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A Hattori chart analysis of body mass index in infants and children

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BACKGROUND: Body mass index (BMI) is widely used as an index of fatness in paediatrics, but previous analysis of the BMI–fatness relationship has been insufficient.
OBJECTIVE: To consider the effects of variation in fat-free mass (FFM) and fat mass (FM) on BMI in infants, children and Fomon's reference child (*Am J Clin Nutr* 1982; 35: 1169–1175).
SUBJECTS: 42 infants aged 12 weeks; 64 children aged 8–12 y; Fomon's reference child.
METHODS: FFM was measured by deuterium dilution. FFM index (FFMI) and FM index (FMI) were calculated. The effects of variation in FFM and FM on BMI were explored using Hattori's body composition chart (*Am J Hum Biol* 1997; 9: 573–578).
RESULTS: In both infancy and childhood, a given BMI can embrace a wide range of percentage body fat. At both time points, the s.d. of FFMI was $>$60% of the s.d. of FMI. Graphic analysis differentiated the effects of lean tissue and fat deposition on BMI with age in the reference child.
CONCLUSION: Although valuable for assessing short-term changes in nutritional status in individuals, and for comparing mean relative weight between populations, BMI is of limited use as a measure of body fatness in individuals in both infancy and childhood. The development of BMI with age may be disproportionately due to either FFM and FM at different time points.
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Introduction

Body fatness is extremely difficult to measure in infants and young children, because accurate techniques require a high degree of subject compliance and are usually only available to specialized research institutions. Despite the use of techniques such as dual-energy X-ray absorptiometry,[1] stable isotope dilution,[2] and total body electrical conductivity[3] in younger age groups, and the application of multi-component models of body composition,[4–6] most clinical and epidemiological work still relies on simple measures, such as body mass index (BMI) or skinfold thickness measurements. The majority of large-scale studies reporting increasing adiposity in children have used BMI as an index of body fatness, and BMI has been recommended as the best measurement for monitoring overweight in individuals in the paediatric population.[7,8]

Theoretically, BMI represents an index of weight independent of stature, such that at any age, greater relative weight may be attributed to increased body fatness. However, the relationship between BMI and fatness in childhood has received insufficient attention. Ideally, two techniques for measuring a variable should be compared using the method of Bland and Altman,[9] but such an approach cannot be used in this instance because BMI does not actually measure percentage fat. Nonetheless, the widespread practice of determining the correlation between percentage fat and BMI is not the best way to assess their agreement.[10]

Although it involves the deposition of both fat mass (FM) and fat-free mass (FFM), growth is generally described in terms only of body weight, which is then normalized for height to give BMI. Various studies have described the development of BMI over time, but the body compartment changes that underlie the characteristic S-shaped curve with age remain obscure. Fomon's reference child[11] describes change in percentage fat for an average male and female child between birth and 10 y. However, percentage fat is not independent of the quantity of FFM,[12,13] so the normalization of fat mass in terms of body mass provides only a crude method of comparing fatness between individuals at a given time point, and within individuals over time.

Hattori's body composition chart resolves this dilemma, by adjusting both FFM and FM for height as described previously.[12,14] Application of the chart provides the opportunity to investigate the nature of weight gain with age in the reference child, and to evaluate the agreement between BMI and body

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fatness in samples of subjects of a given age. The first aim of this paper is to illustrate height-normalized changes in both FFM and FM in Fomon's reference child in order to describe the development of adiposity independent of change in lean body size. The second aim is to illustrate the cross-sectional variability of individuals in relation to this general pattern.

Methods

Subjects were 42 infants aged 12 weeks, and 64 children aged 8–12 y, in whom body composition was measured by deuterium dilution. The methods and the data have been described previously.[6,15,16] Ethical approval was granted by Cambridge Health Authority and the Dunn Nutrition Unit Ethical Committees. Precision of total body water measurement was 1.9% in the infants and 1.1% in the children. In the infants Z-scores were calculated for BMI[17] and for triceps and subscapular skinfolds.[18] Data on FFM and FM from Fomon's reference child[11] were also used in the analysis, with infancy (birth to 12 months) being considered separately from childhood (1–10 y).

FFM was calculated using published values for the hydration of fat-free tissue.[11] Hydration of FFM in 11 and 12 y old children was predicted by extrapolating the curves against age for each sex as described previously.[6] Between-subject variability in the hydration of fat-free tissue has been shown to be relatively low in both infants[19] and children.[6] FM was calculated as the difference between FFM and body mass.

