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Body Composition Analysis in the Pediatric Population

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Abstract

Body composition analysis has become a useful tool in both clinical and research settings. Its use in the pediatric population is complicated by the rapid periods of growth and physical development that are characteristic of infancy, childhood, and adolescence. A thorough understanding of the changing nature of body composition during this time is essential for choosing the most appropriate measurement technique for a given individual, population, or clinical question. Growing evidence suggests that tissues such as fat, muscle, and bone are intimately involved in the regulation of whole body energy metabolism. This knowledge, when coupled with advancements in imaging techniques such as MRI and PET-CT, offers the possibility of developing new models of "functional" body composition. These models may prove to be especially important when assessing malnutrition and metabolic risk in patients with chronic disease.

Keywords

Body Composition; Obesity; Fat Mass Index; Lean Body Mass Index; Body Mass Index; Metabolic Syndrome

Body composition analysis is an important tool for the pediatric endocrinologist with applications in both clinical and research settings. The goal of this review is to outline basic concepts underlying the assessment of body composition in the pediatric population. Particular attention will be paid to the challenges of using these techniques during periods of rapid growth and development. The use of body composition to accurately assess obesity and metabolic risk will be highlighted, as will its use in specific chronic disease groups. Finally, new techniques for the qualitative assessment of adipose tissue will be discussed with a focus on future directions.

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Basic Concepts

Body composition assessment aims to quantify the amount and relative proportions of body tissue compartments, and in some cases, their cellular, molecular, and atomic components. The five-level model of human body composition developed by Wang *et al.* (1) defines a series of interrelated, increasingly complex levels (Table 1) that provide an organizational framework for approaching questions related to body composition and identifying appropriate methods of analysis. For example, an investigator interested in changes in bone mass during growth and development may start with an anthropometric measure such as height as a general measure of bone at the whole body level. Alternatively, total body bone mineral content obtained using dual energy x-ray absorptiometry (DXA) provides an accurate measurement at the tissue level. Total body calcium can be estimated from total body bone mineral content (calcium(gm)=0.34 x bone mineral content(gm)) based on the known composition of hydroxyapatite, yielding a measure (total body calcium) at the atomic level (2).

Beyond the five-level model, approaches to body composition analysis can be organized according to the number of compartments described. Two-compartment models divide the body into fat mass (FM) and fat free mass (FFM) such that total body mass = FM + FFM. Two compartment methods include anthropometry, densitometry, bioelectric impedance, or isotope dilution for total body water. The density of FM and FFM usually are assumed to be constant. This may be a reasonable assumption for FM, which is defined by the ether-extractable lipid fraction of the body(4). FFM, however, is a complex tissue compartment composed of skeletal muscle, organs, bone, and supporting tissue. FFM hydration and the contribution of osseous mineral to FFM in particular are known to introduce uncertainty in the estimation of FFM. This is an especially important consideration in children, as these components of FFM change with growth and development (5–7), and in disease states.

Three-compartment models divide body mass further into FM, non-osseous lean body mass (LBM) and bone mass such that total body mass = FM + LBM + bone mass. DXA offers a quick, convenient means of three compartment analysis. FM, LBM, and bone mass have unique tissue densities and therefore attenuate energy beams differently, allowing for accurate quantification of each tissue. Because DXA measures bone mineral content directly, this method eliminates one of the major sources of variability inherent in the estimation of the FFM in the two-compartment model. Though often used interchangeably in the literature, it is important to note that FFM and LBM differ in that LBM contains a small amount (2–3% of body mass) of essential lipid (8).

Multi-component models using methods or combinations of methods to measure FM + three or more components of FFM have also been developed (Table 2). The accuracy of body composition assessment improves with the number of components measured as there is less dependency on the assumption that FFM density is constant (9). For example, the formula for a four-component model might include density values for fat, water, mineral and protein (0.9007 g/mL, 0.9937g/ml, 3.038 g/mL, 1.34 g/mL, respectively) compared to a two-compartment model which would include density values for only FM and FFM (0.9007 g/mL, 1.100 g/mL, respectively) (10).

