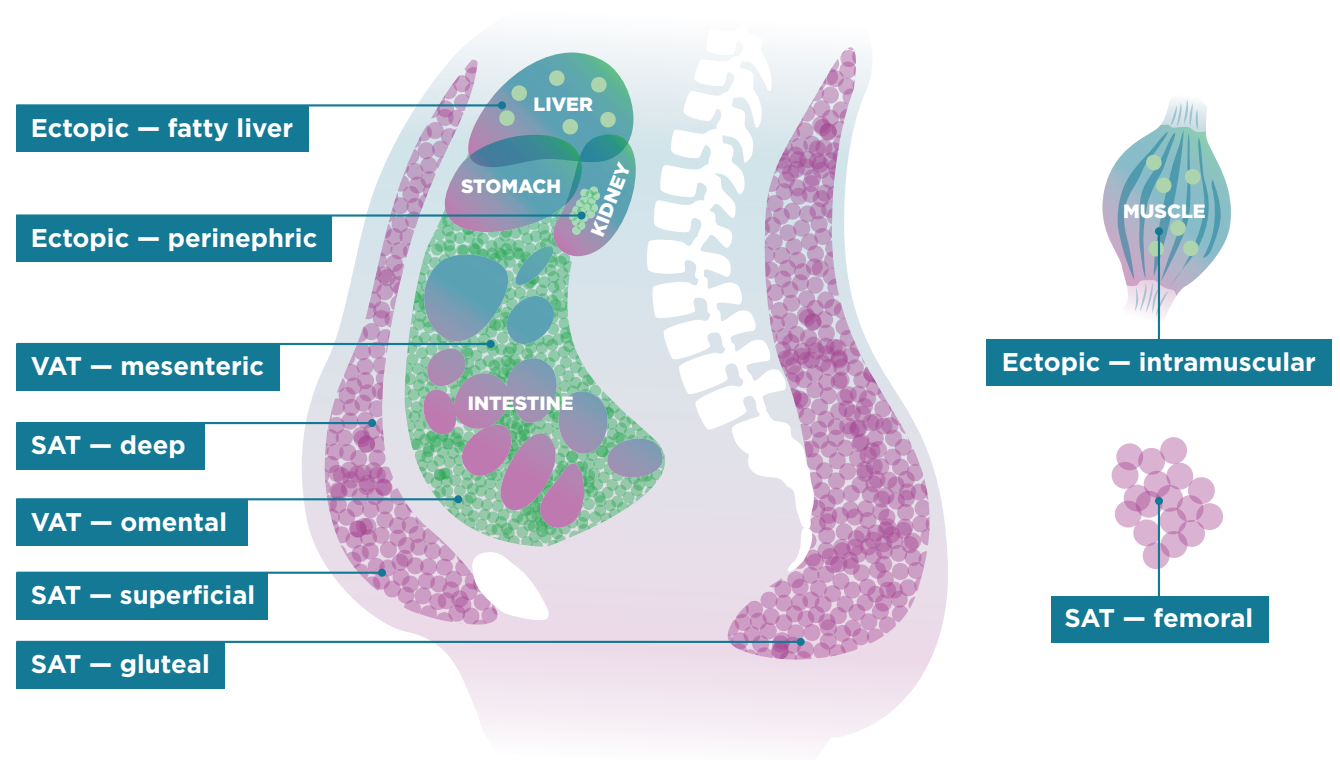
Overview of Body Composition and Measuring Adiposity

Body composition describes the relative proportion of fat mass (FM) and fat-free mass (FFM) in the body.

FM encompasses the adipocytes (fat cells) in adipose tissue (fat tissue) as well as fat deposits found in various other cells and organs in the body. Body fat is stored in adipose tissue in many locations throughout the body such as under the skin (subcutaneous), in the abdominal cavity surrounding internal organs (visceral), between muscles, and in the bone marrow (**Figure 1**). Fat cells also can deposit in locations other than

adipose tissue (ectopic) including within organs such as in the liver, skeletal muscle, and heart. FFM consists of muscle, bone, and internal organs as well as body water compartments. Most of the body's water is stored in the tissues of FFM, and FM is assumed to contain little water. Fat-free mass has the highest water content during the first year of life at ~80%. Water content decreases during growth, plateaus at ~73% in adolescents, and remains relatively stable at 73% of FFM throughout adulthood.¹ Fat-free mass does not contribute in a measurable way to the amount of total body water (TBW) nor to the estimation of TBW.

FIGURE 1: Adipose Tissue Depots



VAT — visceral adipose tissue
SAT — subcutaneous adipose tissue

Adapted from Hormone Molecular Biology and Clinical Investigation; Volume 19; Walker GE, Marzullo P, Ricotti R, Bona G, and Prodam F; The pathophysiology of abdominal adipose tissue depots in health and disease, Pages 57-74; Copyright (2014), with permission from De Gruyter.

MEASURING BODY COMPOSITION

The measurement of body composition at the simplest level refers to the measurement of the body's fat mass and fat-free mass components.

Body weight is the sum of FM and FFM. Increased body FM has been associated with a variety of diseases such as heart disease, some forms of cancer, and diabetes.

Accurate measurement of body fat mass can help explain how increased fat mass as well as the location or distribution of that increased fat mass may affect health and increase risk of complications from specific diseases later in childhood and in adulthood.



Simple, accessible, and accurate methods for measuring body FM directly in human beings are not available because use of such direct measurement methods would harm a person.

For these reasons, researchers and practitioners use indirect and surrogate measures to estimate body FM in living persons. Indirect measures are based on the premise that established relationships exist between specific body components. Obesity in children and adults is most often defined using body mass index (BMI, kilograms divided by meters squared). In children, BMI varies by sex and age, so unlike in adult BMI, children must be compared to a population of the same sex and age. Many growth charts exist. Some growth charts reflect growth standards and are based on data that assumes optimal and desirable growth in children based on selection of children meeting criteria such as breastfeeding, term birth, access to health care, etc. Others reflect a growth reference and are based on data from a specific reference population, often a country, at a point in time. Simply, a growth standard shows how children should grow, while a growth reference shows how they do grow.² The 2000 [Centers for Disease Control & Prevention \(CDC\) Growth Charts](#) ¹ were developed from a reference population of children in the United States aged 2–20 years and are comprised of data from six cross-sectional nationally representative surveys of children during the years 1963 to 1994. The [World Health Organization \(WHO\) has released growth charts](#) ² or growth standards for infants and young children aged 0–59 months based on sites and individuals who met a number of specific conditions related to feeding, term birth, and other factors thought to support optimal growth. Data were collected from sites in six countries. In 2007,

WHO released growth charts or growth references for older children that were based on U.S. data with exclusions based on high body weight but have been smoothed to align with the WHO growth standards for younger children. Many other growth charts are available for individual countries. In addition, growth charts are available for children with specific conditions that affect growth and growth rates, such as for children with Down Syndrome.³ These condition-specific growth charts compare the growth of an individual child who has the condition to a sample of peers of the same age and sex who also have the same condition.

The CDC has provided guidance to health care providers on when to use the CDC and WHO growth charts. (See [Growth Charts](#)). Additional information on the development and use of these growth charts can be found in the following resources. (See [2000 CDC Growth Charts for the United States: Methods and Development](#) and [WHO Child Growth Standards Based on Length/Height, Weight, and Age](#)) In the United States, a free, online [BMI percentile calculator for Child and Teen](#) calculates BMI and the corresponding sex specific BMI-for-age based on the CDC growth charts for children and teens. For children younger than age 2 years, sex specific weight-for-length is used to assess body weight in relation to recumbent length.

DEFINING OVERWEIGHT AND OBESITY IN CHILDREN

Experts have not yet identified or agreed upon a definition of obesity that uses an absolute cutoff or threshold for *increased body fat mass* during childhood.

This is due in part to the lack of empirical data that relates FM to health and disease outcomes for children and adolescents. Instead, overweight and obesity are defined statistically by the BMI-for-age or weight-for-recumbent length percentile values that exceed the level considered normal for a child of a specific sex.

For children and adolescents aged 2–19 years, BMI is compared to the distribution of BMIs from a reference population to yield a BMI percentile based on age and gender, rather than a single absolute value of BMI. For infants and toddlers, weight is compared to the distribution of weight from a reference population to yield a weight-for-length percentile, rather than a single absolute value of weight. The percentile cutoffs are intended to most reliably, and with the least amount of error, define a level above which a child is more likely to have or be at risk of developing obesity-associated adverse health outcomes or diseases.

Based on available data, an expert committee comprised of representatives from 15 professional organizations defined overweight in children aged 2 years and older as the 85th to <95th percentile of BMI for age and sex, and obesity as BMI \geq 95th percentile or an absolute BMI \geq 30 kg/m², whichever is lower based on age and sex using the reference population from the 2000 CDC growth charts.⁴ In addition, CDC recommends that for children birth to age 2, weight-for-length at or above the 97.7th percentile (+2 z-scores) of the sex specific WHO growth charts be used as a cutoff.⁵ The American Heart Association recommends that severe obesity in children aged 2 years and older be defined as having a BMI \geq 120% of the 95th age and sex specific percentile or an absolute BMI \geq 35 kg/m², whichever BMI value is lower.⁶

The measurement and use of BMI and several other indirect measures of FM is described in detail in [Section 4](#).

3

Key Factors Influencing Body Composition and Its Distribution



SECTION 3

Key Factors Influencing Body Composition and Its Distribution

Body composition changes as children grow and mature. Many factors influence these changes, including hormonal, environmental, and disease processes.

Growth is associated with increases in fat-free mass and fat mass, and changes in the relative proportions of these body components, which have important implications for accurate measurement of body composition.

The timing and distribution of changes in FM also have important implications for current and future health, including the risk of developing adult obesity and various metabolic complications such as insulin resistance, type 2 diabetes, high blood pressure, and abnormal blood lipids. These topics are presented in greater detail in this section.

CHANGES IN TOTAL BODY FAT FROM BIRTH TO ADULTHOOD

Total percent body fat is on average 11 to 15% at two weeks of age in a healthy full-term newborn,^{7,8} and this fat is primarily located in the subcutaneous layer.

Amounts of intra-abdominal or visceral adipose tissue are thought to be negligible at birth.⁹ Total percent body fat increases to about 30% by 6 months of age and begins to gradually decline during early childhood to about 19% in girls and 14% in boys at 10 years.¹⁰ Percent body fat then increases in girls between the ages of 9 and 20 years but decreases in boys after age 13 years, due to more rapid increases in FFM in boys than in girls. In both sexes, total body fat mass increases during adolescence as well as slowly with age during adulthood. However, boys have a greater increase in FFM relative to weight than girls, and girls have a greater increase in FM relative to weight than boys, resulting in the decrease in total percent body fat in boys and the increase in girls. Sex differences in percent body fat become more pronounced during early adolescence. Sex specific distributions of percent body fat by age in a nationally representative sample are also available.^{11,12}



CRITICAL DEVELOPMENTAL PERIODS OF GROWTH: ADIPOSITY REBOUND AND PUBERTY

After a period of rapid weight gain in infancy, the velocity of weight gain slows during early childhood before the pubertal growth spurt.

BMI demonstrates an interesting growth pattern during this period. In general, BMI declines after infancy to its lowest individual value at about age 6 years and then increases until adulthood. Longitudinal data on weight collected from birth to 15 years in the Avon Longitudinal Study of Parents and Children (n=625) documented rapid weight gain in infancy and a second period of rapid weight gain that begins between ages 7 and 11 years. The corresponding BMI data demonstrated the occurrence of an adiposity nadir (lowest point) before age 7 years and a rebound in most children between ages 7 and 9 years.^{13,14} The increase in BMI following the nadir is known as the adiposity rebound. Children who experience adiposity rebound at younger ages are more likely to have overweight or obesity later in childhood, adolescence, and adulthood.^{15,16} Longitudinal data on BMI in a New Zealand cohort studied from birth until age 26 years demonstrated different patterns of growth and risk of obesity among those with early (<5.5 years for boys and <5 years for girls), average (between 5.5 and 7.5 years for boys and between 5 and 7 years for girls), and late adiposity rebound (≥ 7.5 years for boys and ≥ 7 years for girls).¹⁵ Those children with early rebound had a higher BMI beginning at about age 5 years that was maintained throughout adolescence and adulthood. The risks

of having overweight and obesity at age 26 years were about threefold higher for the early rebound compared to the average rebound group. These findings suggest that early adiposity rebound correlates with higher risk of overweight and obesity later in life.

During puberty, both FFM and FM increase, and the relative changes and their timing during development differ by sex. Thus, body composition changes during the pubertal period must be evaluated in relation to stage of pubertal maturation for boys and girls.¹⁷

GIRLS: Progressive increases in FM and percentage of body fat during puberty in adolescent girls are documented.¹⁸ Evidence from several epidemiologic studies in the past 30 years indicates a relationship between earlier onset of puberty in girls and increased BMI. Most of these studies examined the age of menarche as the primary marker for the timing of onset of puberty, because it requires only a recollection of age at onset of menarche by the child and no physical examination. However, increased BMI is also correlated with earlier attainment of other markers of female puberty, including breast development and pubic hair. The self-assessment stage of sexual maturation using drawings and pictures may result in girls with obesity overestimating their Tanner breast stage due to the presence of greater breast fat tissue.¹⁹ The question of whether earlier puberty is the cause or the result of increased body fat has not been resolved. However, longitudinal studies suggest that increased body fat or a rapid increase in BMI predicts earlier onset of puberty. Thus, although obesity is not the only factor contributing to early puberty in girls, the downward shift in the United States during the past 30 years in the age of onset of puberty and the age of menarche in girls could be partially explained by the higher prevalence of obesity over this time period.

BOYS: The nature and direction of the relationship between obesity and timing of pubertal onset in boys is inconsistent.²⁰ The relationship between obesity and timing of pubertal onset has been studied in girls, but not as well in boys, possibly because of the lack of a convenient self-report marker for puberty in boys that can be obtained in an interview, such as age at onset of menarche for girls. Therefore, studies of boys must rely on physical examinations with accurate Tanner staging of pubic hair and genital development, and such studies are more difficult to perform on a large scale. It remains unclear whether boys with obesity and those with overweight differ with respect to their pubertal onset, as data are contradictory. Some studies report an association between increased BMI and earlier age at pubertal maturation, whereas other studies have found the reverse association.²¹ Lee et al. have speculated that greater estrogen production in boys with obesity compared to boys at a healthy weight could result in suppression and delay of the pubertal process.²² However, this might not be the case for boys who are overweight.

Like the timing of adiposity rebound, the timing of onset of puberty has important future health implications, as several adverse health outcomes have been associated with earlier onset of puberty, such as glucose dysregulation, higher blood pressure, increased risk of insulin resistance, type 2 diabetes, and cardiovascular disease in women and men. This risk also exists for post-menopausal breast cancer in women.²³ A systematic review of data on the association of pubertal timing and adiposity and cardiometabolic risks in middle to late adulthood in both men and women noted that some studies suggest that earlier menarche may reflect greater childhood adiposity and early menarche itself has little impact on cardiometabolic risk, whereas other studies report that earlier maturation is an independent risk factor for adulthood obesity and other cardiometabolic risk factors.²⁴ Strong evidence exists, however, for an association between earlier pubertal maturation and greater adult adiposity in women.²⁴



FAT MASS DISTRIBUTION

The adverse health effects of body fat are related to its location or distribution in the body as well as to the total amount of fat mass.

Available data suggest that metabolic disease risk occurs differentially by the location of different fat depots and that patterns of visceral adipose tissue (VAT), subcutaneous adipose tissue (SAT), and VAT/SAT ratio vary by age and sex. Higher amounts of VAT and higher proportions of VAT to SAT are major determinants of impaired glucose metabolism and hepatic fat accumulation over time. This altered fat partitioning often is not observed until adolescence and carries a higher risk of metabolic conditions, including insulin resistance and type 2 diabetes, independent of the overall body FM. This is because insulin resistance is related to a particular central and visceral fat distribution (greater VAT relative to SAT) and ectopic fat accumulation.²⁵ These metabolic consequences are more pronounced in girls than in boys.²⁶ Moreover, in adolescent girls with obesity, a low proportion of VAT relative to SAT, regardless of the amount of total body fat, has been reported to protect against fatty liver and glucose dysregulation.²⁶ In a cohort of children and adolescents of Hispanic heritage followed over a 2-year period, accumulations of liver fat and VAT, and reduction in SAT each significantly and independently predicted diminished beta-cell function, an important risk factor for transition to type 2 diabetes.²⁷ The impact of these changes in body fat distribution during puberty are important for understanding the pathophysiology leading to development of type 2 diabetes.

SEX DIFFERENCES

Differences in body fat according to sex are evident as early as birth and extend throughout the life span.¹⁰

It is well established that beginning at birth, the percentage of total body fat differs by sex, such that females have a higher percent total fat than boys.^{8,28} These sex differences in body composition become more pronounced during the adolescent growth spurt and sexual maturation. The sex differences established during adolescence persist through adulthood, with both percentage subcutaneous fat and total body fat higher in females. The percentage differences between sexes in body composition reflect a larger FFM that consists of greater bone mineral content (especially of the limb skeleton) and greater skeletal muscle mass in males compared to females. Therefore, estimated absolute total FM is similar in male and female adolescents, but in terms of percentage of body weight, females have a greater percentage of weight as FM and males have a greater percentage of weight as FFM.

RACE/ETHNICITY

In the United States, striking race/ethnic differences in the prevalence of obesity and in body composition exist among children.²⁹

Race/ethnicity differences have been reported in total body fat beginning at birth,^{28,30} at prepuberty,^{31,32} and during adolescence³³ for studies involving children born in the United States. Among prepubertal children (aged 3 to 12 years) in New York City, children who were Asian had higher percent body fat compared with those who were African Americans and Caucasians.³⁴ Newborns who were African American, Asian, or Hispanic



had greater central fat deposition (by subscapular skinfold) than did Caucasians. Similarly, for the same total FM, race differences in fat distribution are evident as early as prepuberty,³¹ and these differences persist throughout adulthood. Smaller hip circumferences have been documented in females who are Asian at all pubertal stages compared with those who are white or Hispanic,³⁵ and trunk subcutaneous fat is greater in females who are Asian compared with whites.³⁶ Differences have been described in subcutaneous FM and fat distribution in adults who are Asian compared with whites,³⁷ as have race differences in the course of sex-specific fat distribution with the progression of puberty.³⁸ Differences between blacks and whites in the distribution of subcutaneous adipose tissue and in the density of FFM (1.113 g/cm³ vs. 1.100 g/cm³ in blacks and whites, respectively) reduce the validity of some body composition measurement techniques,³⁹ including anthropometry and air displacement plethysmography. As an alternative, the dual energy X-ray absorptiometry method is less sensitive to the density of FFM issue, and magnetic resonance imaging allows for quantification of fat depots and therefore fat distribution. Factors that account for the observed racial/ethnic differences in body composition are not well understood, and despite these observed racial/ethnic differences, no race/ethnicity-specific growth charts for children have been developed.