Two indices of height-normalized body composition were calculated: the fat-free mass index (FFMI), calculated as FFM/height^2, and the fat mass index (FMI), calculated as FM/height^2.[12] Each was expressed in kg/m^2, and the mean and standard deviation calculated for the infants and children. Four sets of data (the reference infant, the reference child, 42 infants and 64 children) were then plotted on Hattori charts. The chart is described in detail elsewhere.[13,14] Briefly, the x-axis represents FFMI and the y-axis FMI, with additional diagonal lines indicating BMI and percentage body fat. The relationship between BMI and FMI was investigated using correlation analysis.

Results

Characteristics of the subjects are given in Table 1. The correlation between FMI and BMI in the infants was 0.79 and 0.77 in males and females respectively ($P < 0.001$), and in the children was 0.89 and 0.76 in males and females respectively ($P < 0.001$).

Figure 1 shows change in FFMI and FMI during infancy in the reference child. In terms of percentage fat, the sexes are almost identical between birth and 12 months, with the female being about 1% fatter. However, the chart indicates that the male infant has a consistently higher FFMI throughout infancy, which accounts for his greater body mass. Hence the girl has similar percentage fat to the boy but lower BMI at each stage.

Figure 2 shows the same changes for the reference child between 1 and 10 y. Here the differences

Table 1 Age, anthropometry and body composition of the subjects

	Infants (n = 42, 45.4% male)		Children (n = 64, 51.6% male)	
	Mean	s.d.	Mean	s.d.
Age (y)	0.24	0.01	9.88	1.22
Weight (kg)	6.06	0.66	34.3	8.3
Height (m)	0.61	0.02	1.39	0.10
BMI (kg/m^2)	16.1	1.4	17.5	2.4
FFM (kg)	4.43	0.44	26.3	5.8
FM (kg)	1.53	0.50	8.0	4.0
Percentage fat	25.2	6.6	22.7	7.8
FFMI (kg/m^2)	11.9	0.9	13.4	1.4
FMI (kg/m^2	4.1	1.3	4.1	1.9

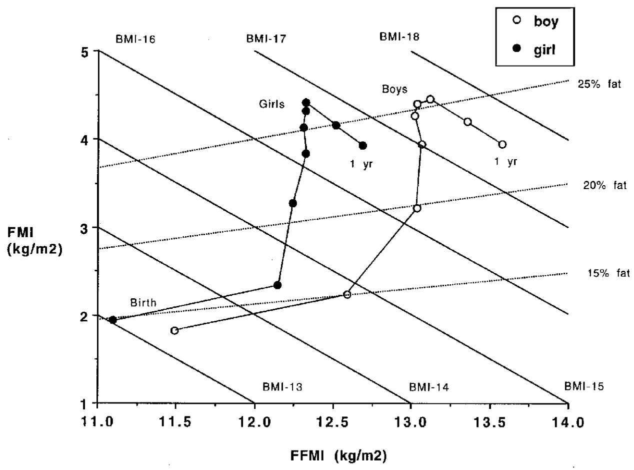

Figure 1 FFMI and FMI in the reference infant by sex. Sequential data points are monthly from birth to 6 months, and then at 9 and 12 months.

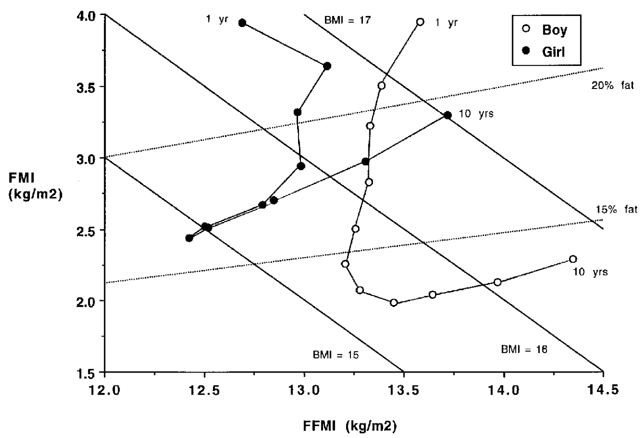

Figure 2 FFMI and FMI in the reference child by sex. Data points are at 1 y, 1.5 y, and then yearly from 2 to 10 y.