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A further consideration beyond the compartment models discussed above is the distribution of adipose tissue on the body (fat patterning). Traditionally fat patterns have been described as “android” with greater trunk fat and less extremity fat and “gynoid” with greater hip and extremity fat and less trunk fat (11). Observations that the risk of cardiometabolic disease may vary based upon these patterns of fat distribution have raised important questions regarding qualitative differences among fat deposits.

Visceral fat, located in the trunk, is thought to be more metabolically active than subcutaneous fat and is a strong risk factor for insulin resistance, type 2 diabetes and cardiovascular disease (12–14). Conversely, lower extremity subcutaneous fat has been found to be associated with increased insulin sensitivity and may be protective against the development of cardiometabolic disease by suppressing the release of free-fatty acids (15, 16). Anthropometric measures such as waist circumference provide simple means of estimating fat distribution that supplement measures of excess adiposity such as BMI, but ultimately cannot definitively differentiate between visceral and subcutaneous adipose tissue (17). Single slice CT and MRI are currently the most frequently used methods for quantifying visceral fat. Recent advances in software technology permit estimation of visceral fat mass, area and volume using DXA(18).

Ectopic fat deposition within and around lean tissue, organs and bone may impair local tissue function and whole body glucose and lipid metabolism via lipotoxicity, impaired blood flow, and cytokine release (19). Studies in adults and children using CT and MRI to assess fat deposition in the thigh have found that adipose tissue below the fascia lata, infiltrating muscle groups (intramuscular adipose tissue, IMAT), and within myocytes (intramyocellular lipid) are all associated with insulin resistance and type 2 diabetes, while subcutaneous adipose tissue is not (20–25). Intrahepatic lipid deposition may hinder glucose metabolism and has been shown to be inversely associated with insulin sensitivity in obese children (26). Accumulation of adipose tissue within the bone marrow may also be detrimental, and has been found to be positively correlated with visceral adipose tissue and inversely associated with bone mineral density in adults (27, 28).

Finally, distinctions between brown and white adipose tissue may be important when considering fat mass. Brown adipose tissue (BAT) is highly vascularized, rich in mitochondria and highly metabolically active. Its primary function is to maintain body temperature upon cold exposure through non-shivering thermogenesis, a mechanism whereby uncoupling of the mitochondrial respiratory chain leads to the generation of heat instead of ATP (29). BAT is most abundant during infancy, a period of increased susceptibility to hypothermia owing to low skeletal muscle content and high body surface area relative to volume (30). It is now known that functional BAT persists beyond infancy, distributed primarily in the supraclavicular, neck, paravertebral, and suprarenal areas of the body (30, 31). The presence and volume of functional BAT increases with puberty and has been found to be positively correlated with muscle volume, amount of cortical bone, and bone size (32–34). BAT activity has also been found to be negatively correlated with BMI and percentage body fat in children and adults, suggesting a possible link between BAT activity and disordered weight gain (35, 36). The quantification and activity of BAT is

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typically determined using 18F-fluorodeoxyglucose positron-emission tomography (PET) integrated with CT.

Measurement and Interpretation of Body Composition

There is no *in vivo* gold-standard for the measurement of body composition in children. One or more methods may be appropriate for use based upon the individual (or population) of interest and the type of information that is desired. A description of the measurement techniques appropriate for a given level or compartment of body composition is available in Tables 1 and 2. Measurement techniques typically increase in difficulty, expense and potential risk to the individual as greater levels of detail are achieved. With the exception of cadaveric studies, most other methods of body composition analysis are indirect and rely on assumptions that have the potential to introduce bias into the results. A detailed technical discussion of the different methodologies is beyond the scope of this review but is available elsewhere (2, 3, 37, 38).

