

Review article

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Body mass index and body composition scaling to height in children and adolescent

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Childhood obesity prevalence has been increased and known to be related to various diseases and mortality in adult and body mass index (BMI) has been widely used as a screening tool in children with obesity. It is important to understand what BMI is and its limitations. BMI is a measure of weight adjusted for height. Weight scales to height with a power of about 2, is the basis of BMI ($\text{weight}/\text{height}^2$) as the scaling of body weight to height across adults provides powers rounded to 2. BMI has the advantage of a simple and noninvasive surrogate measure of body fat, but it has limitation in differentiating body fat from lean (fat free) mass and low-moderate sensitivity is problematic for clinical applications. Among overweight children higher BMI levels can be a result of increased either fat or fat-free mass. BMI could be divided into fat-free mass index and fat mass index. Monitoring of the changes in body composition is important as distinguishing changes in each component occur with rapid growth in adolescents as it is occur in concert with changes in the hormonal environment. Reference values for each body composition indexes and chart created with selected percentiles of a normal adolescent population could be helpful in growth assessment and health risk evaluation.

Keywords: Growth, Obesity, Body mass index, Body composition, child

Introduction

The obesity prevalence in children and adolescents has been increased along with the change of socioeconomic environment and pattern of lifestyle¹⁻³. Obesity in children was assumed to be associated with the risk of adult obesity and the other diseases, such as type 2 diabetes mellitus or cardiovascular diseases. Body mass index (BMI) has been considered as an indicator of body fatness and widely used as a screening method of obesity as it is well known index to predict fatness and health risk assessment. Elevated BMI in childhood is related to adult obesity⁴ and high risk of various disease such as diabetes, atherosclerosis and total mortality^{5,6}.

What is BMI and weight for height

It is important to understand what BMI is and its limitations in clinical practice and public health research, especially in children and adolescent. Although BMI has the advantage of a noninvasive and simple surrogate of body fat, it has limitation in differentiating body fat from lean mass. BMI calculated as weight in kilograms divided by the square of height in meters (kg/m^2), is a measure of weight adjusted for height, as the scaling of body weight to height across adults provides powers rounded to 2⁷⁻⁹.

Certain conditions can influence the interpretation of BMI such as athletes, may have a high

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BMI because of increased muscle mass. Changing relationship between height and weight with age complicated the situation. Women have high percent body fat than men with an similar BMI, older adults tend to have more fat than younger adults for an similar BMI^{10,11}.

For children, BMI is calculated the same way as in adult, but the results of BMI are interpreted differently, should be relative to a child's age and gender. As other factors such as height difference and level of secondary sexual maturation, the relationship between BMI and body fat among children and body fat amount changes with age and varies by gender. BMI rises rapidly from birth to age 2 years then declines until age 5-6 years. After adiposity rebound—when BMI increase again, it increases throughout childhood and adolescence.

BMI for age and growth chart references

BMI for age is the indicator for relative position of the child's BMI value among children of the same age and gender. Percentiles specific to age and sex classify underweight (<5th percentile), healthy weight (5th to <85th percentile), overweight (85th to <95th percentile), and obesity (\geq 95th percentile) in children.

It has also been recommended that children with a BMI for age at or above the 95th percentile be referred for an in-depth medical assessment with a BMI for age at or above the 85th percentile, has been suggested to be referred if there is a family history of obesity or weight-related medical problems, such as high blood pressure, hyperlipidemia, or rapid and marked increase in BMI¹².

Body weight and height are commonly recorded and have been combined as indices. BMI founded on two basic assumptions, first, weight scales to height with a power of approximately 2, and second, fat mass (FM) and fat-free mass (FFM) scale in the similar way as the weight. These assumptions are critical for children and adolescents. BMI is a measure of only excess weight not the excess body fat^{13,14}.