FAT-FREE MASS

Although the primary focus of this guide is the measurement of fat mass, understanding the non-fat compartment, FFM, and changes in its subcomponents, including skeletal muscle, bone, and TBW, can contribute to understanding the challenges related to in-vivo estimates of body components and how they influence the accuracy of available measurement methods.

These challenges are addressed in a review by Toro-Ramos et al. that summarizes the evidence specific to body composition during fetal development and infancy through age 5 years.⁸

Overall, FFM increases during growth and development, is relatively stable throughout adulthood, and declines during senescence. Total body bone mass increases with age during growth, reaching peak bone mass between ages 20 and 30 years, then decreases with age after this peak. In general, there is a rapid accretion of skeletal muscle during growth development, with marked sexual dimorphism developing during adolescence. Skeletal muscle mass is then relatively stable during adulthood up to about age 30 to 40 years, after which it begins to decrease. Total body water is an important component of FFM and body weight. A newborn has a higher TBW relative to body weight (i.e., 81 to 83% at age 1 week) than at any other age thereafter. Total body water then decreases throughout childhood, from 79% at 1 year to about 75 to 76% at 10 years.^{10,40-42} Steady state estimates in normal adults of about 73% are achieved during late adolescence.

4

Clinical Utility of Assessing Adiposity in Children



SECTION 4

Clinical Utility of Assessing Adiposity in Children

Clinical utility refers to the ability of the results of a measure to accurately identify children at risk of specific health outcomes to inform clinical decision-making in meaningful ways, such as guiding prevention and treatment efforts that can lead to improved health outcomes.

Ultimately, the utility of assessing childhood adiposity in research, clinical, and public health practice is driven by this goal, with research providing the evidence base for the use of the measure in practice.

Numerous adverse health outcomes have been shown to be associated with obesity in children, providing strong support for the potential value of measuring adiposity and intervening in children^{43,44} (**Figure 2**).

Childhood obesity has been associated with the development of hypertension, dyslipidemia, insulin resistance, type 2 diabetes, and fatty liver disease. Furthermore, a strong association exists between childhood obesity and developing adult cardiovascular risk factors levels, including blood pressure, triglycerides, and HDL cholesterol,⁴⁵ as well as having obesity in adulthood.⁴⁶ Negative psychological consequences of childhood obesity also are well-established. Weight stigma, primarily expressed as weight-based victimization, teasing, and bullying, can contribute to behaviors such as

binge eating, social isolation, avoidance of health care services, decreased physical activity, and increased weight gain over time, which may worsen obesity and create barriers to healthy behavior change.⁴⁷ Health care providers may exhibit weight bias and stigmatizing behaviors that include use of inappropriate-sized medical equipment as well as negative attitudes, such as associating patients with obesity with being lazy, lacking self-control, and being less intelligent.⁴⁸ This bias may adversely affect quality of care and prevent patients with obesity from seeking medical care.

Given the well-documented negative health consequences associated with obesity in children, the assessment of body fat in clinical and public health practice for the purposes of screening, evaluation, and implementation of effective prevention and treatment strategies can have a major impact on the health and well-being of children. Several agencies and organizations have developed guidelines for screening, evaluation, and treatment of children with obesity in various settings, including schools and clinics (see **Box 1**). These recommendations are beyond the scope of this guide, but **Section 5** of this guide reviews various methods of assessing body composition in children and addresses their validity (accuracy) and feasibility for use in these settings. Both validity and feasibility are important factors to consider when determining their utility in research settings as well as clinical and public health practice.

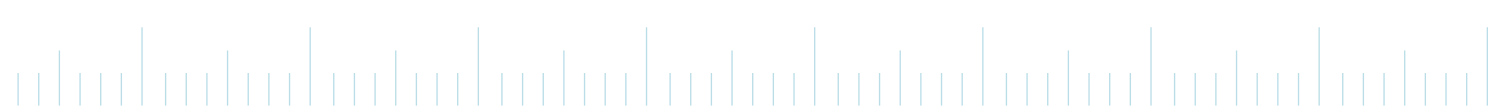
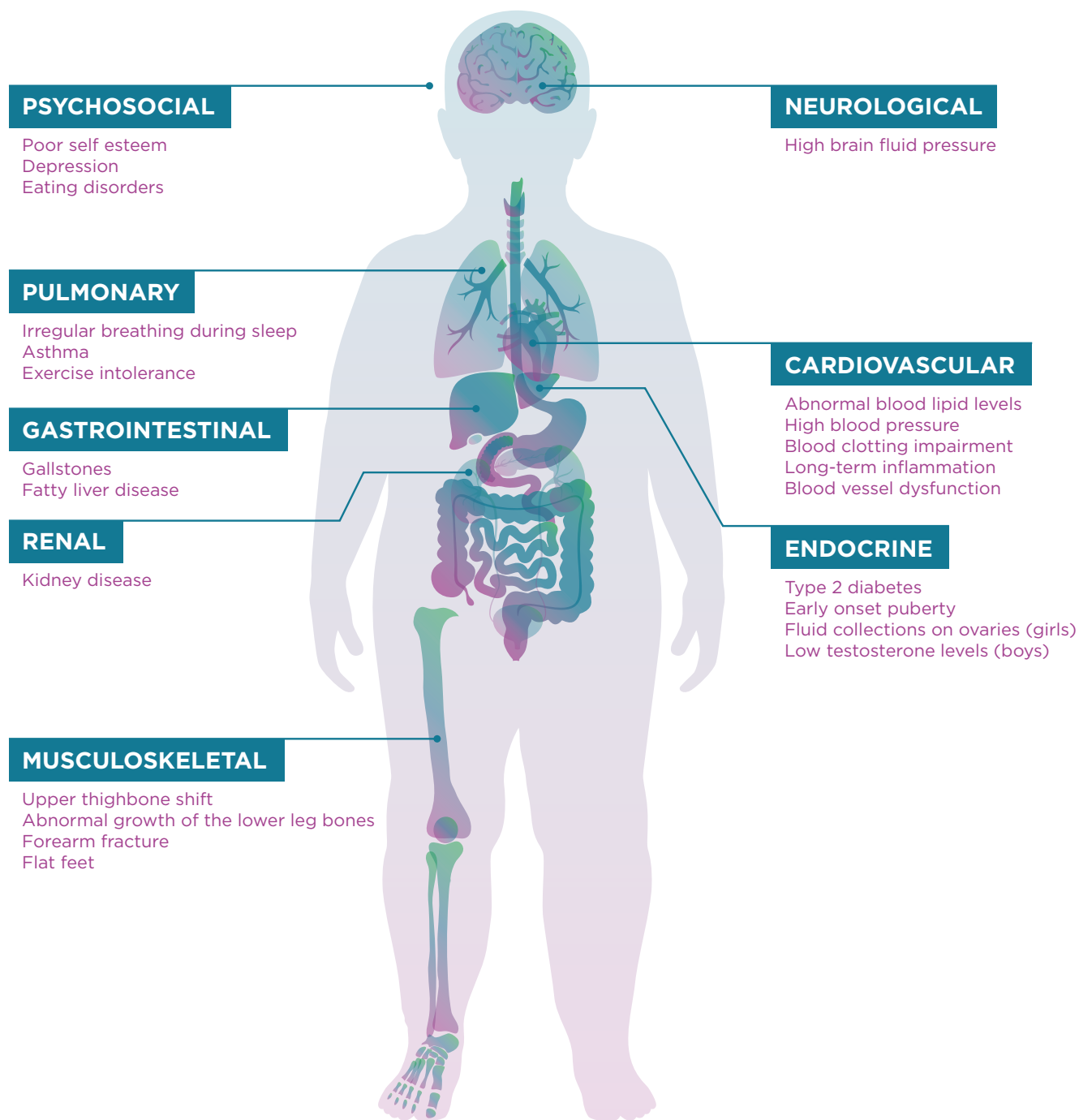


FIGURE 2: Adverse Childhood Obesity Health Outcomes

Adapted from the Lancet; Volume 360; Ebbeling CB, Pawlak DB, and Ludwig DS, Childhood obesity: public-health crisis, common sense cure, Pages 473-482; Copyright (2002), with permission from Elsevier.

BOX 1

Examples of Expert Group Recommendations for Assessment, Prevention, and Treatment of Childhood Obesity

-  [American Academy of Pediatrics: Assessment of Child and Adolescent Overweight and Obesity \(Pediatrics Supplement\)](#)
-  [American Association of Clinical Endocrinologists: Clinical Practice Guidelines](#)
-  [American Psychological Association: Clinical Practice Guideline for Multicomponent Behavioral Treatment of Obesity and Overweight in Children and Adolescents: Current State of the Evidence and Research Needs from the Guideline Development Panel \(GDP\) for Obesity Treatment of the American Psychological Association \(APA\)](#)
-  [CDC BMI Measurement in Schools](#)
-  [Endocrine Society: Pediatric Obesity—Assessment, Treatment, and Prevention: An Endocrine Society Clinical Practice Guideline](#)
-  [Report of the Commission on Ending Childhood Obesity](#)
-  [U.S. Preventive Services Task Force: Screening for Obesity in Children and Adolescents: Recommendation Statement](#)

5

Assessing Adiposity



SECTION 5 Assessing Adiposity

Various measurement methods may be used to assess body composition, and specifically adiposity, when conducting research and evaluation in clinical and field-based settings, such as early care and education venues, schools, and community-based, childhood healthy weight programs.

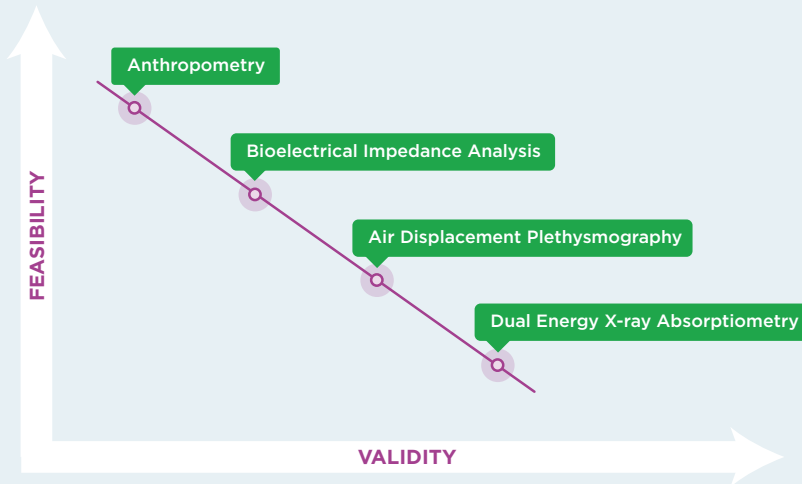
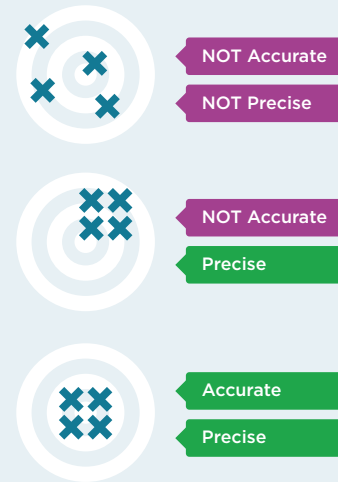
They include anthropometry and in-vivo (within a living organism) body composition techniques. These methods vary in reliability, validity, participant acceptability, cost, and technical complexity. Each method has advantages and disadvantages (summarized in **Table 1**) and some degree of error that relates to the underlying assumptions in the estimate of body fat as well as errors due to the actual measurements (measurement error). Certain methods cannot be used in children with specific health conditions or disabilities because basic assumptions of the method may be violated, or children may have physical or functional limitations that prevent use of these methods.

The choice of a body composition measurement method depends on the goal of the study or evaluation, the type of tissue to be assessed, the study population, and the setting and resources available. Specific factors to consider when selecting a method include

- validity in estimating body fat,
- reliability,
- sensitivity to change over time or with interventions,
- ability to predict health risks or outcomes (i.e., clinical validity),
- availability of reference ranges or norms for the study population (i.e., having data from a standard or reference population for comparisons),

- accessibility of the tools and/or equipment and staff in terms of training and level of skill needed,
- cost, and
- degree of burden and/or risk and acceptability to the participant.

Validity refers to truthfulness of a value obtained or the closeness of a measured value to a gold standard or known value. In obesity-related investigations, the gold standard of direct measurement of body fat and other tissues is difficult to obtain; therefore, the validity of a method for assessing body composition is evaluated by comparison to another method that is considered more accurate but is not the gold standard. In clinical research of body composition, the 4-compartment model is considered the criterion or reference method.⁴⁹ In this model, four components are measured: total body water (TBW) by deuterium dilution technique, body volume by air displacement plethysmography from which body density (Db) is derived, total body bone mineral (M) by dual-energy X-ray absorptiometry (DXA), and body mass (i.e., body weight) using a scale. Combining the output from these four measurements in an equation allows for estimation of FFM and FM or percentage body fat. Because TBW and bone mineral are found within the FFM compartment, an advantage of the 4-compartment model is that it accounts for variations in the composition of FFM due to differences in bone mass and hydration, which are the two components whose variations have the greatest effects on the accuracy of fat estimations. This is important, for example, in maturing children, where hydration of FFM decreases with age while their bone mineral increases.⁵⁰ The use of the 4-compartment model is generally not feasible due to the need for specialized laboratories containing the equipment that can perform all of the assays and component measurements, high cost of these methods, and

FIGURE 3: Feasibility/Validity Continuum of Select Adiposity Measures**FIGURE 4:** Accuracy Versus Precision

time burden for participants. The 4-compartment model also estimates FM and FFM at the whole-body level and does not provide regional or specific tissue assessments. A method is considered valid when the standard error of the difference in the estimate for percent body fat is less than 3%. Errors between 3% and 4% demonstrate limited validity, and errors greater than 4% suggest that variability is too high.^{51,52}

Reliability refers to the consistency with which something is measured. Reliability can be determined by repeating measurements on the same day or on consecutive days. Reliability coefficients are calculated as within-person coefficients of variation (CVs), where the CV is calculated as the ratio of the within-person standard deviation to the mean. Smaller CVs indicate greater reliability and ideally should be less than 2%.

The methods in this section are presented in order of most feasible and often least valid to least feasible and often most valid in population-based studies. Methods that have high validity often lack feasibility, and methods that are more feasible are frequently less valid (**Figure 3**).

Ideally a method should have high accuracy, which is related to validity, and high precision, which is related to reliability (**Figure 4**), and have low cost, participant risk, and burden. In pediatric longitudinal studies, an ideal method can be used across age groups from as early as infancy to childhood and adolescence (0 to 19 years). These and other considerations are discussed in greater detail for each of the methods that follow. Although various methods can be used to assess adiposity in infants and children with disabilities, the procedures for doing so are not covered in detail within this guide.

METHODS

Each section that follows explains a method for measuring body composition and how it is conducted; provides information on the estimates of body fat and their calculation (where relevant), interpretation, and limitations; and summarizes practical issues of accessibility, training, cost, acceptability, participant burden, and risk.

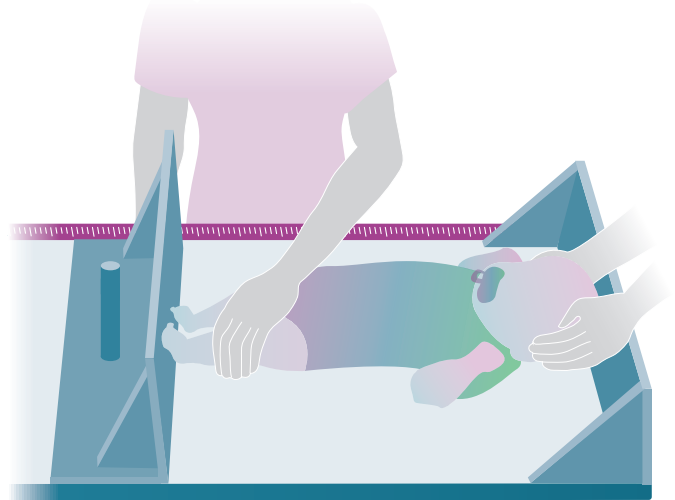
ANTHROPOMETRY

Anthropometry is the study of human body measurements that provides information on body size and dimensions. Anthropometry is composed of physical measurements that include recumbent length (lying down length) or stature (standing height), weight, and regional dimensions, including circumference measurements, skinfold thicknesses, bone breadths, and bone lengths. Methods that are used to assess adiposity include recumbent length/stature and weight, skinfolds, and circumferences. In the context of a research study, assessors conduct these measurements in duplicate or triplicate, ensuring (at least) two measurements are within a pre-specified allowable difference from one another. The maximum allowable difference between repeated measurements will vary by method and should be specified in the study manual of procedures or operations. The average of the two closest measurements will be used in the analyses. In addition, all equipment should be calibrated according to the study manual of procedures or operations and before conducting measurements each day to ensure accuracy.^{53,54}

Length/Stature and Weight

Recumbent length/stature and weight are the most common measurements used to assess weight status and monitor growth. These measurements

FIGURE 5: Recumbent Length Measurement in Infants



are often used to calculate indices that can be used to define obesity across all ages, from infancy through adulthood.

RECUMBENT LENGTH is measured in infants and children from birth to 24 months using an infant length board. The board is placed on a level and hard surface. Research staff place the infant flat on the center line of the board facing upwards with eyes looking straight up and spine straight. The crown of the head is held in position against the headboard and a second staff person straightens the infants' legs by gently placing hands on shins and knees and then moving the footboard so that soles are flat against it. The value of the measurement is recorded to the nearest 0.1 cm (**Figure 5**).