In situations where the goal is simply to quantify a given tissue or body compartment, the measurements attained using the methods outlined above may suffice. Often, however, the goal is to use body composition analysis as a means to describe populations or assess risk of disease in an individual patient. There are a number of indices currently in use that allow for the use of body composition analysis in this manner. Each comes with unique benefits and drawbacks that must be carefully considered in relation to the population and question of interest. Table 3 provides a list of indices for which there are reference data in the pediatric population – an important consideration for interpretation of body composition results.

Weight for length is a simple index commonly used for infants and reference data is applicable for use in diverse populations across the world (39). Waist circumference is another simple anthropometric measure that may be useful as estimates of overall and visceral adiposity and has been associated with cardiometabolic risk factors in childhood (40, 41). Lack of a standard measurement technique and a difficulty in measurement among obese individuals is a limitation of this technique (42–44). Upper arm fat and muscle areas, calculated from measurements of upper arm circumference and triceps skin fold thickness, have been used to predict body composition and nutritional status but these vary as a function of age and body size, and are based on several approximations that may limit accuracy (45).

The body mass index (BMI,) calculated as weight (kg)/stature $(m)^2$ is the most widely used index in children and adults. BMI is easily obtained from simple anthropometric measures and has established reference standards (46, 47) making it an attractive screening tool for the assessment of both malnutrition and excess adiposity (48). Of note, the CDC BMI reference standards excluded children from contemporary NHANES surveys because of the obesity epidemic. Therefore, the charts do not represent the present distributions of BMI among current U.S. children. An important underlying assumption of BMI is that weight scales to height2, and therefore BMI is independent of height. This assumption has generally been found to be true in adult populations (48, 49) but not in children, where greater height is associated with greater BMI (50–54). Another assumption of BMI is that individuals of

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different stature but the same BMI (or BMI percentile) have identical fractional body composition (55). This assumption also has been challenged in the pediatric population, where the proportions of body mass attributable to FM and FFM are highly variable and dependent upon age and pubertal maturation (56).

Compartment specific indices such as the fat mass index (FMI, fat mass(kg)/stature(m)2), fat-free mass index (FFMI, fat-free mass(kg)/stature (m)2), and lean body mass index (LBMI, lean body mass(kg)/stature(m)2) have been proposed as more accurate indicators of adiposity and malnutrition. FM and FFM can be estimated using techniques for assessing two-compartment models, while (non-osseous) LBM requires a three-compartment approach (table 2). There is still an assumption that FM, FFM, and LBM scale to height2 in these indices, however the compartments of total body mass can be assessed independently. FMI and FFMI were found to be more sensitive indicators of nutrition status compared to BMI or percent body fat when applied to data from the Minnesota Semi-Starvation Study (57). Analyses of FMI and FFMI in children have revealed that increases in BMI during childhood are largely driven by increases in FFMI and not FMI, suggesting that BMI may not accurately represent adiposity in all situations (53, 58, 59). The use of FMI, FFMI, and LBMI in children is limited due to a lack of robust reference data.

Percent body fat (fat mass(kg)/body mass(kg)* 100) can be obtained from body composition methods that estimates fat mass and provides more valuable information than BMI by differentiating between fat and fat free mass. A study comparing BMI to percent body fat estimated by DXA found that less than half of children and adolescents defined as overweight by BMI (BMI ≥ 85th percentile) had high adiposity defined by percent body fat (60). The use of percent body fat estimated from skinfold thicknesses has also been shown to discriminate the presence of absence of metabolic syndrome in children and adolescents with moderate accuracy (61). The use of percent body fat is limited by the fact that it does not take into account the effects of height, body proportion, and the independent contributions of absolute amounts of fat and fat free mass to health and disease.

Growth and Development

Body composition changes dramatically over the lifespan in humans. Careful consideration of these underlying changes must be taken into account when applying and interpreting body composition analyses in the pediatric population.