It is important to remember that the accuracy of childhood BMI varies substantially. Setting a definition of childhood obesity that have utility in a clinical practice is more challenging than in adults. Ideally, it should reflect body fatness accurately, and each cutoff points could predict adverse health outcome. The application of BMI contributes to its utility at the population level. Because BMI does not evaluate body fat directly, BMI should not be used as a diagnostic tool, and it should be considered as a reasonable screening tool to track weight in populations to identify potential weight problems in individuals^{11,15,16}.

Height and weight are important anthropometric measures variables in assessing nutritional status. Linear monitoring of the changes in height and weight is important as distinguish changes in each value occur during the adolescent period with hormonal changes.

Growth references and/or growth standards with gender and age specific percentiles and z-scores in anthropometric

measures have been widely used for assessing growth and nutritional status and obesity in children and adolescents. A growth reference is the distribution used for comparison while a growth standard suggests all children have the potential to achieve that level¹⁷. Each child's measurements can be transformed to z-scores with growth reference and can quantify the growth status of a child outside of the percentile ranges. In analysis and research, the use of z-scores is recommended and it can be used as a continuous variable.

Obesity screening with BMI for age

The childhood BMI accuracy as an indicator of adiposity increases with the degree of body fatness¹⁸⁻²⁰, and levels of adiposity among overweight children are more variable²¹. In other word, among obese children, BMI is a relatively good indicator of excess FM. However, among overweight children, elevated BMI levels can be a result of increased levels of either FM or FFM. Similarly, among relatively thin children, differences in BMI are often due to differences in FFM^{15,16,21,22}. A study focused on the ability of BMI with 85th to 94th percentiles to identify children with high body fat correctly²¹. They concluded that BMI is a screening test, not sufficient as a diagnostic test. Among children who had a BMI for age between the 85th and 94th percentiles, about one-half of these children had a moderate level of fatness, but 30% had a normal fatness and 20% had an elevated fatness. An overweight child could have a higher FM or FFM, and furthermore there is ethnical difference, in black children, the prevalence of normal levels of body fatness was higher²¹.

Low-moderate sensitivity as a marker of adiposity is a problem for public health applications such as surveillance of obesity, because large numbers of children with excess body fat will not identified²³. BMI, FM, body fat distribution, relation to various diseases and health risks of children requires additional studies.

Body composition and scaling to height

Weight can be divided into two components; FM+FFM²⁴. FFM is a major component and is the core of the human body²⁴⁻²⁶. FFM is the active metabolic compartment with strong correlation to physiological functions and energy metabolism²⁴. On the organ-tissue level, skeletal muscle, skeleton and organs are the major components of FFM and they are more stable than the amount of FM²⁴. Forbes expressed FFM, in kg, as the cube of height (H, in m); $FFM=10.3 \times H^{3.25,26}$

A study to examined the scaling of weight, FM, FFM, and bone mineral content (BMC) to height in adult population using National Health and Nutrition Examination Survey data concluded that in adult, weight and each body composition scale to height with variable age-adjusted powers that are sometimes outside the 95% confidence interval for a power of 2, but frequently round to 2 as the nearest integer⁹. Weight scaled to

height across race and gender groups; mean powers ranged from 2.11 to 2.48 in men and from 1.72 to 1.95 in women after adjustment for age. The range of height powers for FFM was similar to that observed for weight: from 1.86 in women to 2.32 in men. However, the range for FM was greater than for FFM, ranging from 1.51 in women to 2.98 in men. BMC showed the smallest range of powers among the compartments, from 2.07 in women to 2.41 in men. Although bone mineral density also scaled significantly to height, all of the height power across race and gender was less than 1, ranging from 0.47 to 0.71. These observations have implications for developing height-adjusted body composition indexes⁹.

A comprehensive study of FFM scaling to height with subjects across most of the life span aged from 5 to 59 years, reported that height is the most important factor contributing to the FFM, and nonlinear regression models were fitted; $FFM=10.8 \times H^{2.95}$ for males and $FFM=10.1 \times H^{2.90}$ for females²⁷. Tall individuals tend to have larger FFM regardless of the influence of gender and population ancestry²⁷. Unlike the FFM, FM scales less consistently to height, and it is consistent with the plasticity of fat as an energy storage component that varies widely in mass with nutritional status²⁷. Thus it potentially obscures BMI and body composition associations with height.