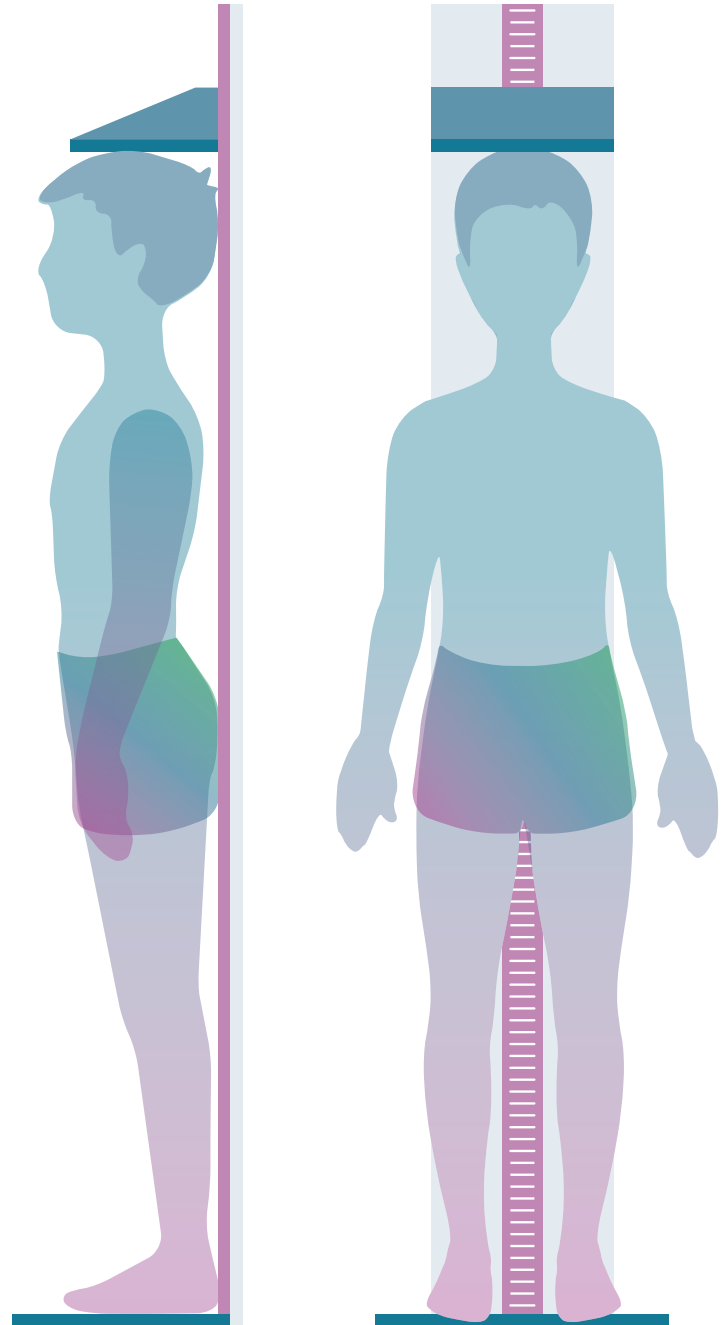
STATURE is measured using a stadiometer for children aged 24 months and older. With shoes removed, the child stands erect with feet positioned on the floor board of the stadiometer, arms by sides (palms facing legs), and back vertical to the backboard of the stadiometer so that the heels, buttocks, and back of head make contact with the back board (**Figure 6**). Children with severe obesity may not be able to have all three body parts touching the back board while standing straight.

The head is positioned in the Frankfort horizontal plane. The measurement bar is lowered to contact the skull (hair should be flat with no accessories where possible) as the participant is asked to take a deep breath in. At the end of inspiration, the value of the measurement is recorded to the nearest 0.1 cm. If a child has braids or hair accessories that cannot be removed, a height adjustment ruler is used to measure the hair piece. Subtracting the height of the braid or accessory from the measured height produces an adjusted height value that better reflects the child's actual height. A wall-mounted stadiometer with a fixed heel plate is recommended for greater reliability. Height bars attached to scales or wall-mounted tape measures are not appropriate for accurate height measurements. A certified calibrating rod should be used to calibrate the stadiometer for quality control before conducting measurements each day.

Children who have conditions that do not allow them to stand erect (e.g., cerebral palsy) can have their height estimated from surrogate measures including upper arm length, ulna length, forearm length, knee height, and lower leg (tibial) length. Measurement of tibial length does not require specialized equipment and is not impacted by knee and ankle contractures. However, whatever surrogate measure is selected, training of observers is required to ensure reliable and accurate results.⁵⁵

BODY WEIGHT is measured using a scale. For infants, an electronic pediatric scale is recommended, and the scale should be placed on a level and hard surface. Staff should confirm that the scale is tared (reads zero when no one is on the scale) before use. Wearing only a dry diaper, the infant is placed on the middle of the scale and weight is recorded. Children who can stand upright unassisted stand on the center of a floor scale with weight equally balanced on both feet. During the measurement, they wear minimal or light clothing and no shoes. The preferred equipment to assess weight is an electronic or beam balance scale that is properly calibrated to the nearest 0.1 kg according to the manufacturer's directions. When the child is standing motionless, the value of the measurement

FIGURE 6: Stature or Standing Height Measurement in Children




is recorded to the nearest 0.1 kg. Spring balance scales, such as bathroom scales, are not sufficiently accurate. Scales also must be able to measure the range of weights, including extremes, in the sample of children under evaluation. For quality control, all scales should be calibrated daily before measurement using certified weights of varying masses across the range of subject weights being measured. It is important to note that a scale may calibrate (be accurate) at lower weight increments but begin to deviate (be inaccurate) at higher weights. For more information about which types of scales are needed, see the following resource:



ADDITIONAL RESOURCE

[National Health and Nutrition Examination Survey \(NHANES\) Anthropometry Procedures Manual](#)

ESTIMATES OF BODY FAT, INTERPRETATION, AND LIMITATIONS


Body mass index (BMI) is calculated from weight and height as weight per height,² expressed in kilograms per meter squared, and is a commonly used index used to assess weight status and define obesity among adults and children aged 2 years and older. Although BMI does not measure body fat, it is highly correlated with total body fat at high levels, and thus values above a specific cut point are used to define obesity or excess adiposity.^{56,57} An online [BMI percentile calculator for Child and Teen](#)  provides BMI and the corresponding BMI-for-age and sex percentile based on the CDC growth charts. Similarly, weight for length, expressed as kilograms per meter, is a commonly used index of weight status and of fatness in infants and children younger than age 2 years as a comparison to sex-specific weight-for-length percentiles. As described in [Section 2: Defining Overweight and Obesity in Children](#), an expert committee comprised of representatives from 15 professional organizations defined overweight in children aged 2 years and older as the 85th to 95th percentile of BMI for age and sex, and obesity as BMI \geq 95th percentile or an absolute BMI \geq 30 kg/m², whichever is lower based on age and sex using the reference population

from the 2000 CDC growth charts.⁴ In addition, CDC recommends that for children birth to age 2, weight-for-length at or above the 97.7th percentile (+2 z-scores) of the sex-specific WHO growth charts be used as a cutoff.⁵ More recently, the American Heart Association recommended that severe obesity in children aged 2 years and older be defined as having a BMI \geq 120% of the 95th age- and sex-specific percentile or an absolute BMI \geq 35 kg/m², whichever BMI value is lower.⁶


Weight and height/recumbent length are relatively simple and inexpensive to collect and widely used to calculate indices (BMI and weight-for-length) that define obesity or excess weight in childhood. However, these indices have limitations for use in research and thoughtfulness must be used in their interpretation:

- BMI, as well as weight-for-length, is a measurement of body mass (the sum of both FM and FFM) and does not provide quantitative information on body composition (i.e., amount of FM versus and FFM) or the distribution of FM and FFM.
- BMI has poor ability to discriminate between FM and FFM because these two components are highly correlated (e.g., having a higher FM is associated with having higher FFM).
- In most children, BMI does not provide a valid index of fatness.⁵⁸ In prepubertal children aged 6 to 12 years, BMI accounted for only 54% and 69% of the variability in percentage of body fat in girls and boys, respectively. The average percent error predicting body fat ranged from 20.3% in girls to 22.5% in boys.⁵⁹
- BMI may overestimate or underestimate body fatness, particularly in the overweight range (BMI 85-95th percentile, and also varies widely by race/ethnicity. For example, about 50% of non-Hispanic white girls aged 8-19 years in the overweight category have excess body fat by DXA, but among non-Hispanic black girls, fewer than 25% have excess body fat.²⁹

- Studies that used BMI to identify children with overweight and obesity based on percentage of body fat have found high specificity (95 to 100%), but low sensitivity (36 to 66%) for this system of classification.^{60,61} This suggests a tendency to misclassify individuals as having overweight or obesity when they do not have excess body fat.

 The current version of the CDC growth charts are not intended to be used for BMI z-scores and percentiles above the 97th percentile because changes in extreme values are compressed into a narrow range of associated z-scores or percentiles that do not reflect meaningful changes.⁶² CDC is undertaking an effort to resolve this and updated guidance will be found on the [CDC Growth Charts](#) webpage.

- Interventions that affect body fat and/or lean mass but use BMI as the outcome measure may fail to detect changes in BMI.^{63–66} For example, higher levels of physical fitness are associated with increases in FFM and decreases in FM. If changes in FFM and FM both occur and are equal, BMI may not change. Therefore, the use of BMI as an outcome measure in fitness interventions designed to affect fat and/or fat-free mass has the potential to miss positive effects of interventions.⁶⁷ Similarly FM and

 The use of BMI in intervention studies as an outcome measure to establish efficacy of dietary and/or physical activity interventions that are intended to reduce adiposity has limitations. That is, some persons with a low BMI may have a relatively high percent body fat (because, for example, they have low muscle mass), while others with a high BMI can have a low body fat (because, for example, they have high muscle and bone mass). One cannot assume that small changes in BMI, or differences in BMI between individuals or subgroups of a population, completely reflect differences in body fat.

FFM, not necessarily BMI, are associated with cardiometabolic risk, and studies using BMI may fail to detect associations with indices of health-related outcomes, such as biochemical markers of cardiometabolic risk.⁶⁸

VALIDITY AND RELIABILITY

As previously described above, BMI does not measure fat mass. Therefore, studies that examine its performance examine correlations of BMI with various other methods that do estimate fat (such as air displacement plethysmography (ADP) and dual energy X-ray absorptiometry (DXA)) and describe the degree to which the relative relationships are consistent. In infants measured at birth and again at 5 months in the Healthy Start study, fat mass by ADP was significantly associated with BMI z-score.⁶⁹ For children aged 6.5–10.9 years in the pre-birth cohort Project Viva, total fat mass by DXA was highly correlated with BMI.⁷⁰ For children aged 8–18 years, correlations between BMI z-score and percent fat mass by DXA were moderate to strong, with the strongest correlations for boys and girls aged 8–11.9 years old.⁷¹ For children aged 8–20 years, the correlations between BMI z-score and fat mass showed strong associations across all participants combined, and moderate associations for participants with moderate or severe obesity.⁶² For more information about BMI validity and reliability see the following resources:



ADDITIONAL RESOURCES

[Relation of BMI to Fat and Fat-free Mass Among Children and Adolescents](#)

[Diagnostic Performance of Body Mass Index to Identify Obesity as Defined by Body Adiposity in Children and Adolescents: A Systematic Review and Meta-analysis](#)

[Fat and Lean BMI Reference Curves in Children and Adolescents and Their Utility in Identifying Excess Adiposity Compared with BMI and Percentage Body Fat](#)

REFERENCE DATA

National reference data for recumbent length for children from birth to 47 months, stature for children aged 2–19 years, weight for children from birth to 19 years, and BMI for children aged 2–19 years old are available from the NHANES 2011–2014 sample that included participants of all ages.⁷² These reference data are the most recent population-based reference data available for comparisons.

ACCESSIBILITY, TRAINING, AND COST

Equipment to measure recumbent length/height and weight is highly accessible, portable, and costs relatively little, although cost can vary considerably depending on the make and model of equipment. Typically, a research-grade portable scale or stadiometer costs about \$300. Training is needed to standardize measurements, but this measurement process requires relatively less skill than do other methods that will be described in this guide.

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability is high, when privacy is maintained, and burden to participants is low. The methods are noninvasive, safe, and low risk.

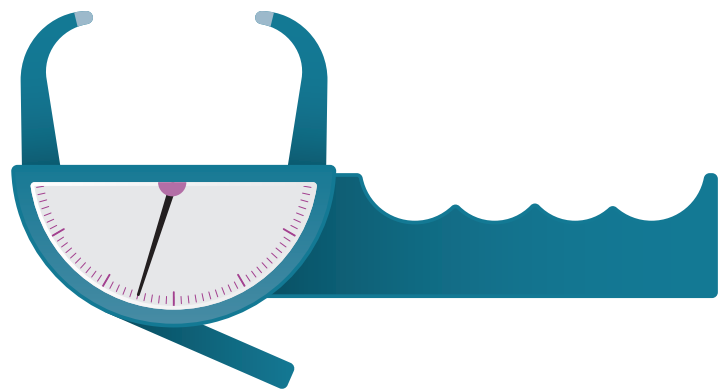
SUMMARY

Recumbent length/stature and weight measurements and the indices of BMI and weight-for-length that are used as indicators of weight status and excess adiposity are simple, safe, quick, and very acceptable. The measurements attained by this method are inexpensive to collect and require less staff training and skill for accurate and consistent measurement than do other methods. These methods are thus appealing for large-scale studies. However, these indices have limitations as they are not measuring body fat, and caution must be used in their interpretation.

Skinfold Thickness

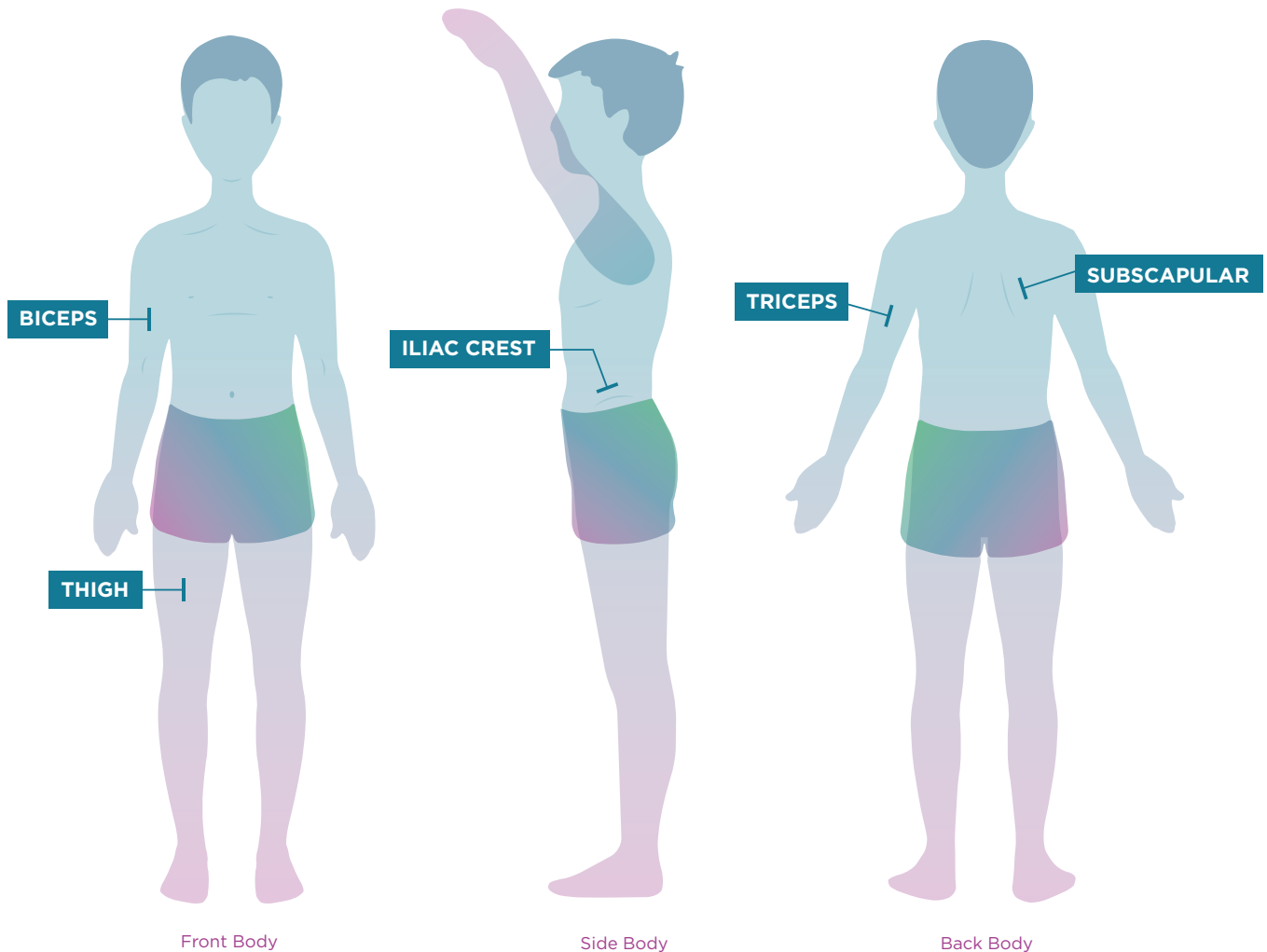
Skinfold thicknesses are measured using calipers (**Figure 7**) to assess the thickness of the subcutaneous fat layer. Because the subcutaneous fat layer varies in thickness across the body, measuring sites at different anatomical locations of the body can assess upper and lower body fat distribution. Skinfold thicknesses can be used across all ages, from infancy through adulthood.