between the sexes are more marked. The boy shows a relatively constant relationship between height and FFM between 1 and 6 y, with the FFMI increasing with age thereafter. The decrease in male BMI between 1 and 6 y is almost entirely due to a relative decrease in fatness, whereas the increase in BMI between 6 and 10 y is due to increasing FFMI, and percentage fat remains relatively unchanged during this period. In contrast, the girl shows a decrease in both FMI and FFMI between 1 and 5 y. The decrease in FMI is less marked than in the boy, and between 5 and 10 y she shows an increase in both components. Despite having a lower body weight and BMI until 8 y, by 10 y the girl has higher FMI, higher percentage fat and higher BMI than the boy. This difference can be attributed largely to the girl's FMI decreasing less in early childhood, and beginning to increase again earlier compared to the boy, so that she has a greater FMI from 3 y of age.

Figure 3 shows the four body composition parameters for the 42 infants aged 12 weeks. The chart indicates the wide variability in percentage fat that can occur for a given BMI value. In both sexes, the standard deviation of FFMI was 0.86 kg/m^2, and of FMI was 1.35 kg/m^2, indicating that after adjusting for length, between-subject variability in FFM is two-thirds that in FM. The two subjects marked on the graph have similar BMI values, but very different values for percentage fat and skinfold s.d. scores, as described in the figure legend.

Figure 4 shows the four parameters for the 65 children aged 8–12 y. The standard deviation of FFMI was 1.2 kg/m^2 in males and 1.6 kg/m^2 in females, and of FMI was 1.9 kg/m^2 in males and 1.8 kg/m^2 in females. Again, in both sexes, a given BMI embraces a wide range of percentage fat, although the 4 y age range makes a small contribution to this disparity.

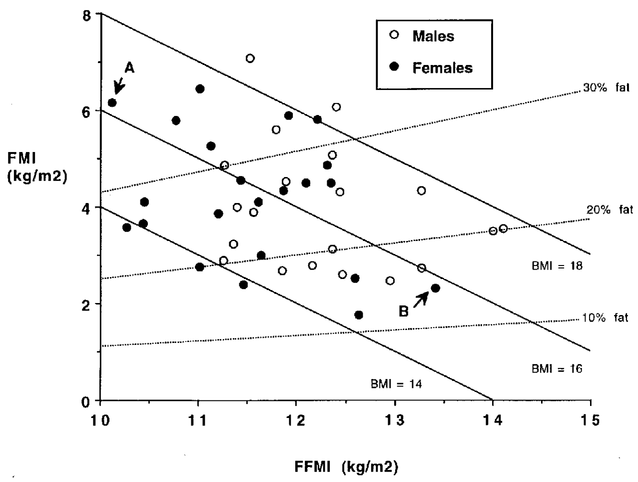

Figure 3 FFMI and FMI in 42 infants aged 12 weeks. Subjects A and B have BMI values of 16.3 and 15.7, equivalent to s.d. scores of −0.09 and −0.49, respectively. Their percentage fat values are 37.9 and 14.7, reflected in mean (triceps and subscapular) skinfold s.d. scores of 1.37 and −0.94, respectively.

Discussion

The difficulty of normalizing body weight and fatness for size and sex is a well-recognised problem in nutritional research. The issue has been considered in detail for adults,[10,12,20] but less attention has been paid to younger age groups, despite the confounding effects of growth.

Several studies have reported a good correlation between BMI and fatness in childhood,[21–23] although in infancy the relationship is poorer.[24] Nevertheless, such evaluations are not the best way