Infancy is a time of rapid growth and is associated with marked changes in compartment, tissue, and chemical composition. In infants, extracellular water and organ mass comprise a larger proportion of body mass compared to children and adults (66). This results in results in a higher hydration of fat-free mass and can bias estimates of body composition (67). Fat mass as a proportion of body weight is also higher in infants. Percent body fat in humans peaks between 3–6 months of age, near 29% in males and 32% in females (68). Sex differences in infant body composition extend beyond percent body fat as males have been shown to have greater fat-free mass, total body water, total body potassium and bone mineral content (68).

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Growth during childhood progresses at a slower pace with less pronounced changes in body composition. The sex differences in percent body fat observed during infancy continue through this period. A small increase in the rate of weight-, height-, and body breadth-gain is observed in the mid-childhood growth spurt occurring around ages 6–8. A rebound in body mass occurs at approximately the same time. BMI peaks near the end of infancy, declines in early childhood before reaching a nadir around age 5–6, then increases throughout the remainder of childhood, adolescence, and adulthood. The timing of this BMI rebound may be genetically regulated (69).

The profound changes in body compartments, chemical, and tissue composition occurring during adolescence are primarily due to the effects of gonadal sex steroids. The adolescent growth spurt results in rapid increases in body mass and height. Existing sex-differences in percent body fat become more pronounced. Females gain more fat mass relative to lean mass, in part due to the growth of breast tissue and the gradual development of the female body shape with fat deposition at the hips and thighs. Many males experience a pre-pubertal fat spurt followed by rapid gains in lean body mass and reductions in fat at the extremities (this includes the triceps, a site of skin fold thickness measurement). These sex-specific changes in body composition are illustrated in Figure 1. Bone mineralization, cortical density and trabecular density all increase during adolescence, with 40% of peak bone mass accruing during this time (70–72).

Body composition continues to change through adulthood, although these changes are less pronounced than those seen during infancy, childhood and adolescence. Adults continue to gain weight throughout adulthood in most westernized societies, a phenomenon not always observed in traditional non-westernized societies. Increases in weight and BMI throughout adulthood are largely attributable to increases in fat mass as both FMI and percent body fat were found to increase with age in a cross sectional analysis of the US population (63).

Applications for Obesity and Metabolic Disease

The prevalence of obesity in the pediatric population has increased dramatically over the past few decades. Currently, 17% of American children and adolescents are identified as obese (73). The societal implications of this obesity epidemic have led to a renewed interest in the study and use of body composition to develop screening tools which can accurately identify patients at risk for the development of obesity-related disease. Excessive weight gain affects children of all ages and a careful consideration of the changes in body composition during growth and development is essential when considering which method of body composition analysis to use.

There is growing evidence that body composition during infancy and early childhood predicts obesity and risk of cardiometabolic disease in later life. Infancy is a period of transition, and both the pre- and post-natal environments contribute to body composition during this time. Birth weight is the most readily obtainable measure of fetal growth and has been studied extensively. A recent meta-analysis found that infants with high birth weight (> 4000 grams) had increased risk for the development of obesity later in life (74). Intrauterine growth restriction is also associated with subsequent obesity, and is a strong risk factor for

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the development of metabolic syndrome, insulin resistance, and cardiovascular disease (75, 76). Interpretation of these studies is complicated by the fact that birth weight has been consistently shown to be associated with subsequent lean mass; however, its association with fat mass is less clear (77). Studies offering more detailed assessments of body composition at birth are lacking; the recent development of air displacement plethysmography devices designed especially for infants may offer a safe and easy approach for this vulnerable population (78).

Consideration of the rate of weight gain during early infancy may be particularly important in predicting future BMI, fat mass and central fat distribution (79–82). Efforts to maximize catch-up growth in small for gestational age infants may lead to altered body composition and metabolic risk. Small for gestational age infants experiencing rapid catch up weight gain during the first two years of life showed increased whole body and central adiposity, decreased lean mass, and increased insulin resistance at 4 years of age compared to average for gestational age infants (83).

