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— ORIGINAL —

The relationships between stature, fat-free mass index, and fat mass index at before and after BMI-rebound in children

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Abstract

OBJECTIVE: The beginning of the post-infancy rise in the body mass index (BMI, kg/m^2) has been termed the BMI-rebound (or adiposity rebound), and the fat-free mass index (FFMI=fat-free mass/stature^2, kg/m^2) and fat mass index (FMI=fat mass/stature^2, kg/m^2) are concepts comparable to that of BMI. We examined whether the relation of stature to FFMI and FMI, respectively, is independent of childhood BMI-rebound.

DESIGN: Cross-sectional study.

SUBJECTS: A total of 752 apparently healthy children in Japan (337 boys and 415 girls), varying in age from 3 to 8 yrs.

MEASUREMENTS AND METHODS: Stature and body mass were measured, and body composition was assessed by bioelectrical impedance analysis (BIA). Fat-free mass (FFM) and fat mass (FM) were both adjusted for stature to give FFMI and FMI.

RESULTS: The relationship between BMI and %FM was linear for boys (r=0.610; p<0.0001) and girls (r=0.596; p<0.001) at ages 3-8 yrs. In both sexes, levels of BMI tended to dip slightly with increasing age from 3 to 5 yrs, at which it reached a nadir, then rose steadily with age, by 1.4 kg/m^2 from 5 to 8 yrs. There were no significant correlations between stature and FFMI and FMI in the 3-5 yrs age group, but there were significant correlations in the 6-8 yrs age group (0.347 for boys and 0.276 for girls, and 0.377 for boys and 0.406 for girls, respectively).

CONCLUSION: The convenience with which BMI can be measured has understandably made it popular with both pediatric clinicians and epidemiologists, despite awareness of its shortcomings. However, the present study has demonstrated that the relationships between stature and FFMI and FMI, respectively, are reasonably sound after the age of 5. This implies that the BMI offers a reasonable measure of fatness in early childhood (~5yrs), but the BMI-rebound is not necessarily equivalent to an increase in fatness. Caution should therefore be used in generalizing from the findings in this study, and further investigation of the issue are required.

Key words: Children, body mass index, body composition, impedance analysis, fat-free mass index, fat mass index

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Introduction

The prevalence of being overweight and obese is increasing worldwide. Furthermore, children who are obese tend to be obese as adolescents[1)2)] and young adults[3-5)]. Obesity is an excess of body fat, not an excess of body mass. Therefore, obesity is the amount of fat in the body, expressed either as total fat mass (in kg) or as the fraction (percentage) of total body fat. However, body fat is extremely difficult to measure in young children, because accurate techniques require a high degree of subject compliance and are usually only available to specialized research institutions.

On the other hand, attention has focused primarily on the methods by which body composition data are obtained, and less on the way in which the data is expressed. Clinically, the presence of obesity is frequently assessed through one of the commonly used body mass indices. These indices are defined as different combinations of body mass and height, such as body mass divided by stature, weight divided by stature squared (body mass index; BMI), and body mass expressed as a percentage of mean body mass for a given stature and sex. The majority of large-scale studies reporting increasing obesity in children have used BMI (in kg/m^2) as the index of body fatness, and BMI has been recommended as the best measurement for monitoring obesity in individuals in the pediatric population.[6)7)] The advantage of using BMI is that stature and body mass are variables readily available and easy to measure.

The BMI is widely used as a measure of relative body mass among adults, and its use among children and adolescents is rapidly gaining acceptance.[8)] Mean BMI levels increase rapidly during the first year of life, subsequently decrease, and reach a nadir at 4-6 yrs of age. Levels subsequently increase, and reach values of 20-25 kg/m^2 by adulthood. The beginning of this second rise in BMI has been termed the 'BMI-rebound' or 'adiposity rebound'.[9)] Individuals in whom the second rise in BMI (adiposity rebound) occurs comparatively early have been found to be heavier as adults than are individuals in whom this rebound occurs relatively later.[10-13)]

