

[Original]

## Body fat estimation in children by body mass index (BMI)

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### Abstract

The body mass index (BMI) of adiposity should indicate the relative fatness of subjects of differing heights unless obesity is itself correlated with height. The practical advantages of BMI as a measure of obesity are obvious. Both body weight and height are easily and accurately measured with simple equipment. We have a weight-height database that is much larger than for any other index of obesity. BMI has been underrated as a measure of obesity in children. It is very easy to apply BMI to subjects with any degree of obesity, and it provides a measure of fatness not much less accurate than specialized laboratory methods.

The purpose of this study was to determine the prediction equation for fat mass (FM, *kg*) determination in children using the regression of the fat mass index ( $FM/Ht^2$ ; FMI,  $kg/m^2$ ) on BMI ( $Wt/Ht^2$ ,  $kg/m^2$ ). Two hundred thirty-three children (98 boys and 135 girls) with ages ranging between 2.4 and 5.1 years participated in this study. Height and weight were measured in the standard fashion, and BMI was calculated from these values. FM was determined by gender-specific formulas, according to Lohman, involving weight and skinfolds, by bioelectrical impedance analysis (BIA) based on body density and underwater measurements of specific gravity, according to Houtkooper *et al.*, and by BIA based on total body water (TBW) measured from deuterium oxide ( $D_2O$ ) dilution, according to Masuda *et al.* The average of the FM determined by these three methods was taken to be the 'true' value for each individual.

Regression of FMI on BMI gave a correlation coefficient of 0.744 for boys and 0.865 for girls. Multiplying both sides of these regression equations by  $Ht^2$  gives:

$$FM, \text{ boys (kg)} = (0.408 \text{ BMI} - 3.937) Ht^2$$

$$FM, \text{ girls (kg)} = (0.462 \text{ BMI} - 4.432) Ht^2.$$

The deviation of the FM estimated from the BMI' formula from the 'true' value was not much greater than that occurring when skinfolds and BIA based on body density or total body water were used as a basis for estimating FM. It is concluded that the BMI' formula is both a convenient and reliable indicator of FM in children.

**KEY WORDS :** body mass index, fat mass, fat-mass index, children; skinfold measurements, bioelectrical impedance

### Introduction

Obesity in children and adolescents has become an increasing clinical and public health concern. Obesity is the result of excess adipose tissue. Unfortunately, the accurate measurement of total fat mass requires sophisticated and often expensive methods that have limited applicability in the clinical setting. The most

commonly used measure of body composition is the body mass index (BMI), which is body weight (*kg*) divided by height (*m*) squared. This measure was first described by the mathematician Lambert Adolphe Jacques Quetelet<sup>1)</sup>, BMI is a name given later by Keys *et al.*<sup>2)</sup>. There are well-known limitations regarding the use of BMI. For example, BMI is generally defined in adults as an index of obesity that is largely

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independent of height; however, this property of BMI in adults does not necessarily hold true in children.<sup>3)</sup> Also, despite high correlations between BMI and total body fat mass (FM) and between BMI and percent body fat (%FM),<sup>4-7)</sup> BMI is also correlated with fat-free mass (FFM).<sup>3)</sup> In children, these relationships between BMI and the FM and between BMI and the FFM of the body are further complicated by varying growth rates and maturity levels.<sup>3,8)</sup> BMI levels among adults are highly correlated with %FM.<sup>9-12)</sup> However, associations among children and adolescents have been more variable, and relatively weak correlations have been reported in several subgroups.<sup>13-18)</sup> These weaker associations among children and adolescents may be attributable to the asynchronous changes that occur in the levels of FM and FFM during growth. On the other hand, the major shortcoming of BMI is that the actual composition of the body mass is not taken into account: excess body mass may be made up either of adipose tissue or muscle hypertrophy, both of which will be judged as 'excess mass'. To resolve these issues, BMI can be separated into two indices according to FFM and FM. These two indices, known as the fat-free mass index (FFMI; FFM,  $kg/m^2$ ) and fat mass index (FMI; FM,  $kg/m^2$ )<sup>19)</sup> are both discrete and adjusted for height. The potential advantage is that only one component of body mass, i.e., FFM or FM, is related to the height squared. Considering that BMI is the sum of FFMI + FMI, an increase (or a decrease) in BMI can be traced to a rise (or a drop) in one or the other component, or in both. Furthermore, the BMI levels were more strongly associated with FMI ( $r=0.93-0.97$ ) in children and adults.<sup>20,21)</sup>

The purpose of this study was to determine a prediction equation for FM ( $kg$ ) in children using the relationship between FMI and BMI.