FIGURE 7: Skinfold Caliper



PROCEDURE

Participants should wear loose clothing and short sleeves so that the targeted area of the body can be freely accessed and measured. All measurements should be taken on dry, oil- and lotion-free bare skin. The type of caliper is important in the assessment of skinfolds. Calipers in which the pressure is built into the instrument itself (spring loaded) and is relatively constant from reading to reading and over the range of skinfold thickness studied are recommended. Spring-loaded levers provide a substantially constant, standard pressure of 10 g/mm² over the entire operating range. Ideally, the same skinfold caliper should be used throughout a single study for all skinfold measures. Examples of spring-loaded calipers include

FIGURE 8: Skinfold Measurement Locations

Harpenden, Holtain, and Lange. These calipers will measure skinfold thickness of up to approximately 50 to 60 mm. The resolution is 0.2 mm units, though it may be accurately read from the scale to the nearest 0.1 mm. Most skinfolds are drawn up in a vertical line at the selected location on the body. A washable marker or cosmetic pencil can be used to mark the location of the skinfold measurement site to ensure consistency for repeating the measurement. The person taking the measurement uses his or her thumb and index finger to pinch the skin at the appropriate site and pull it away from

the underlying muscle. This ensures raising only a double layer of skin and the underlying adipose tissue. The calipers are then applied 1 cm below the pinch at a right angle to the pinch, and a reading in millimeters (mm) is taken 2 to 3 seconds later or when the needle settles, to the nearest 0.1 mm. The value of the measurement is recorded to the nearest 0.01 mm. Skinfold measurements are obtained on the same side of the body, at various locations, with the participant standing, as shown in **Figure 8**. Newborns/infants should be lying down for each measurement.

When all skinfold measurements of interest on the same person have been acquired, a second set of measurements is repeated in the same order as the first set. The skinfold calipers should be calibrated daily for correct jaw tension and gap width before measurement. A standard metal calibration block is used to ensure calibration, which is important for quality control. Calipers are calibrated to exert a constant pressure of 10 g/mm² at all thicknesses.

LOCATION OF MEASUREMENTS

The following locations may be measured depending on the study outcome of interest:

- **BICEPS** are measured at the mid-point between the bony tip of shoulder and the elbow joint on the mid-line of the front of the arm. Pinch the skin over the biceps muscle. Newborns/infants should be placed on their back for the measurement.
- **ILIAC CREST** is measured on the mid-axillary line just above the iliac crest (top border of the hip bone) on a diagonal fold. Pinch the skinfold just above the crest at an angle and place the calipers at an angle. Newborns/infants should be placed on their side.
- **SUBSCAPULAR** area is measured just below the lower angle of the scapula (shoulder blade) at about a 45-degree angle to the spine. Newborns/infants should be placed on their stomach for the measurement.
- **THIGH** is measured at the mid-way point between the inguinal crease (groin region) and proximal border of the kneecap. Mark the skin at that point and place the caliper midway between the inguinal crease and the proximal border of the kneecap. Newborns/infants should be placed on their back for the measurement.
- **TRICEPS** are measured on the back of the arm. Using a tape measure, measure distance between the acromion process (tip of shoulder) and olecranon (tip of elbow) and mark the skin at mid-way point. Acquire the skinfold measure by pinching the skinfold with thumb and index finger above the mark while placing caliper on the vertical fold at the mark, which is over the triceps muscle. Newborns/infants should be placed on their stomach for the measurement.

ESTIMATES OF BODY FAT, INTERPRETATION, AND LIMITATIONS

The sum of skinfold thicknesses measured at biceps, iliac crest, subscapular, thigh, and triceps sites can be used as an estimate of overall body fat. Subscapular and iliac crest skinfold sites are located on the trunk and can be used as an estimate of central fat distribution while biceps, triceps, and thigh skinfolds are located on the limbs and can be used as an estimate of peripheral fat distribution. Percent body fat can be estimated from prediction equations that use skinfold measurements that are age- and sex-specific in adults and children. Overall, skinfold prediction of percent fat has large errors at the individual level and smaller errors at the group level. Therefore, they are not useful for characterizing an individual's body fat but are useful when estimating and comparing group averages. The measurements require skill and well-trained staff, and it is often difficult to capture only the subcutaneous fat when conducting the measurement. In addition, it is difficult to obtain reliable measurements when different staff members take the same measurements. However, with training, high levels of reliability can be obtained.

VALIDITY AND RELIABILITY

For newborns and infants, low correlation exists between body fat prediction estimates from skinfolds and body fat estimates by more accurate methods, including total body water (deuterium dilution technique) and MRI.^{73,74} The widely used Slaughter skinfold percent fat prediction equation was developed in a predominantly lean cohort three decades ago.⁷⁵ When applied to a modern-day sample of children and youth aged 6–18 years, the Slaughter equation was a fairly accurate estimator of percent fat compared to DXA-calculated percent fat among children without obesity. However, it overestimated the DXA-calculated percent fat of children with obesity by 12% in boys and 6% in girls.⁷⁶

Reliability can be strong with well-trained and skilled staff. In a large, international study assessing the precision of measuring skinfold thickness and circumferences to inform on fat distribution, the intra-observer technical error of measurements (TEMs) ranged between 0.12 and 0.47 mm for skinfold thickness (triceps, subscapular, biceps, iliac crest) and between 0.09 and 1.24 cm for circumference measurements. Intra-observer reliability was 97.7% for skinfold thickness (triceps, subscapular, biceps, iliac crest) and 94.7% for circumferences (neck, arm, waist, hip). Inter-observer TEMs ranged between 0.13 and 0.97 mm for skinfold thicknesses and between 0.18 and 1.01 cm for circumferences.⁷⁷

REFERENCE DATA

National reference data for triceps and subscapular skinfold thicknesses are available from the NHANES 2007–2010 sample for infants and children 2 months to 19 years.^{72,78} These reference data are the most recent population-based reference data available for comparisons.

ACCESSIBILITY, TRAINING, AND COSTS

Skinfold equipment is accessible, highly portable, and relatively affordable. Cost of research grade calipers is incurred at time of purchase (\$200 to \$500), and little cost is incurred thereafter. Considerable expertise and training are necessary. Training must be conducted by a skilled technician to achieve high precision (low intra-observer variability). Whether these measurements are being collected at a single study location or across multiple study locations, it is imperative to standardize the methodology, as well as train and certify the participating staff to decrease measurement error.

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability is high when privacy is maintained. The method is safe to conduct and carries little risk to participants. The method is considered noninvasive; however, some participants may experience slight discomfort during the procedure. It may be challenging to conduct in younger pediatric populations, as children are required to be calm and cooperative. Error may result from excessive movement.

SUMMARY

Skinfold measurements are acceptable and feasible for use. They are safe, noninvasive, and relatively inexpensive to collect, but they require more significant training and skill for accurate and consistent measurement than do other methods. They are often used in large-scale studies.

Waist Circumference

Circumferences provide measurements that assess body size or dimensions at the specific region of the body that is measured. Waist or abdominal circumference provides information on central body fat distribution. It is generally conducted on individuals who are older than 8 years of age.

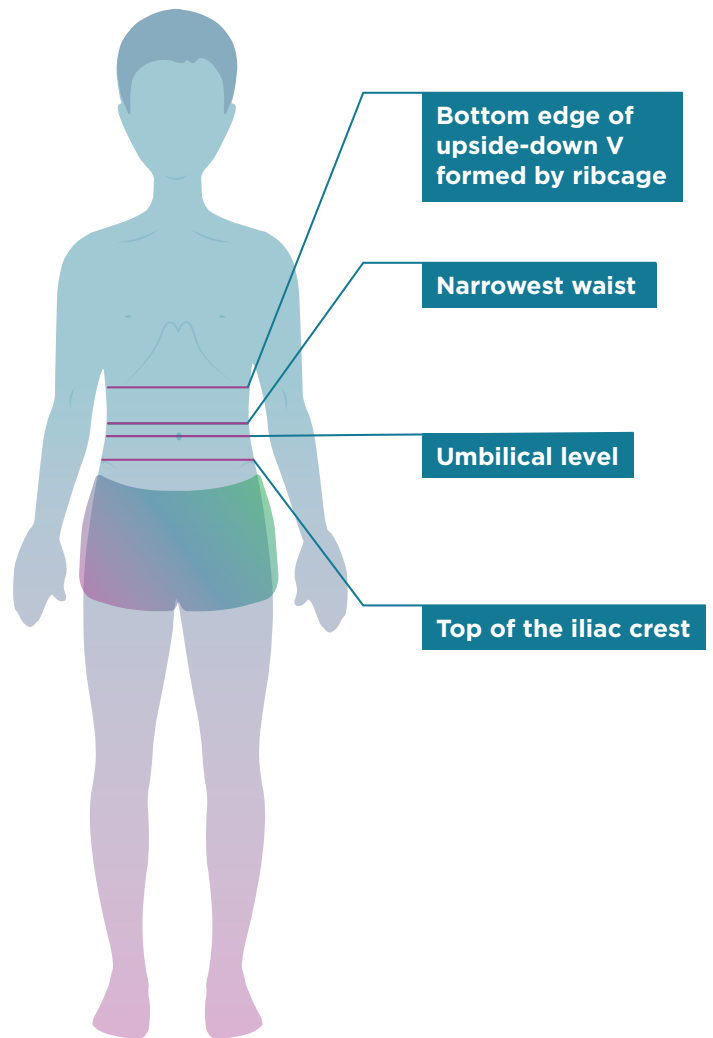
PROCEDURE

Waist circumference is measured using a measuring tape, preferably a tension-calibrated measuring tape. The participant must be wearing loose and movable clothing to allow for locating and measuring the correct site. Commonly measured sites that define the waist include (a) immediately below the lower most rib or the bottom edge of the upside-down V formed by the ribcage, (b) at the narrowest waist, (c) umbilical level, and (d) immediately above or top of the iliac crest (top border of the hip bone)⁷⁹ (Figure 9). Two of these sites include a reference to at least one bony landmark. When lacking a bony landmark, waist circumference is measured at “the narrowest waist” based on visual inspection at the naval or umbilicus. Once the site is located, the tape is applied with minimal pressure against the skin so that the soft tissue is not compressed. The value of the measurement is recorded to the nearest 0.1 cm. The same location should be used consistently in a particular study protocol, and comparisons with other studies need to account for whether the location of the measurements were at the same location.

ESTIMATES OF BODY FAT DISTRIBUTION, INTERPRETATION, AND LIMITATIONS

Waist circumference is a commonly used surrogate measure of central fat distribution in adults. It may be a convenient approach to assess an unfavorable fat distribution in children as it correlates with

FIGURE 9: Commonly Measured Waist Circumference Sites



visceral abdominal fat and with metabolic risk factors in children age 8 years and older. However, waist circumference reflects the sum of abdominal visceral and abdominal subcutaneous adipose tissue (VAT and SAT) and is unable to differentiate the quantity of one from the other. This shortcoming is evident in the fact that circumference measurements alone have a low sensitivity at young ages.⁸⁰ Furthermore, growth-related changes in abdominal fat include changes in both VAT and SAT.

Therefore, if VAT were to increase as SAT decreases, longitudinal waist circumference measurements might indicate no change thereby missing depot-specific changes. Acquiring longitudinal assessments during growth or when weight loss or weight gain occurs during interventions also may be difficult. The “narrowest waist” and level of the naval/umbilicus may change in anatomic location, and therefore follow-up measurements will not be acquired at the same location as baseline measurements. The location of these measurements is subjective and prone to greater measurement error, especially when measuring persons where a discernable “narrowest waist” is not visible, such as in persons with obesity.

VALIDITY AND RELIABILITY

Moderate to high correlation exists for waist circumference with visceral fat in children depending on age.⁸⁰ In newborns, waist circumference is a poor predictor of visceral adipose tissue compared to direct visualization methods such as MRI.⁸¹ Waist circumference measurements performed in triplicate at four sites for males and females (n=93) aged 7–83 years have been shown to have high reproducibility and correlation with total body and trunk adiposity.⁷⁹ Results from a meta-analysis of studies in children and youth aged 7–16 years found that although waist circumference accounted for 65% of the variance in visceral adipose tissue, ethnicity had an independent effect on the visceral adipose tissue-waist circumference relationship.⁸⁰

A major limitation to the use of waist circumference as a methodology in children remains the fact that its use as a longitudinal assessment remains poorly described. Furthermore, the utility of waist circumference for different racial and ethnic groups and weight categories remains to be explored.

REFERENCE DATA

National reference data for waist circumference are available from the NHANES 2011–2014 NHANES sample for children aged 2–19 years.⁷² These reference data are the most recent population-based reference data available for comparisons.

ACCESSIBILITY, TRAINING, AND COST

Waist circumference equipment is highly accessible, portable, and low-cost. The cost of a spring-loaded tape measure is low (<\$30). Tester training is required, but the level of skill is significantly less than that required for skinfold measurements. However, as children mature, the landmarks for determining the correct location to measure waist circumference may vary. High levels of central obesity may make it difficult to identify consistent landmarks for measuring waist circumference.

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability is higher when privacy at time of measurement is maintained. The burden and risk are low, and the measure is noninvasive, but finding the locations for measuring waist circumference may cause significant uneasiness and may feel intrusive or embarrassing to the participant.

SUMMARY

Waist circumference is a relatively quick, safe, and noninvasive surrogate method for assessing central body fat. It is inexpensive to collect but requires some training and skill in the accurate and consistent location of the site for measurement. It is appealing for large-scale studies, but issues with privacy and embarrassment may make it less feasible than previously described methods.

BIOELECTRICAL IMPEDANCE ANALYSIS (BIA)

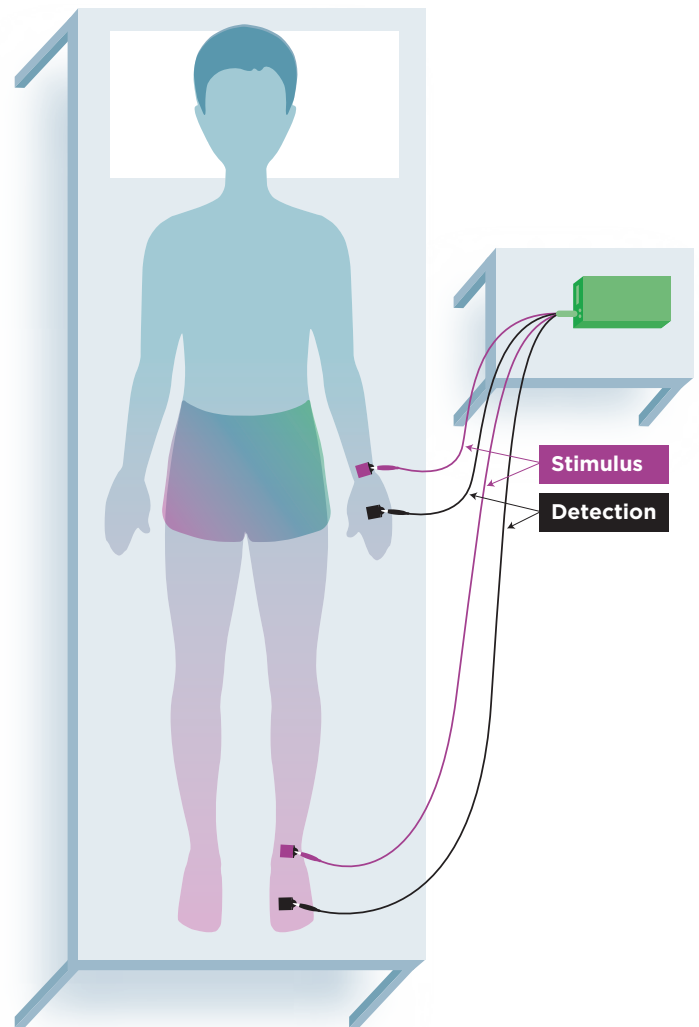
The BIA method estimates FM and FFM by measuring the impedance or resistance of a small, low voltage electrical current as it travels through water in the body tissues. From this, prediction equations estimate total FM and FFM. It may be used across all ages, from birth to adulthood.

PROCEDURE

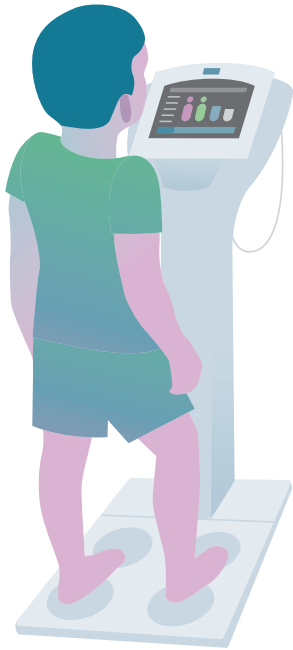
A variety of BIA systems from different manufacturers are available for use. All systems use a specific number of electrodes (four or eight, depending on the system) that make contact at specific locations on the body where the electrical current that is not felt by the person will be transmitted and then measured as it passes through the body, including “hand-and-foot,” “foot-to-foot,” and “hand-to-hand” systems. Some BIA systems require the participant to be tested in the supine position (**Figure 10**) and some in the upright position (**Figure 11**); the former allows for use of the BIA in individuals who cannot stand.

BIA systems may also use a single frequency (50 kHz) or multiple frequencies (frequencies up to 300 kHz) of electrical current, depending on the measurement(s) of interest. Both provide estimates of TBW, although multifrequency BIA allows for the differentiation of TBW into intracellular water (ICW) and extracellular water (ECW) compartments, which is useful to describe fluid shifts and fluid balance and to explore variations in levels of hydration.^{82,83} Single- and multifrequency systems are also available as multisegmental BIAs to allow for regional measurements of body fat (trunk and limbs separately).

FIGURE 10: Bioelectrical Impedance Analysis in Supine Position



Given the variation in systems, the manufacturer's specific guidelines should be carefully followed for testing. In general, measurement of BIA requires that the participant fast for 2 to 3 hours and empty his or her bladder before measurement as well as not participate in strenuous exercise for 12 hours in advance of test to ensure normal hydration. The participant also must have length/height and

FIGURE 11: Bioelectrical Impedance Analysis in Upright Position

weight measured according to the previously described anthropometric techniques. Data on age and sex must be available for use in the estimation equations. The participant must have no skin lesions or significant edema at the site of electrode contact and must not be wearing any metal. The skin should be cleaned with alcohol at the site of electrode contact. The electrode surfaces also must be clean and make proper contact with the body part of interest. The body parts in contact with the electrodes should be appropriately positioned so that the arms and legs do not touch the body or each other. Once the electrodes are in place, an electrical current is transmitted through the body and within a few seconds, an impedance value measured in Ohms (unit of electrical resistance) is displayed. The impedance value produced varies by BIA instrument. BIA instruments use built-in manufacturer prediction equations to then estimate body composition variables.