Theoretically, BMI represents an index of body mass independent of stature, such that at any age, greater relative body mass may be attributed to increased body fatness. However, the major shortcoming of the BMI is that the actual composition of body mass is not taken into account because BMI does not measure fat directly. Although studies have reported high correlations between BMI and percentage body fat (%FM)[14)15)], the relationship between BMI and fatness in childhood has received insufficient attention. Children having the same body mass but at different stages of stature can have widely different levels of adiposity. BMI adjusts for stature by using the square power. Although the adjustment for stature does not completely eliminate the stature effect, it partially adjusts body mass for stature.[16)]

Body mass comprises both the fat-free mass (FFM) and the fat mass (FM), and both of these components can vary between individuals. Therefore, the excess body mass may be made up of adipose tissue or, conversely, of hypertrophic muscle. Although the BMI has attained growing popularity in the past few years, the two components of this index suggest possible limitations on its use. First, stature is one component, and the BMI may be stature dependent over at least part of the relevant age range. Second, the use of body mass as the numerator suggests that the BMI reflects both lean tissue and fat tissue to a comparable degree.[17)]

The %FM is influenced by the relative amount of fat-free tissue in body mass, and, like BMI[18)], is not an independent index of body fatness. The importance of this issue is demonstrated by the fact that, even in the general population, variability between subjects in relative fat-free size is two-thirds the variability in fatness.[18)] Likewise, obesity results in higher FFM and higher FM, and the expression of body fatness in obese children as %FM will both underestimate the absolute amount of FM gained and conceal the changes in FFM. To resolve this issue, both FFM and FM can be normalized for stature. One such approach is to adjust body mass for stature, then divide this adjusted body mass into its fat-free and fat components. These two indices have been termed the fat-free mass index (FFMI) and fat mass index (FMI), respectively. The original idea of calculating the FFMI and FMI in analogy to the BMI was proposed several years ago.[19] The potential advantage of this is that only one component of body mass, FFM or FM, is then related to the stature squared. The FFMI and FMI are concepts comparable to that of BMI, as illustrated by the following definition:

FFMI = fat-free mass/stature^2 (kg/m^2)

FMI = fat mass/stature^2 (kg/m^2).

Note that, mathematically, BMI (kg/m^2) = FFMI (kg/m^2) + FMI (kg/m^2).

The current study examined the BMI-rebound in Japanese children, and investigated whether the relationships of stature to FFMI and FMI, respectively, are independent of childhood BMI-rebound.

Subjects and methods

Subjects

Since 1998, we have been performing body composition analyses on normal, healthy children from the surrounding communities (Fukuoka Body Composition Study; FBCS). The cross-sectional data from 337 healthy Japanese boys and 415 healthy Japanese girls (3-8 years) were used for analysis. The subjects' physical characteristics are summarized in Table 1. The nature and purpose of the investigations were fully explained to each subject's parents before the study. The parents provided informed consent before testing began.

Table 1 Age, anthropometry and body composition of entire subjects

	Boys (N=337)		Girls (N=415)		Sex-difference
	Mean	SD	Mean	SD	
Age, yr	5.53	1.48	5.61	1.50	*ns*
Stature, cm	112.6	10.5	113.0	10.5	*ns*
Body mass, kg	20.37	5.27	20.07	5.13	*ns*
BMI, kg/m^2	15.8	1.6	15.5	1.7	$p<0.05$
FFM, kg	16.59	3.77	15.64	3.36	$p<0.001$
FM, kg	3.77	1.95	4.44	2.25	$p<0.001$
Percentage fat	18.0	4.9	21.4	5.4	$p<0.001$
FFMI, kg/m^2	12.9	1.0	12.1	1.0	$p<0.001$
FMI, kg/m^2	2.9	1.1	3.4	1.2	$p<0.001$
FFMI/BMI, %	82.1	5.0	78.5	5.4	$p<0.001$
FMI/BMI, %	17.9	5.0	21.5	5.4	$p<0.001$

Anthropometry

Body mass was measured with the subject in light clothing and without shoes on a scale to the nearest 0.02 kg using a balance beam metric scale, and was followed by measurement of stature to the nearest 0.1 cm via a fixed, wall-mounted metric ruler. BMI (body mass/stature^2) was calculated for all subjects.