Early nutrition source, in particular, has been shown to impact measures of infant and childhood body composition. Compared to breast fed infants, formula fed infants have increased weight velocity and FFM during the first year of life, though these differences do not persist into the second year (84). Breast feeding has been shown to reduce the risk of future obesity in a dose-dependent manner, with infants who breast fed for at least 26 weeks having a 51% reduction obesity risk at age 9 compared to a 38% reduction for those breastfed 13–25 weeks (85). Feeding mode may also be important, as bottle feeding led to increased weight gain over the course of the first year of life, irrespective of whether it was with breast milk or formula (86).

During childhood, the timing of the body mass rebound may influence the risk of future obesity and cardiometabolic disease. Children who experience this rebound earlier have been shown to be at higher risk for obesity and the development of complications such as type 2 diabetes (87, 88). Rate of weight gain continues to be an important risk factor, and rapid gain in BMI during childhood has been found to be more strongly associated with coronary events in adulthood than a given level of BMI at any age (89).

Adolescence is heralded by the onset of puberty, a process that has a profound impact on glucose homeostasis, lipid metabolism and cardiovascular function. Insulin resistance, blood pressure, and cholesterol all increase during puberty, which may make this a period of increased risk for the development of metabolic syndrome (90–92). The prevalence of metabolic syndrome has been reported to vary from 10 to 12% in the adolescent population. Earlier pubertal development has been associated with increased risk for metabolic syndrome in young adulthood (93–95). The components of the metabolic syndrome (abdominal obesity, insulin resistance, dyslipidemia, hypertension) are all thought to result from the presence of excess adiposity, however clarifying the nature of this relationship has been difficult. This may be in part due to limitations of the commonly used measures of adiposity during this time of rapidly changing body composition.

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BMI is currently the most widely used method of identifying children and adolescents with excess adiposity and related risk for the development of metabolic disease. Children and adolescents are classified as overweight if their BMI is between the 85th and 95th percentile for age and sex and obese if BMI is greater than the 95th percentile (96). BMI was developed as means of assessing obesity in populations and may not be an accurate screening tool for identifying individual patients at risk for the development of cardiometabolic disease. A cross-sectional analysis of children in the Bogalusa heart study revealed that the optimal cutoff for BMI to identify the presence of metabolic risk factors varied from the 50th to the 57th percentile across sex and racial groups (97). The fact that such a low percentile for BMI is required to maximize sensitivity and specificity suggests that BMI may fail as a screening tool for metabolic disease. The risk of metabolic syndrome for a given BMI was also found to differ significantly between white and black obese adolescents, which may have been attributable in part to lower levels of visceral adipose tissue in blacks (98). This study not only illustrated the potential for BMI to misclassify individuals in terms of metabolic risk, but also its lack of generalizability across racial groups in part due to the fact that it does not account for fat distribution.

These limitations of BMI have led investigators to evaluate other indices of body composition for use as screening tools for metabolic syndrome in youth. Cutoffs for waist circumference were found to be similar to those for BMI and have similar sensitivity and specificity (97). A cross-sectional study using contemporary data from NHANES (which includes more obese children than those represented in the BMI charts) determined that the optimal cutoffs for percent body fat to identify metabolic syndrome were the 85th percentile for males and the 68th percentile for girls (61). At this time, it remains to be seen which index will perform best as a screening tool for identifying cardiometabolic disease. Comparison studies using longitudinal data are needed to answer this question.

Applications for Specific Populations

With continued advances in medical care, the number of children surviving and suffering from chronic disease is increasing across all age groups. This represents another population that may benefit from a more comprehensive approach to body composition analysis. These are children who may be defined as normal by weight or BMI, but who in fact may have excess adiposity and are at increased risk for the development of cardiometabolic disease or have lean mass deficits leading to impaired body function.