ESTIMATES OF BODY FAT, INTERPRETATION, AND LIMITATIONS

The measured value of resistance is used in various prediction equations to estimate TBW, FM, and FFM. The impedance index, which is $\text{height}^2/\text{resistance}$ (length can be substituted for height), is proportional to the volume of total water in the body, which allows for TBW to be estimated using specific equations that include participant weight. FFM is derived from age- and sex-specific equations using the measured impedance as well as weight and height. Using this method, the underlying assumption is that 73% of the body's FFM is water.⁸⁴ The difference between body weight and the value derived for FFM is equivalent to total FM. The multisegmental approach measures the impedance of the left and right arms, the left and right legs, and the total body by assuming that the body is made up of a group of cylinders as opposed to a single cylinder. The summed value for the four limbs is subtracted from the total body value to derive the impedance of the trunk. Many other body composition measures may be estimated, depending on the type of system used.

A major limitation of using BIA in children is that the effects of growth and development invalidate several assumptions necessary for the use of BIA. In particular, limb length in children changes frequently with no established pattern. In adults, where trunk and limb lengths are assumed constant, the trunk accounts for ~75% of the body mass and 9% of the total impedance; whereas the limbs account for 25% of the body mass and 91% of the total impedance.⁸⁵ These assumptions are not met in children. Use of BIA prediction equations is therefore inherently limited in children, particularly during periods of rapid growth. In addition, equations are applicable only to the participants who closely match the study population from which they were derived. Their use in children requires age-, sex-, and race/ethnicity-specific modifications.⁸⁶⁻⁸⁸

VALIDITY AND RELIABILITY

The accuracy of body fat measured using BIA is considered to be within 3.5–5.0% when conditions such as ambient temperature, participant hydration status, position of participant, correct electrode placement, use of appropriate equations, and eating and drinking that can affect total body water are regulated.⁸⁹ Total body water is considered the sum of intracellular water and extracellular water. Children have a higher proportion of their TBW as extracellular fluid, and the extracellular fluid has a higher electrolyte content compared with intracellular fluid. Accordingly, the resistivity measured by BIA in children relative to the amount of FFM will be lower than in adults.^{90,91}

The measurement of TBW and FFM using a tetrapolar system showed a 0.99 test-retest correlation coefficient.^{92,93} For resistance measurements acquired on 5 successive days, the coefficients of variation for resistance values ranged from 0.9–3.4%, and the average precision was 2%. Test-retest correlation coefficient was 0.99 for a single-resistance measurement, and the reliability coefficient for a single-resistance measurement over 5 days was 0.99.⁹³ Overall, the reliability of BIA has high test-retest correlation and acceptable levels of within-person CVs between 1% and 6%. However, the violation of key assumptions for use of this technology in children suggests that despite high levels of reliability, its validity in children is not strong.

REFERENCE DATA

National reference data for children in the U.S. population are not available. However, mean body composition estimates for TBW, FFM, TBF, and %BF based upon NHANES III BIA data provide a descriptive reference for the U.S. population aged 12–80 years.⁹⁴

ACCESSIBILITY, TRAINING, AND COST

BIA devices are accessible and portable. Many BIA devices are being marketed, but costs vary widely (\$100 to \$19,000). Not all of these devices are of research grade or standard, which would be more costly. The tester is required to follow the manufacturer's procedures manual, and the level of skill required is low.

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability is moderate to high. The method is noninvasive, and risk is low. It requires some participant preparation, such as fasting, that may be difficult in children, but in general, the burden is low. Participants must minimize movement, which is difficult in young children. It is not recommended for participants with a pacemaker or other electrical implants.

SUMMARY

BIA is quick, non-invasive, easy to use, and requires minimal staff training. It is low in cost, generally safe and portable, thus making it appealing for large-scale studies. However, the effects of growth and development on the limb and trunk in children violates key assumptions in using BIA to estimate fat mass, suggesting it may be an inappropriate choice for use in children. Furthermore, BIA use in children of all ages requires age-, sex-, and race/ethnicity-specific predictive equations that may not always be available for the study population of interest.

AIR DISPLACEMENT PLETHYSMOGRAPHY (ADP)

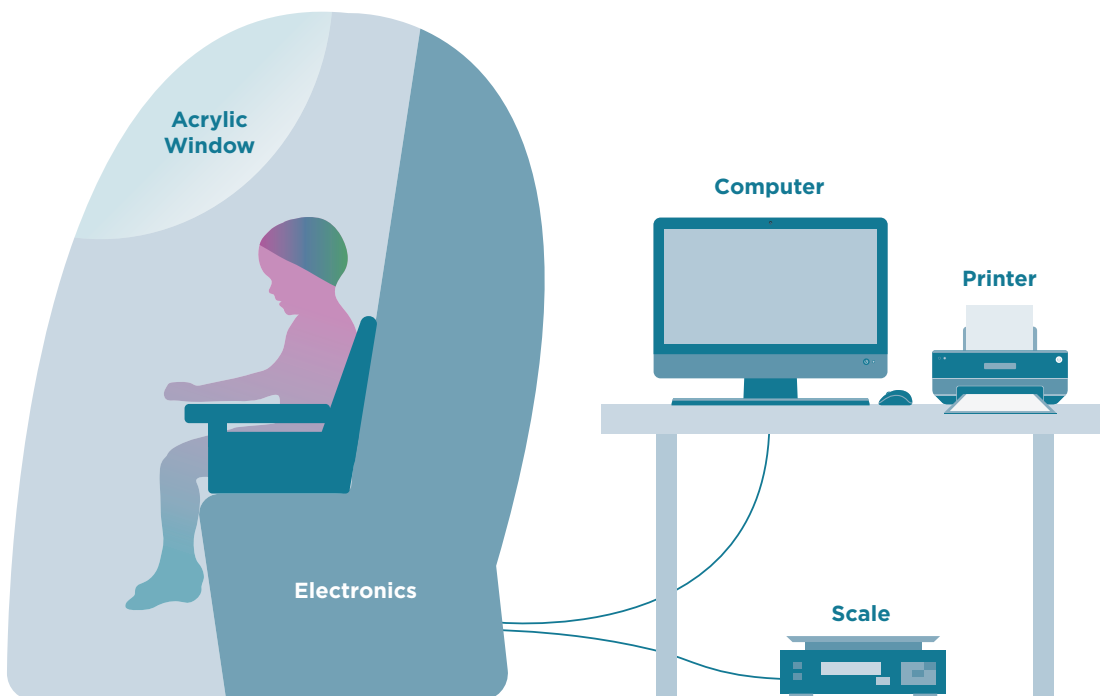
The ADP method uses the volume of air displaced by a participant in a sealed testing chamber to measure the participant's body volume and estimate body density. Predictive equations are then used to estimate values for total FM and FFM. The ADP technique can be used to measure infants beginning at birth through approximately 6 months weighing up to a maximum weight of 8 kg (using the PEA POD instrument) and to measure individuals aged 6 years and older and weighing between 35 and 200 kg (using the BOD POD instrument). However, there is a pediatric adaptor for testing young children between the ages of 2–5 years.⁹⁵

PROCEDURE

Measurement using ADP requires availability of commercial equipment from a sole manufacturer (Cosmed Inc, Concord, CA). The PEA POD is used in infants up to a maximum weight of 8 kg (approximately 6 months) and the BOD POD for persons aged 6 years and older and weighing between 35 and 200 kg. The BOD POD can be fitted with a pediatric adaptor seat for use in children aged 2–5 years⁹⁵ (**Figure 12**).

The BOD POD system is stationary and consists of a front test chamber and a rear reference chamber in a closed system. The participant sits in the front test chamber while the test is conducted. Participants are required to wear a tight-fitting bathing suit or tight-fitting undergarments, and an acrylic cap that covers the head so that trapped air within the hair is minimal. Loose-fitting clothes, scalp hair, and facial hair can introduce error such that percent fat is underestimated.⁹⁶ Participants should

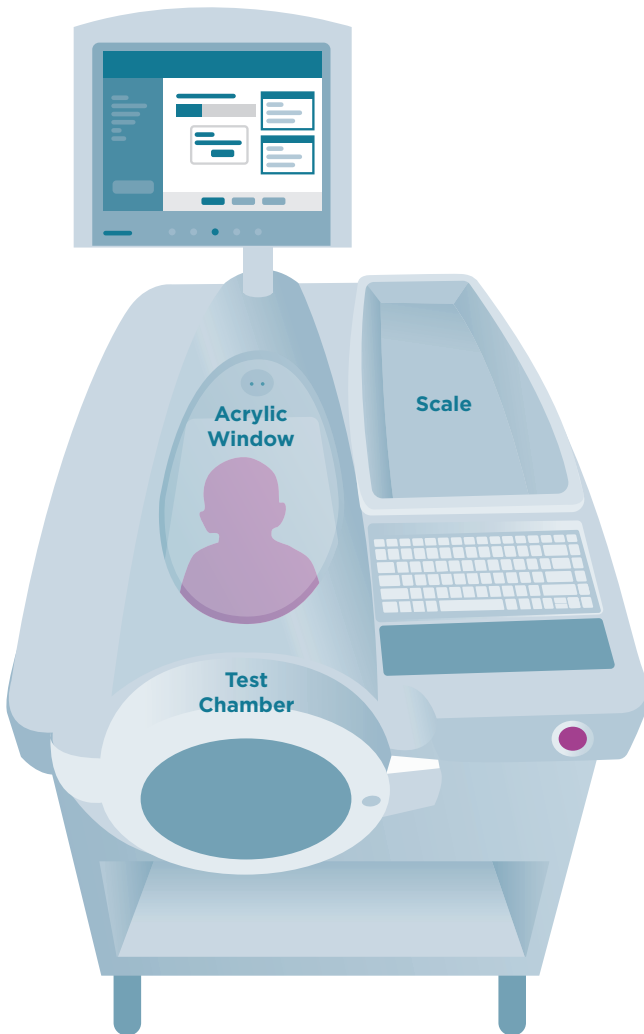
FIGURE 12: BOD POD Fitted with a Pediatric Adaptor Seat



have fasted for at least 2 hours and emptied their bladders immediately before the test. Participants are first weighed on the BOD POD weight scale, and height is measured using anthropometric techniques described in this guide. In addition to the values for body mass and height, the age of the participant is entered into the software algorithm of the instrument before the test is conducted. The participant sits motionless in the BOD POD test chamber with the door closed while the test is performed. Air is gently blown into the testing chamber while the participant breathes normally. Body volume is derived from the ratio of the pressure in the reference and test chambers based on Poisson's law, which states that volume varies inversely with pressure when temperature is constant.⁹⁷ A diaphragm mounted on the common wall between the chambers oscillates during testing under computer control. When the volume is increased in one of the chambers, it is decreased by the same amount in the other chamber and vice versa. The pressure in each of the two chambers responds immediately to this volume change or perturbation by the participant sitting in the chamber, and the magnitude of the pressure changes indicates the relative size of each chamber. The difference in the change in air pressure when the chamber is occupied by the participant can be used to estimate body volume, or the volume of air the participant displaces. The test also requires an estimate of lung gas volume of the participant. This can be estimated using predictive equations that are based on height and age or can be measured directly during the BOD POD testing. If measured directly, the participant is asked to perform a lung volume measurement, which requires that he or she breathe through a disposable tube with gentle puffs of air when cued by the technician. Pressure in the breathing tube changes as the subject's diaphragm contracts and expands, which, combined with BOD POD chamber pressure changes, allows for an estimation of the participant's lung volume. Two lung volume tests

are performed on a participant, and the volumes are averaged when the values are within 150 mL.⁹⁸ The total time to measure body volume while sitting in the closed chamber is about 2 minutes. Results are displayed on the computer monitor. Quality control is conducted regularly. The BOD POD weight scale must be calibrated daily using a certified 20 kg National Institutes of Standards and Technology (NIST) weight. In addition, before each individual participant is tested, a calibration test is performed using a standard 50.218-liter calibration cylinder placed in the empty BOD POD chamber.

The PEA POD system measures body volume in a similar fashion to the BOD POD (**Figure 13**). For the PEA POD, a movable cart houses the reference chamber and calibration volume, which allows it to be brought to the infant bedside in hospital settings. The test chamber along with a weight scale are mounted on the cart's top surface. A volume-perturbing diaphragm is located between the test and reference chambers, and a pneumatic valve (calibration valve) allows the test chamber to be connected to the calibration volume.⁹⁹ Infant length and weight are first measured using the previously described anthropometric techniques. These values and age are entered into the software before the testing is conducted. The ADP testing is conducted with the infant naked, except for a nylon head cap that is used to remove the effect of trapped air among the hairs. Alternatively, the hair can be smoothed flat using oil. The infant is then positioned on a tray that slides into a sealed testing chamber with a clear acrylic covering. When the chamber door closes, pressure changes are measured over a 2-minute period. The test ends with the door opening automatically, and results are displayed on the computer monitor. Similar to the BOD POD, before each measurement, a volume calibration is run using a certified aluminum cylinder (5 L), and the weight scale is calibrated using a certified NIST weight (5 kg) daily.

FIGURE 13: PEA POD

ESTIMATES OF BODY FAT, INTERPRETATION, AND LIMITATIONS

Percent body fat is estimated by prediction equations in the software that use body density, which is calculated using measured body volume and body weight of the participant (e.g., body density is the ratio of the body's weight (mass) to body volume). In this approach, the densities of FM (0.9007 g/cm^3) and FFM (1.100 g/cm^3) are assumed

to be the same across all adults, irrespective of age, race/ethnicity, and disease. For children, the densities of FM (0.9007 g/ml) are assumed constant, and age- and sex-specific FFM density coefficients are used.¹⁰

Limitations of this method include the assumption that the density of FFM is stable irrespective of age, race/ethnicity, and disease and that lung volume is correctly estimated. Age- and sex-specific density of FFM constants applied may not be appropriate for all infants due to the rapid changes in body water in the early weeks of life and in some diseased states with abnormal body water status.

VALIDITY AND RELIABILITY

The ADP has been validated for use in infants from birth to about 6 months and in children aged 6 years and older. However, a gap remains for the use of ADP in children from 6 months through 5 years of age. For adults, the accuracy of percent body fat measures is within -4.0% to 1.9% when ADP is compared to under-water weighing.^{98,100-102} Comparing ADP to DXA (discussed below), the accuracy of percent fat measures are between -3.0% and 1.7% .^{98,102,103} Between-day test-retest correlation coefficients for body density and percent fat using the ADP are 0.95 in adults and 0.90 in children.¹⁰⁰

A recent comprehensive review by Mazahery et al., provides a detailed discussion on PEA POD in full-term and pre-term infants.¹⁰⁴ PEA POD is reliable for assessing percent fat in full-term infants but has only modest accuracy, with overestimation or underestimation of percent fat by 6% to 8%. Few data exist on the validity of PEA POD in preterm infants; performance appears to be reasonable but with modest accuracy, as summarized by Mazahery.¹⁰⁴ The lack of precision of the instrument in young children and especially in children younger than age 5 years may be related to the small body size of younger children within

the chamber.¹⁰⁵ Although one study reported no statistical difference between percent fat by the ADP with pediatric attachment and percent fat measured by 4-compartment model,¹⁰⁶ **it is important to note that the ADP was not well tolerated among children aged 1–5 years (useable data were obtained on 31 of 74 (42%) children enrolled), thereby limiting its use.** When compared to a multi-compartment model, with or without an adapter designed for pediatric use with this equipment, the BOD POD was shown to have reduced accuracy for use in infants and children younger than 7 years due to compliance issues, which included movement, talking, and crying during the test.¹⁰⁶ Reliability was established in 17 infants (1 to 22 weeks) tested three times over two days.¹⁰⁷ The within-day reliability for percent fat was 2.85% and the between-day reliability was 2.95%.

REFERENCE DATA

National reference data for children in the U.S. population are not available.

ACCESSIBILITY, TRAINING, AND COST

Accessibility is low as the equipment is expensive and largely located at specialized medical or research centers. All ADP systems are available from a single manufacturer (Cosmed Inc, Concord, CA). The PEA POD is for use in infants up to a maximum weight of 8 kg (approximately 6 months old) and the BOD POD for persons 6 years and older weighing between 35 and 200 kg. A pediatric option is available for assessing body composition using the BOD POD in children aged 2–6 years. The pediatric option accessory includes a customized seat insert, calibration standards, and modified software program, developed in an effort to allow for longitudinal measures from childhood by the same technology.¹⁰⁶ Costs are high for initial purchase (BOD POD \$50,000; PEA POD

\$90,000) and an annual service contract per system is required (BOD POD \$3,000; PEA POD \$1,500). Testers require training, and the level of skill required is moderate.

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability of the ADP method is moderate to high in adults, but data on its acceptability in children are more limited. One study among children aged 1–5 years found its acceptability was low, with a measurement being obtained in less than 50% of these children. Risk is low, and the measure is generally noninvasive. Burden is low-to-moderate. Wearing a tight-fitting undergarment for the test may be a significant source of embarrassment. Fasting may be difficult in children. Movement during the BOD POD test must be minimal, which is difficult for infants and young children. For the PEA POD, excessive crying can result in a failed test. Persons with claustrophobia and larger persons may be unable to tolerate the sealed chamber despite the window. The BOD POD excludes persons weighing >200 kg.

SUMMARY

ADP is a non-invasive, quick, safe method that does not require sedation. The cost is modestly high in comparison to other methods. Training of staff is required, but it does not require specialized technicians. However, the equipment is not portable, and the availability of the equipment is often limited to hospital-based medical and research facilities due to high purchase cost and storage requirements. Participant burden is modest, requiring fasting and wearing tight-fitting undergarments or swimsuits. The need to have minimal movement during testing is a limitation when assessing children younger than the age of 6.

DUAL ENERGY X-RAY ABSORPTIOMETRY (DXA)

The DXA method uses two low dose X-ray beams and instrument-specific algorithms to estimate total-body and regional estimates of body components, including bone mineral content, “bone-free” FFM, and FM.¹⁰⁸ This method can be used across all ages, from infancy through adulthood.