Body composition

Given that bioelectrical impedance analysis (BIA) and total body water (TBW) data also show a very close correlation in 4- to 6-year-old children[20], we felt justified in taking BIA data as a measure of body composition in our subjects.

Measurement of whole-body bioimpedance in children is described elsewhere.[21] The BIA measurements presented here were performed at a single frequency (50 kHz: TP-95K, Toyo Physical, Fukuoka, Japan) with one pair of electrodes (Red Dot-2330, 3M Health Care, USA) placed on the dorsal surfaces of the right hand and a second pair of electrodes placed on the right foot. Bioelectrical impedance was measured in a standard manner while the subject was laying in a supine position on a flat and non-conductive bed. The arms were abducted slightly so that they did not touch the side of the trunk. The leg were separated so that the ankles were at least 20 cm apart and the thighs were not touching each other. The electrodes were attached in the standard manner to the dorsal surface of the hand and the anterior surface of the ipsilateral foot. One voltage-sensing electrode was attached to the wrist midway between the styloid processes; the other was attached to the ankle midway between the malleoli. The electrodes for introducing the current were attached to the foot and hand at least 5 cm distal to the sensing electrodes, on the third matatarso-phalangeal and third metacarpo-phalangeal joints, respectively. The skin was cleaned with 70% alcohol before attaching the electrodes. To minimize changes in impedance due to gravity-induced fluid shifts in the subjects, impedance measurements were taken within 5 min of lying down. Before each testing session, the calibration of the unit was checked using a 400-Ω precision resistor. Impedance measurements were taken for each subject after a minimum of 2-h following the most recent meal.

It is currently unclear whether age-specific equations should be used for assessing body composition from BIA. Kushner et al.[22] showed that the relationship between stature^2/resistance and TBW is robust across a wide age range, although uncertainty over the relationship in preschool children remains. Goran et al.[20] suggested that the Kushner equation for TBW can be transformed into an equation for FFM by using published age- and gender-specific constants for the hydration of FFM in children.[23] The FFM equation here in used for children is based on TBW and stature^2/resistance, as reported by Goran et al..[20] Total body fat mass (FM, kg) is then calculated as the difference between body mass and FFM.

Calculation of FFMI and FMI

Both FFM and FM were divided by stature^2, to give FFMI and FMI, respectively, as described previously .[19] FFMI and FMI were calculated for each subject, and the data were then subdivided according to values before and after BMI-rebound age. The correlations of FFMI and FMI with stature were then determined.

Statistical analyses

The curves of mean BMI evolution from 3 to 8 yrs in cross-sectional data were drawn, and the subjects were classified into two groups of boys and two groups of girls on the basis of age at BMI-rebound, which is the age corresponding to the lowest value of BMI (5yrs, Fig. 2). The before BMI-rebound group (3-5 age group) consisted of 181 boys and 221 girls, and the after BMI-rebound group (6-8 age group) consisted of 156 boys and 194 girls. The statistical analysis program StatView, version 4.5, was used for statistical analysis. Boys and girls were considered separately in recognition of known sex differences with regard to relative fat and lean deposition in childhood.[18][23] The results were expressed as mean and standard deviation. The differences between age groups were analyzed by unpaired t-test. The relationships between stature and FFMI and FMI, respectively, were investigated within each group by correlation analysis.

Results

Regression analysis was used to examine the bivariate relationship between measured %FM and BMI. Figure 1 shows the plot of the data obtained on boys and girls. An examination of these scattergrams suggested that the relationship between BMI and %FM was linear for boys (r=0.610; p<0.0001) and girls (r=0.596; p<0.001) at 3-8yrs of age.