Survivors of childhood cancer and stem cell transplantation are at risk for altered body composition due to corticosteroid exposure, radiation and chemotherapy leading to endocrine dysfunction, immobility, and nutritional deficiency. Studies have shown that while there is no difference in BMI Z scores of these patients compared to healthy controls, they have significant deficits of lean mass and excesses of fat mass (99, 100). Another study of childhood cancer survivors suggested that these differences in body composition may be associated with metabolic disease, finding a prevalence of metabolic syndrome of twice that of the general population, even though only 17% were identified as overweight or obese by BMI (101).

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Chronic inflammation affects growth and may lead to deficits in lean body mass. Children and young adults with incident Crohn's disease had deficits in lean mass (males and females) and fat mass (females only) at diagnosis (102). These deficits improved with treatment and lean mass was shown to be correlated with reduction of inflammatory markers (103). Chronic kidney disease is also associated with lean mass deficits, especially of the leg, which may be indicative of skeletal muscle wasting (104).

Nutritional status is an important predictor of morbidity and mortality in cystic fibrosis, and is associated with pulmonary function, exercise tolerance, and linear growth in longitudinal studies of children (105, 106). BMI is currently the most often used measure of nutritional status in this population, however it may not identify individuals with deficits in FFM which may be a better predictor of pulmonary function(107). One cross-sectional study of 50 children with mild lung disease found that BMI was more strongly correlated with pulmonary function than either FM or FFM (108). Further studies are needed to fully understand the relationships between body composition, nutritional status, and clinical outcomes in cystic fibrosis.

Future Directions

The term "functional body composition" has been coined to describe approaches to body composition analysis that go beyond the simple quantification of body tissue and aim to integrate body components within the broader regulatory systems of the human body(109). Fat, muscle, and bone are now understood to be important regulators of whole body energy metabolism. The refinement and application of cutting-edge techniques such as MRI and PET-CT will allow for deeper investigations into the nature of adipose tissue. Factors such as fat distribution and metabolic activity can then be incorporated into current models of body composition and may explain some of the individual and population specific variation in risk of disease. Ultimately the goal should be to develop new definitions of obesity and underweight that are based upon metabolic and physiologic function, rather than statistical prevalence.

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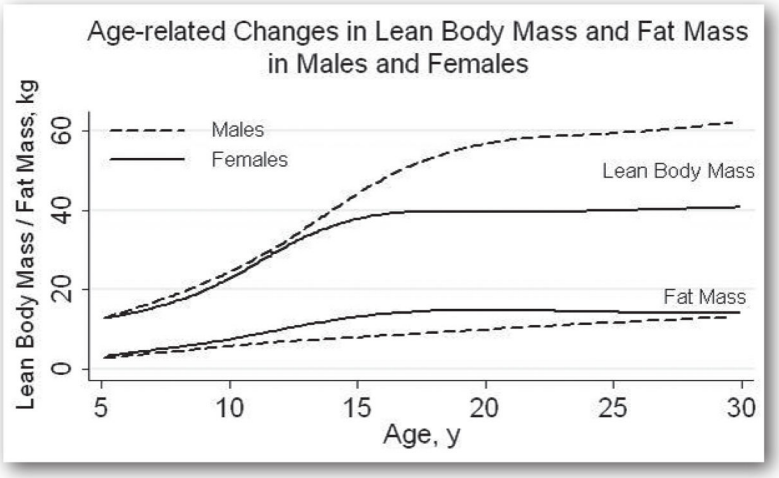

Figure 1.