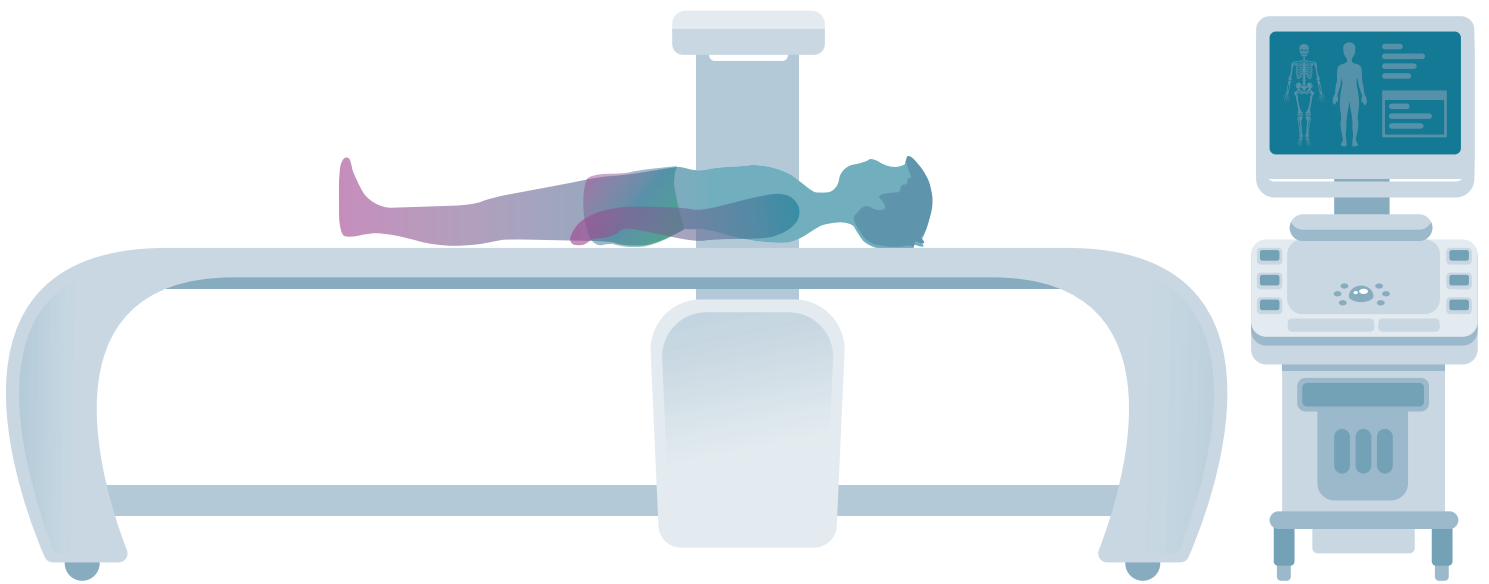
PROCEDURE

The participant, wearing light clothing and with all metal removed from the body, lies flat on their back on the DXA stretcher, with feet pointed up

and secured with a Velcro strap, and arms by the side and not overlapping any part of the body (**Figure 14**).

Persons whose body size extends to the field-of-view limit can be wrapped securely in a bed sheet to ensure that all soft tissue has been retained within the field of view. An invisible beam of low-dose X-rays with two distinct low- and high-energy level peaks is transmitted through the body. The measured attenuation of the two main energy peaks is used to estimate each pixel's fraction of fat and lean mass. Fat and lean components are quantified over regions devoid of bone. Using specific anatomic landmarks from the whole-body scan, the trunk, legs, and arms are identified. The fat tissue in the arms and legs is largely subcutaneous fat. The fat-free soft tissue (i.e., non-fat and non-bone mineral mass) of the arms and legs is largely skeletal muscle.

FIGURE 14: Dual Energy X-Ray Absorptiometry



ESTIMATES OF BODY FAT, INTERPRETATION, AND LIMITATIONS

The dominant commercial DXA systems that supply body composition software are Hologic and GE Lunar. Instrument-specific software algorithms are used to calculate the various values for bone mineral content, “bone-free” lean mass or FFM, and FM, which are based on the differential absorption of X-rays of the two different energy levels by the different body components. The two systems generate different values for bone and soft tissue in the same person due to differences in technology detectors, calibration, bone edge detection, and reference data included in each system’s software. Given this, it is recommended that researchers use the same DXA software system when assessing body composition in the same individuals over time, such as in longitudinal studies and clinical trials. Similarly, upgrades in the hardware and software within the same DXA manufacturer’s system can result in different values on the same person. It is recommended that upgrades be avoided during longitudinal assessments on the same individuals, but if unavoidable, cross-validation studies need to be conducted to assess differences in values in the same individuals due to the upgrade in the system components.

Assumptions associated with DXA include (a) the assumed constant attenuation (R) of fat ($R = 1.21$) and of bone mineral content, (b) minimal effects of hydration on lean tissue estimates, and (c) lack of an effect of variations in regional (e.g., chest, leg, arm) thickness on soft tissue estimates¹⁰⁹ and that the fat content of the area being analyzed (non-bone-containing area/pixels) is comparable to the

fat content of the unanalyzed area (bone-containing area or pixels). When these assumptions are not met, errors occur in the estimation of fat, lean, and bone in both regional and whole-body values. Scenarios when assumptions may not be met include when trunk tissue thickness or depth is high (as in extreme obesity) and clinical states where hydration is abnormal.

VALIDITY AND RELIABILITY

In adults, DXA estimates of FM correlate highly with other established methods for accurately assessing body FM such as in-vivo neutron activation analysis (IVNA)¹¹⁰ and in children aged 6–18 years when compared to under water weighing.⁴⁹ DXA estimates of FM are influenced by “trunk thickness,” with the error increasing as the subject’s trunk thickness increases.

REFERENCE DATA

National reference data are available for the U.S. population aged 8–85 years. During the years 1999–2004, the National Health and Nutrition Examination Survey (NHANES) study acquired whole-body DXA scans on a population-based sample of Americans aged 8–85 years using the Hologic DXA systems. Using this system, national reference values were generated for total and sub-total whole-body results¹¹² and were normalized to age, height, or lean mass.³³ NHANES reference values were later derived from these data for use with the GE Healthcare Lunar DXA systems.¹¹¹

ACCESSIBILITY, TRAINING, AND COST

Accessibility to DXA systems tends to be low to moderate. A whole-body DXA scan for the determination of body composition is primarily available at research laboratories and radiology/hospital facilities with DXA equipment containing whole-body composition software. However, even if a facility has access to a DXA system, it does not mean it contains the software to conduct a body composition scan. DXA systems may be programmed to conduct bone density scans and may require additional software to be used for body composition analyses. Due to the low-dose radiation, the equipment also has special storage room requirements, and a certified radiology technician or physician is required to operate the scanner. Equipment is expensive when first purchased (\$80,000), and the annual cost of a service contract is high (\$8,000–\$13,000).

ACCEPTABILITY, PARTICIPANT BURDEN, AND RISK

Acceptability is moderate and risk is minor, due to the low-dose ionizing radiation exposure. The dose from a single whole-body scan is generally <10 microSieverts.¹¹² This is equivalent to a single day's exposure from natural sources at sea level such as from the sun, ground, and water. Burden for the study participant is low, and the measure is generally noninvasive. Participants who may be pregnant should not be measured, and pregnancy screening is required. In addition, the scanning bed or stretcher of most models has an upper

weight limit (Hologic 159 kg; GE 182 kg) and the whole-body field of view cannot accommodate persons with body weights greater than this limit. The Norland Elite is a newer model that has been designed for whole body composition and can scan larger individuals (283.5 kg (625 lb), 137 cm (54") wide and 228 cm (7'6") tall). Because participants are required to remain motionless during the procedure, and sedation is generally not permitted for research studies, special consideration must be given to immobilizing/restraining infants and young children to prevent movement, especially after 6 months of age, which may limit feasibility. The time to complete the scan varies with the size and compliance of the participant but is generally 10–20 minutes.

SUMMARY

DXA is a relatively more resource-intensive and costly method that is reasonably short in duration. It is generally safe and noninvasive but has a very low-dose ionizing radiation exposure that may limit its acceptability. It requires certified technicians and is not portable and often is only available in clinical/radiology facility settings. People undergoing this measurement must be motionless, and restraints may be required to maintain immobility, limiting its use for many children.

TABLE 1: Summary of methods to measure body composition from infancy through adolescence

METHOD	AGE/WEIGHT LIMITS	INDICATORS OF WEIGHT STATUS AND EXCESS ADIPOSITY/ESTIMATE(S) OF BODY FAT	NATIONAL REFERENCE DATA FOR U.S. POPULATION OF CHILDREN	ADVANTAGES	DISADVANTAGES
Anthropometry: Stature/ Recumbent Length and Weight	All ages	Weight for length Body Mass Index	YES (birth and older)	<ul style="list-style-type: none"> Simple and quick measurements Noninvasive and safe measurements Highly acceptable to participants Inexpensive and portable equipment Minimal staff training 	<ul style="list-style-type: none"> Does not measure body fat Provides only an indicator of weight and obesity status
Anthropometry: Skinfold Thicknesses	All ages	Site specific and sum of skinfold thicknesses Total body fat predicted by regression equations	YES (ages 2 months and older)	<ul style="list-style-type: none"> Relatively simple and quick measurements Noninvasive and safe measurements Acceptable to participants Inexpensive and portable equipment 	<ul style="list-style-type: none"> Greater staff training and skill required Greater privacy needed to conduct measurements Requires greater child compliance; movement may cause inaccuracies particularly in younger children Measures only subcutaneous fat at various body locations Requires age- and sex-specific predictive equations that may not always be available for the study population of interest
Anthropometry: Waist Circumference	Recommended for ages 8 years and older	Abdominal girth Surrogate for abdominal visceral fat /central fat distribution	YES (ages 8 years and older)	<ul style="list-style-type: none"> Relatively simple and quick measurements Noninvasive and safe measurements Moderately acceptable to participants Inexpensive and portable equipment 	<ul style="list-style-type: none"> Greater staff training and skill required Greater privacy needed to conduct measurements Greater source of embarrassment for children during measurement Includes both abdominal visceral and subcutaneous adipose tissue Difficult to find and measure anatomic location of waist consistently over time and on participants with obesity
Bioelectrical Impedance Analysis (BIA)	All ages	Measures the impedance or resistance to the flow of an electrical current through the body to estimate TBW Total FM and total FFM predicted by regression equations	NO	<ul style="list-style-type: none"> Relatively simple and quick measurements Noninvasive and safe measurements Moderate to high acceptability to participants Relatively inexpensive and portable equipment 	<ul style="list-style-type: none"> Requires participant preparation such as fasting and no exercise in advance that may make it less feasible to conduct with children Requires greater compliance; movement may cause inaccuracies particularly in younger children Effects of growth and development on the limb and trunk in children violates key assumptions in using BIA to estimate fat mass unless age-, sex- and race/ethnicity-specific predictive equations are incorporated into the device being used.
Air Displacement Plethysmography (ADP)	Birth to 6 months (up to 8 kg) using PEA POD 6 years and older (35 kg to 200 kg) using BOD POD 2-5 years old using adapter insert made for BOD POD	Measures body volume used to estimate body density Total FM and Total FFM predicted by regression equations	NO	<ul style="list-style-type: none"> Relatively short duration to conduct test Noninvasive and safe measurements Moderate to high acceptability to participants 	<ul style="list-style-type: none"> Greater staff training and skill required Greater privacy needed to conduct measurements Greater source of embarrassment for children during measurement due to need for tight-fitting clothing Equipment is expensive and not portable; only one manufacturer of equipment; generally found in specialized research centers or hospitals Requires participant preparation such as fasting in advance that may make is less feasible to conduct with children Requires greater compliance; movement may cause inaccuracies particularly in younger children
Dual Energy X-Ray Absorptiometry (DXA)	All ages (some instruments have an upper weight limit)	Instrument-specific software algorithms are used to calculate the various values for bone mineral content, "bone-free" lean mass or FFM, and FM	YES (ages 8 years and older)	<ul style="list-style-type: none"> Relatively short duration to conduct test Noninvasive and safe measurements Moderate acceptability to participants 	<ul style="list-style-type: none"> Requires skilled and certified technicians to conduct test or physicians Greater privacy needed to conduct measurements Equipment is most expensive and not portable; generally found in specialized research centers or hospitals Requires greater compliance and movement may cause inaccuracies particularly in younger children; young children must be restrained Low dose ionizing radiation exposure (less than single day's exposure from natural sources at sea level) Requires manufacturer/instrument specific algorithms that may not be available for the population of interest

METHODS NOT FEASIBLE IN POPULATION-LEVEL RESEARCH

The following methods are important in furthering our understanding of body composition but will not be discussed in detail in this review as they lack feasibility outside of specialized research centers, which make them generally unavailable for use in community-based studies or in large population-based studies.

MAGNETIC RESONANCE IMAGING (MRI) is considered a reference method for adipose tissue, including adipose tissue distribution, skeletal muscle mass, and other internal tissues and organs. Its primary application has been in quantifying the distribution of adipose tissue into visceral, subcutaneous, and intermuscular depots. The approach uses complex software to convert instrument-acquired signals into images of the interior of the body and to interpret those images in terms of FM and FFM tissues. Post-processing imaging analysis software quantifies the image area, and thus volume, of a specific tissue. The method is available only in specialized radiology facilities and hospitals. This limited availability, combined with high cost, makes this method feasible only for specialized research studies.

MAGNETIC RESONANCE SPECTROSCOPY (MRS) provides information on the chemical composition or physical nature of a specific structural region within a tissue imaged by MRI. MRS methods have been developed to distinguish the fat within the muscle cell (intramyocellular lipid) from that outside of the muscle cell (extramyocellular lipid) and the fat within the liver (intrahepatic lipid) in-vivo. This method has been used extensively by many groups to report associations between intramyocellular lipid and/or intrahepatic lipid and

insulin resistance as well as the effects of exercise on the intramyocellular lipid of muscle. Post-processing imaging analysis software quantifies the image area, and thus volume, of a specific tissue. The method is available only in specialized radiology facilities and hospitals. This limited availability, combined with high cost, makes this method feasible only for specialized research studies.

QUANTITATIVE MAGNETIC RESONANCE (QMR) is a relatively new non-imaging technique that uses an electromagnetic field to detect the hydrogen atoms in three groups: fat tissue, fat-free tissue, and free water. This technique does not pose any health or safety concerns and can be repeated many times within or across days, allowing for the assessment of short-term changes in body composition. Systems are available for infants, children, and adults. The advantages of the QMR device for studies involving humans include rapid data collection, no special participation requirements on the part of the participant, no sedation, no ionizing radiation, and high precision for FM and TBW measurements. Equipment is available from a single manufacturer only and is very expensive, making this method feasible only for studies in specialized research studies.

DEUTERIUM DILUTION uses the stable isotope dilution tracer technique of deuterium oxide (D_2O) and oxygen-18 labeled water ($H_2^{18}O$) to calculate the volume of TBW. The tracer sodium bromide (NaBr) can be used to measure extracellular water space (ECW). Plasma or saliva samples are obtained at baseline and 3 hours after oral administration of the tracers in adults and 2 hours after in young children. FFM is calculated from TBW/hydration factor, and FM is calculated as measured body weight minus FFM. Administration of these tracers and collection of samples are easy in older children but challenging in newborns. The equipment and labor required for sample analyses are significant; sample analyses must be sent to specialized research centers. The isotopes themselves may be costly depending on amount needed and vendor. Thus, these methods are often impractical for large-scale studies.

6

Using Secondary Data to Assess Obesity



SECTION 6

Using Secondary Data to Assess Adiposity

The methods in Section 5 focus on how to conduct primary data collection for research. Many researchers and practitioners use secondary data to conduct research and evaluation.

In some cases, researchers may have a specific body composition outcome measure in mind and have to look for an existing data set that includes this measure. Alternatively, researchers may have identified a data set of interest with available measures of body composition and need to determine if they can 1) adequately answer their research question with these data and 2) how to analyze and interpret the available measure.

Secondary data can include complex surveys and surveillance systems (e.g., National Health and Nutrition Examination Survey [NHANES]), electronic health records, and data captured from wearable devices. When using secondary data, a research team still needs to consider a method's validity in estimating body fat; precision, reliability or reproducibility; sensitivity to change over time or with intervention; ability to predict health risks/outcomes (e.g., clinical validity); and the availability of reference ranges or norms for the study population (having data from a standard or reference population for comparisons).

When selecting secondary data to create a comparison group, additional considerations arise. It is important that the two groups are comparable on as many attributes as possible—this includes the outcome assessment methodology (e.g., self-reported vs. objectively measured BMI, cut-points used), sampling approach to ensure representativeness of the populations of interest, timing of data collection, and inclusion of socio-demographic characteristics that may confound results. The NCCOR Catalogue of Surveillance Systems can be used to identify and compare surveillance systems that include weight-related outcomes. The webpage for each surveillance system provides user manuals, which may include information about sampling plans, anthropometric

procedures, questionnaires, and analytic guidance. Most nationally representative and state-representative data sets are not over-sampled, which precludes in-depth analyses of specific demographic or health-status subgroups, including those at increased risk of obesity.¹¹³ BMI is the most commonly used measure used to define obesity in surveillance systems. If using secondary data to evaluate change over time, sample size is another relevant consideration.

Sometimes, published values (e.g., from an NHANES surveillance summary) can offer a useful point of comparison. Often, researchers will want to conduct their own analyses using secondary data. CDC provides SAS code to calculate BMI z-scores and percentiles and to identify biologically implausible values.¹¹⁴ Additionally, the World Health Organization (WHO) provides code for researchers to calculate BMI z-scores and percentiles using WHO growth charts for children younger than 2 years of age. Given that body composition varies by age, gender, and race/ethnicity, it is important that existing data include such demographic variables without systematic missing data. Some data sets may include indicators of pubertal status.

Researchers may find it difficult to identify a data set that is comparable across all these criteria and will need to be transparent about any shortcomings or limitations in their approach. For example, a strength of NHANES is that it includes objectively measured height and weight, a detailed dietary record (24-hour recall), and other health measures. If researchers are looking to evaluate the impact of a national policy on high school students' BMI and need to be confident that participants are enrolled in grades 9–12, they might prefer a data set such as the Youth Risk Behavior Surveillance System (YRBS). This system uses a self-reported measure of height and weight, which introduces bias, but it is specific to secondary students.



ADDITIONAL RESOURCE

[NCCOR Catalogue of Surveillance Systems](#)

7

Measuring Body Composition in Population Health Research: Case Studies



SECTION 7

Measuring Body Composition in Population Health Research: Case Studies

Population health research examines health outcomes of groups of individuals and often involves studies that characterize determinants of health and health outcomes as well as factors or interventions that influence health outcomes within and across populations.