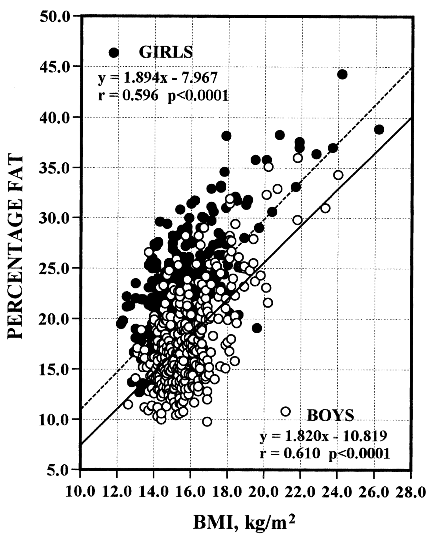


Fig. 1 The relationship between BMI and %FM

Figure 2 illustrates the evolution of BMI curves for the entire study sample. In both sexes, levels of BMI tended to dip slightly with increasing age from 3 to 5yrs, reached a nadir at 5yrs, then rose steadily with age by 1.4 kg/m^2 from 5 to 8yrs.

The changes in FFMI and FMI with age for each sex are given in Figure 3. The FFMI curves show a pattern similar to that of the BMI curves. The boys and girls show a decrease in FFMI between 3 and 5yrs. In contrast, the FFMI in the next age group (5-8yrs) increased. However, the graph indicates that boys have a consistently higher FFMI than girls throughout childhood. The FMI curves did not show a pattern similar to that of the BMI

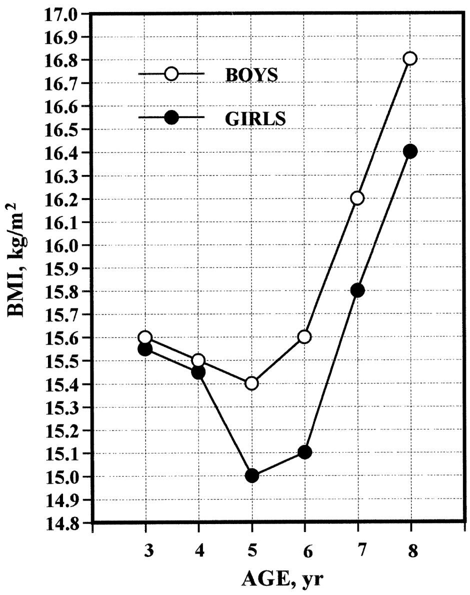
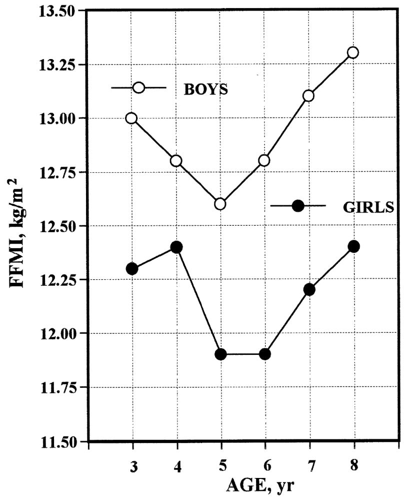


Fig. 2 Evolution of BMI curves for the entire sample in boys and girls

curves. The levels of FMI tended to remain unchanging with increasing age from 3 to 6yrs, then rose steadily with age from 6 to 8yrs. However, in contrast to the case for FFMI, girls showed a consistently higher FMI throughout childhood.

The entire study sample was classified into a 3-5 age group and a 6-8 age group according to BMI-rebound at 5yrs. Table 2 gives the descriptive statistics on the boy and girl subjects contrasted by age group. The data show well-documented anthropometric and body composition age differences. The 6-8 age group was taller, heavier, and fatter than the 3-5 age group. Unpaired t-test was used to evaluate age differences for each sex. This analysis showed that the age difference in FFMI in girls (12.1 kg/m^2) was not statistically significant. On the other hand, in both sexes, the FFMI/BMI (%) of the 6-8 age group was significantly lower than that of the 3-5 age group.