Linear growth, growth velocity and pubertal development are key biomarkers of health status during childhood and adolescence, and are varies according to a variety of factors including age, sex, pubertal development, nutrition, and psychosocial status. Acceleration or deceleration of growth may result from chronic illness, or endocrine dysfunction. There is difference according to ethnicity, for example, African American girls experienced earlier pubertal onset and had greater height velocity at younger ages compared to non-African American girls²⁸.

Like weight, BMI could be expressed into two components; $BMI=fat\text{-free mass index (FFMI)}+fat\text{ mass index (FMI)}$ ²⁹. A normal increase in BMI with marked growth in height and weight is observed in both genders during puberty. The BMI increase consisted of a greater increase in FFM than in FM during growth^{15,30,31}, and FFMI was the major component of BMI (3–5 times greater in FFMI than FMI) in both genders, FMI increased only at higher BMI³².

Application of body composition indices

Puberty is a critical period of rapid physical growth with metabolic, hormonal, and body composition changes, which can influence risk factors for chronic diseases later life. The body composition modification during puberty is sexually dimorphic³³. In normal weight children, total FM increases in both sex, fat percent increases in girls and decreases in boy because of a dramatic increase in FFM in boys. Their FM contributes proportionally less to body weight in boys³⁴. Sexual dimorphism in fat patterning is apparent even in prepuberty, and the difference of the sex is magnified with maturation particularly in late puberty³⁵.

In predicting metabolic syndrome, FFM showed an independent role, however most of the reports have presented reference values for FMI and FFMI are dealing of BMI and percent body fat (PBF) in the adolescents³⁶⁻⁴⁰.

Much more children at risk of obesity related diseases cannot be detected when clinicians use only BMI percentile at a screening, especially in Asians. Asians has higher PBF at a lower BMI⁴¹ and in Asians, higher body fat percentiles was shown to be associated with insulin resistance⁴².

Reference values for BMI and body composition indexed (FMI, FFMI, PBF) of a Korean adolescents aged 10 to 19 years from the KNHANES (Korea National Health and Nutrition Examination Surveys) data were identified⁴³. These percentile values of each index, according to age and gender and charts created with selected percentiles might be helpful for evaluating distribution of body composition in adolescents. During the adolescent period (between the ages of 10 and 19 years), accompanying growth, BMI and FFMI increased in both genders. Korean boys experience greater gains in FFM than in FM. Despite increases in BMI, FMI and PBF decreased and FFMI increased markedly in males, whereas certain increase in FMI was observed in females⁴³. The different relationship in changes in FMI by gender started around 13 years of age⁴³ was consistent with the previous study, that the differences in relationship of FMI and FFMI between genders became remarkable with acceleration of FFM gain in 6th grade school boys in Korea⁴⁴.

The proper accretion of body composition during the adolescent period is necessary to prevent obesity and reduce the risk of associated disease. Extremely low FFMI reflects advanced metabolic disease, and lower FFMI combined with higher FMI could indicate insufficient insulin secretion in diabetes^{45,46}. It was suggested that the combined use of lower FFMI and higher FMI with reference percentile values for body composition indices in evaluating obesity could reflect metabolic dysregulation, as it could be an increase in the absolute value of FMI, especially in adolescence^{43,46}.

Conclusions

The healthy growth and proper accretion of body composition during the adolescent period is important to reduce the risk of metabolic disease and obesity prevention. Monitoring of the changes in growth in terms of body composition is important as distinguish changes in each body composition component occur with rapid growth during the adolescent period with changes in the hormonal milieu. Reference values for each body composition indexed (FMI, FFMI, PBF) and chart created with selected percentiles of a normal Korean adolescents might be helpful in growth assessment and obesity related risk evaluation. Further studies to elucidate the relationship among BMI, body fatness, fat distribution, and various diseases and health risks in children and adolescents should be followed.

Conflict of interest

No potential conflict of interest relevant to this article was reported.

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