As such, it is often conducted in community settings, such as schools, and/or with relatively large samples of participants. In contrast, clinical research focuses on the study of individuals' risk factors for a health outcome and treatment of individuals and is generally conducted with smaller samples and in settings that offer trained staff and specialized equipment. Compared to clinical research, conducting population health research to assess adiposity in children presents several challenges that can make it difficult to use the most accurate and reliable method. Several other considerations common to all research should also be considered. The first is ensuring the assessment method addresses the study goal. Other general considerations include:

- Parental consent and child assent may be difficult to ascertain if methods carry some risk, feel invasive, or cause embarrassment to the participant, particularly when the methods are conducted by individuals who are not familiar to the child and family.
- Availability of private space or rooms to conduct assessments may be lacking, thus limiting the ability to maintain privacy and confidentiality.
- Examiners may be inexperienced and lack relevant skills and training to work with children.
- Equipment often needs to be portable and durable so that frequent movement does not lead to damage or calibrations errors.

- Specialized equipment needed for some adiposity assessment methods is generally not accessible.
- Environmental conditions, such as temperature and humidity, may not be controllable as is required by some adiposity assessment methods.
- Costs to obtain assessments may be a constraint, including both staff efforts and the financial costs associated with equipment.

The following case studies highlight considerations for population health research. They illustrate how these considerations inform the selection of the most appropriate method(s) for a given scenario based on the research aim or question, the study design, and setting, while taking into consideration various pros and cons of different measurement methods (**Table 1**) that are relevant to the study.



Regardless of the case scenario or method used in the research, standardization is key to successful implementation and the accurate and reliable collection of data. It is important that the study team use written protocols (i.e., manuals of operation) that instruct staff on the mechanics of obtaining the measurements and that all staff receive a standardized initial training before implementation, and booster trainings during longer term studies. The manuals and staff trainings also should address how to record data and respond to participant questions regarding the measurement process and the participants' results. Study staff need to be trained to respond to questions in a way that provides accurate information, is consistent across all study staff, maintains participant privacy, and minimizes the potential for participant embarrassment.

CASE STUDY 1:

School-based, Cluster Randomized Control Trial to Prevent Childhood Obesity

BACKGROUND

A cluster randomized controlled trial is designed to evaluate the effects of a multi-component intervention that increases the weekly minutes of physical education offered to elementary students and introduces a nutrition education curriculum, culinary training for food service staff, and modified menu items for school meal programs. All 3rd to 5th grade children attending the 40 intervention schools will be exposed to these interventions for 3 years. Children in the 40 control schools will experience the standard school curricula for health education, the state-mandated minimum amounts of physical education, and the cafeteria menu that meets school nutrition standards. The study team recognizes that children are growing during these ages (8 to 11 years old), and height and weight are therefore expected to increase as part of normal growth during the study. Healthy weight gain with favorable changes in body composition (FM relative to muscle mass) and prevention of inappropriate weight gain rather than weight loss are the primary goals of the intervention. Therefore, the project team would like to evaluate the extent to which the intervention impacts obesity over the 3 years of the study.

CONSIDERATIONS

The study team plans to measure body composition at baseline and at multiple time points during the study, so the measurement method must be able to detect changes over the 3-year study

period. School-based interventions are often not intense enough to lead to large changes in body composition. Thus, the study needs to enroll and measure a large number (about 5,000) of children in order to have enough power to detect small changes in body composition.

Given the scale of the intervention and need for many participants, measurements must be quick and feasible to administer in a school setting. Equipment must be sufficiently portable between schools and/or affordable to allow for the purchase of several sets of equipment for measurements at multiple schools at the same data collection time points.

Schools have significant curriculum time requirements for learning as well as statewide student testing periods, which can limit the time available to conduct research study measurements on children. Furthermore, schools have many open public spaces and limited privacy for the study team to conduct measurements. Measurements must always be taken with children wearing their own light clothing. It is important that the measurement process does not embarrass children or contribute to weight stigmatization. For this reason, the study team may want to consider purchasing screens to set up private areas to take measurements. Lastly, the study team must choose assessment methods that will be acceptable to parents who will provide consent, children who will provide assent, and school leaders (e.g., district superintendent, school principal) who stipulate their terms for participating in research studies. In addition, some school districts have their own institutional review boards that must review and approve research protocols.

METHOD SELECTION

The study team is aware that height and weight are most frequently used in school contexts as a surrogate measure for body composition. They are

the least intrusive of adiposity assessment methods; require little specialized training and equipment; can be conducted quickly, minimizing the time the child is absent from the classroom; and are relatively low in cost. In addition, because height and weight are commonly used across pediatric practices to track growth, parents and children are familiar with them. When height and weight are collected, BMI can be calculated, and some index of BMI (BMI z-score or BMI percentile) is used as the outcome. However, the study team recognizes that BMI and related indices do not provide information on body composition, specifically FM and FFM. Furthermore, the current version of the CDC growth charts are not intended to be used for BMI z-scores and percentiles above the 97th percentile because changes in extreme values are compressed into a narrow range of associated z-scores or percentiles that do not reflect meaningful changes.⁶² Until this issue is resolved, it is a consideration for any study team if the participating student population is known to have a higher prevalence of severe obesity.

The study team considers the feasibility of other potential sources of data and methods. Researchers could consider using secondary data or existing BMI surveillance data as part of their evaluations if the data collection periods sufficiently align with desired outcome time-points for the study and can link individuals' BMI across time.¹¹⁵ Some states and districts require annual BMI data collection in schools, but policies vary in terms of which grades are required to participate. Use of secondary BMI data also prevents the study team from ensuring standardized data collection protocols. Use of longitudinal measures of skinfold thicknesses or waist circumferences are also considered. However, both methods require greater skill and training



If the participating student population in your study is known to have a higher prevalence of severe obesity be sure to consider this when selecting a method. The current version of the CDC growth charts are not intended to be used for BMI z-scores and percentiles above the 97th percentile.

to conduct than does BMI, require more time to collect measurements, and can be intrusive and embarrassing to the child and parent. Bioelectrical impedance analysis (BIA) also may be considered, as it is non-invasive, uses portable instrumentation, and is relatively inexpensive, simple, and quick. It is important for researchers to confirm whether the selected BIA instrument has predictive equations that have been developed and validated in a population of children with similar characteristics to those in the study. BIA requires standardized environmental conditions and participant preparation that may be difficult to consistently implement with large samples of young children. It also will be difficult to compare the study's results to other studies if BIA is selected. Methods that can estimate whole-body FM, such as DXA and ADP, would not be feasible in the school setting for many reasons including lack of accessibility, cost, the need for trained/technical staff, and time.

Ultimately, the study team decides to use measures of height and weight to calculate BMI because, of the possible methods to choose from for this study, it is the least intrusive, requires little specialized training and equipment, and can be conducted quickly. This method of adiposity assessment is typically more feasible and acceptable with children in a school setting.

CASE STUDY 2:

Assessing Adiposity in Infancy to Predict Risk of Developing Overweight and Obesity

BACKGROUND

A longitudinal observational study in pediatrician offices and pediatric health clinics where infants receive routine clinical care is designed by a team of investigators to evaluate changes in adiposity in infants and toddlers aged 0–2 years. Interest in this topic arises from findings that rapid early life adiposity gain is associated with an increased likelihood of later health problems, including cardiovascular disease, insulin resistance, and overweight and obesity. The goal of this study is to describe patterns of growth (changes in adiposity) during the first 2 years of life and observe how these patterns relate to developing overweight and obesity at age 2 years.

CONSIDERATIONS

The study team understands that children grow rapidly during the first 2 years of life, and changes in length and weight will vary considerably across children. Because the body composition assessment methods would need to be conducted at multiple time points after baseline, the methods must be sensitive to detecting changes in body composition over time. The study team will also need to enroll and measure a large sample (n=2,000) of children to model growth-related fat trajectories with sufficient sensitivity to inform on differences in the accumulation of fat.

The study team notes that methods would need to be performed at routine clinical appointments to

avoid the need for extra visits, thereby minimizing burden on families. Pediatric clinics serve as an ideal location for this type of data collection because privacy is ensured, and length, weight, and head circumference measures are components of the routine well-child care (health supervision) visits which are scheduled as follows: the first visit is 3 to 5 days after birth, and subsequent visits are at 1, 2, 4, 6, 9, 12, 15, and 18 months and at 2 years. Study data collection would not need to occur at all these visits but at a minimum of six visits, including at an early and late (2-year) visit. Sufficient time during the clinic visit needs to be allowed for study team members to conduct the additional measurements. Acceptability of the measures to parents who will provide consent is another key consideration.

METHOD SELECTION

The study team recognizes that length and weight are the most common measurements taken, as they are the least intrusive, generally require little training and equipment, and can be conducted quickly and with minimal costs. However, length and weight and their relative indices such as weight-for-length and weight-for-age percentiles do not provide information on body composition, specifically FM or FFM. Such indices assume that a higher percentile reflects additional or excess FM and fail to consider the contribution of the FFM component to weight. The study team finds this to be potentially problematic because a higher index could reflect greater lean mass rather than FM.

The team considers other potential methods to more specifically assess total body fat. Skinfold thicknesses of the triceps, subscapular, iliac crest, and mid-thigh can be used to monitor changes in subcutaneous fat, which is a very good proxy for total body fat at these ages. These methods are noninvasive and often acceptable to parents. However, skinfolds would be difficult to acquire in the context of routine pediatric visits due to their

complexity. These methods require data collector skill and training to conduct and additional time to acquire, especially in older infants and toddlers where compliance with measurement is more challenging. The study outcomes would be skinfold thicknesses of each of the four sites plus the sum of all four skinfold thicknesses, the sum of suprailiac and subscapular skinfolds as an index of central fat, and the sum of triceps and thigh as an index of peripheral fat. Methods that can estimate whole-body FM, such as DXA and ADP, would not be feasible in the pediatric clinic setting for many reasons including lack of accessibility, cost, the need for trained/technical staff, and time.

Ultimately, the study team finds skinfold assessment to be a strong option but decides against it for several reasons. Because the team will need to conduct measurements during multiple routine well-child care visits on a large sample of children, the additional staff time and resources needed to train the team as well as collect five separate measures makes the use of skinfold thicknesses less feasible. They ultimately select assessment of weight and length because it is the least intrusive of adiposity assessment methods. It can also be conducted quickly, making it much more feasible to conduct at multiple time points and with a large sample of children. The trajectories of change for weight-for-length and weight-for-age z-scores from first visit (early after birth) to 2 years would be modeled to identify patterns of increasing adiposity, including a pattern of rapid weight gain, which is a change in weight-for-age z-score >0.67 during the first 2 years. A score of 0.67 represents the difference between centile lines on standard growth charts, and an increase of 0.67 can be interpreted as an upward centile crossing through at least one centile line. The study can also assess differences in trajectory patterns and how they relate to developing overweight or obesity at age 2 years.



CASE STUDY 3:

Effect of Maternal Gestational Weight Gain on Newborn Adiposity

BACKGROUND

Several clinical researchers are designing a randomized controlled trial to evaluate whether counseling women with overweight and obesity to eat a healthy diet and maintain an appropriate level of physical activity during pregnancy affects infant adiposity. Preventing excessive gestational weight gain in the women may lead to a healthier body composition in the offspring at birth (less FM, greater FFM). The study aims to determine whether the intervention delivered to women during pregnancy, when the fetus is developing, has a measurable effect on offspring body composition at birth.

CONSIDERATIONS

The researchers are aware that most births will take place in hospitals and there is a limited time window (1–3 days) in which they can measure most infants before the mother is discharged. Conducting the study in the hospital ensures privacy. Additionally, length, weight, and head circumference measurements are taken routinely after birth to assess overall newborn health. Acceptability of the measurements to parents who will provide consent

is often high. The researchers will be only required to measure body composition of the newborn one time before the mother and newborn are discharged from the hospital following birth, which eliminates the need for a method that is sensitive to changes over time. However, the method(s) needs to be sufficiently sensitive to detect small differences in FM and FFM between the intervention group and usual care group.

METHOD SELECTION

Many methods could be used in this study depending on the resources available to the research team as well as parental preferences and concerns. Length and weight are the most common measurements taken as they are the least intrusive; generally require little skill, training, and equipment; and can be conducted quickly with minimal costs. However, length and weight and their relative indices such as weight-for-length and weight-for-age percentiles do not provide information on body composition, specifically FM or FFM. Such indices assume that a higher percentile reflects additional or excess FM and fail to consider the contribution of the FFM compartment to weight. The study team finds this to be potentially problematic because a higher index could reflect greater lean mass rather than FM.

The team considers other potential methods to more specifically assess total body fat. Skinfold thicknesses of the triceps, subscapular, and iliac

crest can be used to assess between group differences in subcutaneous fat, which is a proxy for total body fat. These methods are noninvasive and often acceptable to parents. These methods do require data collector skill and training to conduct and additional time to acquire and can be burdensome to the parent and child.

Methods that have been validated to measure whole-body FM and FFM with high precision in the newborn are air displacement plethysmography (ADP, PEA POD) and dual energy X-ray absorptiometry (DXA). These instruments may be available in the hospital setting but require higher cost, the need for trained/technical staff, and time. They all require that the infant be as still as possible during testing. For DXA, the infant is measured swaddled in a blanket. For ADP, the infant must be naked in a chamber where air temperature is comfortable. DXA also involves a small amount of radiation. For these reasons, these methods may be not be acceptable to the parent who will provide consent.

Ultimately, the study team decides to use DXA for the primary outcome as it is available in this setting and can precisely assess FM and bone-free lean mass. The study will also measure length and weight and use their indices (weigh-for-length and weight-for-age) as a secondary outcome as these measures are commonly used in clinical practice to assess growth and commonly used in other studies for comparison.

CASE STUDY 4:

Assessing Adiposity Changes in a Community-Based Healthy Weight Program

BACKGROUND

A community-based healthy weight program (HWP) conducted in a neighborhood recreation center in an urban area plans to evaluate the effectiveness of its 12-week evidence-based program for children and adolescents aged 6–13 years. The HWP includes goals that are common to many similar programs: providing a safe and trusted setting for children and families who often combat obesity-related stigma, teaching behavior skills to make healthy choices easier, and improving health and social outcomes, as well as weight status. Key components of the evaluation will assess changes in behaviors and adiposity.

CONSIDERATIONS

This community-based HWP operates out of a recreation center with one health coach and one health assistant trained to deliver an existing healthy weight intervention curriculum and collect evaluation data. The program receives referrals from primary care providers and schools in the surrounding areas and self-referrals. Because this program is also reimbursed by health insurers for the services it provides, it must take into consideration the outcomes the insurers want evaluated. In this case, the insurers are primarily focused on results of changes in adiposity of participants.

In order to assess changes in adiposity, the program team will have to collect measurements at a minimum of two timepoints: at baseline and at the end of the 12-week program. Methods to assess adiposity changes must therefore be sufficiently sensitive to detecting changes in body composition over time. Given the small sample of 16 participants and the short duration of the intervention (12-weeks), the project team is aware the intervention may not detect changes in body composition. They opt to collect additional measures of health, such as changes in self-esteem, psychological health, and physical fitness, to highlight the overall effects of the intervention.

This two-person team with their limited resources will need to select a method that does not pose a collection burden on staff and allows for measurements to be collected feasibly during the limited hours of the intervention. Because measurements must be collected during the time available for participating in the intervention activities at the center, they must also be taken quickly in order to reduce time taken away from intervention participation. Furthermore, the recreation center has many open public spaces and limited privacy for the project team to conduct measurements, so it is important that measurements are collected in a secure area to avoid embarrassing or stigmatizing the children and adolescents. The project team must also take into consideration that methods need to be acceptable to parents who will provide consent and children who will need to assent.

METHOD SELECTION

The study team is aware that height and weight are most frequently used across similar programs to assess changes in adiposity. They are the least intrusive of adiposity assessment methods; require



If the participating cohort is known to have a higher prevalence of severe obesity be sure to consider this when selecting a method. The current version of the CDC growth charts are not intended to be used for BMI z-scores and percentiles above the 97th percentile.

little specialized training and equipment; can be conducted quickly, minimizing the time the child is absent from the intervention; and are relatively low in cost. In addition, because this method is commonly used across pediatric practices to track growth, parents and children are familiar with them. When height and weight are collected, BMI can be calculated. However, the study team recognizes that BMI and related indices do not provide information on body composition, specifically fat and fat-free mass. Additionally, the current version of the CDC growth charts are not intended to be used for BMI z-scores and percentiles above the 97th percentile because changes in extreme values are compressed into a narrow range of associated z-scores or percentiles that do not reflect meaningful changes.⁶² This issue is of particular concern for the project team because a majority of children in this cohort meet the definition of severe obesity.

Given the limitation of using height and weight in this cohort, the project team considers other options. Skinfold thicknesses are discussed as another possibility; measurements can be limited to two of the most accessible areas of the body

such as triceps and subscapular and used to monitor changes in subcutaneous fat, a proxy for body fat. Waist circumference may be included as an index of change in central fat distribution. However, this tends to be more difficult to measure consistently in children who are severely obese. Both skinfold and waist circumference methods require skill and training to conduct, require time to collect measurements, and can be intrusive and embarrassing to the child. Methods that can estimate whole-body fat mass, such as DXA and ADP, would not be feasible in the community-based HWP setting for many reasons, including lack of accessibility, cost, the need for trained/technical staff, and time.

Given the limitation of using BMI with children who are severely obese, the difficulty in finding waist circumference landmarks in children with severe obesity, and the lack of privacy in the HWP, the project team decides to measure triceps and subscapular skinfolds as well as height and weight to calculate BMI. Triceps and subscapular can potentially support changes in BMI as being accounted for by changes in fat or show changes in fat that may not have translated to changes in BMI in this short time frame or with this population of children with severe obesity. Height and weight are typically feasible to assess in a community setting where staff, time, and resources are limited. BMI is also commonly used in other studies and in clinical settings for comparison purposes.

CASE STUDY 5:

Assessing, Analyzing, and Presenting Health Data from Electronic Health Records (EHRs)

BACKGROUND

A pediatric primary care system (PCS) has recently decided to address childhood obesity as a population health issue among the child and adolescent patients that it serves. Health care providers are increasingly using electronic health records (EHRs) and related electronic infrastructure to prevent and treat chronic diseases. As a result, PCSs, Federally Qualified Health Centers, hospitals, and health systems are in a unique position to analyze relevant patient panel EHR data on BMI, obesity-related comorbidities, the response to lifestyle or medical interventions, and trends over time. The PCS leadership convenes to discuss this approach with stakeholder representation from the information technology office, provider representatives, and community liaisons. One of the goals is to assess changes in adiposity over time in their patient population.