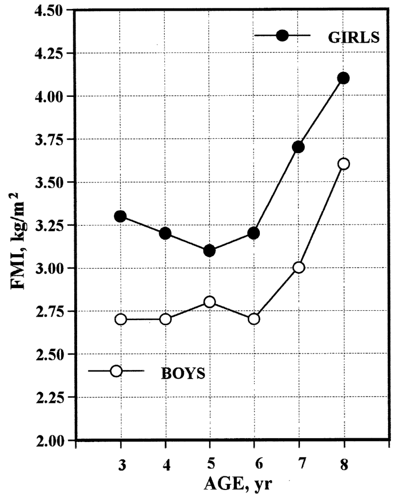


Fig. 3 Evolution of FFMI and FMI curves for the entire sample in boys and girls

Table 2 Age, anthropometry and body composition of subjects by age-group

	Boys (N=337)					Girls (N=415)				
	3–5 yr (n=181)		6–8 yr (n=156)		p	3–5 yr (n=221)		6–8 yr (n=194)		p
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Age, yr	4.37	0.70	6.88	0.90	***	4.40	0.69	6.98	0.87	***
Stature, cm	105.4	6.0	121.0	8.1	***	105.5	6.0	121.5	7.6	***
Body mass, kg	17.34	2.73	23.88	5.33	***	17.05	2.19	23.52	5.35	***
BMI, kg/m^2	15.5	1.3	16.1	1.9	***	15.3	1.2	15.8	2.1	**
FFM, kg	14.28	2.04	19.28	3.54	***	13.53	1.71	18.04	3.18	***
FM, kg	3.06	1.14	4.59	2.34	***	3.52	1.08	5.49	2.74	***
Percentage fat	17.4	4.4	18.6	5.4	*	20.5	4.8	22.5	5.8	***
FFMI, kg/m^2	12.8	0.9	13.1	1.1	**	12.1	0.9	12.1	1.1	ns
FMI, kg/m^2	2.7	0.9	3.1	1.3	**	3.2	0.9	3.6	1.5	***
FFMI/BMI, %	82.6	4.4	81.5	5.5	*	79.5	4.8	77.4	5.8	***
FMI/BMI, %	17.4	4.4	18.5	5.5	*	20.5	4.8	22.6	5.8	***

Significant differences between 3-5yr and 6-8yr: * p<0.05, **p<0.01, ***p<0.001

Table 3 Correlation coefficients (*r*) between BMI and anthropometric or body composition indices

	Boys			Girls		
	Entire sample (N=337)	3–5 yr (n=181)	6–8 yr (n=156)	Entire sample (N=415)	3–5 yr (n=221)	6–8 yr (n=194)
Stature	0.366***	0.179*	0.447***	0.247***	0.166*	0.430***
Body mass	0.724***	0.700***	0.838***	0.683***	0.474***	0.870***
FFM	0.601***	0.538***	0.706***	0.527***	0.230***	0.722***
FM	0.792***	0.715***	0.843***	0.769***	0.599***	0.861***
FFMI	0.765***	0.748***	0.771***	0.703***	0.652***	0.751***
FMI	0.768***	0.717***	0.785***	0.815***	0.700***	0.859***

Significant level: *$p<0.05$, ***$p<0.001$

Table 3 shows that the coefficients of correlation between BMI and stature, body mass, or body composition indices are high, and are significant for the two age groups in both sexes. However, the coefficients of correlation between BMI and stature are low in boys and girls under 5yrs.

Non-linear plots of the relationship between measured %FM and FMI in the two age groups are shown in Figure 4. This analysis showed that the test for coefficients of correlation between %FM and FMI in these two age groups were statistically significant in both sexes (0.965 for boys and 0.969 for girls; p<0.001).

Plots of FFMI against stature are given in Figure 5. There was no significant correlation between FFMI and stature in the 3-5 age group. Correlations of 0.347 and 0.276 (p<0.001) were observed in the 6-8 age group in boys and girls, respectively.

Figure 6 is scatter graph for FMI against stature. No significant correlation was found between the two variables in the 3-5 age group, whereas the two variables in the 6-8 age group showed clear correlations (0.377 in boys and 0.406 in girls; p<0.001).