## Method

Data from 233 healthy children ranging from 2.4 to 5.1 years of age, including 98 boys and 135 girls selected from the ongoing FUKUOKA Body Composition Study (FBCS), were used for these analyses. The procedures were explained to all parents. All parents gave their informed consent.

Anthropometric data were assessed for the height and weight of the children. Height was measured to the nearest 0.1  $cm$  and weight was measured to the nearest 0.5  $kg$  on a calibrated balance-beam scale with subjects wearing light underwear. All anthropometric measurements were performed by trained observers, according to standard techniques.

Skinfold thickness was determined to the nearest 0.2  $mm$  at the right biceps, triceps, subscapular and suprailiac sites, with a Harpenden skinfold caliper calibrated to exert a constant pressure of 10  $g/mm^2$ . Fat mass (FM) was determined by the age- and gender-specific formulas according to Lohmann.<sup>21)</sup> These involve weight and the log-transformed sum of biceps, triceps, subscapular and suprailiac skinfolds for subjects.

$FM (kg) = \text{weight} * ((5.28/D) - 4.86)$ , where ( $D$ =body density).

$D$ , boys ( $g/ml$ ) =  $1.1690 - 0.0788 * (\log (\text{sum of four skinfolds}))$

$D$ , girls ( $g/ml$ ) =  $1.2063 - 0.0999 * (\log (\text{sum of four skinfolds}))$

Fat free mass (FFM) was calculated as the difference between weight and FM.

Measurement of whole-body bioimpedance in children has been described previously.<sup>22)</sup> The bioelectrical impedance analysis (BIA) measurements presented here were performed at a single frequency (50 kHz) (TP-95K, Toyo Physical, Fukuoka, Japan) with one pair of electrodes appropriately placed on the dorsal surfaces of the right hand and a second pair of electrodes placed on the right foot.<sup>23)</sup> With the subjects lying in a supine position, measurements were performed while the hands and feet were extended from the side of the trunk.

The equation used for children was based on body density and underwater measurements of specific gravity, as reported by Houtkooper *et al.*<sup>24)</sup> The equation provides an estimate of percent body fat mass (%FM) as follows:

$$\%FM = (-1.11) * ht^2 / R + 1.04 * wt + 15.16,$$

where  $ht$  is the height ( $cm$ ),  $wt$  is the body weight ( $kg$ ), and  $R$  is the body's resistance ( $\Omega$ ). FFM is then calculated as the difference between body weight and FM.

The equation used for children was based on total body water (TBW) as determined by the deuterium oxide (D<sub>2</sub>O) dilution technique<sup>25)</sup> and BIA measurement as previously described.<sup>26)</sup> The equation provides an estimate of TBW (kg) as follows:

$$\text{TBW (kg)} = 0.149 \cdot (\text{ht}^2/\text{R}) + 0.244 \cdot \text{wt} + 0.460 \cdot \text{age} + 0.501 \cdot \text{sex} \text{ (boy}=1, \text{ girl}=0) + 1.628.$$

FFM is then given by TBW/hydration of FFM.<sup>27)</sup> FM was calculated as the difference between wt and FFM.

Thus each individual had 3 estimates of FM:

FM (S)=FM derived from measurements of skinfold thickness

FM (D-BIA)= FM derived from a measurement of density and BIA

FM (W-BIA)= FM derived from a measurement of TBW and BIA

The average of the estimates made by these three methods was taken to be the 'true' value for each individual (FM, kg).

Body mass index (BMI) was calculated as wt (kg)/ht (m<sup>2</sup>). Similar to the standardization of weight for height<sup>2</sup> in BMI, we standardized the two components of weight, FM and FFM, for height<sup>2</sup>. These are FM/ht<sup>2</sup> (kg/m<sup>2</sup>) and FFM/ht<sup>2</sup> (kg/m<sup>2</sup>); that is, BMI = wt/ht<sup>2</sup> = (FM + FFM) / ht<sup>2</sup> = FM/ht<sup>2</sup> + FFM/ht<sup>2</sup>.

## Statistical analysis

All statistical analyses (calculation of correlation and regression analyses, statistics) were performed using StatView, version J-5.0. The data are presented as mean values and standard deviation. One-way analysis of variance (ANOVA) was used to test for differences between gender groups. In addition to the standard procedure, for the assessment of agreement between a new method and the traditional method, a Bland and Altman plot<sup>28)</sup> was used to compare the difference between the two methods with the mean values.

## Results

There were 233 subjects, 98 boys and 135 girls. Both boys and girls were similar in mean age, height, body weight and BMI. The girls in the sample had

greater sums of the four skinfolds ( $p < 0.001$ ) than the boys (Table 1).