Body composition differences between males and females are present at all ages, but pronounced differences emerge in adolescence with greater lean body mass in males and greater fat mass in females

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Table 1

The five-level model of body composition[1]

Level	Information Obtained	Methods of Determination
I. Atomic	Elemental: O,C,H, N, Ca, P, S, K, Na, Cl	Neutron Activation, total body potassium counting with 40K
II. Molecular	Water, protein, lipid, osseous and extraosseous mineral, glycogen	Total body water, neutron activation, magnetic resonance spectroscopy
III. Cellular	Fat, body cell mass, extracellular fluid, extracellular solids	Total body water, isotope dilution for sodium bromide, total body potassium counting with 40K
IV. Tissue	Adipose, skeletal, muscle, organs	Hydrodensitometry, dual energy X-ray absorptiometry, bioelectric methods, computed tomography, magnetic resonance imaging
V. Whole Body	Height, weight, circumferences, segment lengths, skinfold thickness	Anthropometry

[1] Adapted from Zemel and Barden 2004 (3)

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Table 2

Examples of multi-compartment models of body composition[1]

Model	Components Measured	Techniques	Assumptions
Two-Compartment	Fat mass + fat free mass	Anthropometry, underwater weighing, isotope dilution for total body water, bioelectric methods	Constant densities of fat mass and fat free mass
Three-Compartment	Fat mass + lean body mass + bone	DXA	Constant densities of fat mass and lean body mass
	Fat mass + total body water + non-aqueous solids	Underwater weighing, Bod Pod, isotope dilution for total body water	Fixed ratio of protein to minerals
Four-Compartment	Fat mass + lean body mass + intracellular water + extracellular water	DXA, isotope dilution for total body water and sodium bromide (or bioelectric methods for intra- and extracellular water	
	Fat mass + lean body mass + total body water + protein	DXA, underwater weighing, isotope dilution for total body water	Fixed ratio of K, 2H20 or 2H180 and NaBr in cellular components
	Fat mass + body cell mass + extracellular water + extracellular solids	DXA, isotope dilution for total body water, total body potassium counting with 40K	
Five Compartment	Fat mass + lean body mass + total body protein + total body nitrogen + glycogen	Neutron Activation	Glycogen estimated from total body protein or by magnetic resonance spectroscopy
	Fat mass + total body protein + total bone mineral + extracellular water + intracellular water	Neutron Activation	

[1] Adapted from Zemel and Barden 2004 (3)

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Table 3

Sources of Body Composition Reference Data in Children and Adolescents

Measure	Source	Comment
Percentage Body Fat	Ogden 2011 (62)	Percentage body fat estimated by DXA, available for ages 8–19 (NHANES)
FFMI	Kelly *et al.* 2009 (63)	Described as LBMI, actually FFMI estimated by DXA, available for ages 8-adult (NHANES)
Waist Circumference	Fernandez (64)	Available for ages 2–19, includes group-specific percentiles for Whites, Blacks, and Mexican Americans
Bone Mineral Content, Bone Mineral Density	Zemel *et al.* 2011 (65)	Total body, lumbar spine, total hip, femoral neck, forearm for African Americans and non-African Americans ages 5–20 (Bone Mineral Density in Childhood Study) includes equation for adjusting for height
	Baxter-Jones *et al*	Longitudinal reference ranges for bone mineral content, for ages 8 to 25 years for African Americans, Whites, Asians and Hispanics from Canada and the U.S. {Baxter-Jones, 2010 #4032}
Total Body Water and other components	Ellis *et al*	Reference ranges for total body water, total body potassium and total bone mineral content for European-Americans, African Americans and Mexican Americans based on 856 healthy children, ages 5 to 18y {Ellis, 2000 #210}
	Fomon *et al.* 1982	Reference ranges for composition and density of fat free body mass (protein, total body water, intra- and extracellular water, osseous and non-osseous mineral, carbohydrate, total body potassium and density of fat-free mass for birth to 10 years of age {Fomon, 1982 #55}
	Butte *et al.*	Reference ranges for fat mass, fat-free mass, percent body fat, and composition and density of fat free mass for infants, birth to 24 months of age based on a longitudinal sample of 76 infants.{Butte, 2000 #211}
Density and hydration of lean tissue	Wells *et al.*	Based on 533 individuals (91% white), ages 4–23 y in the U.K. {Wells, 2010 #499}