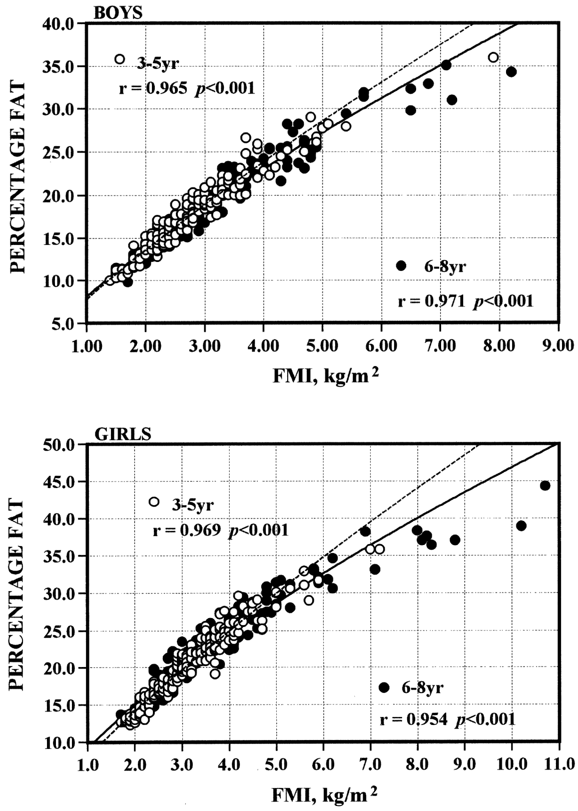


Fig. 4 The relationship between FMI and percentage fat

Discussion

Currently, the BMI has been proposed as a simple, accurate, and valid measure of fatness in childhood and adolescence that has potential for use worldwide.[24] The advantages of the BMI are that it is easy to compute, is relatively independent of stature[25], and correlates with other indices of fatness (Table 3).[26-28] Several studies have reported a good correlation between BMI and fatness in childhood.[14)15] In the present study, BMI-measured %FM correlations were slightly lower in the pediatric subjects (0.596-0.610; Fig. 1) than those of 0.60-0.82 reported previously in adult males and females.[29]

BMI curves in early life display three successive phases, with mean levels increasing rapidly in the first year of life, decreasing until about age 5 (Fig. 2), and subsequently increasing until early adulthood. Furthermore, BMI does not measure fat directly. However, BMI has been proposed as a simple and valid measure for monitoring fatness. In published studies, the tracking of BMI has emphasized correlations between childhood and

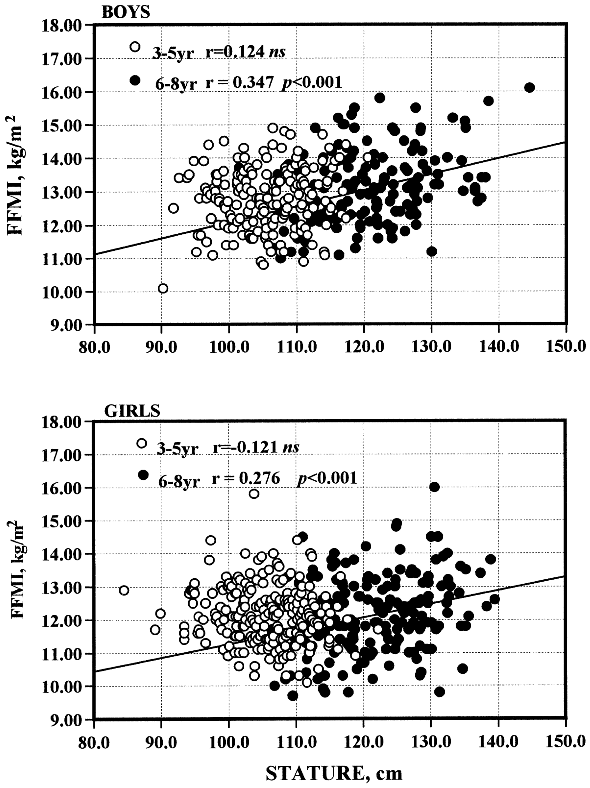


Fig. 5 The relationship between stature and fat-free mass index (FFMI)