Table 1. Characteristics of the children

	Mean $\pm$ sd (range)	
	Boys (n=98)	Girls (n=135)
Age (years)	3.9 $\pm$ 0.7 (2.4 - 5.1)	3.9 $\pm$ 0.7 (2.4 - 5.1)
Height (cm)	99.0 $\pm$ 6.6 (82.3 - 115.0)	98.2 $\pm$ 5.8 (83.6 - 112.0)
Weight (kg)	15.23 $\pm$ 2.09 (10.10 - 20.60)	15.03 $\pm$ 2.07 (10.58 - 21.25)
BMI (kg/m <sup>2</sup> )	15.5 $\pm$ 0.9 (13.5 - 17.4)	15.6 $\pm$ 1.1 (13.5 - 18.3)
Sum of four skinfolds (mm)	29.9 $\pm$ 5.5 (20.8 - 43.9)	34.5 $\pm$ 7.7 (18.9 - 56.2)***

BMI=body mass index; Sum of four skinfolds=biceps+suprailiacal+subscapular kinfold thickness; Gender differences were analysed by ANOVA;\*\*\* $p < 0.001$ .

The mean values for estimates of FM by the three methods are set out in Table 2. The FM tended to be greater in girls, while %FM calculated from TBW measurements and BIA were increased in girls.

Table 2. Estimates of body fat in children by methods based on skinfold thickness(FM-S), bioelectrical impedance analysis(FM-BIA), total body water(TBW)from deuterium oxide dilution method and BIA(FM-TBW).

	Body fat mean $\pm$ sd (range)	
	Boys (n=98)	Girls (n=135)
FM-S (%)	15.3 $\pm$ 3.0 (9.7 - 21.9)	15.8 $\pm$ 4.2 (6.9 - 25.9)
FM-S (kg)	2.34 $\pm$ 0.61 (1.34 - 3.91)	2.41 $\pm$ 0.84 (0.73 - 5.27)
FM-BIA (%)	14.9 $\pm$ 1.7 (10.4 - 18.3)	15.7 $\pm$ 1.5 (11.0 - 19.1)***
FM-BIA (kg)	2.26 $\pm$ 0.33 (1.57 - 3.23)	2.35 $\pm$ 0.35 (1.40 - 3.49)
FM-TBW (%)	16.1 $\pm$ 4.4 (3.4 - 24.1)	21.2 $\pm$ 3.9 (9.0 - 31.1)***
FM-TBW(kg)	2.49 $\pm$ 0.86 (0.41 - 4.21)	3.22 $\pm$ 0.88 (1.01 - 5.68)***

Gender differences were analysed by ANOVA;\*\*\* $p < 0.001$ .

As shown in Table 3, in both genders significant relationships ( $p < 0.001$ ) were observed between the FM values derived using skinfold (S), D-BIA, and W-BIA on the one hand and the value derived from the mean of the three methods on the other.

Table 3. Pearson correlation analysis between FM-S, FM-BIA, and FM-TBW and the value derived from the mean of the three methods (FM). (column heads boys, row heads girls)

	FM-S	FM-BIA	FM-TBW	FM
FM-S	-	.775	.774	.907
FM-BIA	.774	-	.889	.928
FM-TBW	.776	.910	-	.963
FM	.925	.928	.953	-

The correlation of BMI with height, body weight, FM, and %FM by gender is presented in Table 4. There were no statistically significant differences between BMI and height in either gender. BMI was significantly and positively correlated with body weight, FM, and %FM in each gender group.

Table 4. Correlation coefficients between body mass index (BMI) and height, weight, fat mass (FM), and percentage of fat (%FM).

	Height	Weight	FM	%FM
Boys	.122	.297*	.587***	.615***
Girls	.022	.485***	.741***	.716***

Significant different from zero; \* $p < 0.05$ . \*\*\* $p < 0.001$

There was a significant linear correlation between FMI and BMI in both boys ( $r = 0.744$ ,  $p < 0.001$ ) and girls ( $r = 0.865$ ,  $p < 0.001$ ) (Figure 1). Regression of  $FM/Ht^2$  on  $Wt/Ht^2$  (BMI) yielded lines with relatively similar slopes of 0.408 for boys and 0.462 for girls.

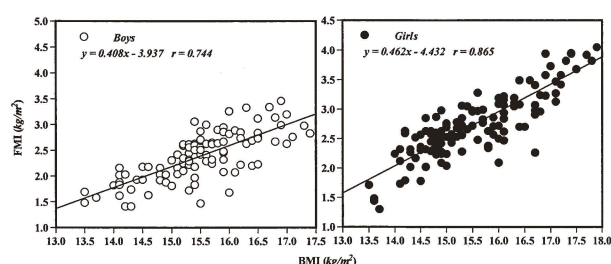


Figure 1. Correlation between BMI and fat-free mass index (FMI) in children aged 2.4-5.1 y. Boys ( $p < 0.001$ ) and girls ( $p < 0.001$ )

The mean values of the estimates of body fat (FM, kg) based on BMI and the values derived from the mean skinfolds (S), D-BIA, and W-BIA are set out in Table 5. The mean values of the FM estimates based on BMI were very similar to the mean values of the estimates of the three methods (2.34 vs. 2.36 for boys and 2.66 vs. 2.66 for girls). The mean differences between the FM based on BMI and the FM obtained as the mean value of these three methods were 0.023 kg for boys and -0.001 kg for girls.