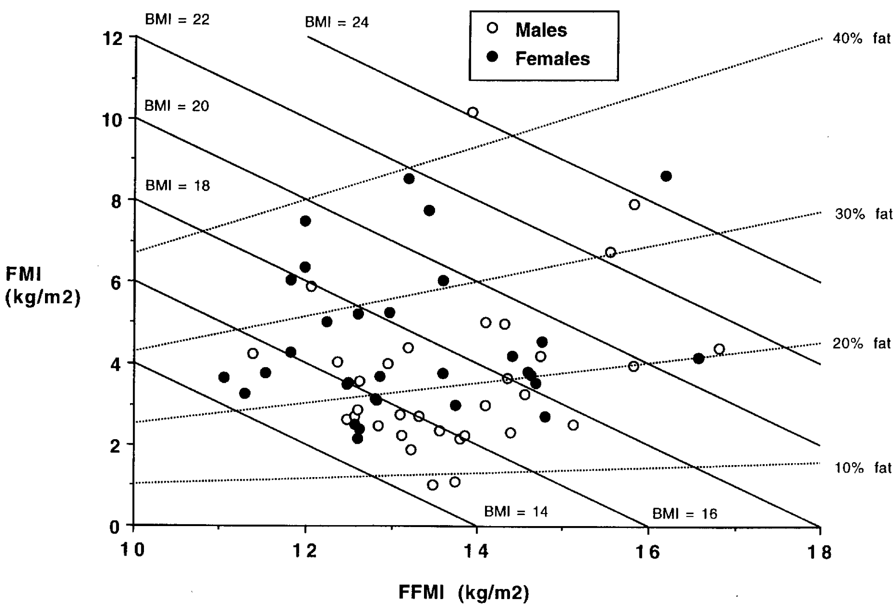

Figure 4 FFMI and FMI in 64 children aged 8–12 y.

to assess their relative agreement, since the regression of percentage fat, or even fat mass, on BMI is unlikely to yield the best fit.[10] Instead, fat should be expressed in kg and adjusted for height, and the most appropriate comparison is between FMI and BMI.[10] In the present study, BMI–FMI correlations were substantially lower in infancy than the values of 0.94 and 0.95 reported previously in adult males and females, respectively.[10] The childhood values were closer to the adult values, despite the relationship being unadjusted for age, but the graphic analysis indicates that a given BMI can embrace a wide range in fatness in each sex. In the present study, after normalizing for height, the variability in FFM was consistently at least two-thirds that in FM in both infants and children for both sexes.

Previous research has identified various factors which influence the BMI–fatness relationship in children. In addition to the well-known age and sex effects, ethnicity, sexual maturity, sitting height, fat distribution and disease state have all been shown to affect the general relationship between BMI and percentage fat.[25–27] Those studies reporting high correlations have tended to include extreme ranges of BMI and fatness. For example, in one study,[22] BMI ranged from 10 to 30 kg/m^2 in children aged 8–12 y, equivalent to a range of 9 UK s.d. scores,[17] while in another,[23] the BMI range was 14–44 kg/m^2, and the range of percentage fat 8–55%. These wide ranges inevitably produce a high value for the correlation, but the confidence limits of the association remain wide.[23]

Despite an awareness that various factors influence the BMI–fatness relationship, the specific contribution of FFM to BMI has been relatively ignored. The general increase in BMI from mid childhood has been termed the 'adiposity rebound',[28] but between 6 and 10 y of age the increase in BMI in the reference boy cannot be attributed to increasing fatness. There is a need to investigate how various factors such as exercise level and endocrine status influence FFM and hence BMI. Exercise influences muscle growth even in young children,[29] while growth hormone also has an effect.[30] The dual role of physical activity in the development of both FFM and FM is likely to confound the BMI–fatness relationship in epidemiological studies, and may account for disagreement between studies concerning the relationship between vigorous activity level and either BMI[31] or whole-body fatness.[32]

The present study has also illustrated how growth may affect lean and fat development differentially at different times. While the general relationship between age and fatness has been revealed by trends in percentage fat,[11,33] the development of FFM is less well understood, and significant sex differences become apparent after normalization for height. These differences, and individual variability within these general patterns, require further investigation.

The potential pitfalls of using BMI as an index of fatness in early life have been noted previously,[8,34,35] but, paradoxically, much of our understanding of the development of fatness is based only on such proxy measures. For example, to date, no large-scale study has tracked whole-body fatness from early life into adulthood. Instead, various studies have followed either BMI or, less commonly, skinfold fat thickness from childhood to adulthood, and have concluded that the relative risk of childhood fatness for adult obesity is low.[36] The reliability of such conclusions may be jeopardized if proxy measures provide a better index of adiposity in adulthood than in childhood. The actual relationship between early fatness and later obesity is unknown, and will remain so until whole-body fatness is measured at each time point.

The convenience with which BMI can be measured has understandably made it popular with both paediatric clinicians and epidemiologists, despite awareness of its shortcomings. For clinicians, the BMI s.d. score represents a valuable way to assess short-term changes in nutritional status within individuals, for example in the treatment of obesity or the refeeding of eating disorder patients. Likewise, average BMI is a useful way to compare relative weight between populations, and within populations over time. However, the present study has demonstrated that the relationship between BMI and fatness in individuals is poor, both in infancy and childhood. Obesity is an excess of body fat, not an excess of body weight. The continued emphasis on BMI for routine assessment of body fat in individuals risks failing to identify both excess fatness and its risk factors in the paediatric population.

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