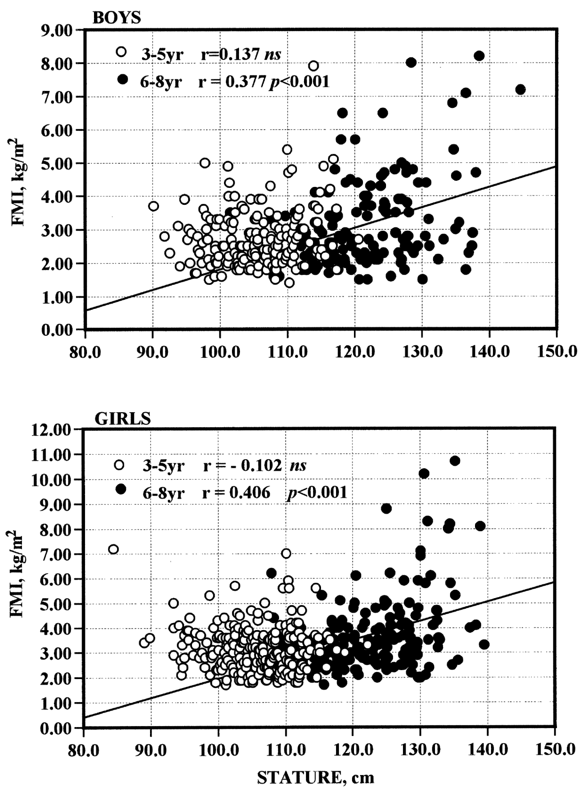


Fig. 6 The relationship between stature and fat mass index (FMI)

adulthood values. BMI values during adulthood are largely independent of values during infancy, but are related to BMI at ~6yrs of age.[30] The beginning of the post-infancy rise in the BMI has been termed the BMI-rebound, and several studies have found that an early rebound increases the risk for obesity in adulthood.

Body mass is comprised of the FFM and the FM. Traditionally, FM has been normalized by being expressed as a percentage of body mass, whereas FFM tends to be expressed in absolute units unadjusted for body size.[31] The %FM is influenced by the relative amount of FFM in body mass. To make informative comparisons of children's body composition, normalization for body size is required. Appropriate normalization is particularly important in research on childhood obesity. The difficulty of normalizing body mass and fatness for body size is a well-recognized problem. Although this issue has been considered in detail for adults[19,27,32] less attention has been paid to pediatric subjects, despite the confounding effects of growth.

BMI is widely accepted as an index of body mass that has minimal correlation with stature throughout the period of childhood and adolescence.[33,34] Hence, via the approach of Van Itallie et al.[19], separate indices for FFM and FM may be derived by dividing these variables by stature^2. Considering that BMI is the sum of FFMI+FMI, an increase (or a decrease) in BMI could be accounted for by a rise (or a drop) in one or both components. Note that, for a given BMI, if FFMI increases then FMI should decrease, since, at a constant BMI, there is an inverse mathematical relationship between the two. Therefore, the advantage of using these indices in combination is that one can judge whether the deficit or excess of body mass is selectively due to a change in FFM *vs* FM or a combination of them. One advantage of FMI, as compared to BMI, is that the former amplifies the relative effect of aging on body fat. Despite an awareness that various factors influence the BMI-fatness relationship, the specific contribution of FFM to BMI has been generally ignored.

The general increase in BMI from mid-childhood has been termed the 'BMI-rebound'[9], and between 5 and 10yrs of age the increase in BMI cannot be attributed to increasing fatness.[18] Up to now, however, the relationships of stature to FFMI and FMI, respectively, between before and after BMI-rebound have not been clearly defined in apparently healthy Japanese children. The significant correlation between BMI and %FM (Fig. 1) gives the impression that BMI is a good index of fatness. Nevertheless, such a correlation does not represent the best approach for assessing this proposition. Our findings have important implications for the normalization of children's body composition data; they show that there is a significant difference in the relationship between body composition and stature between before and after BMI-rebound. Namely, there were no significant correlations between stature and FFMI or FMI in the 3-5 age groups, and there were significant correlations in the 6-8 age groups of boys and girls, respectively (Fig. 5 and 6). This implies that neither BMI nor %FM is independent of relative lean size after the age of 5 .

The convenience with which BMI can be measured has understandably made it popular, despite its known shortcomings, with both pediatric clinicians and epidemiologists. However, the present study has demonstrated that the relationships of stature to FFMI and FMI, respectively, are somewhat sound after the age of 5. This implies that the BMI offers a reasonable measure of fatness in early childhood, but the BMI-rebound is not necessarily indicative of increasing fatness.

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