CONSIDERATIONS


The PCS and its partners consider how they can analyze, assess, and present data, including information from the EHR, in a way that informs population health. Providers in the PCS routinely use the EHR for basic functions, such as to calculate BMI, plot the BMI on the appropriate growth charts, display BMI percentile, and use clinical decision supports (CDS) to prompt appropriate screening, prevention, and management decisions. The PCS has successfully developed standardized EHR reports on a number of parameters, including the proportion of children being screened for BMI, the prevalence of overweight and obesity in their patient population over time, the proportion of children with overweight or obesity and a co-occurring condition (e.g., asthma), and the

proportion of children with overweight or obesity referred to weight management programs. As part of these efforts, the PCS was assisted by informatics and clinical experts to identify the most appropriate protocols for data cleaning and defining which data points will be used in an analysis.

PCS leadership and stakeholders decide to develop relationships with local weight management programs and other community resources to better track and understand how members of the PCS patient panel access and use community resources. This also will inform how these community resources may improve the health of patients. The PCS leadership and stakeholders identify data use agreements with these groups as a critical step. In doing so, they identify key measures of interest, as well as potential data cleaning and analysis protocols for these new data as the PCS group works with community resources to inform information technology infrastructure and final selection of measures.

METHOD SELECTION

The PCS leadership and stakeholders identify two change-sensitive weight-related measures from the EHR as candidates for outcome measures. These measures include an age- and sex-specific measure of BMI (see Section 5). Weight, height, and calculated BMI may be collected from community partners as well as PCS providers. They will highlight changes in the prevalence of overweight and obesity over the course of months to a few years as one important outcome in their patient population.

Several other outcome measures in children with overweight or obesity are selected as well, including systolic and diastolic blood pressures, hemoglobin A1C, and liver function tests. Data cleaning protocols specific to each of these measures will need to be used or developed as well. For children aged 2–19 years, the Daymont Method (see [Automated Identification of Implausible Values in Growth Data from Pediatric Electronic Health Records](#)  in the [Resources](#)) can be utilized for cleaning BMI.¹¹⁶ The group will analyze and describe the relationship between changes in weight-related measures and improvements in the co-occurring conditions.

CASE STUDY 6:

A Clinic-based Intervention to Promote Weight Loss in Adolescents with Severe Obesity

BACKGROUND

A research grant is awarded to a team of clinical investigators to conduct a randomized controlled trial to evaluate the effects of Liraglutide, a glucagon-like peptide-1 receptor agonist drug, when compared to a lifestyle counseling intervention to promote weight loss in adolescents aged 13–18 years with severe obesity. The trial is being implemented in a multidisciplinary weight management clinic located in a tertiary care hospital. The project team would like to evaluate the extent to which the drug leads to greater weight loss over 52 weeks compared to the lifestyle intervention. The team must also assess relevant safety parameters.

CONSIDERATIONS

The clinical investigators expect that treatment with the drug will result in significant weight loss, which raises concerns about normal growth in this study population. Many adolescents are undergoing puberty and rapid growth during these ages, therefore normal growth in height/stature and normal bone development are critical to monitor. In addition, given that the study is targeting significant weight loss, it is important to assess whether favorable changes in body composition occur during growth (fat mass relative to muscle mass) so that muscle mass is maintained or not adversely affected while loss of fat mass takes place.

Adolescent females face additional considerations. Girls who are sexually active and not using a reliable form of contraception may be at risk of pregnancy. Therefore, they need to be excluded from both the

drug and lifestyle interventions due to weight gain associated with pregnancy and because the drug intervention may put the fetus at risk of harm.

The study needs to assess changes in body weight and composition, and the measure of body composition needs to be conducted at baseline and at multiple time follow-up points. Therefore, the measure needs to be sensitive to detecting changes in body composition over time.

Although the multiple assessments will add to study costs and participant burden, smaller samples of participants are needed in comparison to prevention trials because effect sizes are expected to be larger between the drug and lifestyle treatments. In this trial, the study staff anticipate about a 10% reduction in BMI, on average, in the drug + lifestyle arm and a 5% in the lifestyle only arm. This trial requires about 100 adolescents per study arm at completion as compared to hundreds or thousands of participants in population-based studies focused on the prevention of obesity. Therefore, costs of more expensive and accurate body composition methods may be less prohibitive.

Unlike research conducted in community settings, the clinical setting offers privacy and exam rooms for research teams to conduct measurements. Participants can wear hospital gowns to facilitate examination. Even so, adolescents who have severe obesity and are developing secondary sex characteristics, may feel embarrassed during measurements or examinations. They often prefer to wear their own loose-fitting clothing with minimal to no intrusive physical measurements.

In addition, preparation for clinic visits may be difficult (such as fasting or limited physical activity), and visits need to avoid time away from school and are often scheduled in the afternoons after school. Acceptability of the measures with regard to safety, burden, time of day, and intrusiveness to both parents who will provide consent and adolescents who will need to assent is a key consideration.

METHOD SELECTION

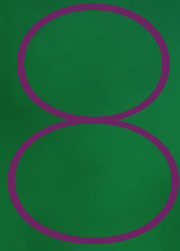
Given the considerations outlined above, the researchers agree it will be important to have a method, such as DXA, that can separate body weight into fat mass and fat-free mass as well as measure bone density. The hospital in which the clinic is located offers the availability of sophisticated measures of body composition, such as DXA, and well-trained staff/technicians to conduct the measurements. DXA costs are higher than other measurement methods, but the relatively small samples of adolescents may make it feasible. The test takes about 15 minutes and the adolescent can remain fully clothed. On the other hand, DXA machines have size limitations that may make it infeasible to measure participants with extreme obesity.

The research team also debates other methods that can estimate whole-body fat mass and fat-free mass without radiation exposure, such as ADP (BOD POD) and bioelectrical impedance analysis (BIA), if they choose not to measure bone density. The BOD POD assessment is simple and less expensive than DXA and is fast and safe; however, special compression clothing is necessary. Teens with severe obesity may be deterred by this requirement or find it uncomfortable. Participants also need to fast, which may be feasible in the morning, but morning visits require missing school. Similarly, BIA is non-invasive, safe, quick, and relatively inexpensive but use of BIA requires standardized participant conditions, such as fasting and lack of strenuous activity for 12 hours before the test, which are difficult to implement. In addition, prediction equations used to estimate fat-free mass and fat

mass are population specific. Therefore, equations for estimating fat-free mass in the study population would have to be available for the estimates to be valid.

Ultimately, the investigators select DXA as the method for this study because it separates body weight into fat mass and fat-free mass as well as measures bone density. With many adolescents in the study expected to be undergoing puberty and rapid growth during these ages, the investigators conclude that the benefits of monitoring body composition and bone development outweigh potential radiation risks. The investigators also opt to include BMI as a study method. Even though BMI does not provide information on body composition, specifically fat and fat-free mass, this method will be included in the trial because it can be used to monitor normal growth and to assess the efficacy of the weight loss intervention as a secondary outcome. Because BMI is used extensively in assessments of other weight management interventions, it also would be useful as a common measure for comparison to these other trials.

In terms of outcomes, the study team will be able to compare the changes from baseline to end of intervention in whole body fat or BMI outcome between the two study arms. The team also may examine changes in the percentage of participants classified as having obesity or severe obesity (using BMI percentiles) from baseline to the end of the intervention.



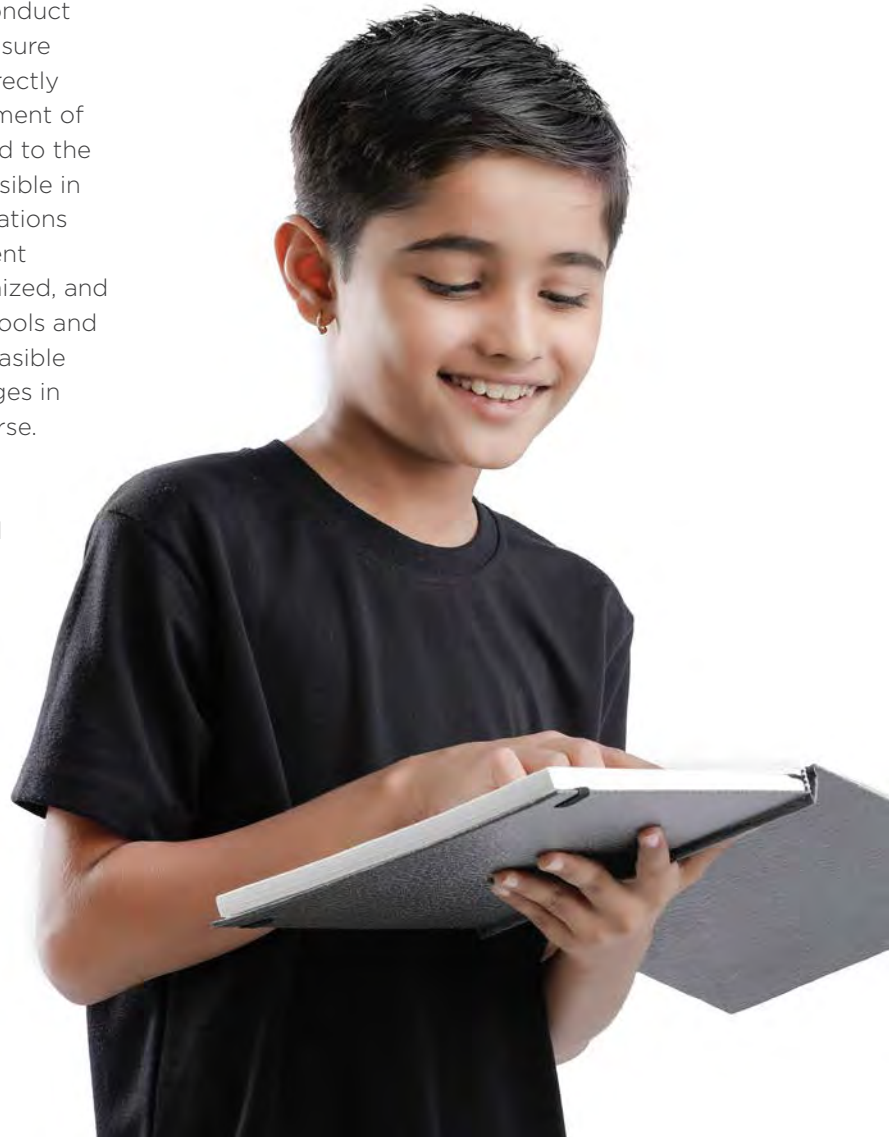
Conclusion



SECTION 8 Conclusion

The use of accurate and reliable methods to assess body composition is critical to understanding the role of adiposity on health and disease throughout the lifespan. Beginning with infancy, a greater understanding of how exposures to nutrients, hormones, and environmental factors relate to and influence fat mass increases and fat distribution and the development of diseases later in life can contribute to the development of more effective obesity prevention and treatment strategies.

To accomplish this, researchers need to conduct investigations involving methods that measure total body fat mass and fat distribution directly and with less error. However, the measurement of adiposity in childhood is more often limited to the use of indirect measures that are most feasible in practice, such as anthropometry. The limitations of available body composition measurement methods during childhood are well recognized, and additional research is needed to develop tools and methods that are accurate, reliable, and feasible and which can measure longitudinal changes in body composition throughout the life course. As science and technology evolve in this area, new or improved methods will undoubtedly reduce many of the potential limitations of existing methods. Until then, it is important to select the best possible method(s) for the goal of the study and population of interest, taking into consideration and acknowledging the strengths and limitations of available methods, and make proper interpretations of the findings.



9

Additional Resources Relevant to Select Adiposity Methods



ADDITIONAL RESOURCES RELEVANT TO SELECT ADIPOSITY METHODS

2000 CDC Growth Charts for the United States: Methods and Development details the development of the 2000 CDC growth charts.

https://www.cdc.gov/nchs/data/series/sr_11/sr11_246.pdf

American Association of Clinical Endocrinologists: Clinical Practice Guidelines offers guidelines for prevention and treatment of metabolic and endocrine diseases and care of patients with obesity.

<https://www.aace.com/disease-state-resources/nutrition-and-obesity>

The **Anthropometric Standardization Reference Manual** details several anthropometric measurement procedures and also addresses special issues such as reliability and accuracy. (*Book for purchase*)

Assessment of Child and Adolescent Overweight and Obesity, a *Pediatrics* supplement article, highlights approaches to childhood overweight and obesity assessment and shares the evidence available to support key aspects of assessment.

https://pediatrics.aappublications.org/content/120/Supplement_4/S193

Automated Identification of Implausible Values in Growth Data from Pediatric Electronic Health Records describes the development of an automated method for identifying implausible values in pediatric EHR growth data.

<https://academic.oup.com/jamia/article/24/6/1080/3767271>

The **BMI Percentile Calculator for Child and Teen** calculates BMI and the corresponding BMI-for-age and sex based on the CDC growth charts for ages 2 through 19.

<https://www.cdc.gov/healthyweight/bmi/calculator.html>

Body Mass Index (BMI) Measurement in Schools offers information on the types of BMI measurement programs and what to have in place before launching a BMI measurement program.

https://www.cdc.gov/healthyschools/obesity/bmi/bmi_measurement_schools.htm

Bright Futures: Guidelines for Health Supervision of Infants, Children, and Adolescents, 4th ed.

Promoting Healthy Weight is a chapter that provides an overview of body mass index and defines overweight and obesity in several special populations.

https://brightfutures.aap.org/Bright%20Futures%20Documents/BF4_HealthyWeight.pdf

CDC Growth Charts represent revisions to the 14 previous charts, as well as the introduction of two new body mass index-for-age (BMI-for-age) charts for boys and for girls, ages 2 to 20 years. They consist of a series of percentile curves that illustrate the distribution of selected body measurements in U.S. children.

https://www.cdc.gov/growthcharts/cdc_charts.htm

Clinical Practice Guideline for Multicomponent Behavioral Treatment of Obesity and Overweight in Children and Adolescents: Current State of the Evidence and Research Needs from the Guideline Development Panel for Obesity Treatment of the American Psychological Association provides treatment recommendations regarding the use of family-based multicomponent behavioral interventions for overweight and obesity in children and adolescents based on a systematic review of the evidence.

<https://www.apa.org/about/offices/directorates/guidelines/obesity-clinical-practice-guideline.pdf>

Diagnostic Performance of Body Mass Index to Identify Obesity as Defined by Body Adiposity in Children and Adolescents: A Systematic Review and Meta-analysis assesses the ability of BMI to detect adiposity in children up to 18 years. It concludes BMI has high specificity but low sensitivity to detect excess adiposity.

<https://pubmed.ncbi.nlm.nih.gov/24961794/>

Growth Charts is a CDC webpage that provides guidance to health care providers on when to use the WHO growth standards or the CDC growth charts.

<https://www.cdc.gov/growthcharts/>

Pediatric Obesity—Assessment, Treatment, and Prevention: An Endocrine Society Clinical Practice Guideline offers clinical practice guidelines for the assessment, treatment, and prevention of pediatric obesity.

<https://academic.oup.com/jcem/article/102/3/709/2965084>

Fat and Lean BMI Reference Curves in Children and Adolescents and Their Utility in Identifying Excess Adiposity Compared with BMI and Percentage Body Fat provides pediatric reference curves for fat mass index (FMI) and lean body mass index (LBMI) and evaluates the effects of population ancestry and lean body mass on measures of excess adiposity. It concludes the use of FMI and LBMI improves on the use of percent body fat and BMI by allowing for the independent assessment of fat mass and lean body mass.

<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3683820/>

The **National Health and Nutrition Examination Survey (NHANES), Anthropometry Procedures Manual** details how body measures are conducted for the National Health and Nutrition Examination Survey.

https://wwwn.cdc.gov/nchs/data/nhanes/2015-2016/manuals/2016_Anthropometry_Procedures_Manual.pdf

The **NCCOR Catalogue of Surveillance Systems** provides easy to navigate, one-stop access to over 100 publicly available datasets relevant to childhood obesity research and evaluation. It can be used to identify and compare surveillance systems that include weight-related outcomes.

<https://www.nccor.org/nccor-tools/catalogue/>

Recommendations for Data Collection, Analysis, and Reporting on Anthropometric Indicators in Children Under 5 Years Old provides guidance to technical staff experienced in conducting surveys to collect anthropometric data. It proposes a set of recommendations to enhance quality reporting for the global nutrition targets and the Sustainable Development Goal target 2.2.

<https://www.who.int/nutrition/publications/anthropometry-data-quality-report/en/>

Relation of BMI to Fat and Fat-free Mass Among Children and Adolescents is a peer-reviewed paper that examines the relation of BMI to levels of fat mass and fat-free mass among healthy 5- to 18-year-olds. It concludes that although a high BMI-for-age is a good indicator of excess fat mass, BMI differences among thinner children can be largely due to fat-free mass.

<https://www.nature.com/articles/0802735>

Report of the Commission on Ending Childhood Obesity shares a set of recommendations to successfully tackle childhood and adolescent obesity in different contexts around the world.

<https://www.who.int/end-childhood-obesity/publications/echo-report/en/>

U.S. Preventive Services Task Force: Screening for Obesity in Children and Adolescents: Recommendation Statement offers an obesity screening recommendation along with a rationale and considerations for the recommendation.

<https://jamanetwork.com/journals/jama/fullarticle/2632511>

The **WHO Child Growth Standards** provide an international standard of growth for infants and young children aged 0 to 59 months and are comprised of data from a sample of infants measured longitudinally starting at birth during the years 1997 to 2003.

<https://www.who.int/childgrowth/en/>

WHO Growth Standards Are Recommended for Use in the U.S. for Infants and Children 0 to 2 Years of Age provides recommendations to health care providers on when to use which growth charts.

https://www.cdc.gov/growthcharts/who_charts.htm

WHO Child Growth Standards Based on Length/Height, Weight, and Age describes the methods used to develop the WHO Child Growth Standards based on length/height, weight and age, and to present resulting growth charts.

https://www.who.int/childgrowth/standards/Growth_standard.pdf?ua=1





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