Table 5. Estimates of body fat in children by equation based on body mass index (FM-BMI). The difference is expressed as a deviation from the value derived from three methods (FM).

	Boys (n=98)	Girls (n=135)
FM-BMI (kg)	2.34 ± 0.45	2.66 ± 0.58
FM (kg)	2.36 ± 0.56	2.66 ± 0.64
Deviation from FM (kg)	0.023 ± 0.303	-0.001 ± 0.276

Figure 2 shows the difference between the FM based on BMI and the FM obtained using the mean values of these three methods plotted against the their means of these differences. The limits of agreement (-2 to +2 SD of the difference) were -0.58 to +0.63 kg for boys and -0.55 to +0.55 kg for girls.

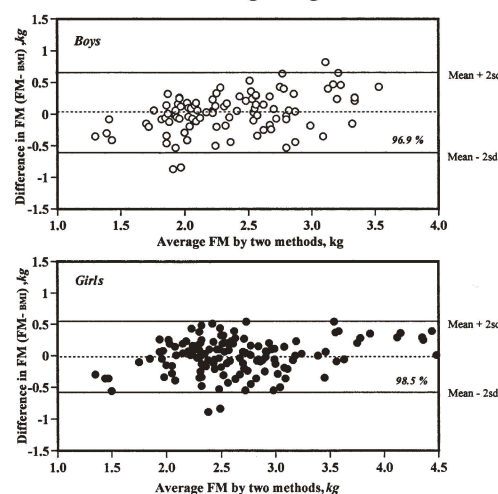


Figure 2. Difference against mean for FM data.

## Discussion

BMI has been recommended as an appropriate measure of adiposity for use in the clinical setting. It is an attractive measure because it is relatively easy to obtain in a variety of settings and is reliable. The main criticism made of BMI as a measure of adiposity is that this index should be totally independent of height.<sup>29</sup> The present study found that the correlations between BMI and height were generally not as high as the correlations between BMI and both FM and %FM (for boys,  $r = 0.122$ ; for girls,  $r = 0.022$ ). On the other hand, several studies have reported a good correlation between BMI and fatness in childhood.<sup>7, 16, 30</sup> The sex-specific correlations of BMI with FM and %FM were moderate ( $r = 0.587 - r = 0.741$ ,  $p < 0.001$ ) in the present study. The strength of the associations



between BMI and both FM and %FM indicates that BMI is a suitable measure of adiposity.

The purpose of the present study was to establish a reasonable prediction equation with which to estimate FM from BMI in children. The major shortcoming of BMI is that the actual composition of body mass is not taken into account. However, BMI represents an index of weight that has been normalized for height. Once weight has been normalized in this way, it can be divided into FFM and FM:

$$\text{BMI} = \text{Wt} / \text{Ht}^2 = \text{FFM} / \text{Ht}^2 + \text{FM} / \text{Ht}^2$$

These two indices have been termed the fat-free mass index (FFMI) and fat-mass index (FMI), respectively.<sup>19)</sup> BMI was strongly associated with FMI.

In this study, regression of FM/Ht<sup>2</sup> (FMI) on Wt/Ht<sup>2</sup> (BMI) among boys gave the formula: FM/Ht<sup>2</sup> = 0.408Wt/Ht<sup>2</sup> - 3.937, with a correlation coefficient of 0.744. A similar analysis of the data for girls gives: FM/Ht<sup>2</sup> = 0.462Wt/Ht<sup>2</sup> - 4.432, with a correlation coefficient of 0.865. Multiplying both sides of these equations by Ht<sup>2</sup> gives:

$$\text{FM} = (0.408\text{Wt}/\text{Ht}^2 - 3.937) \text{Ht}^2, \text{ for boys}$$

$$\text{FM} = (0.462\text{Wt}/\text{Ht}^2 - 4.432) \text{Ht}^2, \text{ for girls.}$$

A high correlation and a small difference were found between FM as determined using BMI and the average of the FM values determined by three methods, which was taken to be the 'true' value for each individual. This equation is very easy to apply to children with any degree of obesity, and provides an estimate of FM that is not much less accurate than that obtained by specialized laboratory methods.

It is concluded that the BMI formula is both a convenient and reliable indicator of body fat mass in children.

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